The Fishery Independent Hydroacoustic Survey Of Inshore Gulf of Maine Atlantic Herring

1999-2004
Final Report*

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1. Background Information

1.1. Abstract

The 2004 fisheries independent acoustic survey of the inshore Gulf of Maine Atlantic herring stock component was conducted from August 26 to October 22, 2004. This was the sixth year of the survey, which has been carried out by the Gulf of Maine Research Institute since 1999. The objective of the survey is to monitor the status of the inshore herring spawning stock. The project used commercial fishing vessels as acoustic platforms to conduct fall acoustic surveys over the range of historical herring spawning grounds along the coastal Gulf of Maine, from Cape Ann, Massachusetts, to West Quoddy Head, Maine. This survey complements the acoustic surveys of the Southwest Nova Scotia – Bay of Fundy herring stock component and the Georges Bank – Nantucket Shoals herring stock component.

An independent panel consisting of three fisheries stock assessment and fisheries acoustics scientists reviewed the survey in March 2005. The scientists evaluated the survey based on the terms of reference and made the following conclusions:

1) The diversity of platforms, locations and degree of coverage, sampling levels and general evolution of the methods compromise the use of existing data as a series. Current data are best treated as six years of exploration.

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2) By applying a test of consistency (one vessel, one sampling gear, similarity in transect approach, adequate sampling), it may be that the data from some areas in 2003 and 2004 are comparable. The 03/04 data should be explored (combined with critical thinking about objectives and sampling plan) as the basis for development of consistent methods and survey design for future surveys.

3) The historical data from the acoustic surveys could be used, in combination with literature records and other knowledge of herring spawning to define the precise areas and times of relevance for a 'sentinel' approach to monitoring spawning ground performance.

Additional conclusions and recommendations from the panel are found in the Northeast Consortium's Consensus Report.

1.2. Gulf of Maine Atlantic Herring Population Dynamics and Stock Assessment

The Atlantic herring (*Clupea harengus*) is a commercially important species used for human consumption and bait for the American lobster fishery in New England and the Canadian Maritimes. Herring is also an import forage species, providing a crucial trophic link between zooplankton and larger fish in the Gulf of Maine ecosystem. Ranging from Labrador to New Jersey, Atlantic herring spawn in discreet units with some site fidelity (Tupper et al, 1998; Kornfield et al., 1982; Iles and Sinclair, 1982).

Population rich species such as Atlantic herring have a number of separate spawning grounds throughout their range (Smedbol and Stephenson, 2001; Stephenson et al, 1999), and the preservation of within species diversity is of increasing importance to scientists (Stephenson and Kenchington, 2000). The maintenance of a diverse population structure may allow populations to adapt to environmental and human disturbances (Smedbol and Stephenson, 2001; Stephenson et al, 2001). Smedbol and Stephenson (2001) argue that the spatial structure of a population gives it resilience and adaptability, and therefore should be of importance to the short-term management of commercially exploited fish species.

There are three separate stock components in the Gulf of Maine/Bay of Fundy region (Figure 1.2.1): Southwest Nova Scotia-Bay of Fundy (4WX), coastal waters of the Gulf of Maine (5Y), and Georges Bank (5Z) (Overholtz et al, 2004). Minimum population estimates of the three US spawning areas (Georges Bank, Nantucket Shoals, and coastal Gulf of Maine) indicate that the coastal Gulf of Maine area comprises approximately 25% of the stock complex biomass (Overholtz et al, 2004). The coastal Gulf of Maine stock component biomass is estimated as a proportion of the total biomass calculated from the overall stock assessment model, with no direct estimate of biomass or biomass trend available. Given the information provided by the stock assessment of the complex, TACs are set for four different management areas (Figure 1.2.2). The highest landings (~60,000 mt) are from area 1A, which is primarily in coastal Gulf of Maine waters. As a result, the highest proportion (~64% in 2004) of the total catch is from the smallest component of the Gulf of Maine/Georges Bank complex (Maine Department of Marine Resources (MEDMR), 2005).

The National Marine Fisheries Service (NMFS) initiated acoustic surveys of Georges Bank Atlantic herring in 1998. The Canadian Department of Fisheries and Oceans (DFO) initiated acoustic surveys of Gulf of Maine-Bay of Fundy herring in 1996 (Figure 1.2.3). These surveys target spawning herring on Georges Bank and in the Scotia/Fundy region respectively. These surveys do not cover herring spawning grounds along the coasts of Maine, New Hampshire, and Massachusetts, though the NMFS survey does cover Jeffreys Ledge (Figure 1.2.1). Atlantic herring spawn in the Gulf of Maine from mid- to late-August through early November, although the precise timing and duration are highly variable. Spawning generally commences off downeast Maine in mid- to late- August and progresses west through the months of September and October, sometimes into November (Creaser et al., 1984; Creaser and Libby, 1988; Tupper et al., 1998). The highly aggregated distribution of herring is typical of this season and advantageous for acoustic surveys (Simmonds et al., 1992).

Development and execution of a reliable annual inshore Gulf of Maine acoustic survey, which complements the NMFS and DFO surveys, is a critical step in understanding the population dynamics of the inshore Gulf of Maine herring stock component. The Gulf of Maine Research Institute (GMRI) has conducted comprehensive fishery independent acoustic surveys on this separate stock component since 1999. This survey accomplishes one of the research recommendations made by the most recent (1998) Northeast Regional Stock Assessment

Workshop and the 2003 Transboundary Resources Assessment Committee. By designing surveys that complement one another, the three groups work in concert to assess the three principal herring stocks present in the Gulf of Maine without duplicating efforts. In addition to these surveys, Maine Department of Marine Resources' (DMR) Matt Cieri, NMFS's Bill Overholtz, and fisheries scientist Dave Stevenson are developing a new model to assess the inshore Gulf of Maine herring stock component. This model would refine the stock assessment of Gulf of Maine Atlantic herring by incorporating finer scale catch data, biological parameters, and an index of spawning stock biomass. Current models assess the Georges Bank/Nantucket Shoals and Gulf of Maine stocks as a single unit.

Figure 1.2.1: Gulf of Maine/Bay of Fundy Atlantic Herring Spawning Grounds

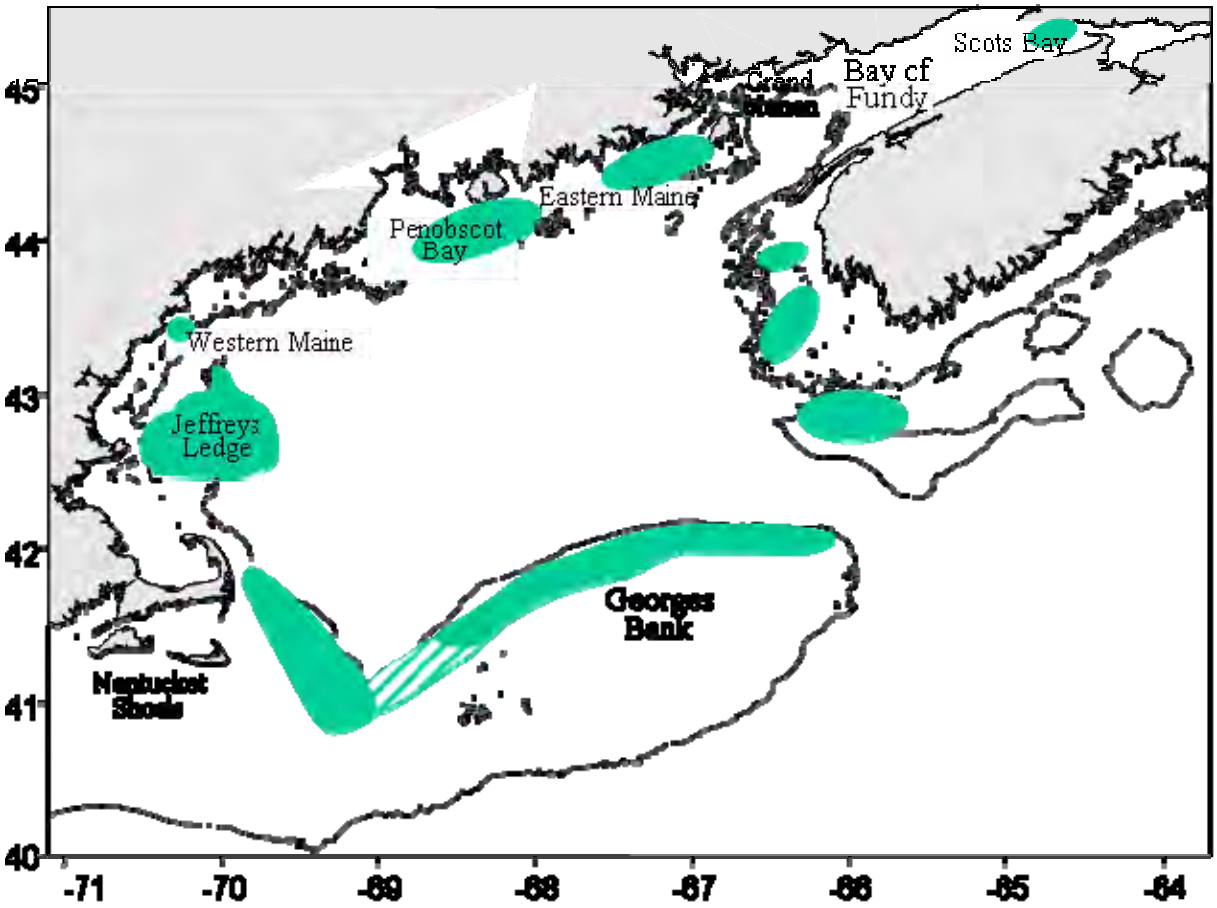


Figure 1.2.2: U.S. Atlantic herring fishery management areas

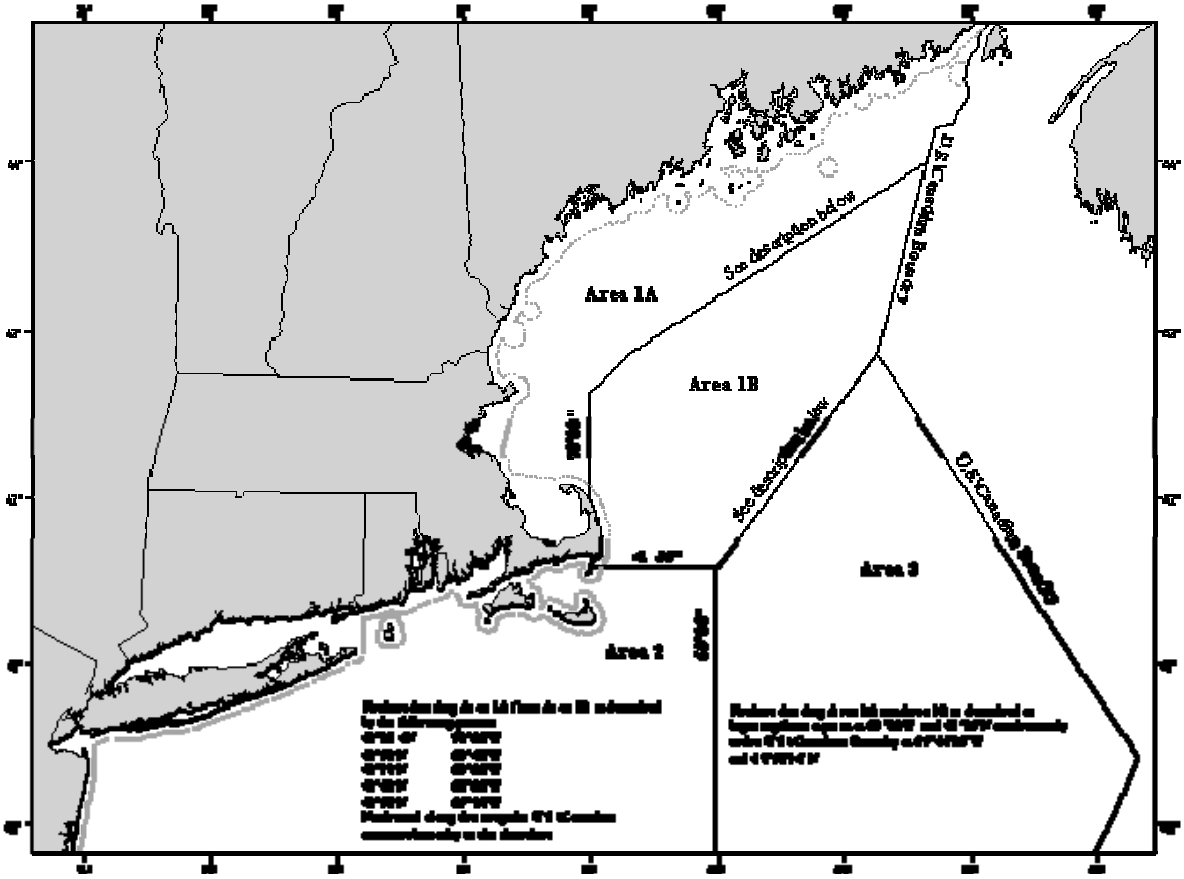
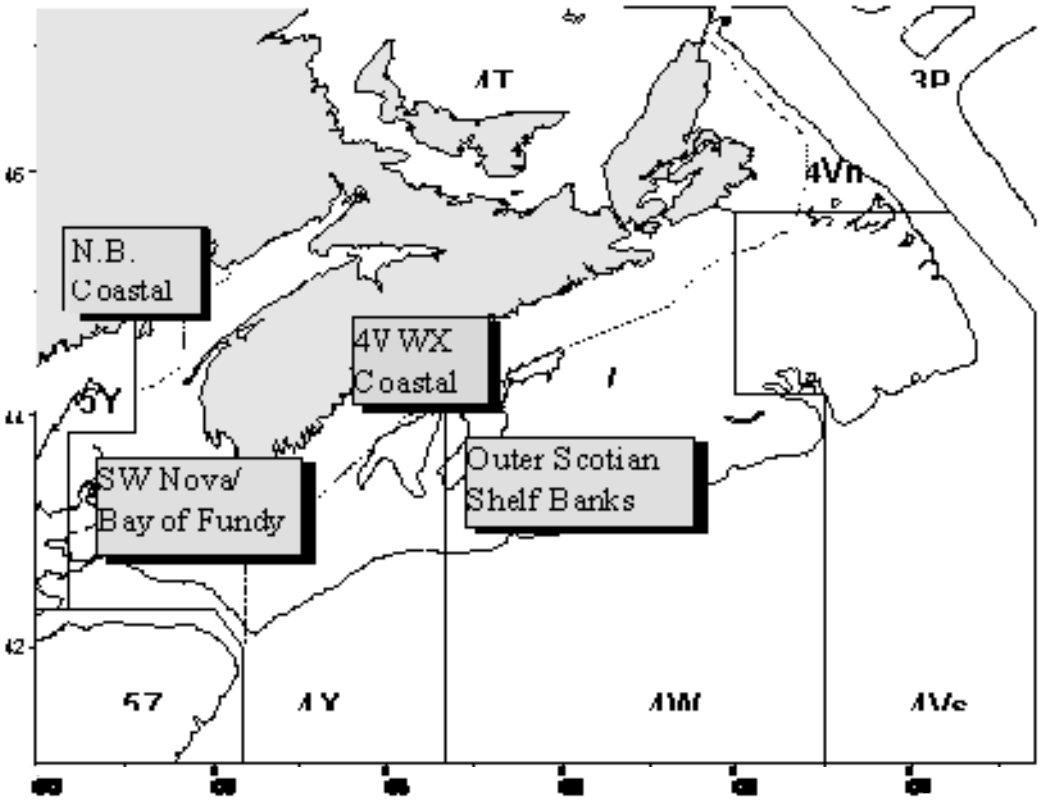


Figure 1.2.3: Canadian Maritimes Atlantic herring management areas



*1.3. **Project History***

In 1996, the Gulf of Maine Research Institute (GMRI) provided a neutral forum for herring fishermen, processors, scientists and managers to develop research priorities for the Gulf of Maine herring fishery. This effort produced a consensus about research needs, established a foundation for collaboration among the herring industry and state and federal herring scientists, and set the stage for a variety of entrepreneurial research institutions to seek and secure funding to address herring research priorities in the Gulf of Maine.

One of the research priorities identified during this process was the need to develop a means of monitoring spawning stocks in the Gulf of Maine. State and federal fishery research institutions could not do so in addition to meeting the assessment demands of various fishery crises and were severely limited in their human and financial resources. In the course of discussing how to address this challenge, a herring vessel captain suggested that the logical way to solve the problem was to involve the vessels. In his words, "we're out there every night, we live and die by our ability to find and catch herring, we're the first to see them spawn, we're out there anyway. Why not use us?" This concept brought herring researchers and fishermen together to assess and monitor herring spawning stocks.

In 1998, the GMRI initiated a pilot project to explore the feasibility of collecting acoustic data on herring abundance with commercial fishing vessels (Yund, 1999). The initial project revealed that there were few technical impediments to equipping commercial vessels with relatively inexpensive scientific-grade acoustic systems. Substantial fishery dependent acoustic data were collected in the course of normal fishing operations, but performing fishery independent scientific surveys with commercial herring vessels proved substantially more difficult.

A full-scale fishery independent acoustic survey was conducted with more success in 1999, using a commercial groundfish vessel. This survey was a prototype for subsequent surveys that built on its basic design and premise, with some variation from year to year. In 2000, the project experienced many changes including a large staff turnover after the fall survey. Both the primary investigator (PI) and the data analyst left the project, and interim responsibilities were distributed between the GMRI and the Maine Department of Marine Resources (DMR). In 2000, the survey area was expanded from the previous year, a new commercial groundfish vessel conducted the surveys, two new acoustic systems were tested and deployed, and new funding sources were secured. This was also the first year that oceanographic data were collected.

The 2001 project year had more staff and funding changes while the survey was more consistent in the surveyed area and design, survey vessel, and acoustic equipment. This was the first year that a herring fishing vessel participated in the survey. In 2002, the project retained relative stability in staffing and funding. The survey had difficulty in finding herring fishing vessels willing to participate, and as a result, a number of different vessels and systems were used. The survey design and surveyed area was relatively the same as the previous year.

Project staffing remained stable through 2004, though funding for the entire project was more tenuous. The survey design changed slightly and a herring fishery vessel was contracted for the majority of the survey work in 2003, and all of the survey in 2004. After six years of full-scale independent surveys, an independent review of the project was necessary to certify the results and receive recommendations for standardized design and operations. The consensus report from this review is available upon request to the GMRI or the NEC.

1.4. Collaborative Research Vessels and Acoustic Systems

The GMRI has secured funding over time to equip fishing vessels with an acoustic system and to contract with the vessels to conduct fishery independent surveys. The only permanent part of the acoustic system is the transducer, which is installed when the vessel is hauled out of the water. The transducer is never removed unless it is lost off the hull or otherwise inoperable. The rest of the system is relatively portable and capable of being secured in the wheelhouse of the survey vessel in less than an hour. Complete descriptions of the acoustic system and annual configurations are in section 3.1, and Table 1.4.1 lists vessels and acoustic systems by year.

1998

Two herring fishery vessels, the F/V Western Wave and F/V Providian, were part of the pilot project to collect acoustic data on fishing vessel platforms. Both vessels conducted small scale acoustic surveys in limited areas, but the majority of the data collected was during fishing operations.

1999

The F/V Mary Ellen was contracted for the survey and is a 70' groundfishing stern trawler. Herring vessels were not willing to commit to survey work during this time. The vessel was equipped with a Femto DE9320 digital echosounder interfaced to a Furuno 50B12 50 kHz transducer. Surveys were conducted from August 16 to October 22. The main sampling gear was a modified shrimp trawl. Charlie Saunders was the captain for all surveys.

2000

The F/V Adventurer was contracted for the survey and is a 73' groundfishing stern trawler. Herring vessels were not willing to commit to survey work during this time. The vessel was equipped with a Femto DE9320 75 kHz digital echosounder interfaced to a hull-mounted Femto 75 kHz transducer. Surveys were conducted from August 22 to November 20. The main sampling gear was a bottom trawl. Cameron McClellan was the captain for all surveys.

2001

The F/V Adventurer was again contracted for surveys. The Femto 75 kHz sounder used the previous year was reinstalled. A dual frequency (40/120 kHz) towed body was also used on various surveys. Adventurer conducted surveys from September 4 to October 18.

The F/V Western Wave, a 68' purse seiner already equipped with a Femto 75 kHz transducer, was contracted for 9 days of survey work which was conducted from November 3 to November 15. The dual frequency (40/120 kHz) towed body was also used. Mandatory days out of the herring fishery created the opportunity to work with a herring vessel that had previously been unavailable. Steve Gough was the captain for all surveys.

2002

Surveys were planned based upon using the Western Wave as the primary survey vessel for 28 days of survey and the Adventurer for 10 days of survey. After conducting two days of surveys, the captain and crew of Western Wave expressed disinterest in conducting surveys and the 26 remaining days were divided among Adventurer, F/V Western Hunter (a drum seiner), and F/V Thunder Bay (a midwater trawler). Jamie Matthews was the captain on the Western Hunter, and Dave Reingardt was the captain on Thunder Bay. The Western Wave, Adventure, and Thunder Bay used 75 kHz systems, and the Western Hunter used the 40/120 kHz towed body system.

2003

A herring midwater trawler, F/V Jennifer & Emily, was contracted to conduct the majority of the survey time. The vessel is also outfitted for groundfishing from November until early summer. Unlike other contracts in the past, the agreement allowed for the vessel to be available at our request for much of the fall spawning season. The vessel made very few commercial herring trips and conducted surveys from September 10 to October 31. The standard Femto 75 kHz system was installed and calibrated during the summer of 2003. Mark Bichrest was the captain on all surveys.

The F/V Adventurer was used for 10 day of survey from September 16 to October 1, with the 75 kHz system continuing to function and calibrate well.

The F/V Western Wave surveyed one night on October 10, with the original transducer (installed 1998) functioning well, though the system was not calibrated.

2004

The F/V Jennifer & Emily was used exclusively from September through October, with the vessel being available whenever needed. The Femto 75 kHz system performed well.

The F/V Safe Haven searched primarily the midcoast and Casco Bay areas for herring aggregations before the Jennifer & Emily conducted formal surveys in a particular area. This was a new approach to targeting spawning herring. It had limited success because there were no large aggregations of spawning herring found in the midcoast and Casco Bay area. Bryan Bichrest was the captain on Safe Haven, and Mark Bichrest was captain and owner on Jennifer & Emily.

Table 1.4.1: Survey Vessels and Acoustic Systems by Year

Year	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Vessel 1	*Mary Ellen*	*Adven-turer*	*Adventurer*	*Adventurer*	*Jennifer & Emily*	*Jennifer & Emily*
System	50 kHz	75 kHz	75,40/120 kHz	75 kHz	75 kHz	75 kHz
Vessel 2			*Western Wave*	*Western Wave*	*Adventurer*	*Safe Haven*
System			75,40/120 kHz	75 kHz	75 kHz	Search
Vessel 3				*Western Hunter*		
System				40/120 kHz		
Vessel 4				*Thunder Bay*		
System				75 kHz		

*1.5. **Project Resources***

1.5.1. Personnel

The GMRI herring acoustics program has traditionally supported a primary investigator (PI)/project manager and a vessel observer/data analyst. The program operated from the University of Maine Darling Marine Center in Walpole, ME, from 1998 to May 2001. Don Perkins, president of the Gulf of Maine Research Institute, was responsible for convening the industry/science meetings in 1996, hiring the first PI in 1998, and project financial management through 2001. Don Perkins continues to secure industry, foundation, and federal funding for the program. Phil Yund at the University of Maine was the PI from 1998 to 2001, responsible for project research management. Joel Wezowicz was the data analyst/vessel observer from 1998 to 2000. Cristina Dyke was hired as vessel observer for the 1999 fall independent survey, to assist Joel Wezowicz with vessel observer time and data management. Shale Rosen was hired in August 2000 for the vessel observer/data analyst role to replace Joel Wezowicz. During this period of time, the GMRI provided a portion of the funding for Phil Yund's position, full funding for the data analyst and vessel observer positions, and funding for project equipment and operations.

A transition in research management and location occurred in 2001, when Linda Mercer and then Matt Cieri at the DMR in West Boothbay Harbor, took on the role of PI for the independent survey. Mercer's and Cieri's time was considered in-kind funding, so all the funds raised by the GMRI paid for project expenses and salaries. Shale Rosen (GMRI) continued as data analyst with some project management responsibilities, working at the DMR with Cieri. Andy Johnston was hired as vessel observer for the 2001 independent surveys. Laura Singer (GMRI Collaborative Research Manager) oversaw project financial management in 2001 as well. In 2002, Shale Rosen was managing the project with Laura Singer, Matt Cieri continued as the independent survey PI, and Kevin Scheirer (GMRI) was hired as vessel observer and data analyst. This configuration continued into 2004, when project activity was occurring mostly at GMRI offices in Portland and Shale Rosen was sharing PI responsibilities with Matt Cieri. Shale Rosen and Kevin Scheirer exchanged roles in 2004. Program staff from 1998 to 2004 are listed in Table 1.5.1.1.

