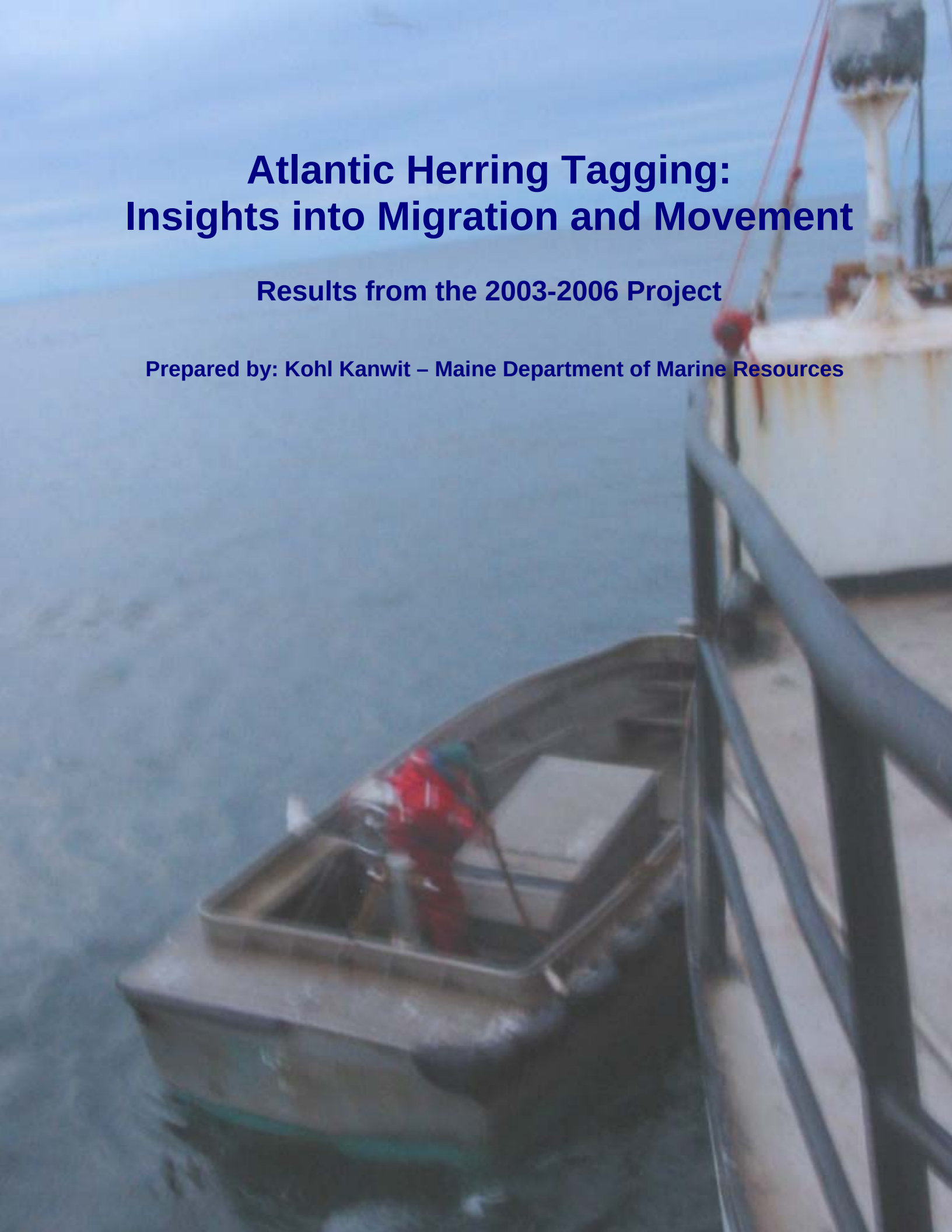

Atlantic Herring Tagging: Insights into Migration and Movement

Results from the 2003-2006 Project

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INTRODUCTION

Atlantic herring (*Clupea harengus*) is a schooling, pelagic species that occurs on both sides of the Atlantic Ocean. The range of the western Atlantic population extends from Northern Labrador to Cape Hatteras, NC. Atlantic herring on the East coast of the US have been exploited since pre-Colonial times and a robust commercial fishery has persisted since the 19th century with a peak in the late 1960s and early 1970s. With an estimated biomass of 1.8 million metric tons (mt) for the US coastal complex, herring provide a major forage base for other fish species, marine mammals, and sea birds, as well as supporting the second largest commercial fishery in the region. Landings in the last five years have averaged 100,000 mt with an estimated direct value in excess of $16 million.

Since the last large scale tagging project 20-30 years ago, the herring fishery has evolved from using fixed gear to mobile gear and the Georges Bank stock has fully recovered. The recent Atlantic herring tagging initiative for the US coastal complex began in 2003 and was designed to provide information on migration patterns and stock intermixing rates. The objectives of the study were to;

1) implement an effective herring tagging project in the context of the recovered US coastal stock complex
2) develop a methodology for adjusting tag returns based on catch and effort and;
3) estimate proportional movement between stock and management areas using the adjusted returns

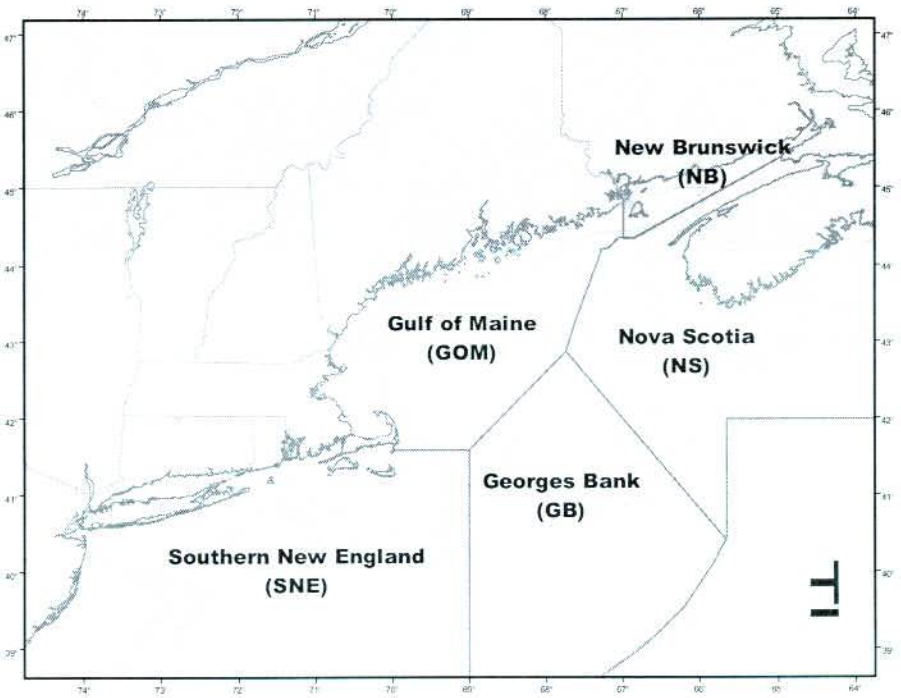
MATERIALS AND METHODS

Tagging events and tag returns were categorized in the context of spatial and temporal strata. In the Gulf of Maine/Bay of Fundy region five major spatial strata were defined: Nova Scotia (NS), New Brunswick (NB), the Gulf of Maine (GOM), Georges Bank (GB), and Southern New England (SNE; Figure 1, Appendix A). The four temporal strata used in this study were largely based on previous tagging work and were defined as: Spring Migration (SM: May-June), Summer Feeding/Spawning (SFS: July-October), Fall Migration (FM: November-December), and Winter Feeding (WF: January-April; Appendix A).

US Tagging efforts in 2003 and 2004 were conducted in an opportunistic manner due to a lack of dedicated funding and the challenging logistics associated with the offshore herring fishery. In 2005, dedicated funds were received and tagging efforts were targeted in all three of the US strata (GOM, GB and SNE). The last year of the project (2006) was funded by the remaining balance from the 2005 grant. Over the course of the tagging project, releases occurred in the GOM and GB during the SFS stratum and in SNE during the WF stratum. Herring were

also released by the Canadian Department of Fisheries and Oceans (DFO) in the NB stratum for all years of the project and for one year in the NS stratum. Atlantic herring in pre-spawning condition were targeted for tagging in the GOM and GB strata under the assumption that they were representative of the spawning stock in that area. Groups of age three plus herring were targeted in the SNE stratum assuming that they were representative of the spawning stock from which they originated.

Figure 1: Atlantic herring tagging project spatial strata



Marking Techniques

T-bar or anchor tags made by two manufacturers were used in this study. Tags made by Floy Tag Inc. (4616 Union Bay Place NE; Seattle, WA 98105), had an overall length of 6.0 cm and included the following information on a bright yellow, plastic sleeve: "MAINE DMR - # # # # # #". Tags produced by Hallprint PTY LTD (15 Crozier Rd. Victor Harbor; South Australia 5211) had an overall length of 6.5 cm and included the following label on a bright pink, plastic sleeve: "# # # # # # $1000 LOTTERY 207-633-9535 // PO BX 8 W BOOTHBAY ME 04575". All tags were imprinted with a unique identification number in sequential order. Both types of tags were applied using the Western States Supply Co. Mark III Tag Fast application gun fitted with stainless steel needles.