Table 1.5.1.1: Herring Acoustics Program Staff from 1998 - 2004

Project Year	(PI) Primary Investigator	Financial Manager	Co-PI/Project Manager	Data Analyst	Vessel Observer
1998	Yund	Perkins	Yund	Yund/ Wezowicz	Joel Wezowicz
1999	Yund	Perkins	Yund	Yund/ Wezowicz	Christina Dyke
2000	Yund	Perkins	Yund	Yund/ Wezowicz	Shale Rosen
2001	Mercer/Cieri (DMR)	Perkins/ Singer	Perkins/ Singer	Rosen	Andy Johnston
2002	Cieri (DMR)	Singer/Rosen	Rosen (CoPI)	Rosen	Rosen/Scheirer
2003	Cieri (DMR)	Singer/Rosen	Rosen (CoPI)	Rosen/Scheirer	Rosen/Scheirer
2004	Cieri (DMR)	Singer/Scheirer	Scheirer(CoPI)	Rosen	Rosen

1.5.2. Advisors and Partners

Allen Clay of Femto Electronics has always supplied acoustic equipment and expertise for the project. Gary Melvin at the Canadian Department of Fisheries and Oceans (DFO) in St. Andrews, New Brunswick, also provided initial training in data analysis procedures. Collaboration with the Fisheries Acoustics Research Group (FARG) at the NMFS Northeast Fisheries Science Center (NEFSC) in Woods Hole, MA, has continued from the beginning of the project to the present time. Bill Overholtz, Bill Michaels, and Mike Jech are the primary stock assessment and acoustics scientists in the FARG and provided advice and technical expertise in refining the independent survey over time. Numerous herring industry members have provided information and support including Peter Mullen, Walt Raber, Al West, Jeff Kaelin, Mary Beth Tooley, and others.

Partners of the independent survey project have generally been the owners, captains, and crew of the fishing vessels contracted for survey work. Several partnerships have developed from this project specifically, others have developed as a result of the fishery dependent survey project, and still others have resulted from involvement with fishermen in both projects. Peter Mullen is one of the more active, long-term partners. He provided his purse seiner, F/V Western Wave, as one of the first acoustic data collection platforms in 1998. He funded acoustic equipment purchases and has contracted with GMRI for independent survey work from 2001 to 2003. Steve Gough has been the captain of Western Wave for over four years, and he has often called in information about spawning herring and has been good to work with on surveys. Walt and Ryan Raber have also been long-term partners, using the F/V Providian as a fisheries dependent acoustic data collection platform since 1998. GMRI staff have had long-standing relationships with the captain and crew of the Providian, which has changed little over the past five years. These relationships have been valuable in teaching us about the herring fishery and the behavior of herring schools, and in designing the independent surveys.

Cameron McClellan conducted survey work from 2000 to 2003 with the F/V Adventurer. This partnership worked well for GMRI because McClellan was available for scheduled survey time during spawning season. Unfortunately, Adventurer was not equipped for midwater trawling, which led to the transition to using Mark Bichrest's F/V Jennifer & Emily. He made the Jennifer & Emily available on call for independent surveys in 2004. In 2002, two herring fishery vessels, the F/V Western Hunter and F/V Thunder Bay participated in surveys. Paul Morse, owner of the Western Hunter responded to a last minute request by GMRI to the herring industry for a survey vessel. The portable dual frequency system was the only acoustic system that could be used on this vessel, which limited the vessel speed and survey area. Dave Reingardt, owner of the F/V Thunder Bay, became involved in both projects in the fall of 2002. He offered the Thunder Bay as an acoustic data collection platform and conducted several independent surveys as well.

1.5.3. Program Finances

The proposed annual budget for the herring acoustics program, which includes the fisheries independent acoustic survey project and the fisheries dependent acoustic data project, has ranged from $150,000 to $360,000. The revenue for expenses has come from a wide range of sources including federal and state grants, private foundations, and the herring industry. Program revenue has usually been less than the proposed budget. The Northeast Consortium has provided the majority of funding for the independent survey since 2000.

2. Survey Design

2.1. General Approach

The independent survey has been conducted in the same three major areas of the Gulf of Maine. Survey areas of interest (AOI) are Downeast, Midcoast Maine, and Western Gulf of Maine/Jeffreys Ledge (Figure 2.2.1.1). The prevailing generalization that herring spawn in a progression from east to west (Tupper et al, 1998) has guided the scheduling of surveys. Therefore, surveys have generally started in the Downeast area in late August or early September, progressing into the Midcoast during the rest of September, and then concluding in the Western Maine and Jeffreys Ledge areas from late September through October (Figures 2.2.1.2 – 2.2.1.7). Surveys were extended into November in several years (Table 2.1.1).

In 2001, the approach to surveys was outlined in a funding proposal to the NEC:
"Our basic approach will be to perform repeated surveys of pre-defined strata (survey areas) throughout the season, combined with occasional "adaptive" sampling if necessary to respond to variation in spawning location. We will focus on areas of historical spawning importance in combination with spawning and pre-spawning staging areas detected during the preliminary two years of this project. From northeast to southwest, we will survey a series of previously surveyed strata off Cutler, Schoodic Ridge, Mount Desert Rock, Monhegan Island, Casco Bay, Platts Bank, and Jeffreys Ledge. Each survey trip will cover one area with suspected spawning activity and the next closest area to the southwest (to ensure that spawning has not yet been initiated in the next sequential area). Temporal variation in spawning status along the coast (obtained from fish samples) will be used to distinguish different spawning groups. Because herring stay down on the bottom when they actually spawn (where accurate acoustic data are difficult to obtain), our goal is to survey each group as close as possible before it actually spawns."

The practical execution of this approach has proven to be more difficult as herring do not spawn in the predictable pattern that was assumed at the time. However, the rationale behind this approach continued into 2004, with renewed and varied attempts each year to survey particular spawning groups or aggregations as close to their spawning activity as possible.

Table 2.1.1: 1999-2004 Survey Weeks

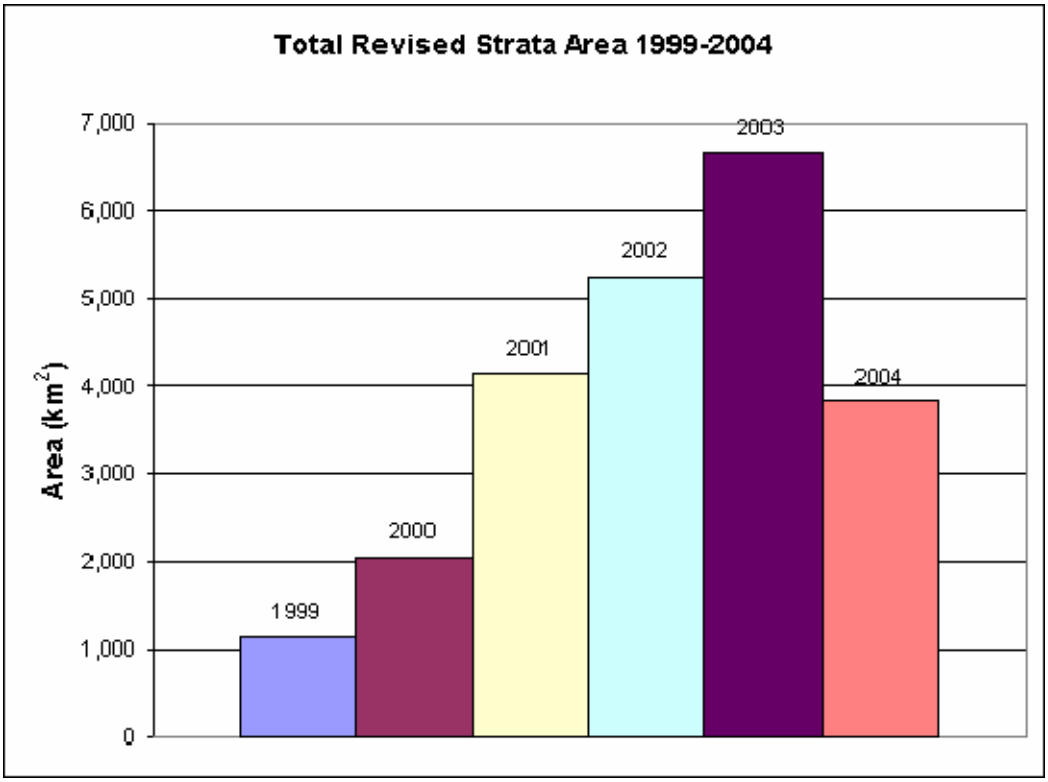
Year	August				September				October					November			
	1-7	8-14	15-21	22-28	29-4	5-11	12-18	19-25	26-2	3-9	10-16	17-23	24-30	31-6	7-13	14-20	21-27
1999																	
2000																	
2001																	
2002																	
2003																	
2004																	

2.2. Survey Locations

After the 1999 surveys, one objective was to standardize the areas surveyed to allow comparisons among years. No defined strata were set, but future surveys were located in the same areas that were surveyed in 1999. The total strata area surveyed doubled from 2000 to 2001, as larger portions of coastal waters were surveyed to reduce the potential of missing fish (Figure 2.2.1). This area is from the 2004 revision of strata and biomass estimates and does not represent all strata or multiple surveys of single strata. In 2004, an attempt to better target surveys was made by locating spawning herring with a search vessel. This strategy was the result of a recommendation from an advisors meeting to use a faster boat to learn when herring were spawning in different areas. The search vessel was not able to locate spawning herring, but the information gathered from searches allowed us to be more confident that we were not missing spawning events with the survey vessel.

Surveys are constrained in their placement by bathymetry and by lobster gear. For example, transects have been shortened or moved to allow the survey vessel to steam a safer distance from islands and shoal water areas. Lobster gear can be very dense in water depths of 40 meters and less. Damage to large amounts of buoys, pot warp, and traps can occur by steaming transects through these areas. In addition, the survey vessel may sustain damage to its drive components from entanglement in pot warp.

Figure 2.2.1: Total Area of 2004 Revisions to Strata and Biomass Estimates



2.2.1. Areas covered by year: 1999 - 2004

The following figures show the maximum extent of survey transects and depict the changes in coverage from year to year in the three major survey areas. The 2004 areas were drawn at a separate time with different software and therefore do not appear in Figure 2.2.1.1.

Figure 2.2.1.1: 1999-2003 Survey Areas of Interest

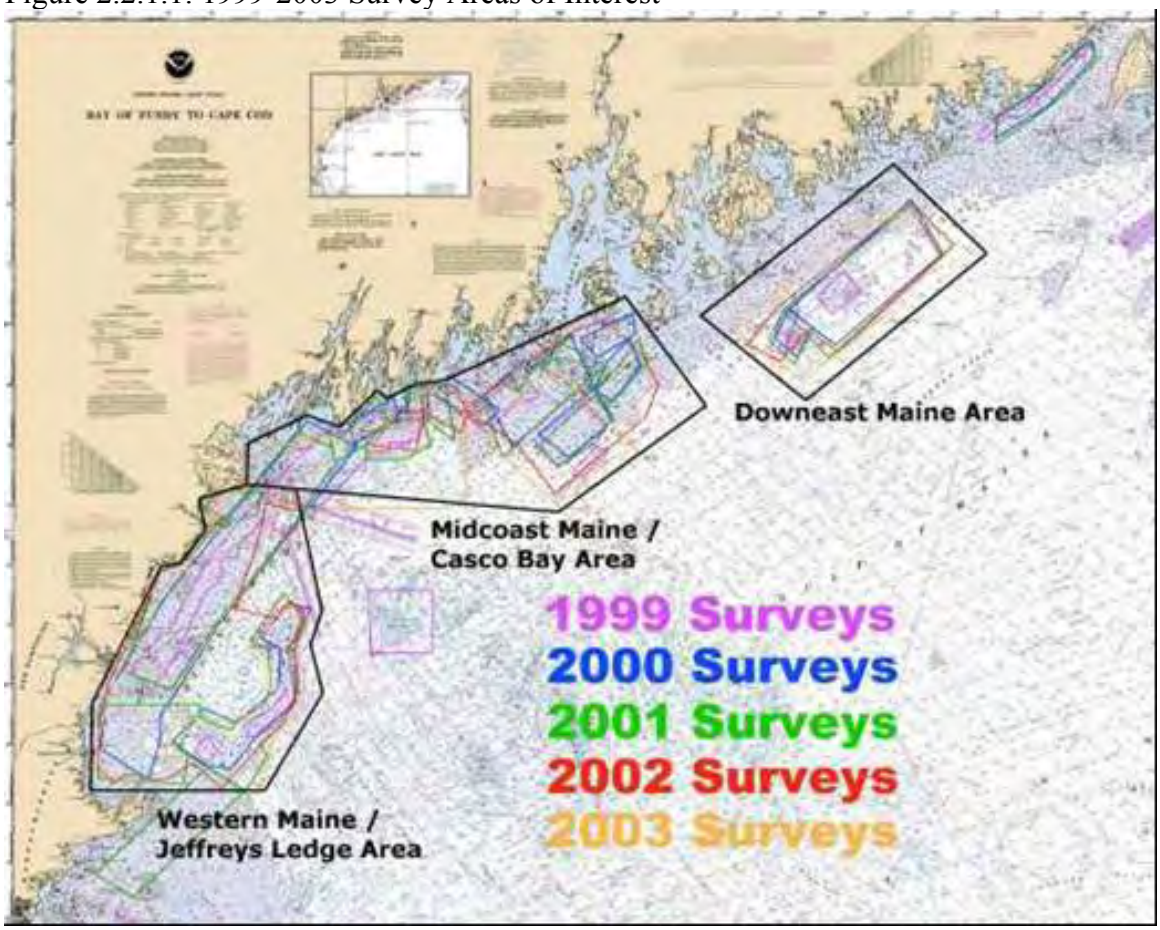


Figure 2.2.1.2: 1999 Survey Areas

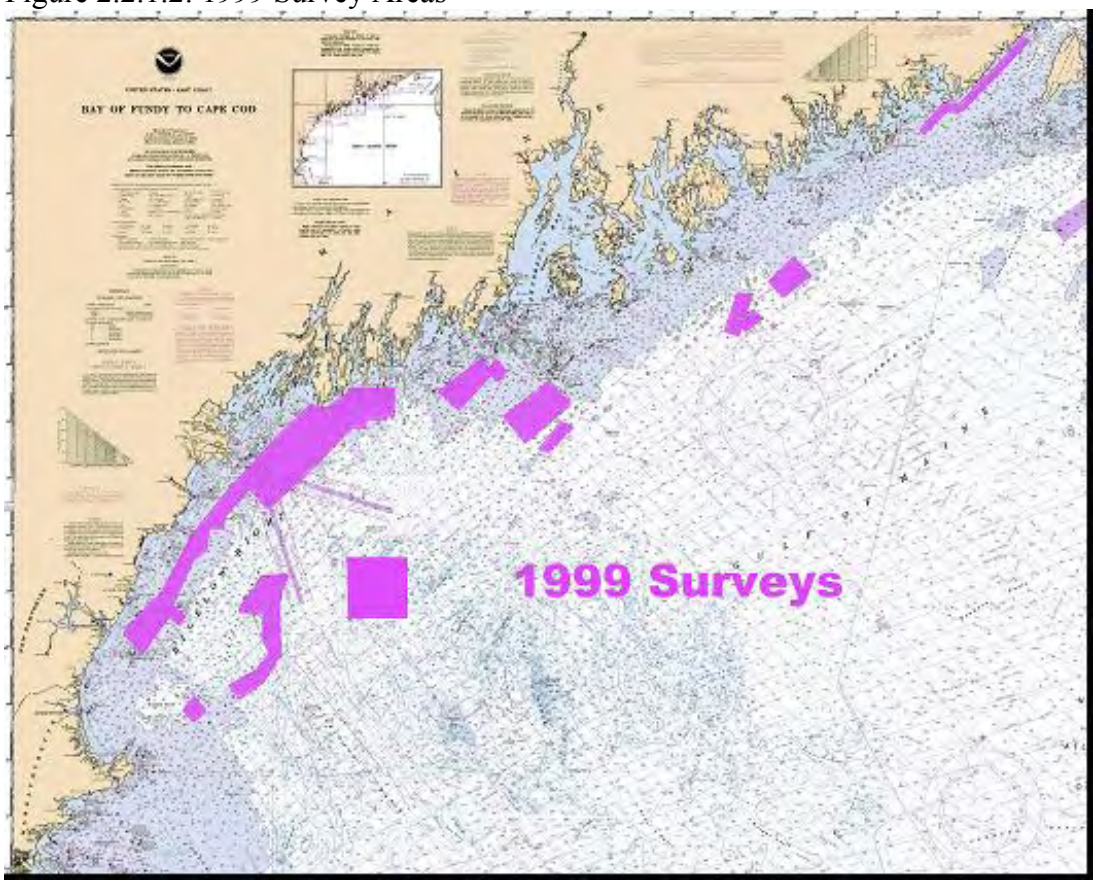


Figure 2.2.1.3: 2000 Survey Areas

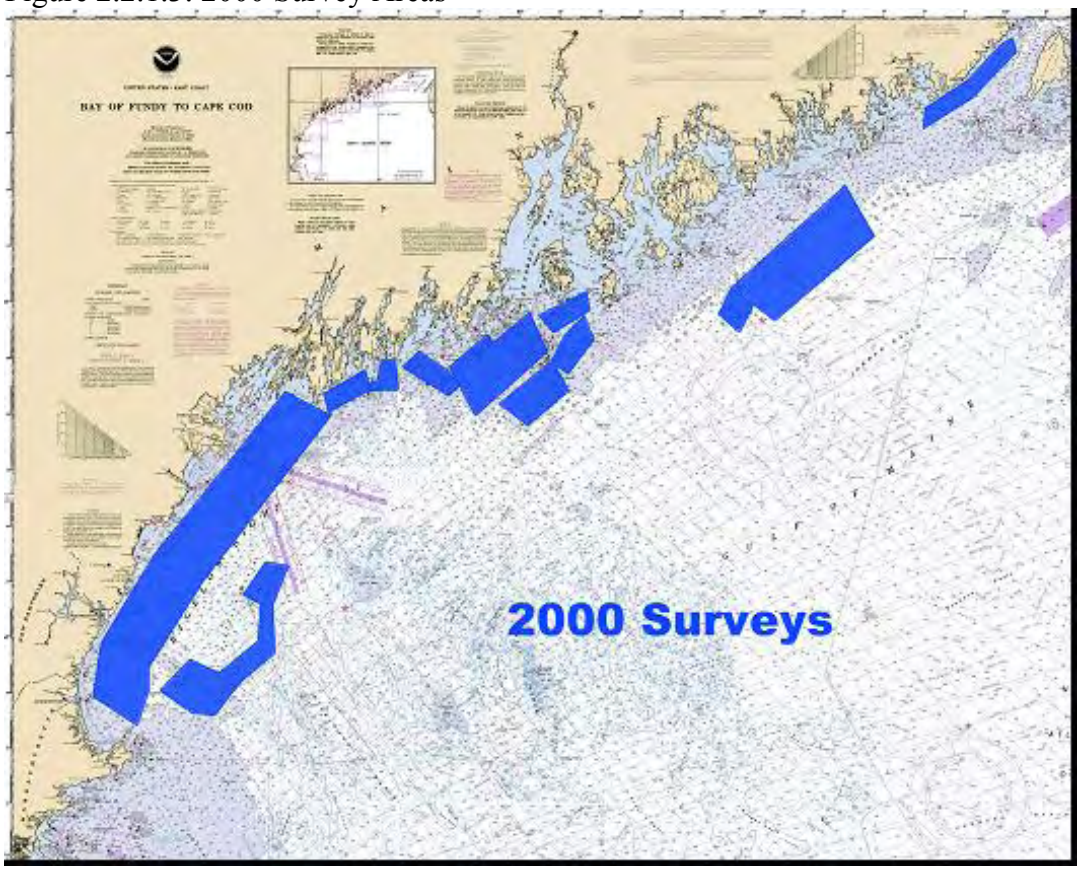


Figure 2.2.1.4: 2001 Survey Areas

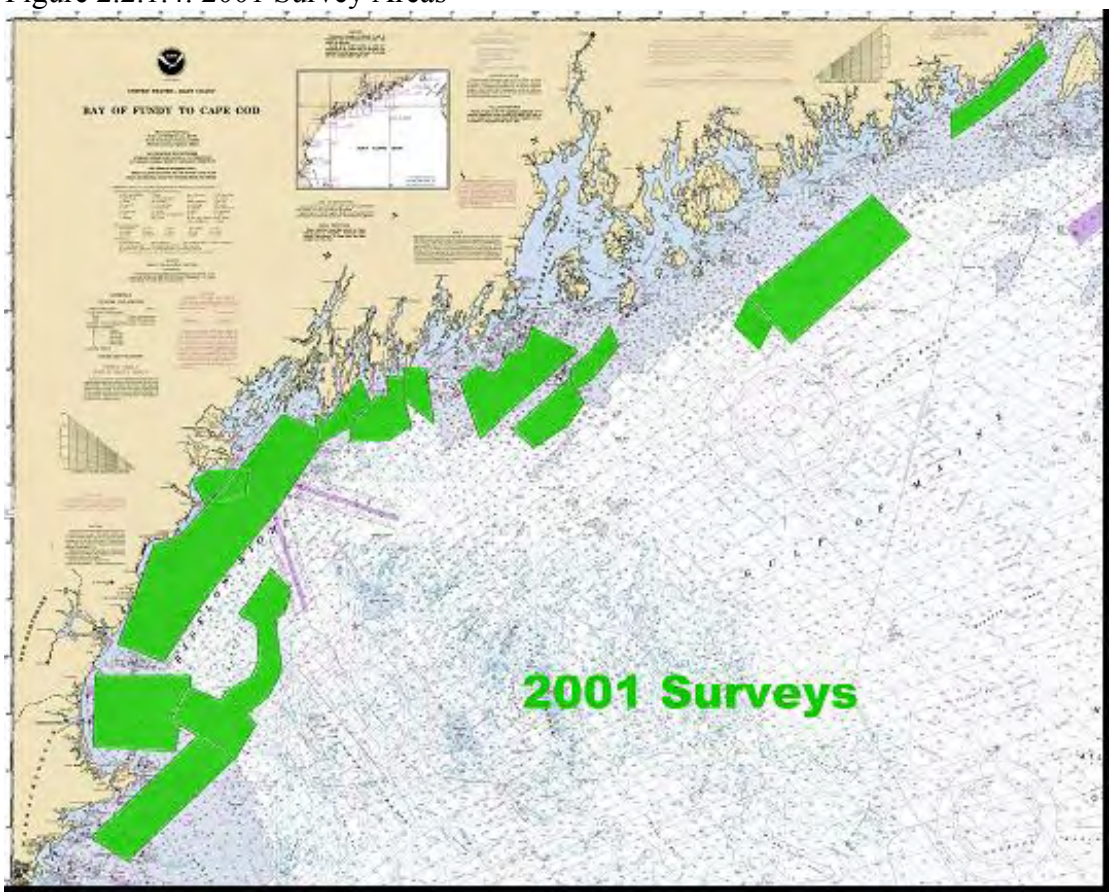


Figure 2.2.1.5: 2002 Survey Areas

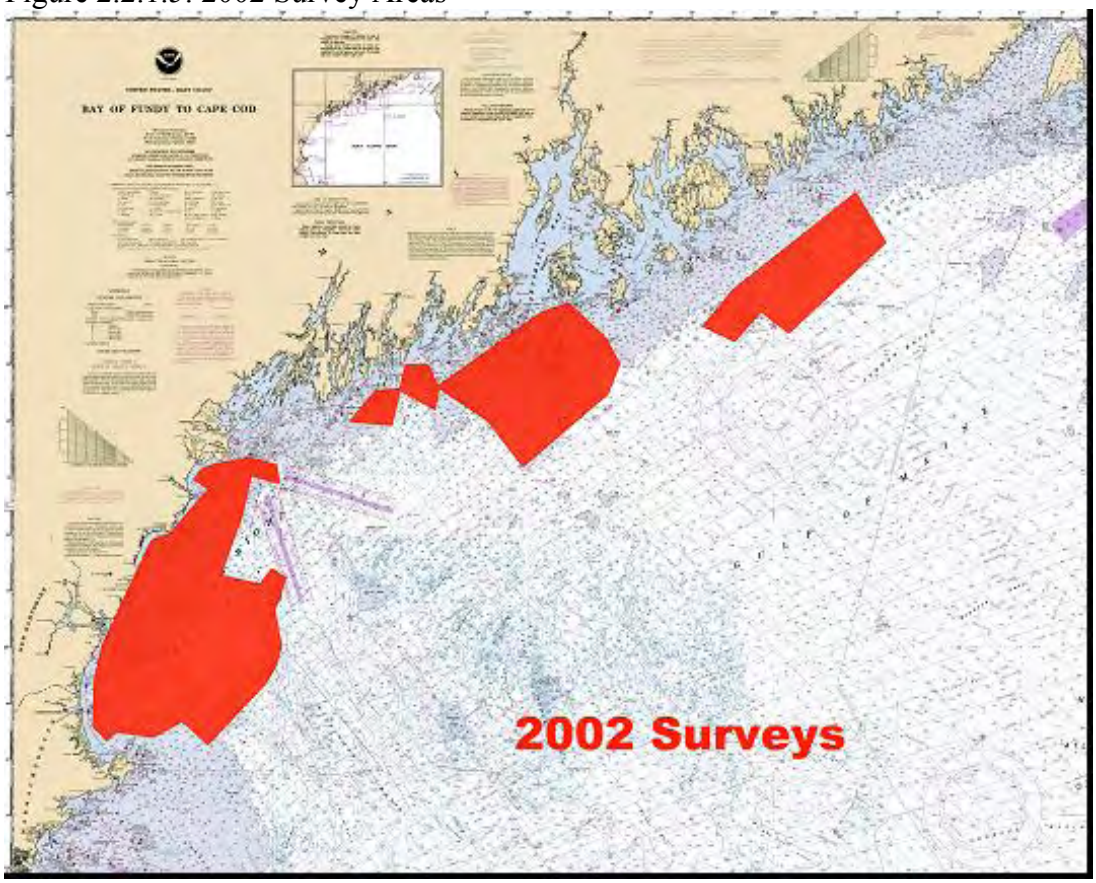


Figure 2.2.1.6: 2003 Survey Areas

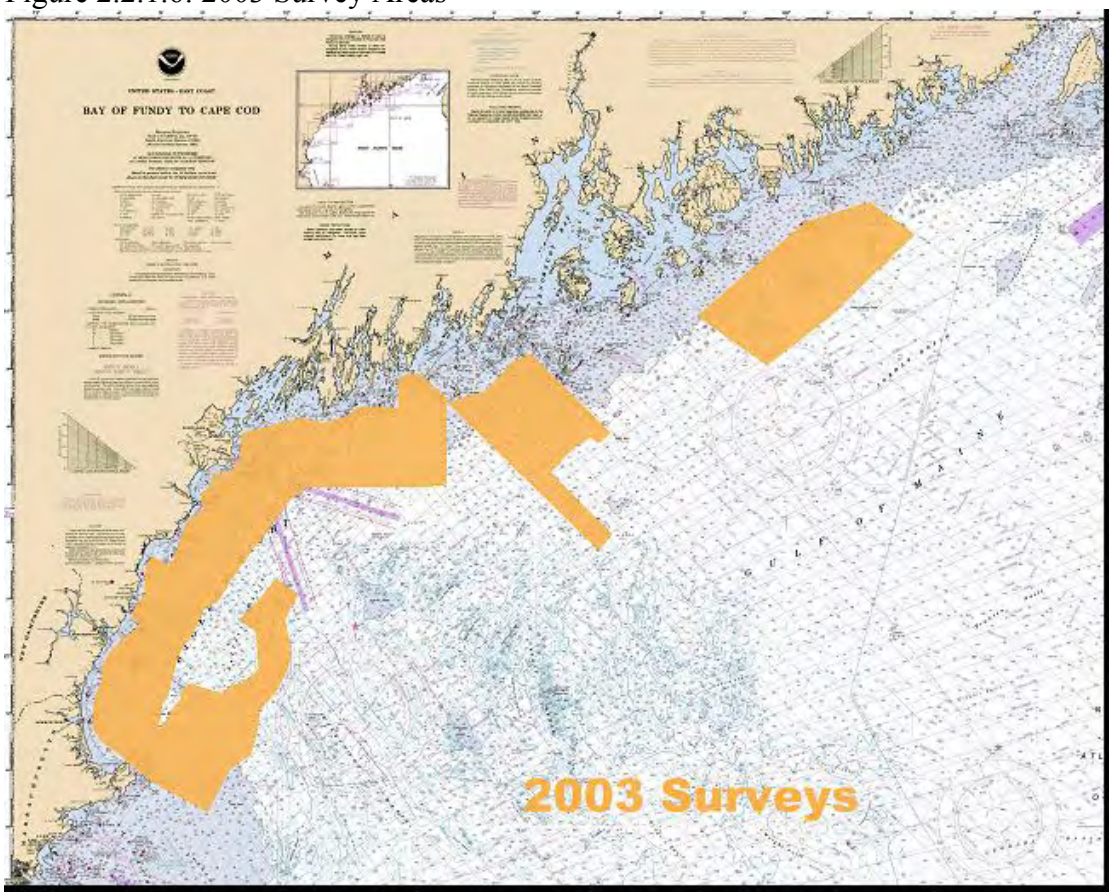
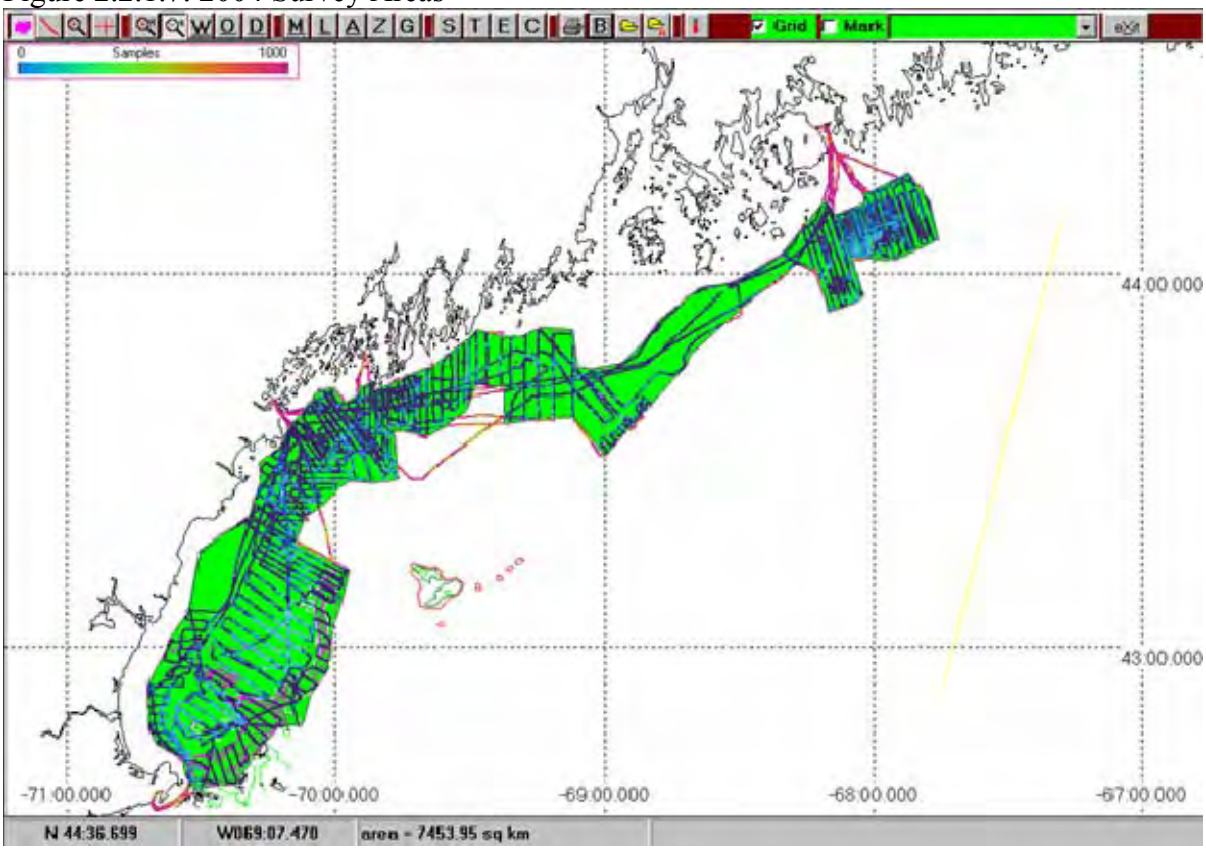


Figure 2.2.1.7: 2004 Survey Areas



*2.3. **Transect design***

From 1999 – 2000, planned survey transects were plotted in Femto's Hydroacoustic Data Processing Software (HDPS) and the waypoints entered into the vessels' plotter. Planned survey transects have been plotted as routes in Maptech's Chart Navigator software since 2001. These routes are easily imported into a vessel's Maptech Offshore Navigator software. If the vessel uses WinPlot or another type of software, the waypoints are entered manually before the survey can be conducted. The actual placement and planning of the transects may have taken place in a meeting among survey personnel well ahead of surveys, or only hours in advance of the survey if new information becomes available. Transects often are shifted inshore or offshore, depending on the distribution of fish schools or the location of lobster gear. Transect length may be extended or shortened mid-survey to match aggregations of fish. On occasion, adaptive surveys have been conducted. For example, in 2003, a known spawning aggregation was located just off Portland (10/8/2003 Portland Lightship). Ad hoc parallel transects were run north to south and east to west over the aggregation (Figure 2.3.1).

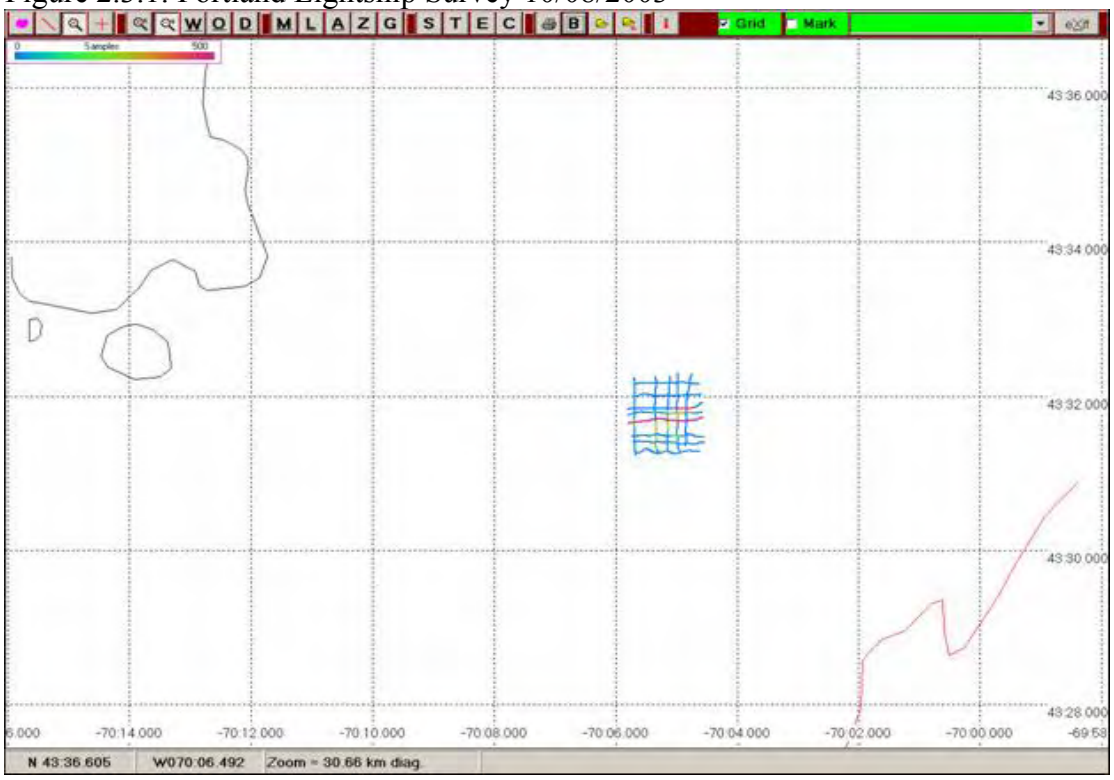
The type of transect employed has changed over time. Surveys have been conducted using parallel and zig-zag transects. The current approach used in 2003 and 2004, is regular parallel transects spaced 1-2 miles apart. The rational for the transect designs used from 2000 to 2002 is found in the following excerpt from the 2001 funding proposal to the NEC:

"Each survey will consist of a series of transects fit within the rectangular area of the stratum. Our preferred survey design consists of a set of evenly-spaced, straight transects oriented parallel to each other and to the short axis of the stratum, with the position of the first transect randomly determined. This design is considered optimal when fish aggregations can be expected to be randomly distributed within the stratum, and hence with respect to the transects (Simmonds et al., 1991). Transect spacing can be adjusted to accommodate a range of sampling intensities.

When scheduling concerns (e.g., weather, the need to perform multiple surveys within a restricted time frame) require us to cover larger areas more efficiently, we may sometimes employ a zigzag transect design that does not include travel legs between transects. The one weakness of this design (potential double-sampling of aggregations located near the ends of transects) can be minimized by extending each transect outside of the stratum boundaries (Simmonds et al., 1991), while still yielding more efficient coverage of the area."

To model the survey design used by the NMFS acoustic survey on Georges Bank, parallel transects were re-introduced starting in 2003. Comparisons of parallel and zig-zag transect designs conducted on Georges Bank by the NMFS acoustic survey showed that there was no significant difference between the two methods in biomass or variance. Systematic parallel transects are most likely the best approach for precise abundance estimation, even though the random parallel design improves variance (Michaels et al, 2001; Rivoirard et al, 2000).

Figure 2.3.1: Portland Lightship Survey 10/08/2003



2.3.1. Maps of transects by year

Figure 2.3.1.1: 1999 Transects - Pre-planned and adaptive transects were employed using parallel and zig-zag designs.

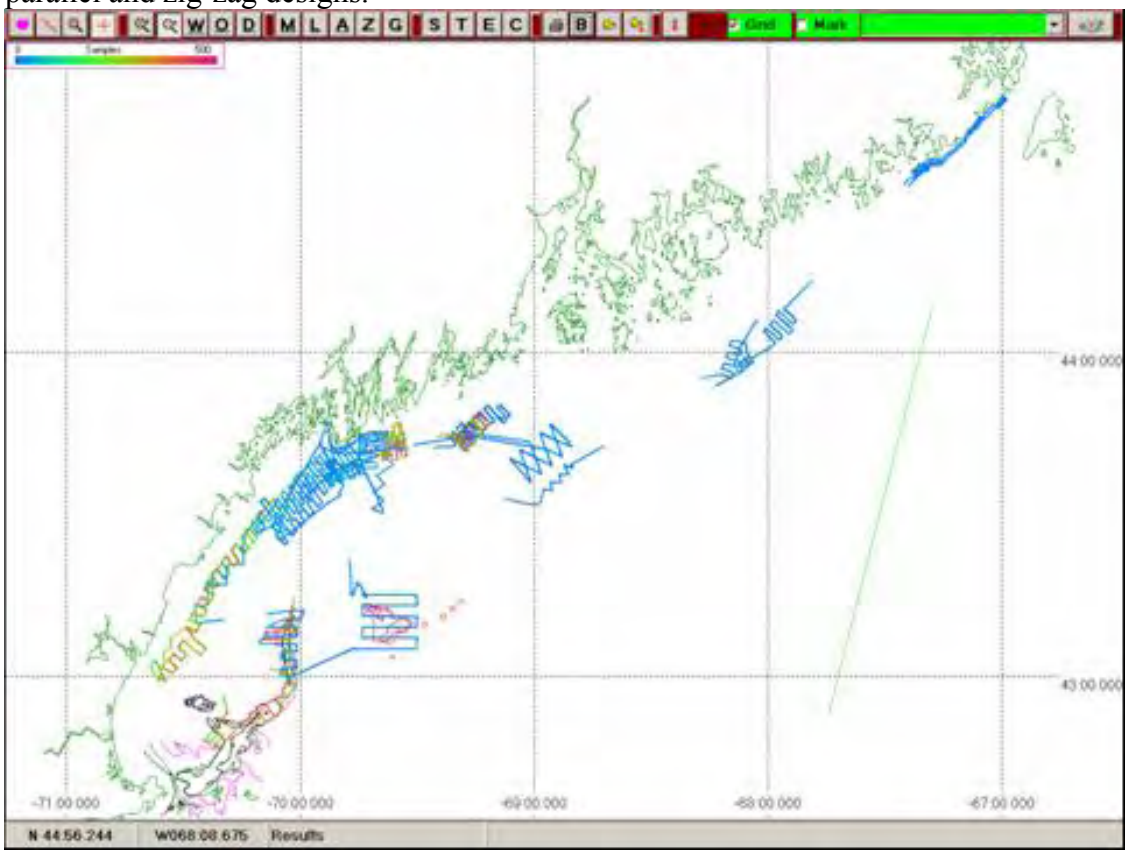


Figure 2.3.1.2: 2000 Transects - Pre-planned transects were employed using zig-zag design.

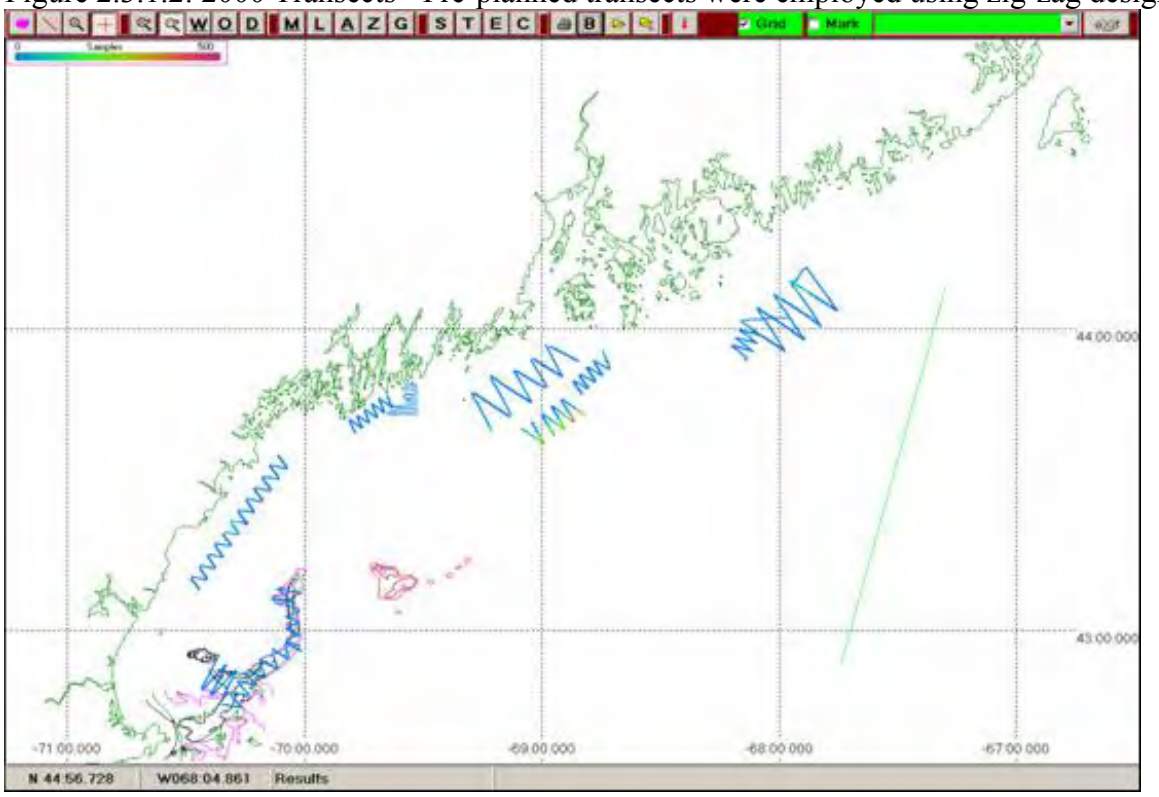


Figure 2.3.1.3: 2001 Transects - Pre-planned transects were employed using zig-zag design.

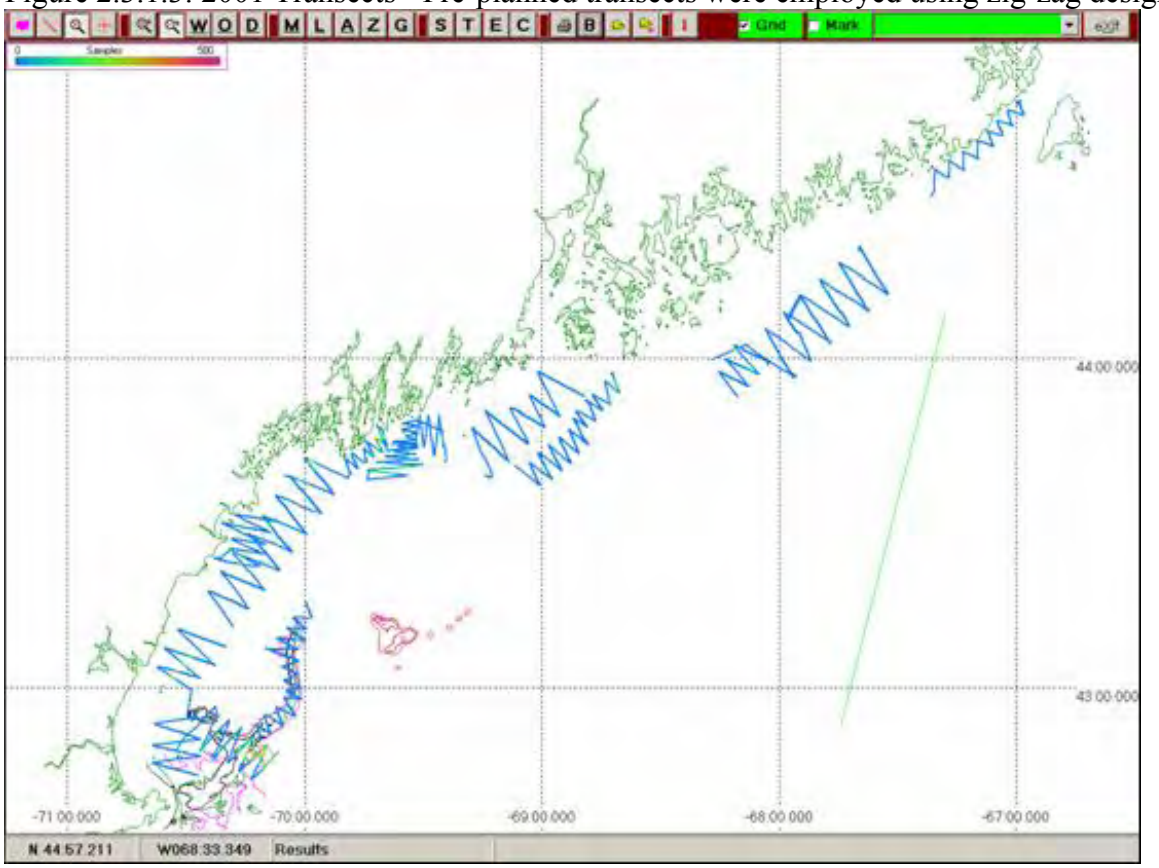


Figure 2.3.1.3: 2002 Transects - Pre-planned and adaptive transects were employed using zig-zag and parallel designs.

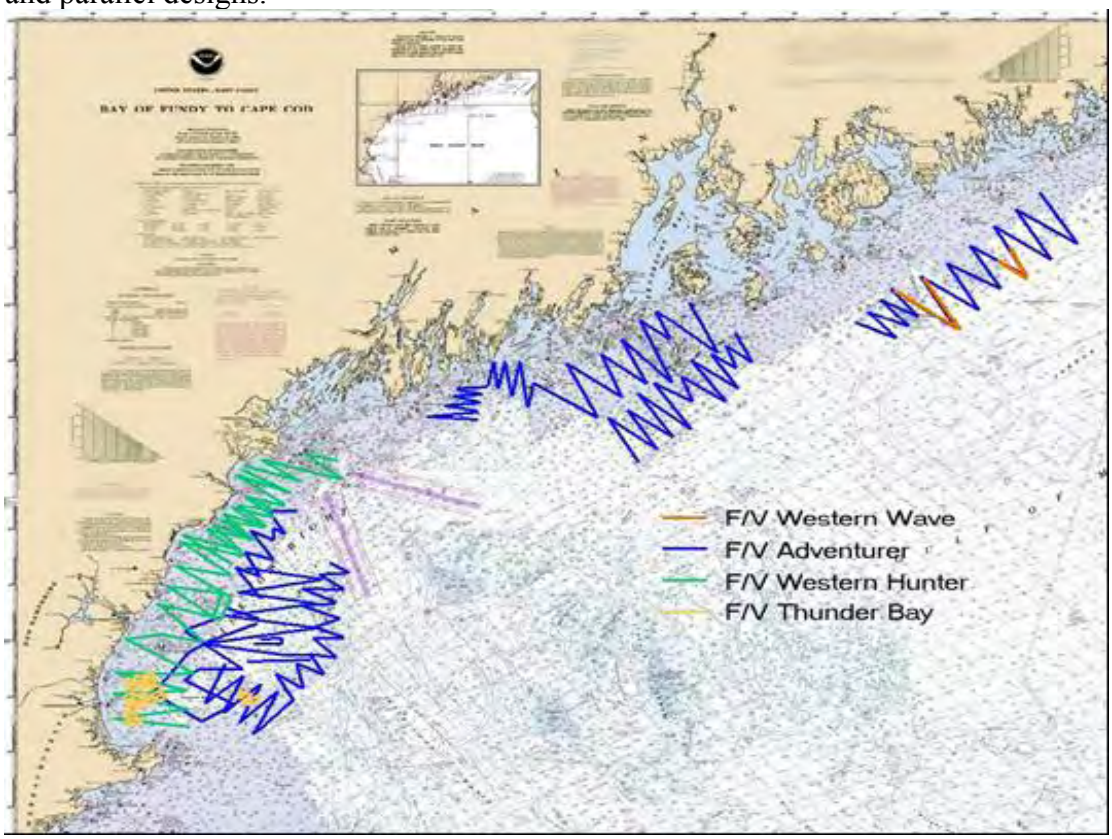


Figure 2.3.1.5: 2003 Transects - Pre-planned and adaptive transects were employed using parallel design with 1-2 mile spacing.