Tagging Events

US Tagging excursions were made on two classes of commercial fishing vessels, purse seine and midwater trawl (Figure2). The purse seine vessels (three) ranged in size from 65-95 ft. and fish commercial seine nets, averaging

1,800 ft. long and 250 ft. deep with 1⅛ in. mesh throughout. All tagging on purse seine vessels was undertaken during normal commercial fishing operations. Fish were located using a combination of a low frequency, long range sonar and a high frequency, short range sonar. Once a school of herring was encircled by the seine the fish were dipnetted out as they freely swam along the perimeter of the net close to the working side (starboard) of the vessel. The fish were removed from the seine well before they were "hardened", in other words concentrated in a small pocket of the net in preparation for pumping the fish onboard. Live herring were transferred to a holding tank with a controlled flow of fresh sea water (at a rate of 5 gal/min) provided by a submersible pump. Fish were selected randomly and tagged after a cursory determination of health. Fish that were judged to have less than 80% scale coverage or any indication of injury were discarded without a tag. Herring that appeared healthy and active had a conventional anchor tag inserted between the interneural rays of the musculature directly below the dorsal fin on the left side. The herring were released on the non-working side of the vessel immediately after tagging.

The midwater trawl vessels (two) were 75 and 90 ft. and both fished a Swan Net pelagic midwater trawl net with 12 ft. mesh at the head rope grading down to ¾ in. mesh in the codend. An aquarium codend, originally developed by the National Marine Fisheries Service (NMFS) for the capture of salmon smolts at sea was attached to the existing commercial herring net. Tagging aboard midwater trawlers was only carried out when the vessel was under contract because of the gear modification involved. Before deployment, the aquarium codend was filled with seawater to prevent it from rolling over and twisting the net while it was being set. Fish were located using a short range scanner and a 50 kHz third wire transducer was used to estimate the amount of fish captured during each tow. Tows were made as short as possible and targeted small aggregations of fish. A controlled flow of fresh seawater was introduced into the aquarium codend immediately after it was brought back onboard the vessel. Tagging was conducted as previously described.

Figure 2: Tagging aboard a purse seine vessel and preparing the aquarium codend for deployment from a midwater trawl vessel

Project Outreach and Tag Return Incentives

Extensive outreach efforts to inform the public were made to encourage tag returns. A lottery system with a $1000 prize was established in 2003 in lieu of more conventional individual tag rewards. This lottery system was continued and expanded to three annual prizes: one for $1000 and two for $500 each. The results of the lottery drawings were announced in fisheries publications and project bulletins. The 2006 winners were Steve Butler of Buxton for $1,000 and Nancy Harrington of Milbridge and Carla Bradford of Breadlebane, NB for $500 each.

RESULTS

Tagging Events

Herring were released by Canadian and/or US taggers in all five spatial strata (GOM, SNE, GB, NS and NB) throughout this study. The following table summarizes the numbers of herring released over the four years in all areas.

Table 1: Number of fish tagged by spatial strata

SPATIAL STRATA	2003	2004	2005	2006	TOTALS
GOM	15275	13525	5250	6100	40150
SNE	4536	5875	20000	15000	45411
GB	0	0	10325	0	10325
NS[1]	0	0	13739	0	13739
NB	32570	31627	25394	11585	101176
TOTALS	**52381**	**51027**	**49314**	**32685**	**210801**

[1] – Cooperative effort between Canada and the US

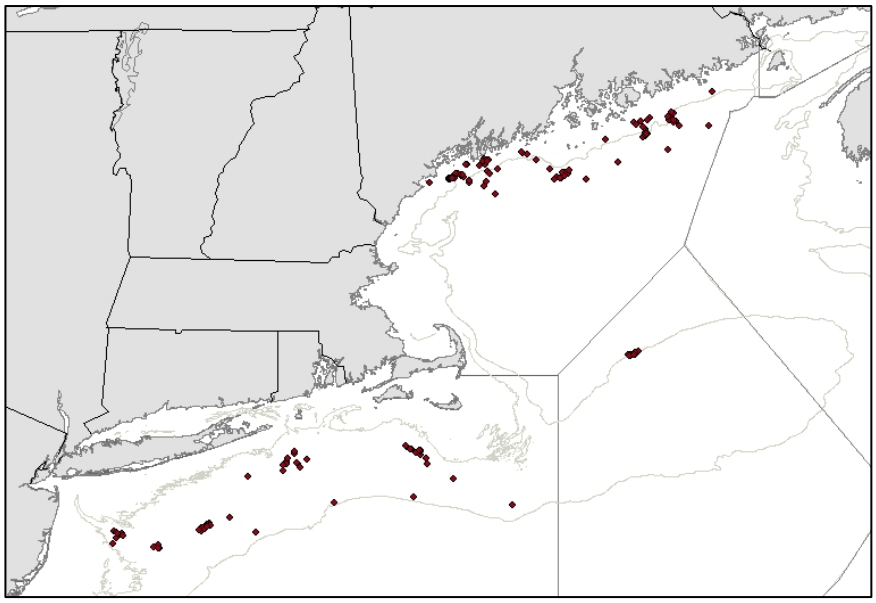
In US waters, a total of 68 trips were made over the four years resulting in 95,886 herring released. Seventy percent of these releases (67,586) were made from mid-water trawl vessels employing the aquarium codend while 28,300 were made from commercial purse seine vessels. Herring were tagged from 165 individual sets and 22 sets were made where no fish were tagged. The average number of fish tagged per set was 580 although it ranged from 10 to 1500 depending on fish quality and the number of tagging personnel. Figure 3 shows the location of each set where fish were tagged and released.