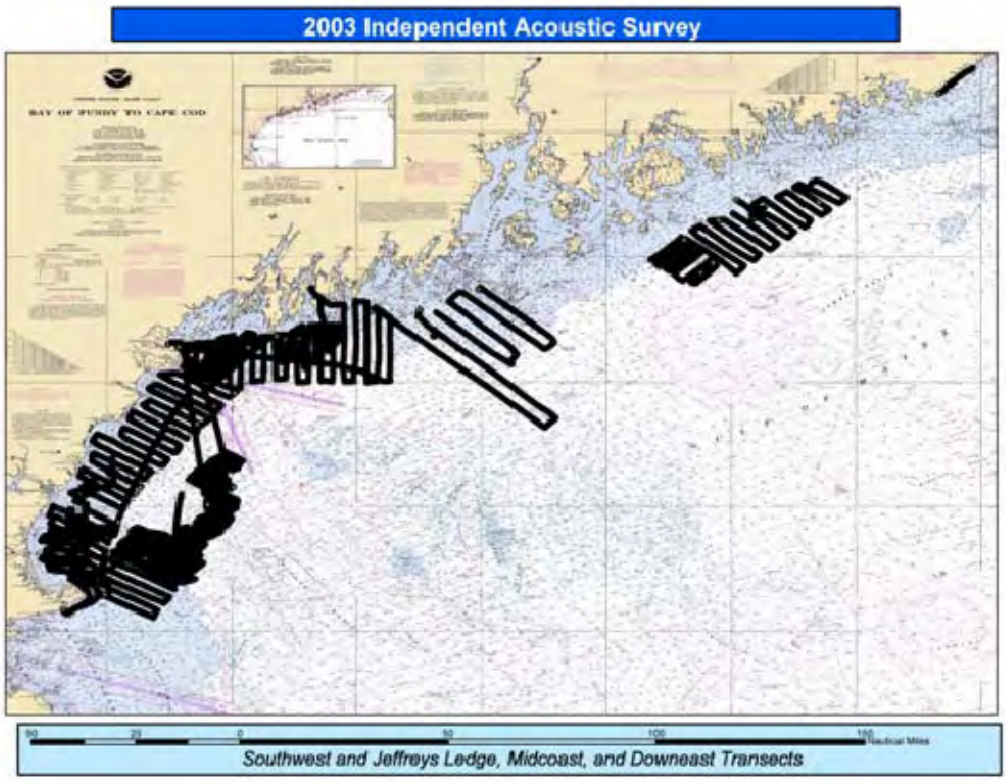
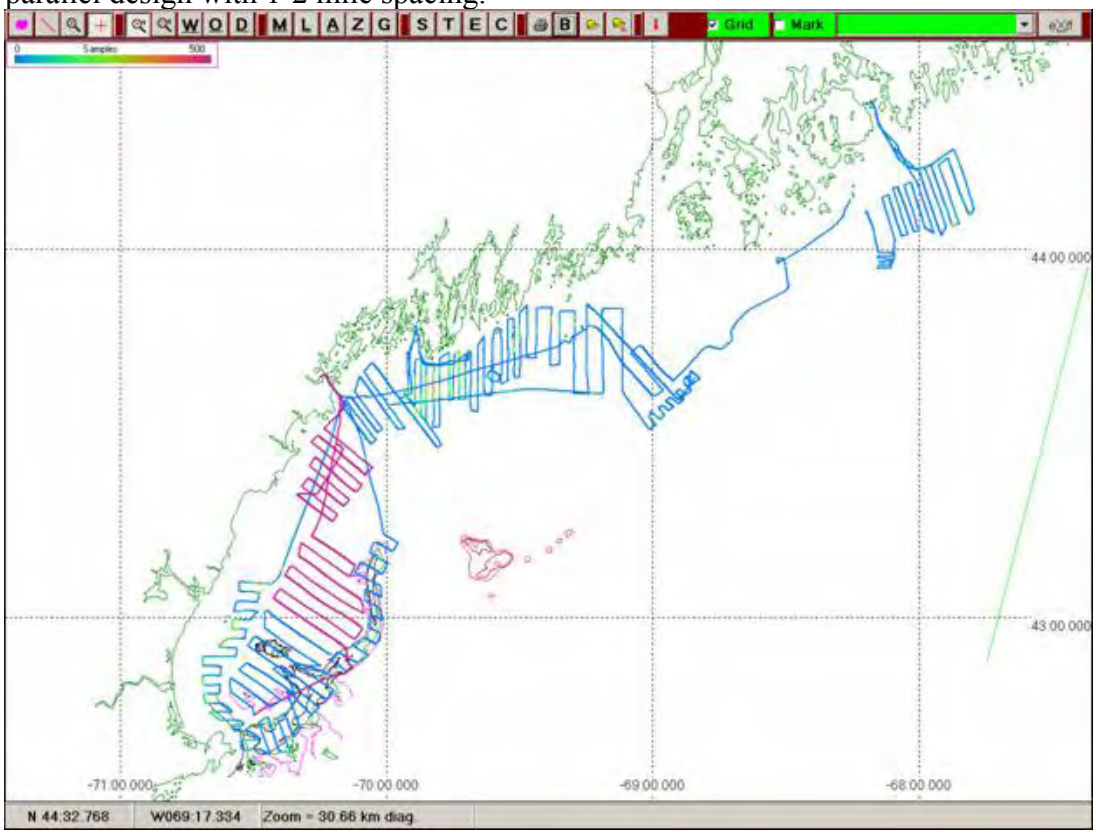


Figure 2.3.1.6: 2004 Transects - Pre-planned and adaptive transects were employed using parallel design with 1-2 mile spacing.



*2.4. **Survey Timing***

2.4.1. Survey Start and End

The start of surveys has varied by about three to four weeks each year (Table 2.1.1). The ability to start surveys has been dependent on funding, calibrations of survey vessels, and other non-biological factors. In addition, the maturity of herring in commercial catch samples often influences where and when surveys start. If stage 4 or 5 herring are caught in an area, surveys are targeted around the general location of the fishing trip. If information from the fishery provides no guidance, a general start time of the first week in September has been observed. This has occurred most often when spawning closures are in effect.

Surveys end when the number of days of funding runs out or the vessel contract is satisfied. The option to extend or cut short the vessel contract days is reserved by GMRI. Apart from this, surveys end in late October or early November when herring are generally finished spawning and are migrating south. Migrating fish have been surveyed in most years, and it is always difficult to determine what surveys have covered spawning fish towards the end of the survey season. Patterns of southern migration are not clear, and information from the herring industry is valuable in this respect. We rely on samples to detect the presence of resting fish in an area surveyed. If stage 8 fish are present, it is likely that they have migrated from another area and cannot be included in the total biomass estimate.

2.4.2. Mid-season Timing

Areas are often surveyed twice to attempt to cover fish that might be spawning. An amount of uncertainty usually accompanies these re-survey efforts, and information from the herring fishery influences where and when surveys take place. Again, this source of information is affected by the timing of month-long spawning closures. A log of conversations with herring vessel captains and DMR biologists was kept in 2004, to track how information was acted on. Some captains tend to be secretive if they have found spawning fish and will only share that information after the fish have spawned and left the area. Attempts have been made to contact members of the lobster and groundfish fleets for information on sightings of herring schools or of herring eggs sticking to gear, but this has gained limited information. In 2004, a lobster boat equipped with sonar was contracted to search areas before surveys were conducted there. This approach did not target spawning fish well, but it did help to avoid surveying where there were no herring aggregations.

A strict schedule has never been followed given that new information about potential spawning herring aggregations will influence the decision of where to survey next. Numerous other issues such as weather, a vessel's fishing schedule, or difficulty in acquiring crew also have played a role in timing surveys. In 2002 for example, a vessel that had agreed to conduct surveys during weekends out of the fishery backed out just before surveys were to begin. Eventually two other herring vessels were found to conduct surveys, but their fishing schedules often conflicted with plans to survey. Weather plays a role every year, because for the most part, the vessels we use for surveys are not able to steam on transects in rough seas (i.e. over 6 ft.) and avoid noise at the transducer surface.

2.4.3. Time of Day

Experiments were conducted in 1999 to determine the difference between surveying fish at night or during the day. The following is an excerpt from Rosen et al (2001):
"A series of repeat day and night surveys of the same area were conducted in 1999, and indicated the night-time surveys consistently yielded larger estimates of biomass. The likely explanation for this discrepancy, described in Yund (2000), is that herring are located close to the bottom during the day, and cannot be resolved from the bottom by the acoustic equipment. During the night, the same fish come off bottom to feed and can be more readily observed acoustically."
This pattern of vertical migration seems to continue, so surveys are conducted at night, from around 1800 to 0600 hours.

3. Survey Operations

3.1. Femto Electronics DE9320 Hydroacoustic System

3.1.1. Annual System Configurations

3.1.1.1. 1999

"Acoustic data were logged and stored aboard the F/V Mary Ellen using Femto Electronics Limited's DE9320 digital echosounder in conjunction with a PC-based J3920 Transceiver Logging Module. Data were subsequently downloaded to a shore-based computer at the Darling Marine Center where they were archived to permanent media (CD-R) and post-processed using Femto's Hydroacoustic Data Processing System (HDPS).

The DE9320 digital echosounder vertically integrated acoustic signal coming directly from the Furuno 50B12 50 kHz single beam transducer in 0.05 m increments. During post-processing in HDPS the volume backscatter (s_v) was averaged over 0.1m increments and a TVG correction is applied. The volume backscatter was then vertically integrated from a range of 10 to 200 meters below the surface. The transducer beam configuration was conical with a 10 degree angle."(FV Mary Ellen data.doc, 1999; GMRI Herring Project file)

3.1.1.2. 2000

"The vessel was equipped with a FEMTO DE9320 digital echosounder interfaced to a FEMTO 75 KHz transducer and customized datalogging PC. The system was calibrated according to the procedure outlined in Yund (2000) and described in 3.1.3. The transducer was initially mounted to a pole clamped to the side of the vessel. While this mounting system worked well in open water, we encountered major problems when operating around fixed gear (lobster pots and gillnets). During the first leg of the survey (August 21-26) the pole was first bent nearly double (subsequently straightened and re-deployed), then snapped off completely. On both occasions the transducer was recovered without damage and repairs were made without substantial loss of survey time. Fearing the chance of catching fixed gear would increase as the pole was lowered further into the water, the transducer was kept approximately two meters below the surface. This led to problems with cavitation of air bubbles beneath the transducer in rough seas. Two weeks into the survey season F/V Adventurer was hauled out of the water and the transducer mounted to the vessel's hull. This eliminated the problem of the transducer catching on fixed gear and increased the vessel's ability to conduct surveys in rough weather." (Rosen et al, 2001: pp. 5-6) *The system was not calibrated in this configuration until the summer of 2001.*

3.1.1.3. 2001

"Our principal research vessel was the F/V Adventurer; fitted with a hull mounted 75 kHz Femto transducer interfaced with the standard Femto DE9320 echosounder system. The portable system, with its dual 40 kHz / 120 kHz transducer, was also deployed from F/V Adventurer during five survey nights. Entanglement with fixed gear off Cutler snapped the towed body's protective nose cone on September 5. Repairs were performed while at sea and the system was re-deployed the following night. The transducer's coaxial data cable was damaged during a subsequent encounter with fixed gear on September 10. The cable was repaired during the next port call. The failure of a shackle on the main towing cable on September 24 snap-loaded the

data cable and cracked its urethane jacket. Water entered the cable and was wicked into the transducer. The transducer was returned to the manufacturer where it was determined that no significant damage was sustained." (July-Oct2001news.doc: pp. 1-2; GMRI project update)

"Western Wave was originally part of our fishery dependent survey project, and was fitted with a hull mounted 75 kHz Femto transducer for this purpose in 1998. It was decided the data collected was of little value and the sounder and logging computer were removed in October 2000. The 75 kHz transducer was not removed and communications with the vessel's crew indicated it was not being used. We used the transducer in conjunction with the electronics package assembled for the portable system (GPS, sounder and logging computer) for our surveys." (July-Oct2001news.doc: p. 3; GMRI project update)

3.1.1.4. 2002

The F/V Adventurer continued to use the 75 kHz system with the hull mounted transducer installed in 2000.
The F/V Western Hunter used the 40/120 kHz dual frequency system with the towed body. The cable was snapped on one survey night, but reliable data were collected on other survey nights.
The F/V Thunder Bay was outfitted with a Femto 75 kHz system in July 2002, and the vessel conducted surveys in late October and early November.

3.1.1.5. 2003

The F/V Adventurer again used the Femto 75 kHz system effectively, and the F/V Jennifer & Emily used the same system as well.
The Western Wave's 75 kHz system continued to function well and was used for the one night of survey the vessel conducted.

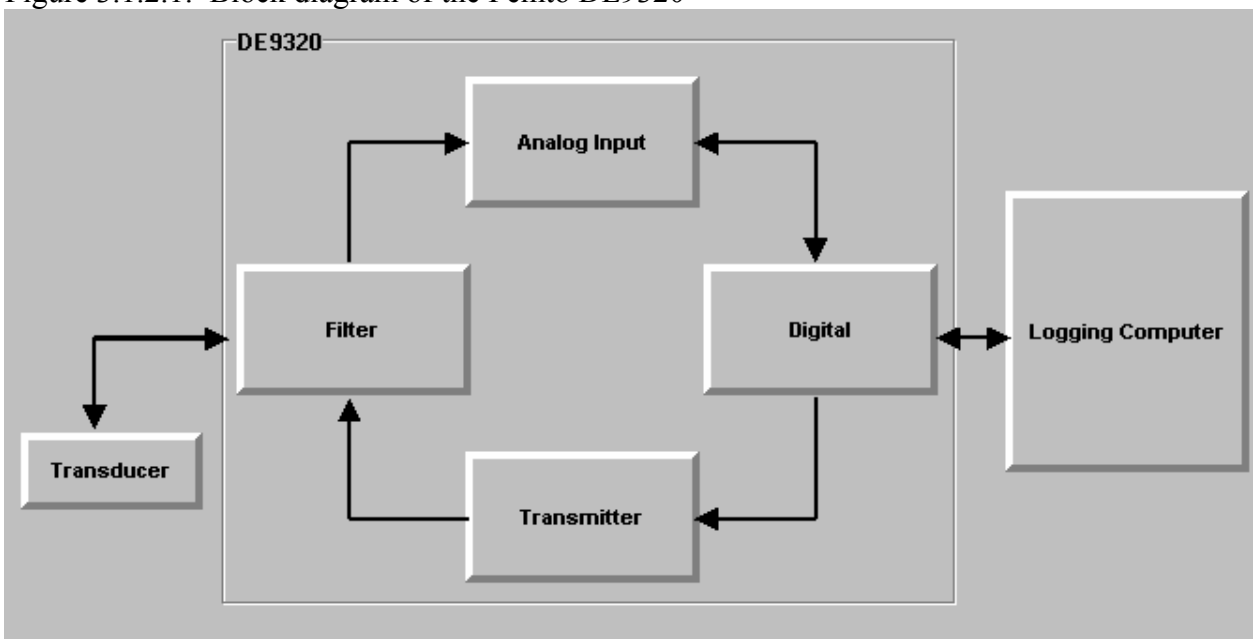
3.1.1.6. 2004

The Jennifer & Emily 75 kHz system performed well and had a good calibration in July 2004.

3.1.2. Electronics and connections diagrams

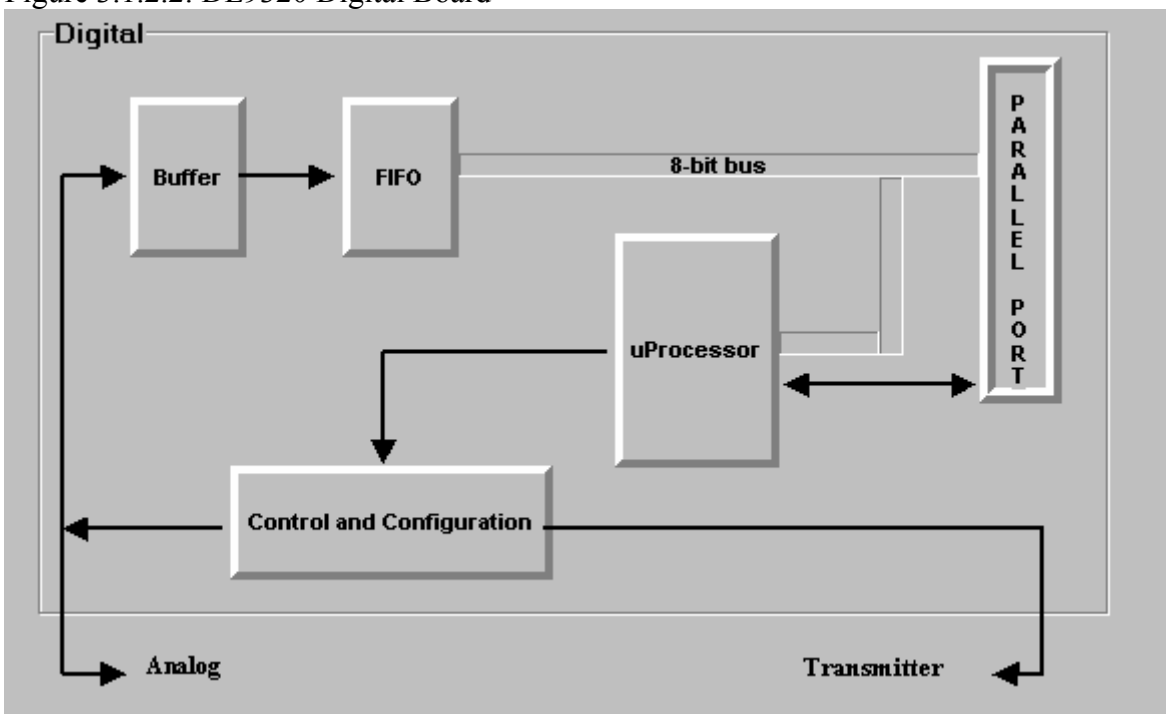
The heart of the acoustic system is the Femto DE9320 Digital Echosounder. This unit is designed to be interfaced with a general purpose personal computer and a variety of transducers. The DE9320 sends a pulse to the transducer and digitizes the echoes under the control of the logging computer. The DE9320 consists primarily of four printed circuit boards as shown in Figure 3.1.2.1.

Figure 3.1.2.1: Block diagram of the Femto DE9320



The **Digital Board** (Figure 3.1.2.2) is responsible for the communication with the logging computer and the control of the DE9320. To accomplish these functions, a microprocessor is employed. To interface the synchronous A/D with the asynchronous nature of the logging computer, a FIFO buffer has been employed.

Figure 3.1.2.2: DE9320 Digital Board



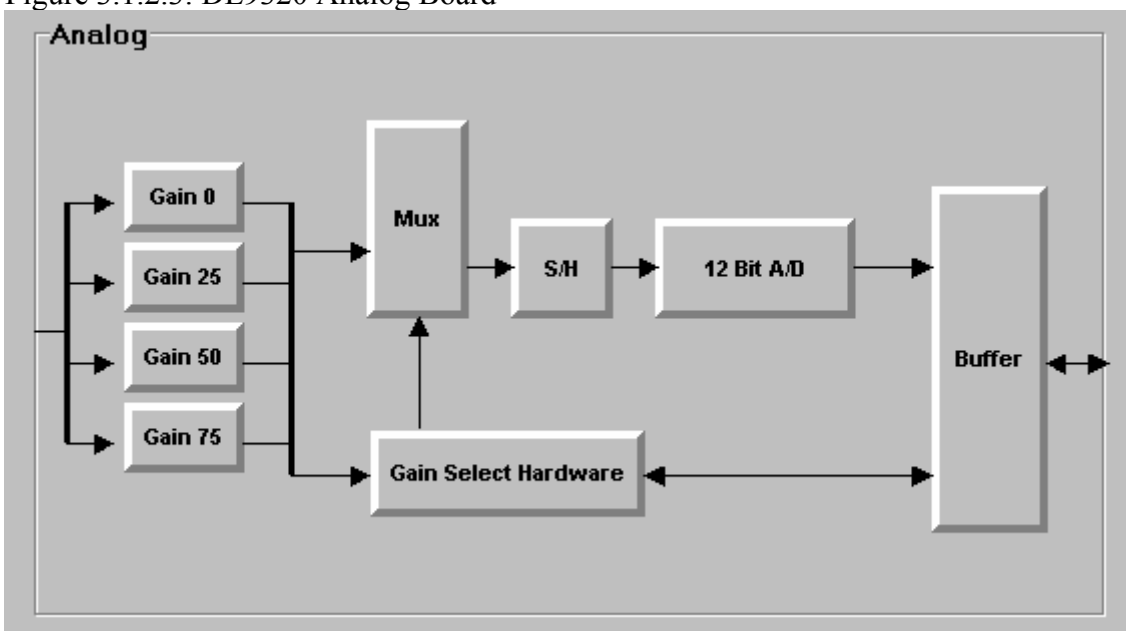
When commanded to do so by the logging computer via the parallel port, the microprocessor sends the appropriate transmit command to the transmitter board to initiate a transmit pulse. It then sets up the communication channel with the logging computer to receive the data.

The microprocessor, through the Control and Configuration circuitry then provides the step by step sampling process of selecting the correct gain of the preamps, multiplexing the input signal, sample/holding the signal, converting the signal to digital, and loading the resulting gain and amplitude to the FIFO.

This process is repeated for each ping. A number of diagnostics functions and specialty configurations are available for different applications.

The **Analog Board** (Figure 3.1.2.3) is responsible for digitizing the analog signal from the transducer. To accommodate the large dynamic range of the transducer, it was necessary to create an A/D converter hybrid that had 4 fixed gain stages and a 12 bit converter. As the signal is received from the transducer, it is buffered by two ultra low noise preamp stages, one with 0dB gain and the other with 50dB gain. The output of each of these preamps is directed to two ultra low noise amplifiers; one with 0dB gain and the other with 25dB gain. The combination of these two stages provides four individually gained results with identical input impedance.

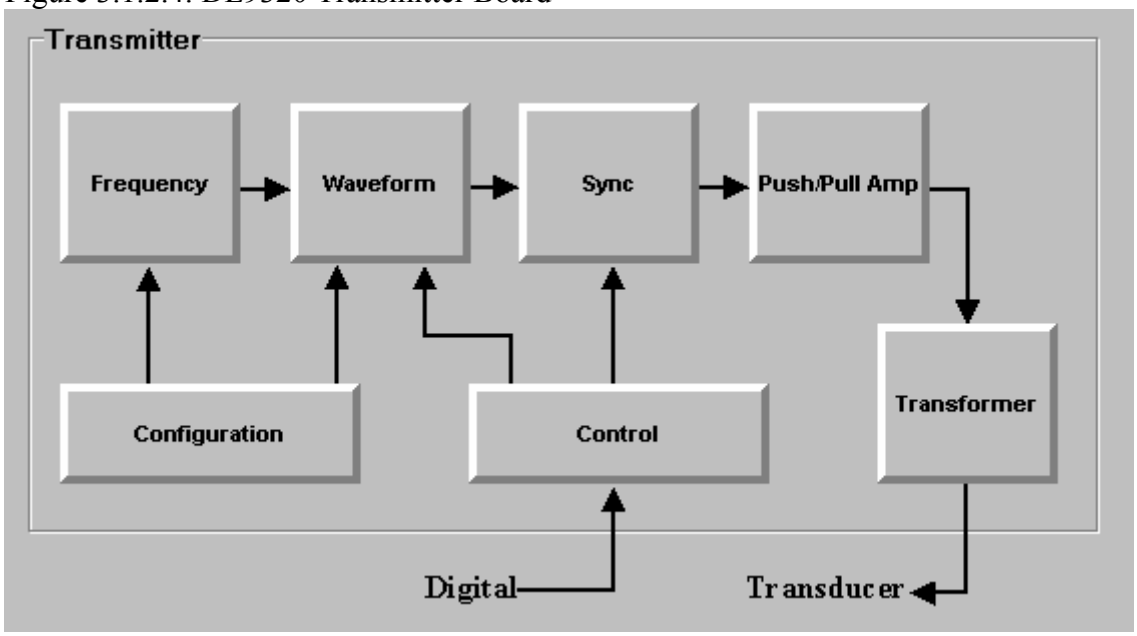
Figure 3.1.2.3: DE9320 Analog Board



Each gain stage is then followed by an envelop detector consisting of an active full wave bridge and filter. The outputs of the envelop detectors are tested by the Gain Select Hardware to determine which output is most appropriate to digitize. This output is then channeled through the Mux to the Sample and Hold and on to the A/D converter. The results of the conversion along with the identification of the gain stage are buffered and sent to the Digital Board for output to the logging computer.

The **Transmitter Board** (Figure 3.1.2.4) is responsible for sending the high-energy pulse to the transducer on command from the digital board. The base frequency is continually generated and sent to the waveform generator. The waveform generator takes this symmetrical square wave and adjusts the waveform to drive the push-pull amplifier. The transmit pulse from the digital board controls the duration of the pulse. The frequency and intensity of the pulse are controlled by onboard hardware configuration. The transmit pulse is synchronized to the base frequency to ensure that the pulse does not start midway through a base waveform.

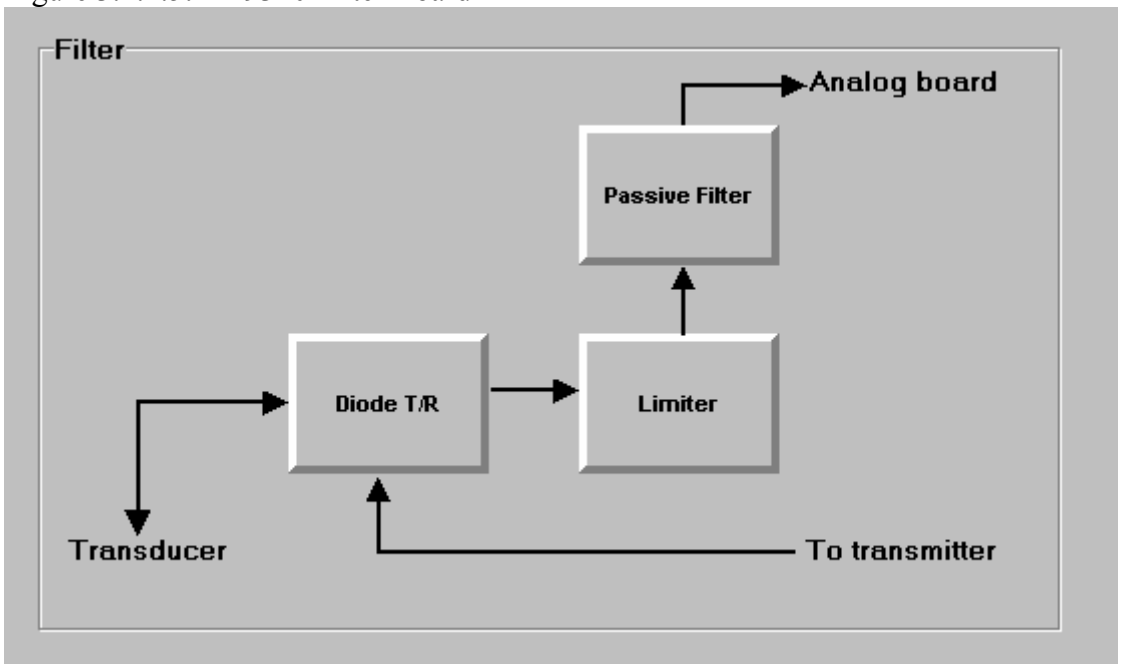
Figure 3.1.2.4: DE9320 Transmitter Board



The resulting transmit signal is sent to a high energy push/pull amplifier which drives a custom pulse transformer. The output of the pulse transformer is sent to the transducer via the T/R switch of the Filter Board.

The **Filter Board** performs two functions. Its primary function is to filter out unwanted frequencies from the incoming signal before passing it on to the analog board. It also provides the Transmit/Receive (T/R) switch that protects the receiver (analog board) from the high power transmit pulse from the transmitter board by using a voltage limiting circuit.

Figure 3.1.2.5: DE9320 Filter Board



3.1.3. Calibration

There are four steps to doing a complete calibration and creating a calibration file:

1. TVG Calibration (The user may choose):
    a. Actual calibration data using an injected target signal
    b. Artificially generated ideal TVG function
    c. DE9320 Digital TVG
2. Ball Calibration - To account for errors in SL and RS
3. Integration Factor Calibration
4. Beam Angle Calibration

3.1.3.1. Calibration #1 - TVG Calibration

3.1.3.1.1. Known Input Method

If an actual TVG calibration is necessary the user must create a data file with a known input. If a ball calibration is to be performed, the absolute value of the input is not critical as long as the ratio between the various levels is accurately known. To create this file, first make sure the logging configuration is set to log with:

Narrow Beam(ch0) Enabled	Wide Beam(ch1) Disabled
Noise Disabled	Sample Rate = 7.5 KHz
Sample Window 1 to 600M	Sample Continuous
Bottom Window 1 to 600M	False Bottom

Disconnect the receiver input and connect a calibrated AC signal generator capable of providing the transducer resonant frequency. Make sure the output of the signal generator is isolated from the transmit pulse! The receiver TVG must be set to the same parameters as used to collect the raw data that is to be analyzed.

Set the transmitter to transmit at a prr of 60 pings per minute.	
Log data using a known input voltage (0.4Vrms) for pings	1..20
Reduce the input by 10 dB for pings	20..40
Reduce the input by another 10 dB for pings	40..60
Reduce the input by another 10 dB for pings	60..80
Reduce the input by another 10 dB for pings	80..99

3.1.3.1.2. Ideal TVG Method

If the user wishes to assume that the sounder TVG is correct (i.e. ideal), the user may bypass the actual TVG correction by selecting the menu item to create an ideal TVG calibration file. This is sometimes selected for digital sounders of which TVG's are implemented in software. Analog sounders, however, are notorious for having less than ideal TVG's and the user is cautioned to always do a TVG calibration on these sounders. When choosing the ideal TVG fixed gain remember that 0dB gives a constants file consisting of all 1's which ensures that the results are not effected by the calibration file. The user may wish to create an ideal TVG with a gain of 0dB to use when checking the processing results.

3.1.3.1.3. DE9320 Digital TVG Method

If the DE9320 is used to collect the acoustic data, the TVG is precisely known as a table of digitally stored factors. No calibration is necessary.

3.1.3.2. Calibration #2 - Ball Calibration

The most widely accepted method of calibrating a sounding system is using a ball calibration. The TVG calibration discussed above creates a set of correction factors at 0.1 meter intervals that fit the curve of the TVG. The ball calibration is used to provide a fixed gain offset to this curve. The procedure simply involves logging a file of data with the calibration sphere on the acoustic axis of the transducer at a range of at least twice the transition range of the transducer. This file is then processed for target strength.

The frequency distribution of TS is reviewed to determine the amount by which the estimated TS of the sphere varied from the known TS of the sphere. This correction, computed as:

Correction (dB) = Estimated TS(dB) - Known Sphere TS(dB)

is applied to the TVG calibration file as a fixed gain.

At this point, the system is now calibrated for TS work but not for Integration work.

3.1.3.3. Calibration #3 – Integration Factor Calibration

Having completed the ball calibration, the next step is to calculate the correction factor for the integration analysis to account for the non-square waveform of the returned echo due to electronic and acoustic filtering as well as electrical mismatch between the transducer and transmitter. This factor typically lies between 0.7 and 1.2 (1.0 for an ideal square wave). Failing to evaluate and incorporate this factor will, in most cases, cause HDPS to underestimate the biomass.

In order to ensure that this process produces an accurate result, the operator must ensure that the integrated ball file contains a representative ball echo and only the ball echo in each ping. This means that there can be NO empty pings and NO other echoes than those from the ball. Ping having mal-formed echoes due to other targets besides the ball must also be removed.

3.1.3.4. Calibration #4 – Beam Angle Calibration

The beam angle calibration is a procedure to ensure that the beam of the transducer is as supplied and has not been compromised by the destruction of one or more transducer elements or by the presence of nearby structures.

There are many ways to determine the health of the beam, some more robust than others. It is left to the user to determine the most practical method of calibrating the beam angle. Femto performs this test during the ball calibration by moving the ball off-axis to the 6dB down point in 6 directions on the edge of the beam and computing the angle moved by geometric methods.

The results of these calibrations from 1999 - 2004 are in Appendix I.

3.1.4. Data collection

Data are collected at a sample rate of 15000 samples per second to a resolution of 12 bits plus 2 gain bits. The gain bits identify which of the four gain stages were used to log the data. The output power of the transmitter is nominally 2Kw RMS. The transmit pulse is normally 75 KHz with a duration of 1.0 msec.

Raw data sent to the computer is converted to a 16bit dB value and saved in the Femto DE9320 format. This format consists of a file header defining the conditions under which the data were collected followed by zero or more ping records. Each ping record consists of a 40byte ping header followed by zero or more data scans. The ping headers contain information regarding record size, data, time, record type, navigational information, and auxiliary analog channel data. Each data scan consists of data whose echo strength has exceeded a user-defined threshold. This threshold is a voltage threshold as opposed to an Sv threshold since signal to noise decreases with depth due to spherical spreading and attenuation. Therefore the thresholding will eliminate very few targets at short ranges but as the depth increases, larger and larger targets will be removed. The threshold has been set at values ranging from .001 to .0001 volts for the narrow beam threshold.

The format of the scan is two to four 16bit values. The first word is the range counter to identify the depth at which the sample was taken. The second word is the echo amplitude in dB of the primary channel. The format provides for 2 other data channels which would appear after the primary channel for different applications.

The primary transducer used by GMRI is the Femto 75KHz transducer with the following specs:

Table 3.1.4.1: Femto 75kHz transducer specifications

Specifications:

75 Khz

Beam Angle	9.8
2-way Equivalent Ideal Beam	-17.7 dB
Power (Kw RMS) 2% duty	2.0
Beam Pattern	conical
PZT Elements	19
Impedance (Ohms Nominal)	70
Insertion Loss	-10 dB
Transmitting Response	172 dB
Receiving Sensitivity	-182 dB
Q (Transmit nominal)	6

The GMRI has also used the Femto Dual Frequency Transducer with the following specs:

Table 3.1.4.2: Femto Dual Frequency (40/120kHz) transducer specifications

40 Khz		120 Khz	
Beam Angle	9.2	Beam Angle	9.2
2-way Equivalent Ideal Beam	-18.3 dB	2-way Equivalent Ideal Beam	-18.3 dB
Power (Kw RMS) 2% duty	4.2	Power (Kw RMS) 2% duty	3.4
Beam Pattern	conical	Beam Pattern	conical
Barium Titanite (BT) Elements	12	Barium Titanite (BT) Elements	12
Impedance (Ohms Nominal)	70	Impedance (Ohms Nominal)	70
Insertion Loss	-7 dB	Insertion Loss	-14 dB
Transmitting Response	171 dB	Transmitting Response	172 dB
Reseiving Sensitivity	-178 dB	Reseiving Sensitivity	-186 dB
Q (Transmit nominal)	6	Q (Transmit nominal)	12

*3.2. **Biological Sampling***

Biological samples are important for determining species composition, converting acoustic signals into biomass, and evaluating spawning state or maturity. The intent during each survey was to sample major herring aggregations detected via acoustic methods. If no major aggregations were found, a sample tow was not made. Depending on the vessel used, samples were obtained by purse seine, midwater trawl, or bottom trawl. Gill nets and jigs were sometimes used if other methods prove unsuccessful or impractical.

3.2.1. Methods of sample collection, processing, and recording

No written protocols existed prior to 2003. General methods for collecting, processing, and recording samples from sample tows from 1999 – 2002 were as follows:

- Randomly sample approximately 100 fish from the catch, or collect all herring if less than 100 fish are caught.
- Record species of bycatch if possible
- Ice or freeze fish for processing at the dock or in the lab (scales do not work on vessels)
- Measure fish to the nearest 1 or 5mm in total length (no standardization; lengths are rounded to the nearest 5mm for length frequency and target strength calculations)
- Weigh fish to the nearest 0.1 – 0.01 g (no standardization)
- Weigh gonads to nearest 0.1- 0.01 g (no standardization)
- Determine sex and ICNAF gonad development stage (these data were not always recorded; fish were often recorded as simply not spawning or juveniles)
- Record all data on paper data sheets to be entered in Excel later

Inconsistencies existed in sample processing and recording. Table 3.2.1.1 summarizes what and how sample attributes were recorded by year. ICNAF gonad development stages (2-8) are somewhat subjective and can be hard to determine in the field. If the sample processor was unsure of the stage, the fish might have been recorded as a range of stages (>3<4, 3+, 5-, etc), not spawning, juvenile, virgin, or spawning.

Table 3.2.1.1: Sample Processing and Recording Methods by Year and by Attribute

Year	Nearest Length	Nearest Weight	Sex	Maturity/Stage#	Gonad Wt
1999	1 mm	0.1 g	NA	N,">#<#"3-8	NA
2000	5mm	0.1g	M/F	3-7, "+"	NA
2001	5mm	0.01g	M/F	No, 3-"spent"	0.01g
2002	5mm	0.01g	M/F	Juv, 2-8	0.01g
2003	1-5mm	0.1g	M/F, 1/2	J,V,1-8, "+"	0.1g
2004	1-5mm	0.1g	M/F	1-8, "+,-"	0.1g

Key: NA=not measured; **Maturity/ICNAF gonad development stage 2-8:** ">#<#" = >3<4, etc; "+,-"= 3+, 4+,5-, etc; N=not spawning; V=virgin; J/Juv=juvenile; "spent" = 7, 8

The coordinates and times of sample tows were sometimes entered in paper logbooks, but generally, the acoustic data were relied on for tow information. More specific logbook information began to be recorded in 2001. Percentage of bycatch was sometimes recorded as well. Bycatch differs among gear types, and the largest amount of bycatch was generally observed in bottom trawls. Large catches of dogfish have occurred however in midwater trawls and purse seine sets. The rationale for the approach to accounting for bycatch is found in the following paragraph:

"The most common by-catch in samples of herring aggregations are spiny dogfish (*Squalus acanthia*) and Atlantic mackerel (*Scomber scombrus*). Both dogfish and Atlantic mackerel lack a swimbladder and generate a considerably weaker signal than herring (Clay and Castonguay, 1996). Silver hake (*Merluccius bilinearis;* also known as whiting) have an acoustic signal more similar to that of herring, and can be locally abundant, but are usually rare on spawning grounds." (Herring acoustics NEC proposal, 2001: p. 7)

Protocols for biological sampling were developed in 2003 and 2004, in an attempt to standardize survey operations. These protocols are still being revised and improved and are found in Appendix II.

3.2.2. Length frequencies from survey biological samples

Length frequencies are useful in understanding the size distribution of herring schools encountered by the survey each year. In every year from 1999 to 2004, this size distribution included both juveniles and adults, ranging in length from 60mm to 320mm. An important aspect of the sampling to note in examining the length frequencies is the trend from bottom sampling in 1999 and 2000, to a mix of bottom and midwater sampling from 2001 to 2003, and midwater sampling in 2004 (Table 3.2.3.1). The following figures show the length frequencies from the combined annual survey samples, and do not include any commercial surrogate samples.

Figure 3.2.2.1: 1999 Survey Sample Length Frequencies

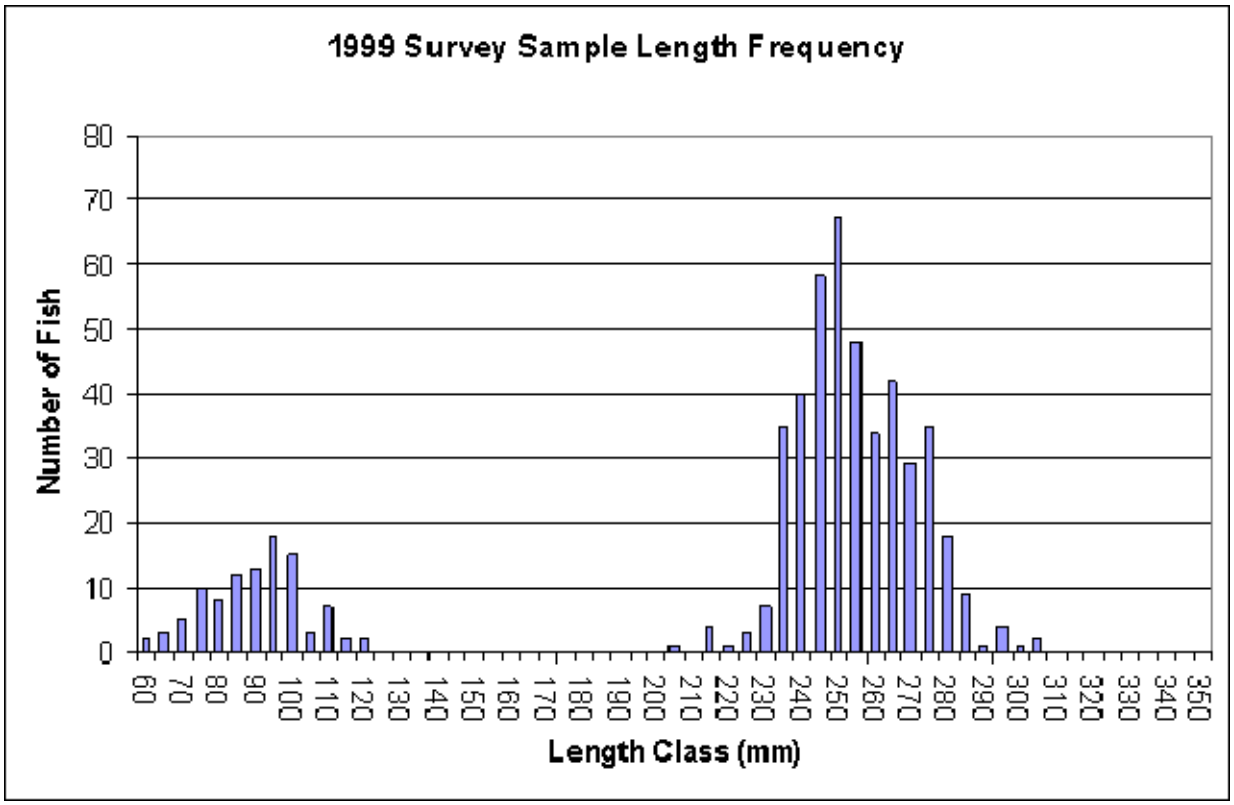


Figure 3.2.2.2: 2000 Survey Sample Length Frequencies

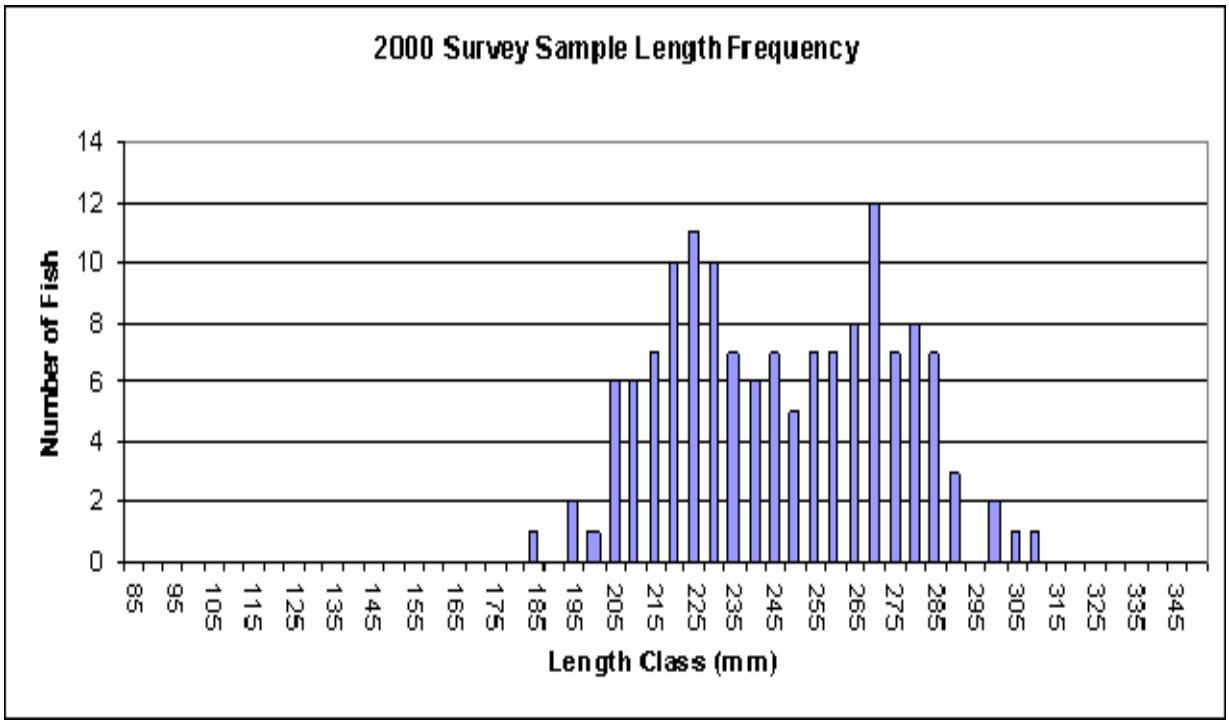


Figure 3.2.2.3: 2001 Survey Sample Length Frequencies

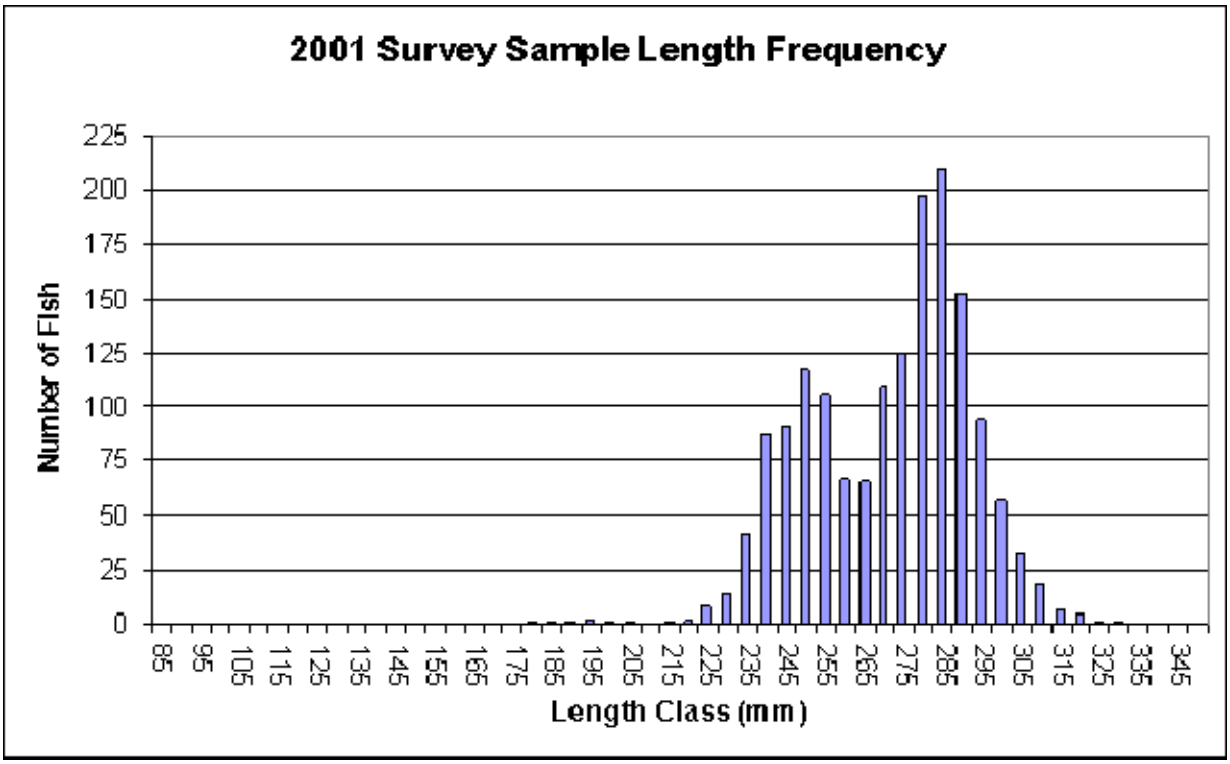


Figure 3.2.2.4: 2002 Survey Sample Length Frequencies

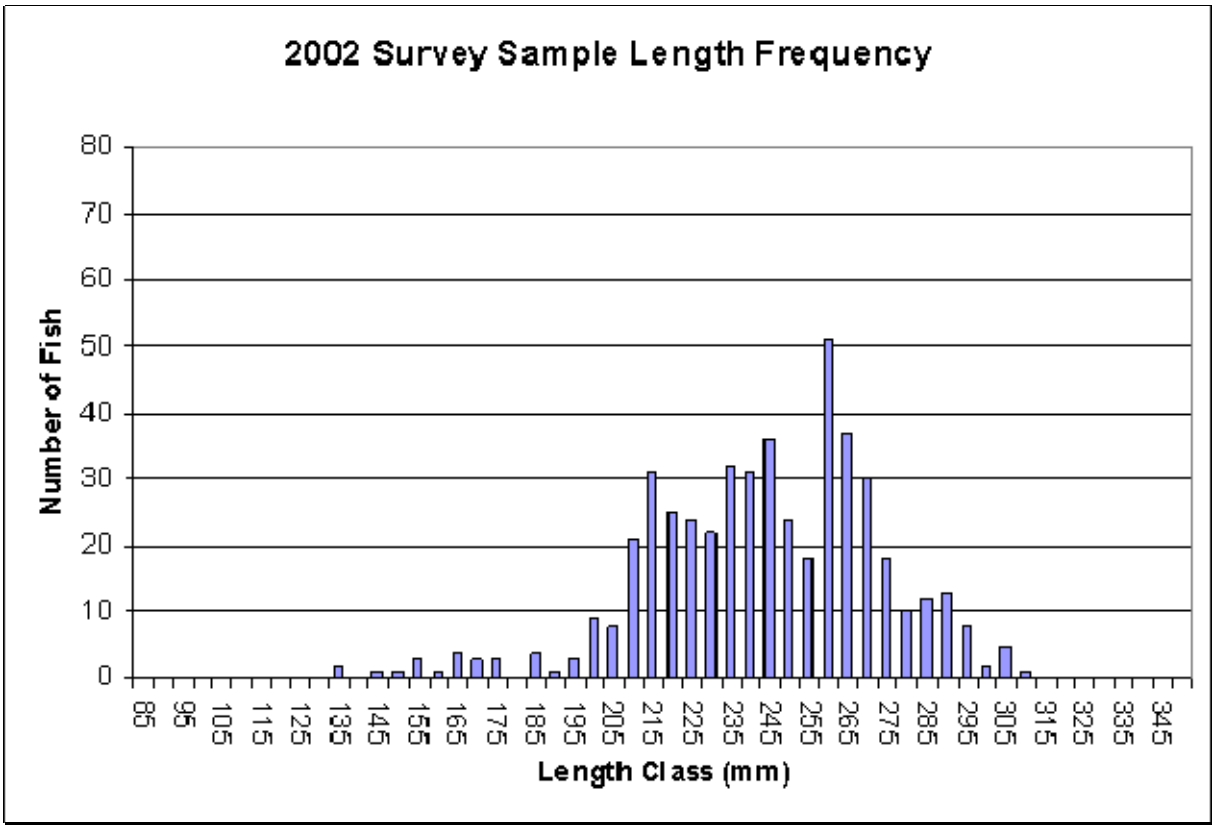


Figure 3.2.2.5: 2003 Survey Sample Length Frequencies

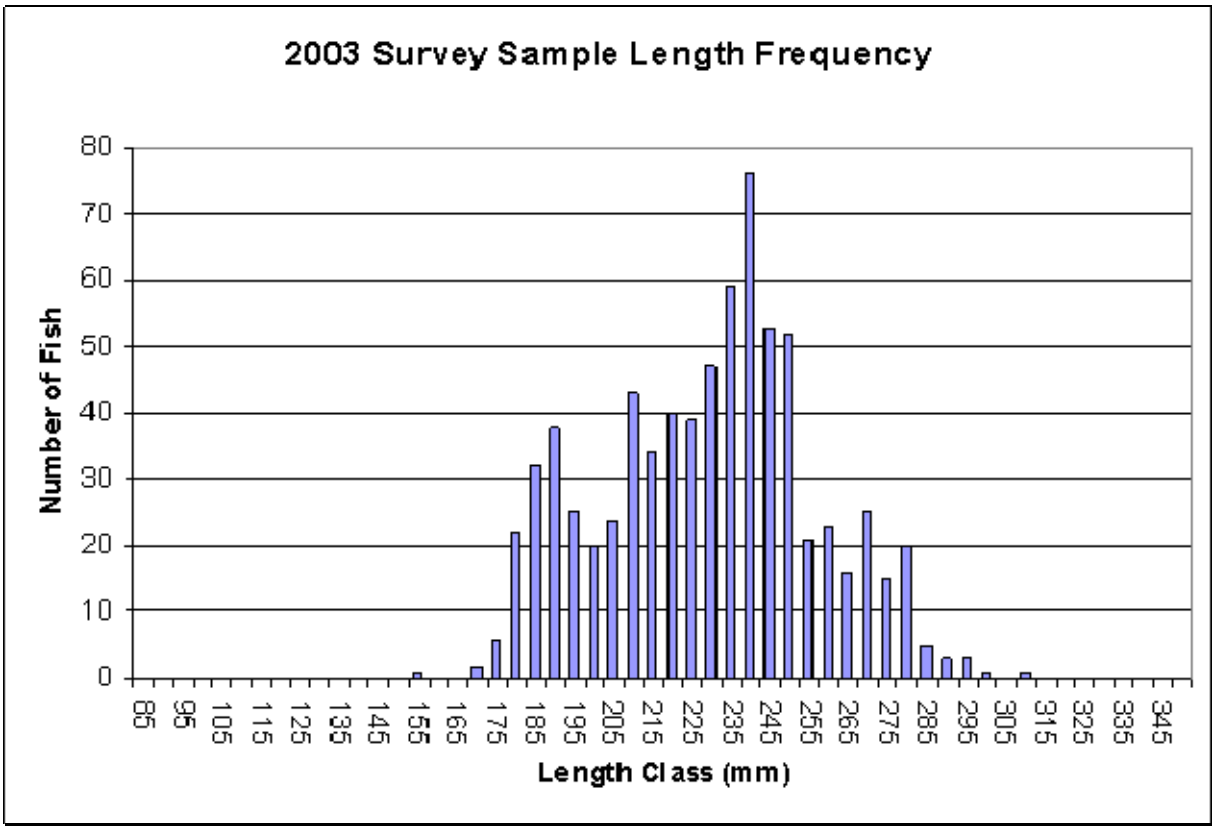
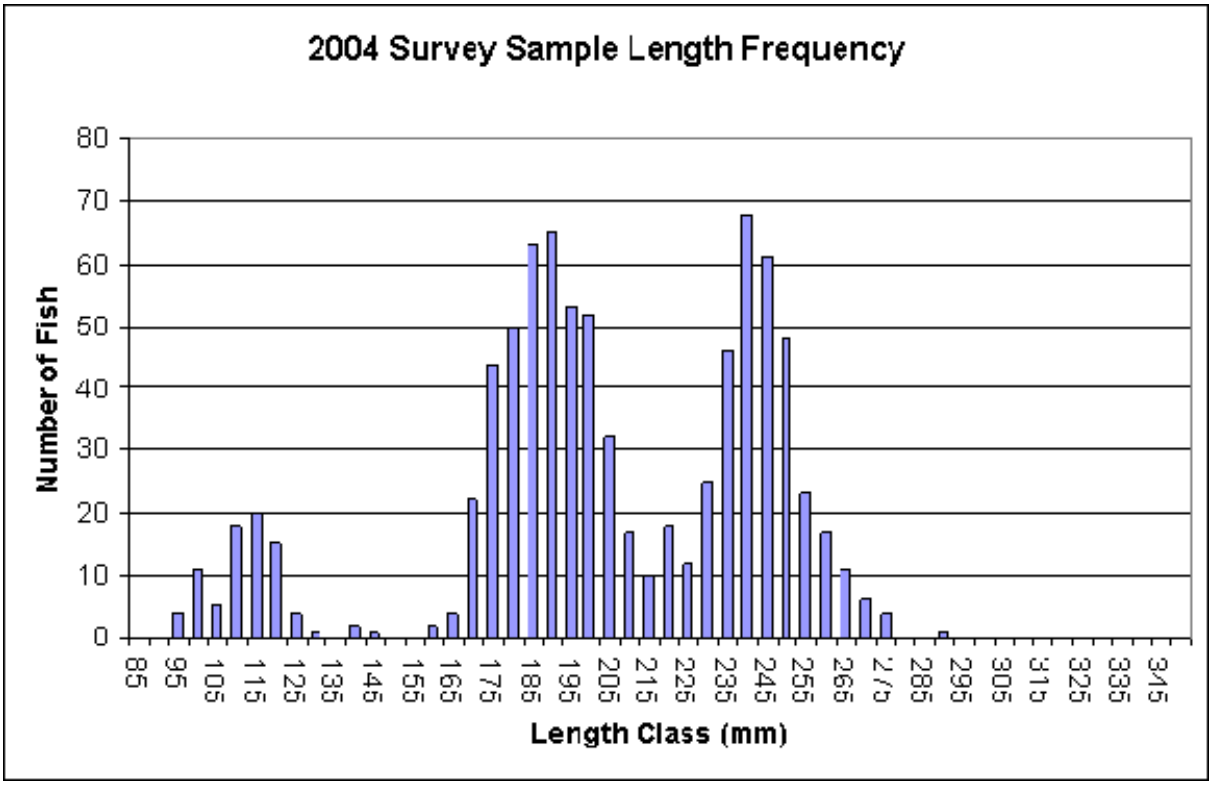


Figure 3.2.2.6: 2004 Survey Sample Length Frequencies



3.2.3. Sampling Gear

After the 1999 surveys, the need to use a midwater trawl for biological sampling was obvious. Bottom trawl sampling is successful in capturing herring during the day when they are closer to the bottom, but they are also mixed with other species at this time. At night, they are up in the water column and separated from other species, and therefore can be distinguished acoustically and captured by a midwater net. However, even at night, herring are not always able to be captured by midwater trawl. They may aggregate close to ledges, peaks, or other bathymetric features that might destroy an expensive midwater net. The same is true of lobster or gill net gear that can cause extensive damage to a midwater net. Herring may stay close to the bottom even at night, and this behavior is often described as "pre-spawning behavior". Pre-spawning herring aggregations seen at night on the bottom are not necessarily available to a bottom trawl, as the bottom may often be rocky or be generally unsuitable for a bottom trawl.

The preference has always been for midwater samples, because most of the acoustic data that is kept during the editing process is in the water column. Therefore, midwater samples are most representative of the acoustics data, though not always of the sizes of herring that are present. Stevenson et al. (1999) made the assumption based on both midwater and bottom tows that during the spawning season, most herring in the water column are juveniles, and herring near the bottom are a 50/50 mix of juveniles and adults.

This project used vessels-of-opportunity that are often groundfishing vessels. The captains are more comfortable using bottom trawls rather than midwater trawls, and as a result, most of the sampling with these vessels occurs during the day with a bottom trawl. When herring vessels with midwater trawls or purse seines were willing to take time out from fishing, these gear types were preferred and used. Midwater sampling has usually occurred between dusk and dawn. The variability in gear type may bias the target strength data, biomass estimates, and the percentage of biomass considered as the spawning stock. This bias is likely introduced by the apparent segregation of adults and juveniles to different parts of the water column during spawning season. Table 3.2.3.1 summarizes the number of samples by gear type collected by the survey each year. This table does not include commercial samples used as substitutes or in addition to survey samples.

Table 3.2.3.1: Number of Survey Samples Collected by Year and by Gear Type

Year	Bottom Trawl	Midwater Trawl	Purse Seine	Total	Total # of Fish
1999	11	0	0	11	511
2000	3	0	0	3	142
2001	5	0	6	11	1613
2002	1	3	2	6	494
2003	4	6	0	10	746
2004	0	11	0	11	835

3.2.3.1. 1999 – Bottom Trawl (Modified Shrimp Trawl)

Excerpt from August 1999 Update: "The Mary Ellen is equipped with a modified shrimp trawl (finfish excluder removed, bag reduced in size, and mesh oriented on square to increase water flow) that permits efficient sampling on sand and gravel bottoms, but has very limited utility on rocky ledges. The captain has also been experimenting with using the net to sample in mid-

water (by shortening the cables and flying the doors above the bottom), but with mixed results. We will continue to experiment with this form of mid-water sampling during the next couple of weeks and evaluate its potential for long-term use. "

3.2.3.2. 2000 – Bottom Trawl and Gill Net

Excerpt from Rosen et al, 2001: p.7: "Pervasive fixed gear along the inshore Gulf of Maine also frustrated attempts to consistently collect biological samples of targets seen acoustically. F/V Adventurer was selected as a survey vessel in part because of her ability to fish a midwater trawl. However, the captain judged it would have been impractical to tow his large midwater trawl in many of the areas surveyed. State regulations prohibit trawling for herring in state waters (within 3 miles of shore), so much of the territory surveyed is not normally fished by the herring trawling fleet. Deploying a gill net and F/V Adventurer's bottom trawl led to limited, but valuable success in collecting samples for establishing species composition and assigning values for target strength. "
Only one herring was captured with the gill net, so all survey samples were obtained with a bottom trawl. A small mesh liner was used in the cod end built for groundfishing.

3.2.3.3. 2001 – Bottom Trawl and Purse Seine

A bottom trawl with small mesh liner was used on the F/V Adventurer, along with gill nets and jigs. Samples were only obtained with the bottom trawl.
The F/V Western Wave crew deployed its commercial purse seine for samples. These samples were not used in the revised data however (section 3.2.3).

3.2.3.4. 2002 – Bottom Trawl, Purse Seine, and Midwater Trawl

The F/V Adventurer deployed a bottom trawl with a small mesh liner. No gill net sets attempted.

The F/V Western Hunter is a drum-style purse seiner and used the seine to collect samples.

The F/V Thunder Bay used its midwater trawl to collect samples.

3.2.3.5. 2003 – Midwater Trawl and Bottom Trawl

The F/V Jennifer & Emily used a 15 by 17 fathom opening midwater trawl with 1 7/8" mesh cod end to collect samples. An aquarium cod end was attached to the mesh cod end on several sample tows to collect fish for tagging.
The F/V Adventurer used a bottom trawl with a small mesh liner.

3.2.3.6. 2004 – Midwater Trawl

The F/V Jennifer & Emily used the 15 by 17 fathom midwater trawl with 1 7/8" mesh cod end to collect samples. Gill net sets and jigging with shrimp flies were also attempted but did not capture any fish. Project advisors recommended an increase in rate of sampling in 2004. While the greatest number of midwater trawl samples was collected in this year as compared to other years, the total number of samples was no more than were collected in 1999 and 2001 (Table 3.2.3.1). This was partially due to the malfunction of the vessel's third wire, so that tows could not be made for the first six surveys. The sampling of the catch was improved with greater confidence in the samples represented the herring schools observed acoustically.

3.2.4. Sample revisions

The way in which samples were processed and recorded varied over time (section 3.2.1). Target strength conversion calculations varied as well (see section 5.1 and Appendix IV). Project advisors reviewed the process of calculating target strength in May 2004 and recommended a clearer, standardized calculation. In conjunction with a revised method of calculation, the samples that were used for target strength calculations were changed. Often a more appropriate sample was available for a survey, or a commercial sample closer in time and area to the survey was available. Other survey samples with a larger sample size, better proximity in time and area to the survey, or with better maturity information were used. Sometimes samples were combined to represent an entire area of the coast for a certain period of time. Commercial samples were often combined with survey samples to increase sample size and the representative nature of the samples (bottom and midwater samples combined). These revisions may be changed in the future as more analysis is done on the differences between commercial and survey samples. *The revisions should be considered preliminary with the recognition that further revision may result in significant changes in the biomass estimates of a number of strata.*

The revision of samples collected from 1999 – 2004 occurred in conjunction with biomass estimate revisions. As a result, samples were revised only if necessary **(**Appendix III). Revision of other samples will be done as needed. Revisions to the length, weight, sex, and maturity of samples consisted of:

- correcting recorded lengths if the sample was frozen using DMR's correction equation (Appendix IV):

$$L_{mm} = 4.1825+1.0051*[\text{Frozen_SAMPLE_LENGTH(mm)}],$$

- standardizing how sample information is recorded
    - maturity in stages 2-8 vs. spawning or not spawning; for instance, some sample data sheets record maturity as "N" for not spawning, so maturity was assumed to be stage 2
    - sex: male = 1; female = 2; sometimes "V" for virgin or blank if sex could not be determined

Revisions to length/weight regressions and target strength are detailed in section 5.1.

3.3. Oceanographic Sampling

There was a concerted effort to increase physical and biological oceanographic sampling in 2001 and 2002. In addition to continuous data taken at the surface, Sea Bird CTDs measured water temperature, salinity, density, and chlorophyll at depth. The purpose of collecting this data was to allow oceanographic variables to be studied in three dimensions and at the depth where herring were located. Collecting and analyzing this data would increase understanding of the physical and biological oceanographic variables governing herring distributions, both within and among years, and may help to target future surveys. However, only the surface CTD data has been partially processed. Software was developed in late 2001 to incorporate the surface oceanographic information into the HDPS acoustic data files by synchronizing time and date between the two logging devices. No analysis or contouring of at depth or surface data has been performed.

3.3.1. CTD sampling by year

3.3.1.1. 1999

No oceanographic data were collected

3.3.1.2. 2000

Oceanographic data were collected at the surface along the survey transects by towing a SeaBird CTD on a door wire behind the F/V Adventurer. Analysis of the data indicated the CTD was at the surface of the water during transects, and likely broke the surface at times.

3.3.1.3. 2001

Oceanographic data were collected at the surface along the survey transects placing the SeaBird CTD in a cooler fed by the deck hose on F/V Adventurer. The CTD was later placed in an upright wood box to log data while on the Western Wave. Depth casts were made as well. The CTD was attached to the door wire on the F/V Adventurer and to an auxiliary winch on the F/V Western Wave.

3.3.1.4. 2002

Data were collected at the surface along the survey transects by running a deck hose into an upright wooden box holding the CTD. Depth casts were made at various intervals during each survey. The CTD was attached to the door wire on the F/V Adventurer and to a rope wound on a purse line winch on the F/V Western Hunter.

3.3.1.5. 2003

Data were collected at the surface along the survey transects by running a deck hose into an upright wooden box holding the CTD. Depth casts were made at various intervals during each survey. The CTD was attached to the door wire on the F/V Adventurer and the F/V Jennifer and Emily.

3.3.1.6. 2004

Data were collected at the surface along the survey transects by running a deck hose into an upright wooden box holding the CTD. Depth casts were made at various intervals during each survey. The CTD was attached to the door wire on the F/V Jennifer and Emily. Both CTD's malfunctioned in late September and were not operable for the rest of the surveys.

4. Data Management and Editing

4.1. Data recording and management methods

4.1.1. Logbook

Paper logbooks have been the method of recording survey information including start and end of surveys, sample tows, and CTD casts. Observations on when herring schools are seen, departures from normal survey practice, and other miscellaneous notes are kept in these logbooks. An MS Excel logbook was kept for the 2003 Jennifer & Emily surveys, and logbook notes from 2004 surveys were transposed into electronic format. Logbooks are kept in the project office, and electronic files on project computers.

4.1.2. Biological samples

Sample tow data are initially recorded on data sheets and later entered into MS Excel file templates that are setup to calculate length/weight relationship and target strength. The most recent revision of this template was in 2004 (Appendix III).

4.1.3. Acoustic data archiving

Raw acoustic files (.hyd) are initially recorded on the internal hard drive of the logging computer. These files have been transferred to removable drives (Jaz, Kanguru) and archived on CD and office computers. The edited data are later archived on the CD with the raw data source files. Some processed files (.hyp) and strata files (.run, .set) have been archived, but generally only the edited transect files are kept with the assumption that they can be processed again if needed and the run and set files can be re-created as well.

4.1.4. CTD data backup

CTD data files are downloaded to a laptop or the acoustic data logging computer on the vessel after one or two survey nights. Files logged on the surface CTD are large and need to be cleared from the memory after two nights. These files are transferred from the computer to an office computer and archived on the CD which contains the acoustic data for that survey night.

4.1.5. Metadata

Survey data are compiled in semi-annual and annual reports for funding agencies and in monthly or bi-monthly reports for project stakeholders. These reports reside on project computers and on the GMRI network computer. Unpublished and published project reports are listed in the references.

4.1.6. Data access

Project data and reports are available to the public upon request. No funding has been available to process and post data on the GMRI website or other websites. CTD data may be posted on the Northeast Consortium's website in addition to project updates and annual reports.

4.2. Data editing

Raw acoustic data files are edited and processed in a series of steps detailed in Appendix V. Editing is mainly a visual process with some automated functions to expedite basic operations such as bottom removal or random noise filtering. Some of the editing functions from the HDPS editor's course manual (Femto Electronics Ltd) are described below (with images removed).

“The first step in re-computing the bottom is to do a very rough edit of the data to remove all data below the bottom and any reverberation near the surface. This is done by first loading the data file into the editor. Only one file can be loaded into the editor at a time.

Adjust the echogram so that the entire file is displayed on the screen and the bottom is visible for the entire width of the screen. The left most pair of buttons control the echo gain. The center buttons control the depth scale and the right most buttons control the time scale. Of each pair, the top one increases the respective parameter and the lower one decreases it. (eg. The lower left button decreases the echo gain of the data)

Next, use the bottom polygon editing tool to remove under the bottom followed by the surface polygon editing tool to remove the surface reverberation. Click the M button to modify the data. Now reload the file using the small button under the open folder icon and check the results of your editing.

It is now time to perform the fine editing of the echogram... Although there is no best method to proceed, a recommended method is to perform the following functions in the order given.

1. Using the surface removal tool remove the reverberation near the surface caused by storm turbulence, wake, etc.
2. Next, using the pelagic polygon or rectangle, eliminate the returns from those targets that are not of interest to this survey.

Now ... display only the bottom on one screen. Use the lower right button to expand the screen horizontally until you are comfortable that you can easily draw a line between the fish in the water column and the bottom and use the bottom polygon to draw a line just above the bottom:

Now that the file is completely edited we need to check to make sure we removed all the bottom reverberation since any left in would contribute to the final biomass estimate in a significant way.

The next step is to check the integrity of the bottom edit to make sure that no bottom reverberation remains in the data file. By selecting the A command and then checking the Show Maximum Sv and then redisplay, the location of the maximum Sv value is shown in the status bar. The user should now zoom in on this location to check if the “high” value is actually bottom reverberation. The zoomed echogram indicates that at about the center of the screen there is some bottom left in. Use the Bottom Polygon and then the M command to remove this data. The edited echogram now has no more bottom left in it. When all bottom is removed the edited data files can be delivered for analysis.”
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5. Data Analyses

5.1. Length Weight Regression and Target Strength

The process of using biological sample length and weight data to calculate a target strength to apply to a survey strata has changed somewhat over time. As mentioned in other parts of this text, our project advisors recommended standardizing a method that closely followed methods used by others in fisheries acoustics. We revised our calculations and spreadsheets as a result. Our methods now follow the St. Andrews and Moncton DFO methods for calculating length/weight coefficients and TS values (Appendix IV). The methods and calculations are explained more briefly in this section.

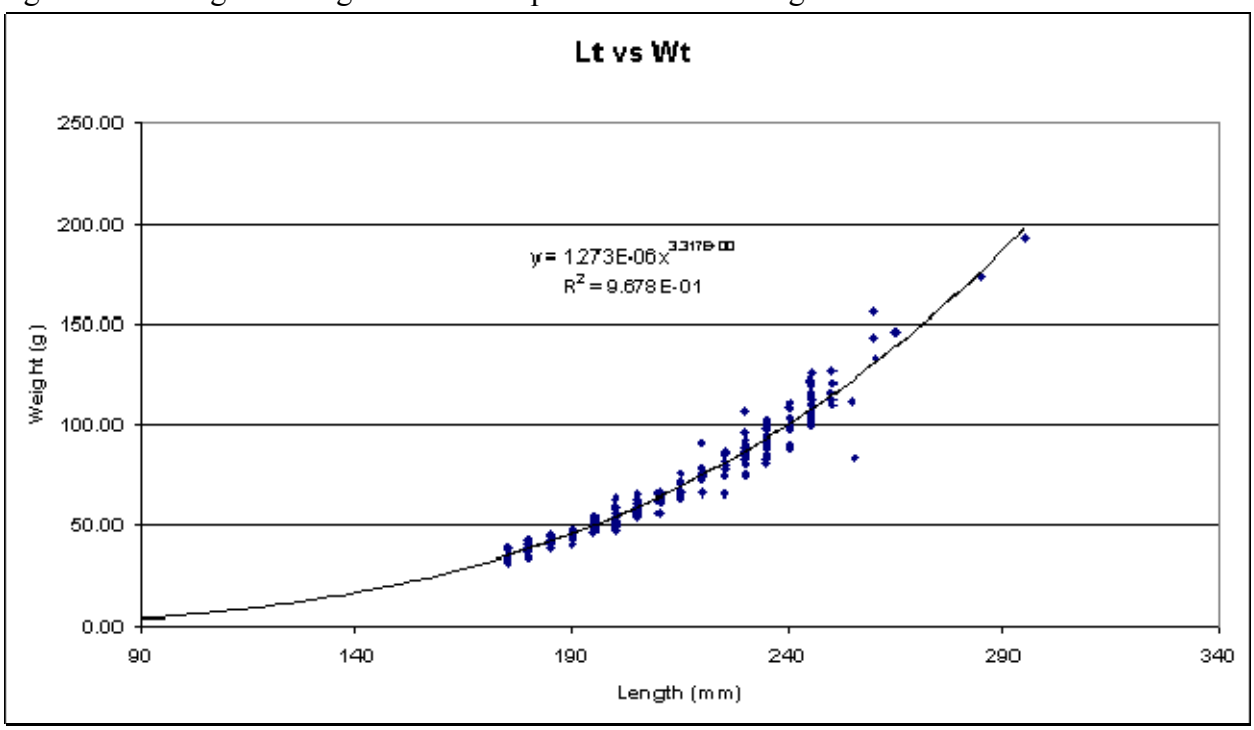
Length vs. Weight Regression

Slope (*b*) and intercept (*a*) values for the equation

$$W = aL^b$$

are calculated from the sample data using a power fit regression in an x,y scatterplot (Figure 5.1.1).

Figure 5.1.1 Length – Weight Relationship with Power Fit Regression Line



Target Strength Calculations
The target strength equation

$$TS = 20 \text{ Log } (L) - b$$

has been used since 1999, but the same intercept (*b*) was not. The intercept from the Rudstam et al (1988), study on herring and sprat was used in 1999, but the intercept used from 2000 to the present was from Foote (1987). The revised sample worksheets (Appendix III) use Foote's intercept (-71.9 dB) in calculating TS. All target strengths have been recalculated if necessary using this intercept. Foote's intercept is calculated from 38 kHz data, so a correction factor for 50 kHz and 75 kHz is applied to the appropriate data.

Length frequency in 5mm bins is calculated in the target strength worksheet (Appendix IV). Weight in kilograms for each 5mm length bin (L_{5mm}) is calculated using *a* and *b* in the equation:

$$W_{L5mm}(kg)=a*L_{5mm}^{b}/1000.$$

Lengths are converted to centimeters in the target strength equation

$$TS_{L5mm} \text{ (dB/kg)} = (20 \text{ LOG } (L_{5mm}/10)-71.9) - (10*\text{LOG } W_{L5mm})$$

which gives a target strength in decibels per kilogram by incorporating the second part of the equation. The target strength for each length bin is converted to linear units,

$$\text{Linear } TS_{L5mm} \text{ (dB/kg)} = 10^{(TS/10)}$$

multiplied by the number of fish (n) in that length bin (L_{5mm}),

$$\text{Length frequency weighted Linear}TS_{L5mm} \text{ (dB/kg)} = n(L_{5mm})\text{fish} * \text{Linear}TS_{L5mm}$$

and the sum of all weighted, linear target strengths (LinearTS_{L5mm}) is calculated and divided by the total number of fish (N).

$$\text{Weighted mean LinearTS (dB/kg)} = \sum (\text{Linear}TS_{L5mm})/N$$

The weighted mean linear TS is converted back to log scale to give the weighted mean TS.

$$\text{Weighted mean TS (dB/kg) at 38 kHz} = 10*\text{LOG(LinearTS)}$$

Love's equation (1971), is used to calculate a correction factor for 50 and 75 kHz data.

$$\text{TS Correction Factor (75kHz)} = 0.9 * \text{Log(38kHz/75kHz)}$$

Target strengths calculated from the samples revised for particular surveys are plotted in Figures 5.1.2-5.1.7. These figures indicate the target strength range in a given year, the target strength for a particular range of survey dates, and the target strength by major survey area.

Figure 5.1.2 1999 Target Strengths Used for the Range of Survey Dates by Major Survey Area

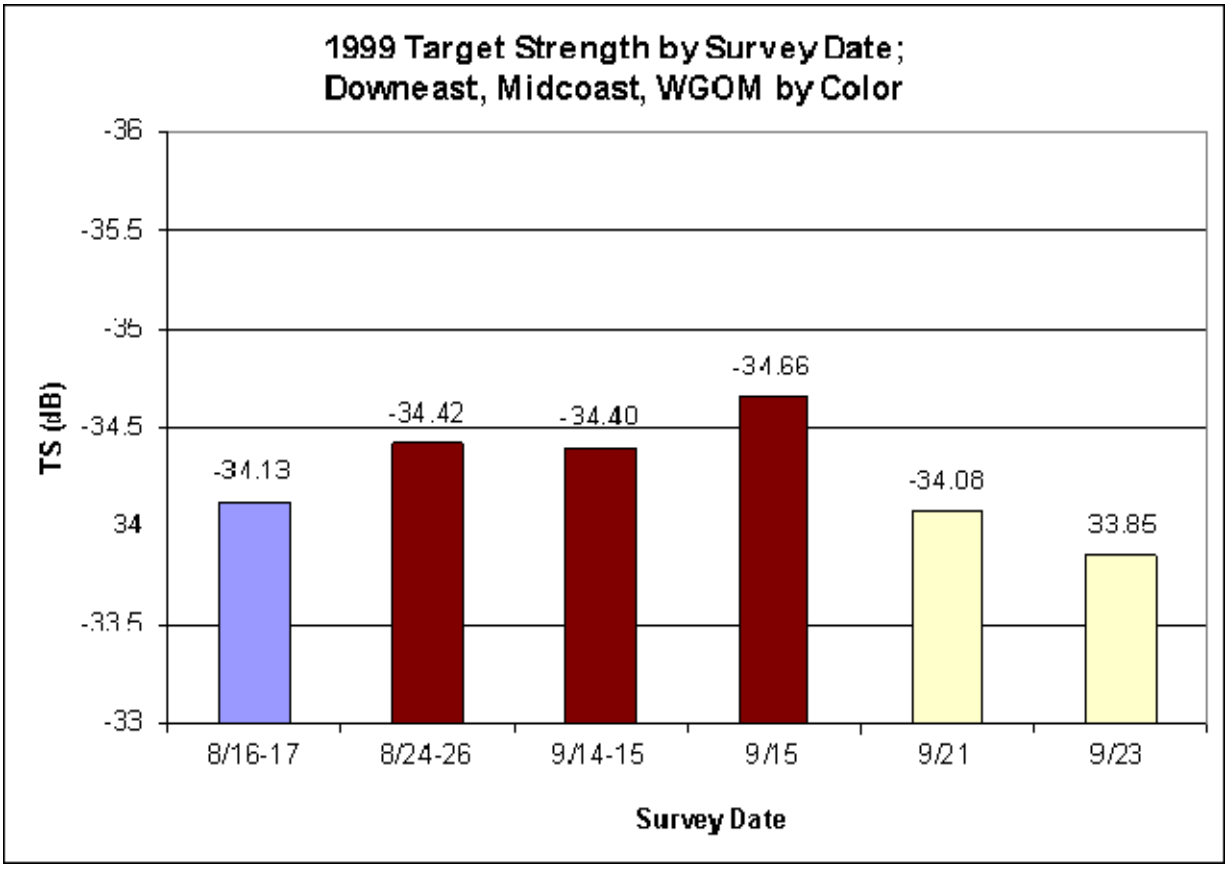


Figure 5.1.3: 2000 Target Strengths Used for the Range of Survey Dates by Major Survey Area

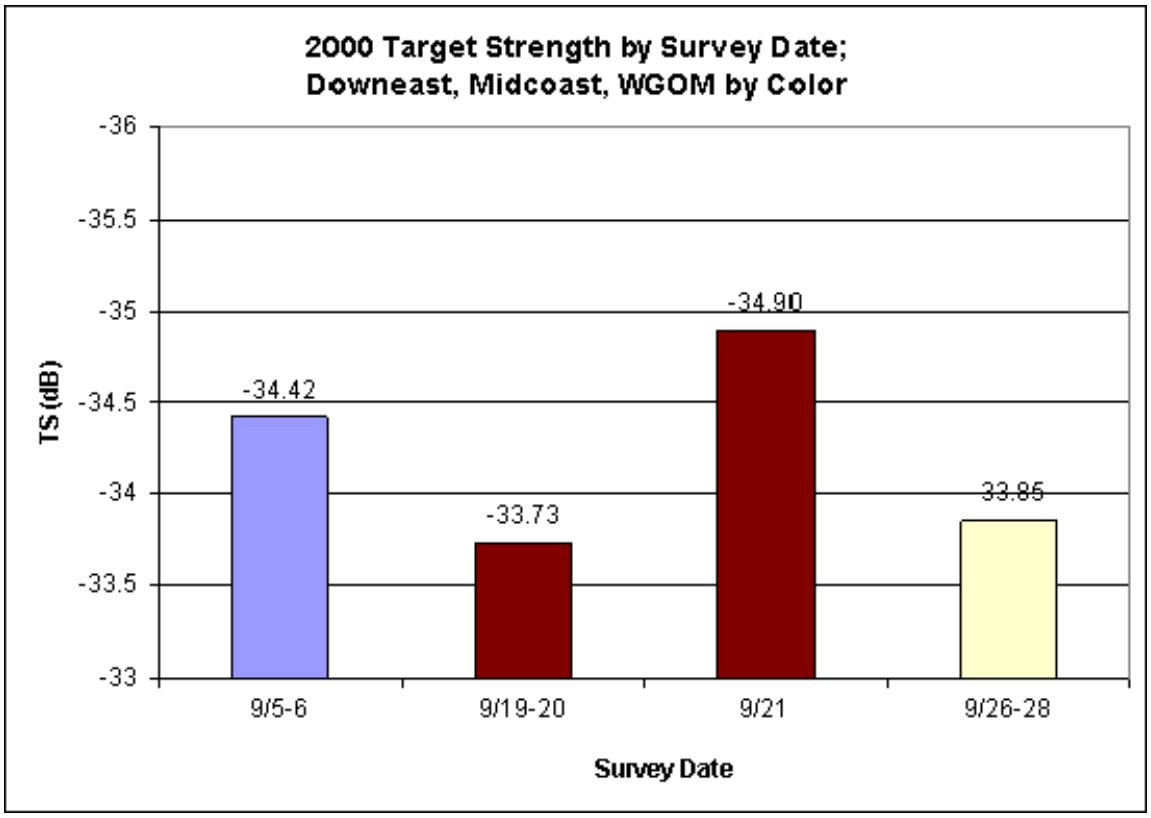


Figure 5.1.4: 2001 Target Strengths Used for the Range of Survey Dates by Major Survey Area

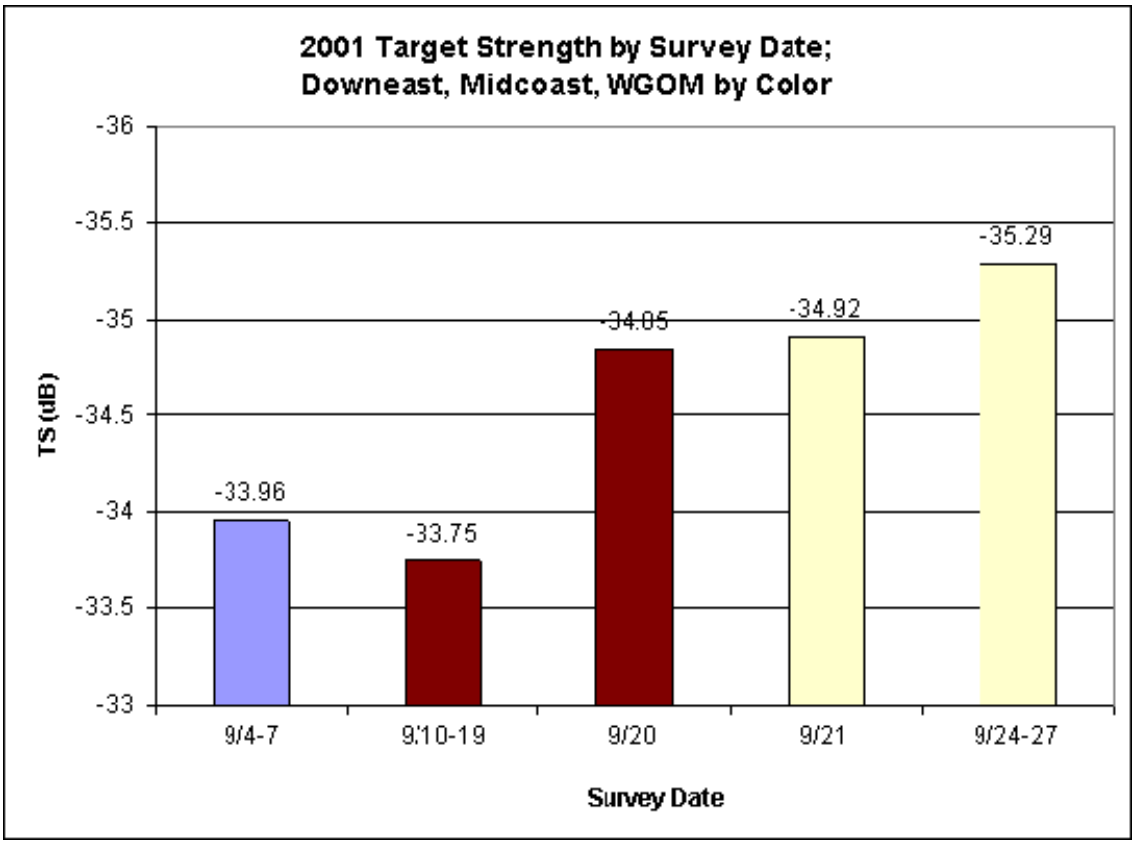


Figure 5.1.5: 2002 Target Strengths Used for the Range of Survey Dates by Major Survey Area

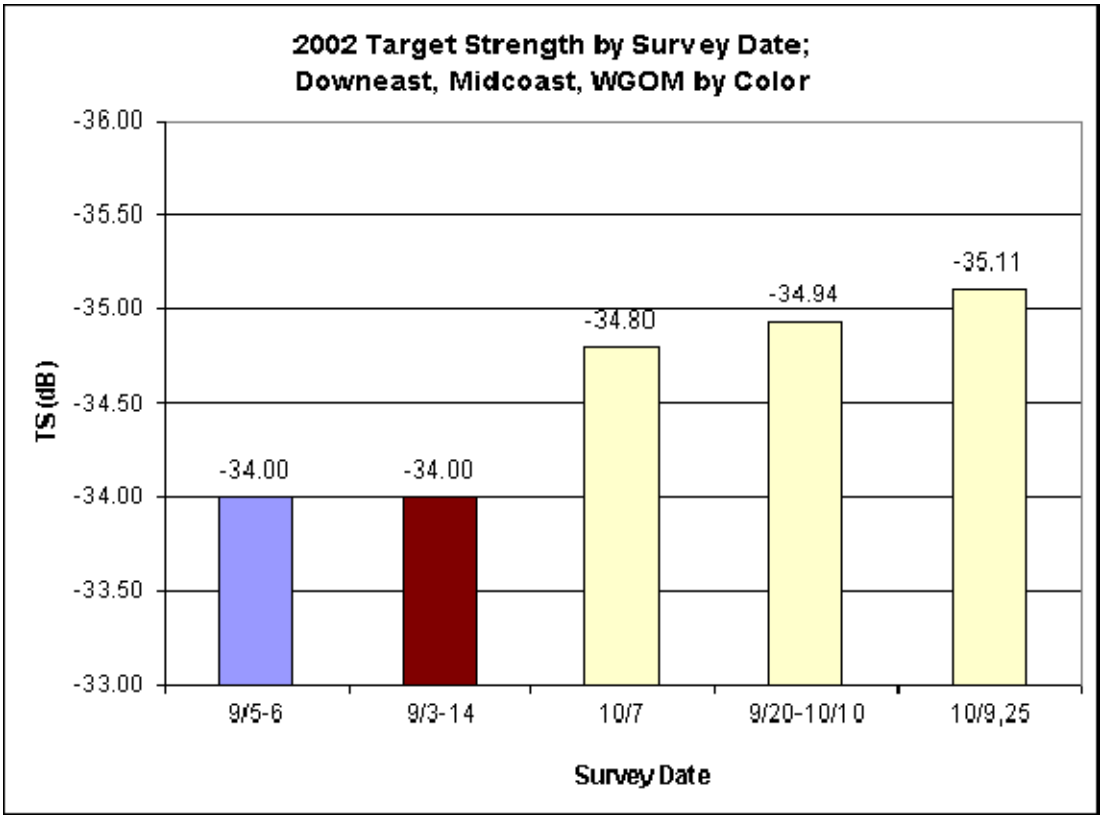


Figure 5.1.6: 2003 Target Strengths Used for the Range of Survey Dates by Major Survey Area

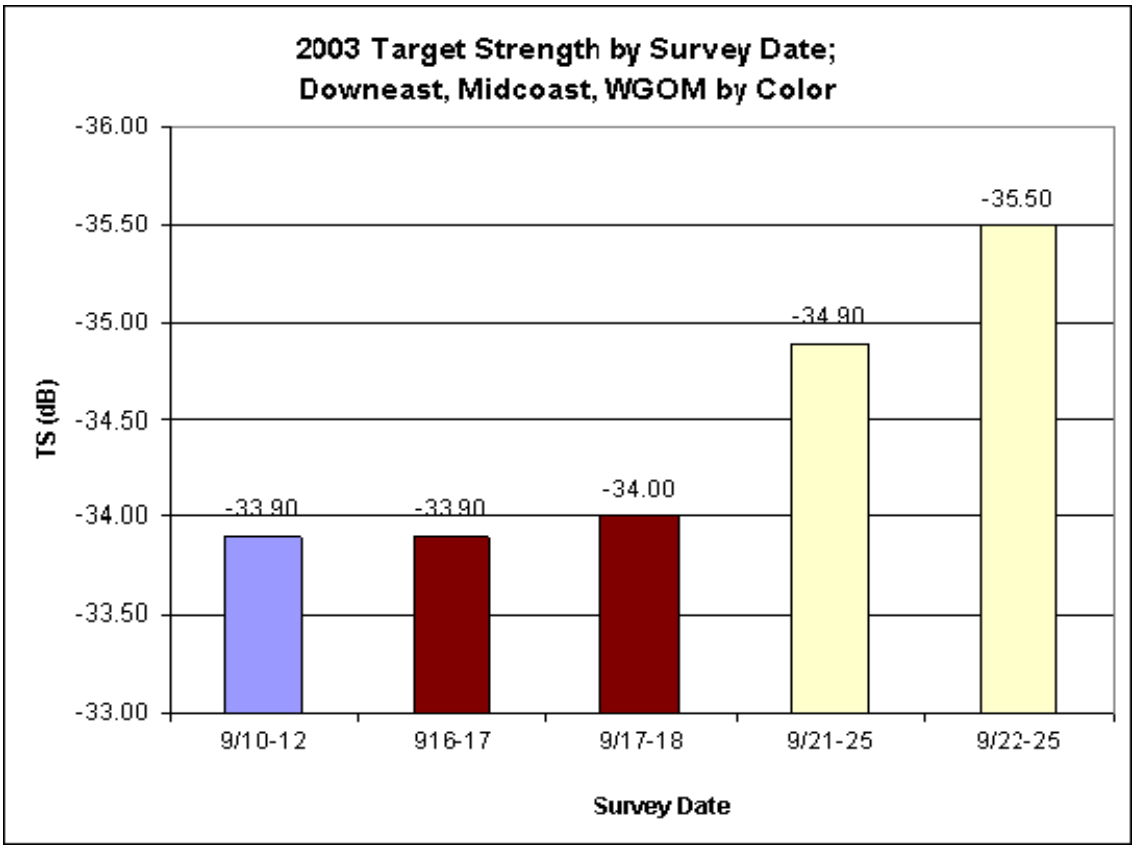
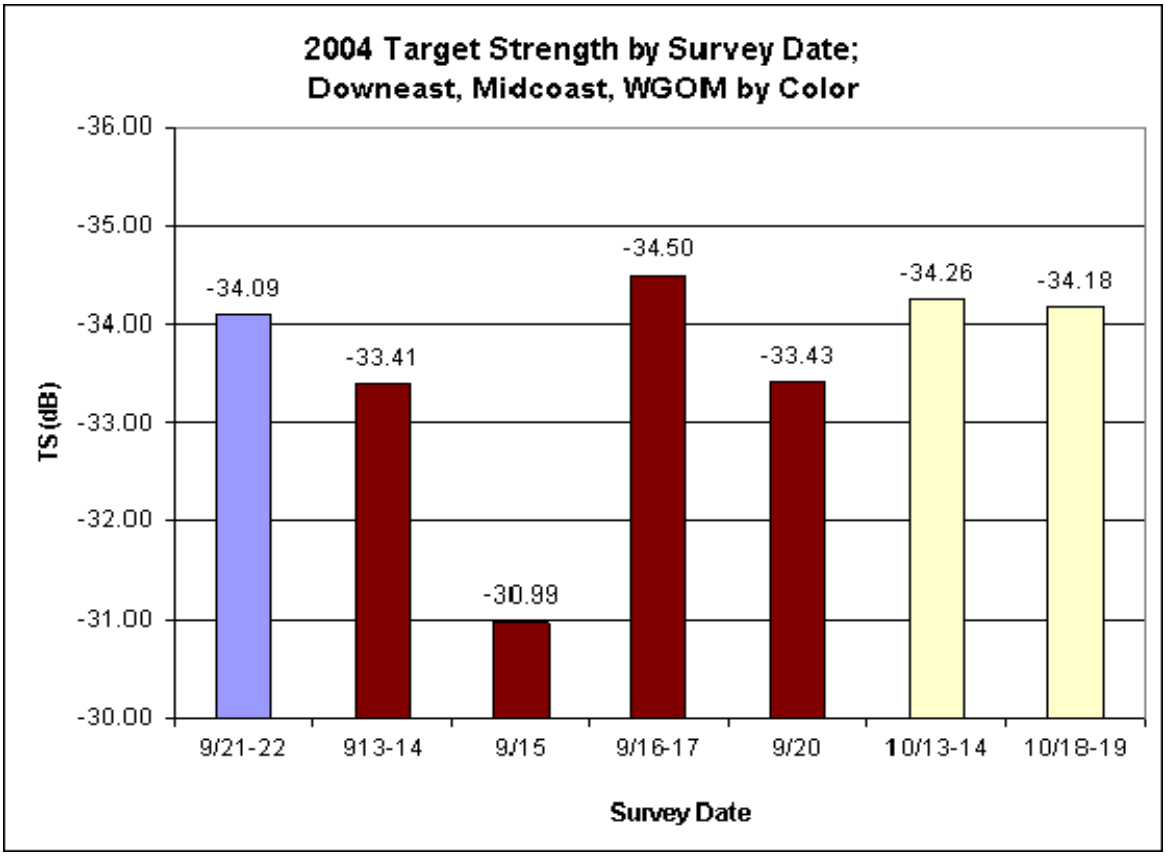


Figure 5.1.7: 2004 Target Strengths Used for the Range of Survey Dates by Major Survey Area



5.2. Acoustic Data Processing and Biomass Estimation

5.2.1. Femto Hydroacoustic Data Processing Software (HDPS) calculations

5.2.1.1. Introduction

HDPS performs the process of integration in such a manner as to compute overall biomass per survey assuming a set of one or more user-defined strata each of which consists of two or more random or systematic transects. That data can be further stratified into depth layers for other studies.

5.2.1.2. Ancillary Files

To assist in the integration and reports there are four ASCII data files that provide additional information on the data files and stratification:

1. Calibration Cross Reference (XRef) File
2. Layer Table File
3. Run File
4. Set File

The XRef File associates a particular calibration file with a data file. This file consists of one or more lines each containing the names of the data files associated with the selected calibration file.

The Run File defines the physical survey by grouping the transects into one or more strata. This is done by specifying the strata name, the area in the strata, and the transect numbers within the strata.

The Set File associates the fishing sets (biological samples) with the transects. This file provides no information to the integration calculations.

The Layer Table File defines the depth layers over which the integration is performed. It consists of 20 lines defining 20 different layers with a start depth and an end depth. Normally, the first layer consists of the entire water column of interest (e.g. 0 to 599.9 meters)

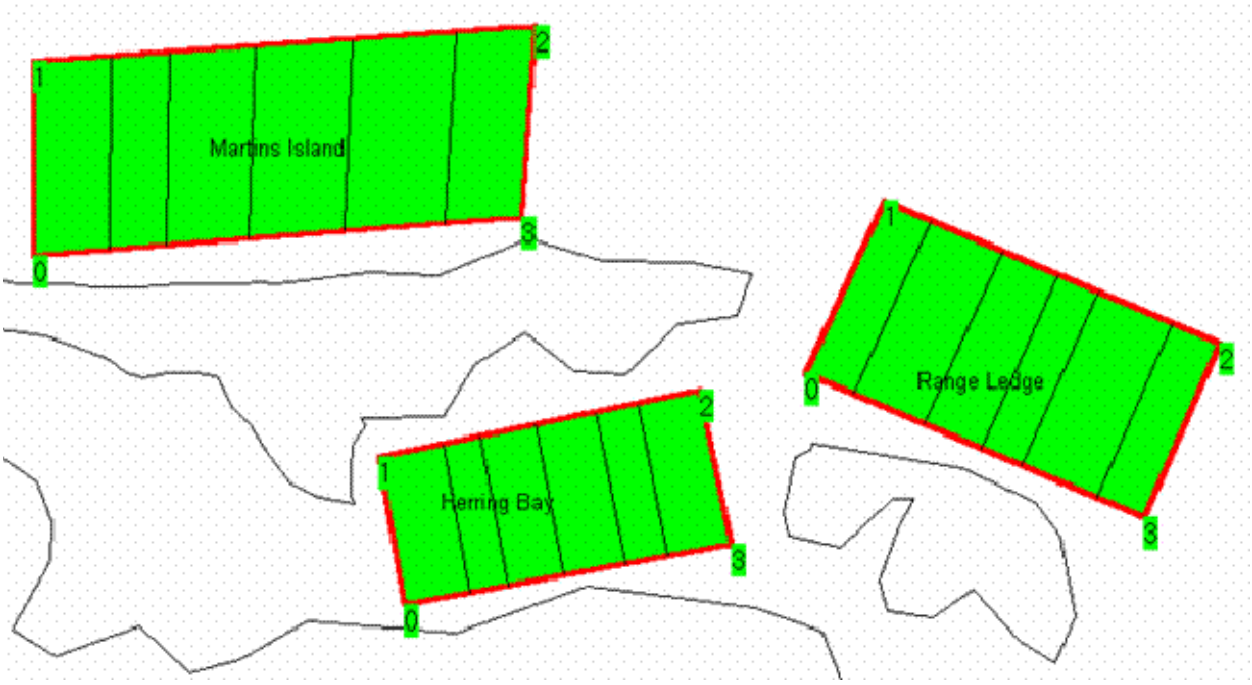
5.2.1.3. Integration

The integration process merely reads in the appropriate calibration factors used to convert the raw data samples to Volume Scattering(Sv). The software then reads and processes the raw data file one ping at a time. For each ping, the sample data are converted to Sv data at a depth resolution of 0.1 meters. The Sv data from each ping is aggregated with that of the other pings up until the end of the user defined integration interval (number of navigation fixes) at which point, the data is averaged for each 0.1 meter depth bin. The data is then summed and converted to Area Scattering(Sa) for each of the 20 depth layers defined by the layer table. Additionally, the Sa values are multiplied by the distance from the beginning to the end of the interval to achieve distance weighting per interval over the transect. When all pings are done, the average Sa per depth layer is computed and then divided by the sum of the interval distances to complete the distance weighting process. The output from the integration process per transect is a Hydroacoustic Processed (HYP) file so named by the extension of the file.

5.2.1.4. Stratification

The next step is to define the grouping or stratification of the data. A strata is a group of transects having similar characteristics. Typically, the stratification takes place over geographic regions such that transects in a particular area or fishing ground are combined. The reason for stratifying the data is to reduce the variance among the transects within the strata to give a measure of the confidence in the estimate of biomass. Stratification can also be done by time, tidal cycle, sea-state, etc. An example might be to group all daytime transects in one strata and all nighttime transects in another to research fish behavior.

Figure 5.2.1.4.1 Example of stratification



The stratification is defined in the Run File discussed above. When the reports of the integration are generated, the HDPS reads the run file and groups the data accordingly. For the biomass estimation of the strata each transect in the strata is considered a single point. To this end, the average distance weighted Sa from each transect (Sai) along with the distance (Di) over which the transect was collected are read for each transect in the strata. The strata Sa is then computed as the Sum(Sai x Di) / Sum(Di). The variance in the estimate is also computed as a measure of confidence in the estimate.

The Run File also contains the assumed estimated target strength per kilogram (TSkg) of all targets on a particular transect. The Strata Sa is then divided by the Strata TSkg to arrive at an average Biomass density in Kg per square meter.

Finally, the area of the strata is read from the Run File and applied to the biomass density to get an estimate of biomass in the strata.

5.3. ***Biomass estimates***

5.3.1. Survey selection for annual biomass estimates

Areas have been surveyed more than once with different lengths of time between surveys. The surveys were often of varied spatial extents because strata were not defined in advance. Transects were grouped into strata based on: 1) how closely in time the transects were surveyed; 2) where a biological sample was collected; 3) bathymetry; or 4) the orientation and spacing of the transects. Strata were selected for the annual biomass estimate according to how close in time and space they were surveyed. If several weeks passed between surveys of adjacent strata, the potential for "counting fish twice" was increased. Of primary concern in surveying small aggregations of herring is the potential of the same aggregation or aggregations to add to the mean density surveyed in two different strata or in two separate surveys of the same strata.

Herring generally move long distances in a short period of time when feeding or migrating, but local movements during spawning are unpredictable. An aggregation may stay in one area for several weeks or move back and forth along a bathymetric edge. Fishermen often return to an aggregation or school night after night until the fish move or disperse. A vessel will try several locations in one night to find schools or areas worth fishing in. Our operations take a similar approach in asking the question of whether an area is worth surveying at that particular time given the likelihood of quantifiable, spawning aggregations being present. This approach has given us the flexibility to attempt to survey spawning fish when they can be located, but on the negative side, surveys have often progressed somewhat randomly up and down the coast in response to information or an educated guess as to where fish may be getting ready to spawn.

The analyst often relies on information from biological samples to make a judgment on the stage of maturity of fish in a surveyed area. Further compounding the issue of local migration is the mix of juveniles and adults found in coastal waters. The percentage of juveniles and adults in a given catch sample varies widely. For instance, the lengths in 2004 survey tows ranged from 9 – 29 cm (Figure 3.2.2.6). We expect that the local movements of an aggregation during spawning times will be affected by the maturity of the fish in the schools. Mature fish will be "staging", getting ready to spawn at a particular site, while immature fish will be feeding and moving about more. Commercial samples often contain immature fish that are starting to develop but will never fully ripen their gonads. These fish may be stimulated to develop by the presence of mature fish that will develop fully and spawn.

In 2004, many survey and commercial samples had larger fish (>25cm) that were either not developing or were only partially developed at a time when spawning had occurred in other parts of the coast. The question becomes then whether these fish have been moving among areas of the coast, or if they have stayed in one area with fish that are spawning. Diel, vertical migration seems to be reduced somewhat when spawning, and fishermen often avoid towing or setting nets near the bottom of aggregations when spawning closures are in effect. The places where spawning fish aggregate may not be suitable for fishing near the bottom as well, but the potential for spawning fish to avoid capture by staying near the bottom adds a layer of uncertainty to the selection of surveys. Bottom tows tend to have higher percentages of larger, developing fish than midwater tows (Stevenson et al, 1999). This may be an artifact of net avoidance ability, the location and time that midwater and bottom tows are made, or it may be revealing an important behavior pattern.

Southern migration may occur either as soon as a school has rested from spawning or it may be delayed. Migration is assumed to be in progress when stage 8 fish are caught in samples. The assumption here is that fish that are rested will move off the spawning area and start moving south while feeding. The potential for fish that have spawned in the Bay of Fundy or SW Nova Scotia to be migrating south along the coast is great. These fish tend to spawn several weeks to a month earlier than Midcoast and Western GOM aggregations. Once this occurs along the coast, survey of strata where migrating fish are present will be inaccurate. This migration is difficult to time, and even though spawning is thought to occur from east to west, surveys often double back east to resurvey strata in case spawning activity is occurring there. However, once into mid-October, the likelihood of surveying migrating fish from the Bay of Fundy, Nova Scotia, or Downeast is quite high, and rested fish have routinely been sampled in the second and third weeks of October from the southern Maine coast. When spawning occurs on Jeffreys Ledge in late October, as it did in 2002, this presents a great difficulty in determining which strata to include as having contained spawning aggregations.

5.3.1.1. Revisions to annual biomass estimates

The strata estimates used for an annual biomass estimate are influenced by the above information. The revision of selected surveys for the years 1999 – 2003, took into consideration the timing of surveys, the spatial extent of the surveys, and the biological samples obtained (Appendix IV). Annual biomass estimates had consisted of strata estimates compiled from almost all the individual survey nights. The assumption was made that fish were spawning in "waves" and if several weeks separated surveys, then new aggregations of fish were present for the second survey. Late October and early November surveys were included as well, when fish were clearly migrating into the Western Gulf of Maine area. These assumptions can easily lead to overestimating biomass, so a more conservative approach was adopted. One complete pass of each major survey area (Downeast, Midcoast, WGOM) was selected. If several complete surveys of an area were conducted, the surveys closest in time to each other and to potential spawning events were selected. Surveys occurring from mid August to late September were generally preferred over mid to late October surveys. However, spawning was reported to have occurred later in time starting around 2001, and definite spawning events from the Downeast to the Western GOM areas in early to late October were surveyed in 2002 and 2003.

5.3.2. Biomass Partitioning

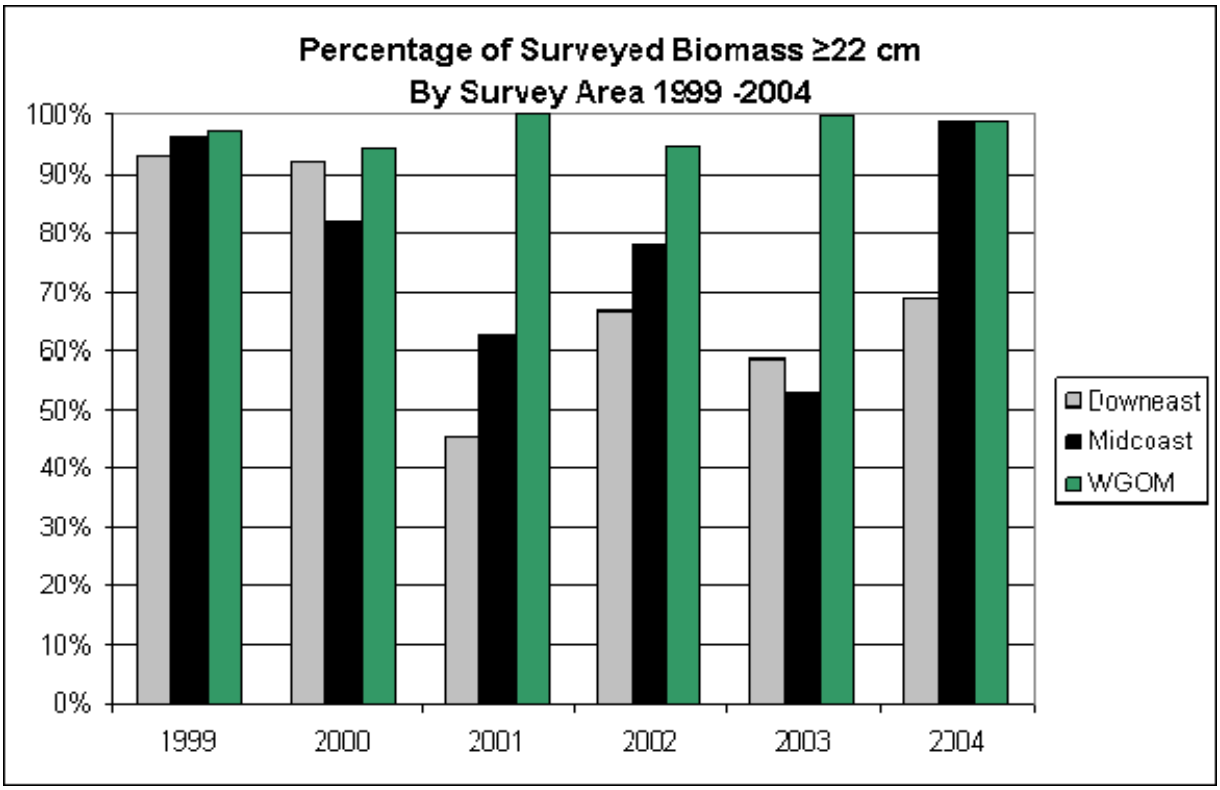
The biomass estimate calculated for each stratum is an estimate of the biomass of juveniles and adults present in the stratum. It is not the spawning stock biomass. 1999-2001 estimates considered all fish surveyed to be mature or spawning, but beginning in 2002, stratum biomass was partitioned by the maturity stage and length frequency of the sample (survey or commercial) applied to that stratum. Fish in a sample that were stage 4 or greater were assumed to be mature. Also, in a separate calculation, fish that were ≥23 cm were assumed to be mature. The analyst could choose which estimate to report as the spawning stock biomass. DMR scientists use the Gonadal Somatic Index (GSI) as a measure of maturity, and they consider any fish with over a 10% GSI to be mature. This would have been the preferred method to partition the spawning stock biomass, but gonad weight was not measured from survey samples in the1999 and 2000 surveys.

Therefore, an alternative approach was needed to calculate the spawning stock proportion of the herring biomass in a stratum. This approach needed to be standardized for all years of the survey. The smallest mature fish (10% GSI) ever measured from DMR commercial samples is 22 cm.

This measure of minimum length at maturity, similar to the formerly used length of 23cm, was used to partition the biomass of each stratum. The length at which 50% of fish are mature could also be applied, but minimum length at maturity was used for this analysis. The proportion of the weight of fish ≥22 cm in the stratum target strength sample was used to partition spawning stock biomass (SSB) from the total stratum biomass (Appendix V-Figure 1). The percentage of SSB varied noticeably from year to year and area to area, with the WGOM area generally being the highest (Figure 5.3.2.1).

Species composition has not been taken into account in biomass partitioning partly because the measurements of species composition from biological samples has not been consistent over time. The mix of sampling gears has confounded the issue as well, because the bycatch in a bottom tow cannot be treated the same as bycatch in a midwater tow. The species composition is completely different and attempting to relate species composition from the benthic community to acoustic backscatter from the water column would be inaccurate at best. The basic assumption throughout the history of the project has been that no other species of similar target strength are present in pre-spawning and spawning herring schools (section 3.2.1). Other species such as dogfish and mackerel are segregated and can be edited out of the echograms, or if they are present in herring schools, they represent a small percentage by weight (less than 1%) and contribute little to the measured backscatter.

Figure 5.3.2.1: Mean Percent SSB Determined by Strata TS Samples



5.3.3. Total standard error calculation

Total standard error for all strata has typically been calculated by summing the standard errors of each stratum. This method is statistically incorrect because the standard error for a population estimate should be calculated from the sum of the variances, not the sum of standard errors. The revised method is to square the standard error of the surveys (calculate variance), sum the

squared standard errors (variances), and take the square root of the total variance as the standard error of the total estimate. This calculation reduced the previously reported standard error of the total estimates considerably.

5.4. Index of Spawning Stock Biomass for the Inshore Gulf of Maine

The consensus from the March 2005 independent review was that neither the original nor the revised annual estimates from 1999 to 2004 could be used as part of an index of spawning stock biomass. The 2003 and 2004 data may be useful in part with further revision and analysis. A better use of the data would be to provide information for further spawning stock studies.

Major revisions to the biomass estimates for the surveys from 1999 – 2003, and the revised methods applied to the surveys in 2004, changed the former estimates (Figure 5.4.1) considerably in some cases. Most of the original edits and transects were kept with some re-editing necessary due to corrupted data (Appendix V, 2000 survey revisions). The estimates were the highest in 1999 at approximately 170,000 tons, and the lowest in 2001 at approximately 17,000 tons (Figure 5.4.2). Estimates by area varied from year to year with no clear pattern emerging (Figure 5.4.3). The revised acoustic estimates by strata are in Appendix V.

Figure 5.4.1: Original SSB Estimates 1999-2003

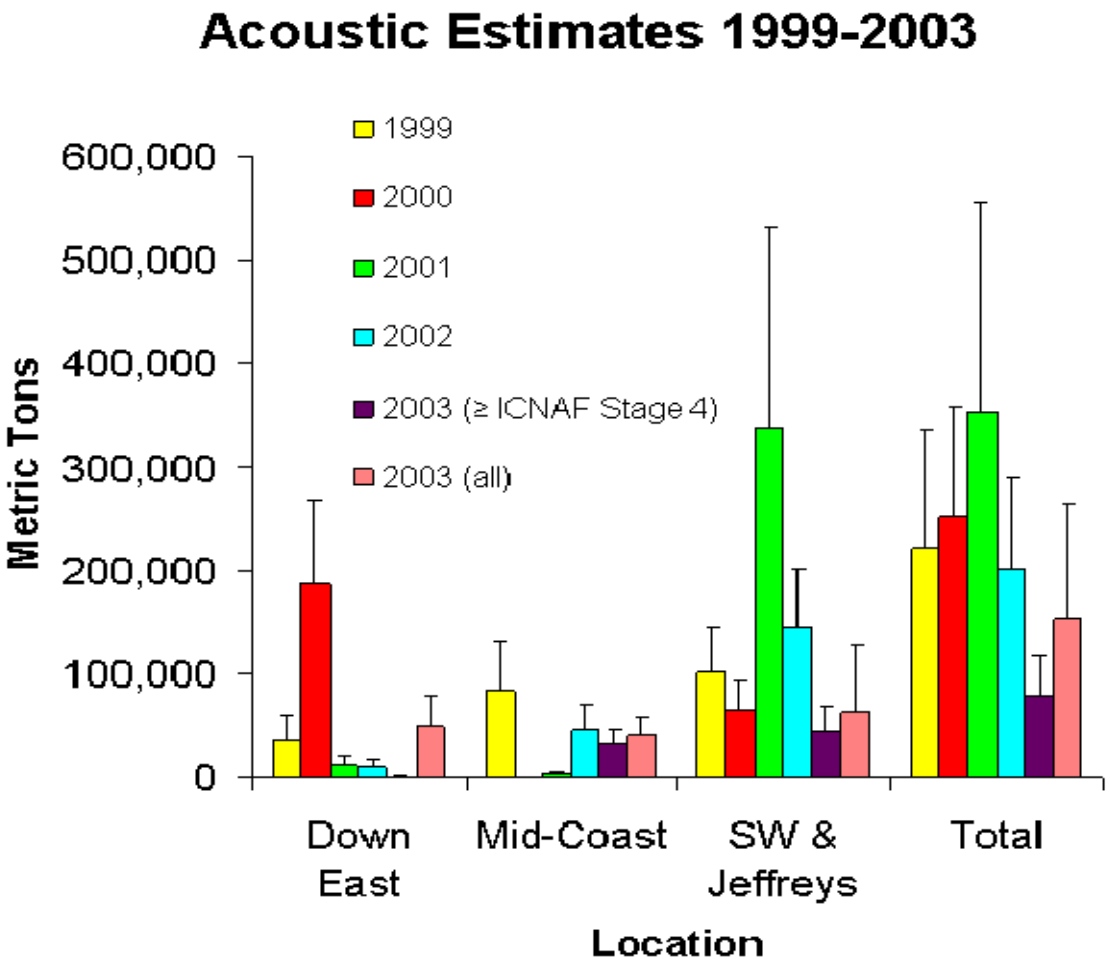


Figure 5.4.2: Revised SSB Estimates 1999-2004

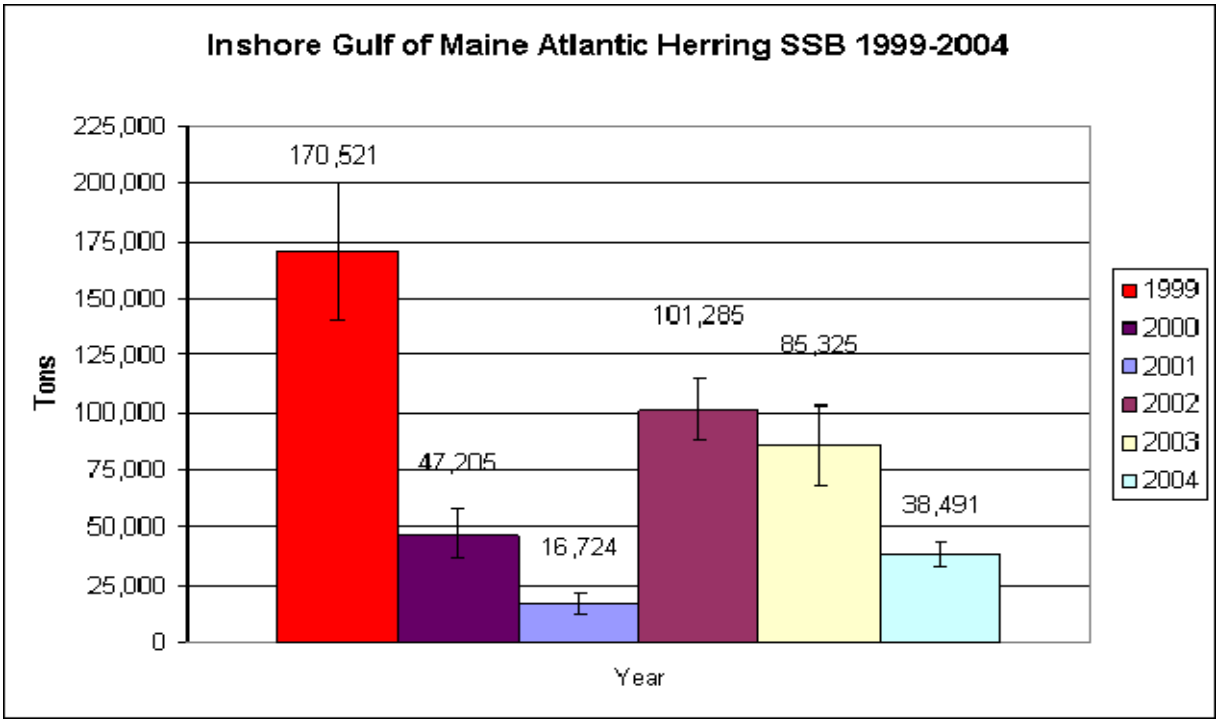
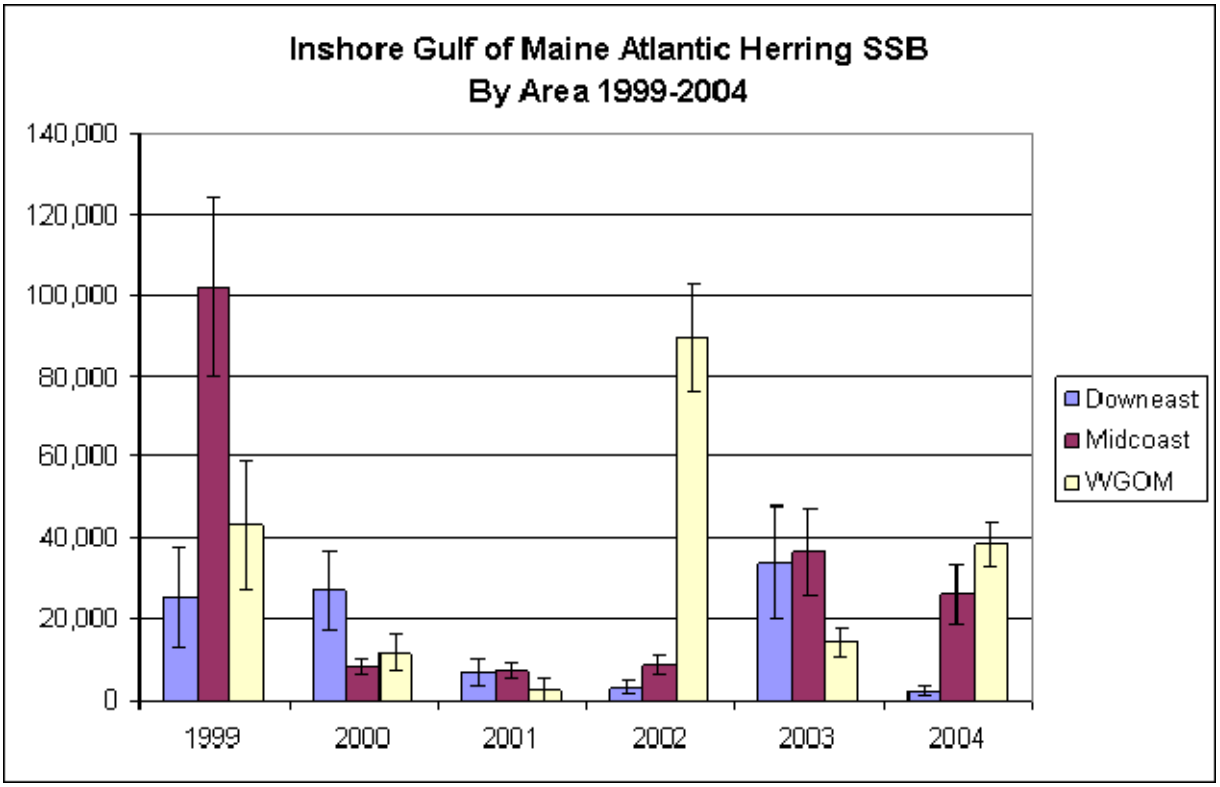


Figure 5.4.3: SSB by Survey Area 1999 - 2004



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Herring Acoustics Program Updates to the Public, available from GMRI						
1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Aug	Dec98-Jan	Jan	Jan-Feb	Winter/Spring	Jan	Feb-Mar
Sept	Feb	Feb-Mar	Mar-Apr	June	Feb	Apr-May
Oct	March	April	May-June	Oct	Mar	Jun-Jul
Mid-Oct	May	May	July-Oct		May	Aug-Sept
Nov	June	June			June-July	Oct-Nov
Dec-Jan99	July	July			Aug	
	August	August			Sept-Oct	
	Sept	Sept			Nov-Dec	
	October	Oct				
	Nov	Nov-Dec				
	Dec					

Annual and Special Reports for Funding Sources and General Distribution; Available from GMRI and from Funding Sources					
1999	**2000**	**2001**	**2002**	**2003**	**2004**
1998 Project Report to all funding sources	NMFS Award 1999-2000 Project Report	NMFS Award 2000 - 2001 Project Report	2001 NEC Annual Report	2002 NEC Annual Report	2003 - 2004 NEC Annual Report
		2001 NW Atlantic Herring Workshop	2002 NEC Semi-Annual Report	2002 Maine Science and Technology Foundation Report	"Notes From the Field" 2004 Survey Report
					1999-2004 NEC Interim Final Report

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