Representative biological samples (N=50) were taken on each trip in order to categorize the size and maturity of the captured herring (refer to Appendix B for length frequency plots by spatial strata).

Tag Returns

Tag returns from fish released in the GOM between 2003-2006 were recovered in each of the five defined spatial strata (Table 2 and Figure 4). A total of 146 fish were recovered as of May 2007. Recoveries occurred from as far east as Scots Bay, Nova Scotia and as far west as Hudsons Canyon off the New York/New Jersey shore.

Figure 3: Location of tagging sets



Fish tagged in SNE between 2003-2006 were recovered in four of the five spatial strata (Table 2 and Figure 5). No recoveries were made in the GB stratum from fish released in SNE. With this exception, the pattern of recoveries mirrored the range of the GOM returns from Scots Bay to Hudsons Canyon. As of May 2007, 160 fish were recovered from the SNE releases.

Tagging in the GB stratum only occurred in 2005 due to funding limitations. Nine tags were returned between the release date (August 2005) and the spring of 2007 (Figure 6). Of these tags two were recovered in the GOM during the fall, six were recovered in the SNE winter fishery and an additional fish was recovered in the NS winter fishery (although exact coordinates were not reported).

Table 2: Numbers of US tags by release and recovery strata (2003-2006)

	RECOVERY STRATA						
RELEASE STRATA	**GB**	**GOM**	**NB**	**NS**	**SNE**	**UNK**	**TOTAL**
GB		2		1	6		9
GOM	6	101	5	16	12	6	146
SNE		54	10	46	34	16	160
TOTAL	6	157	15	63	52	22	315
% GB	0	1	0	2	12	0	3
% GOM	100	64	33	25	23	27	46
% SNE	0	34	67	73	65	73	51

Figure 4: Tag returns from fish released in the GOM stratum

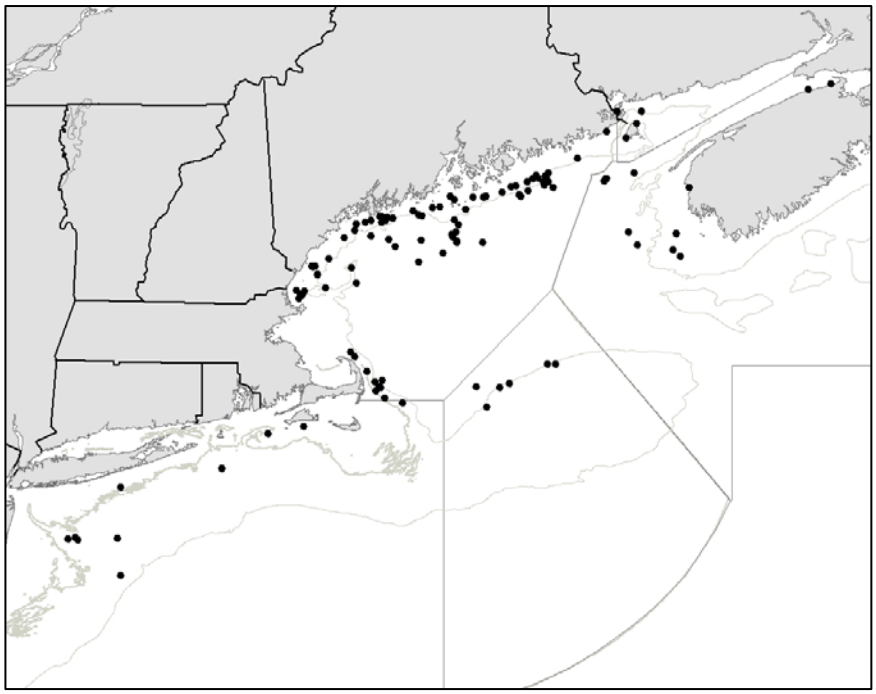


Figure 5: Tag returns from fish released in the SNE stratum

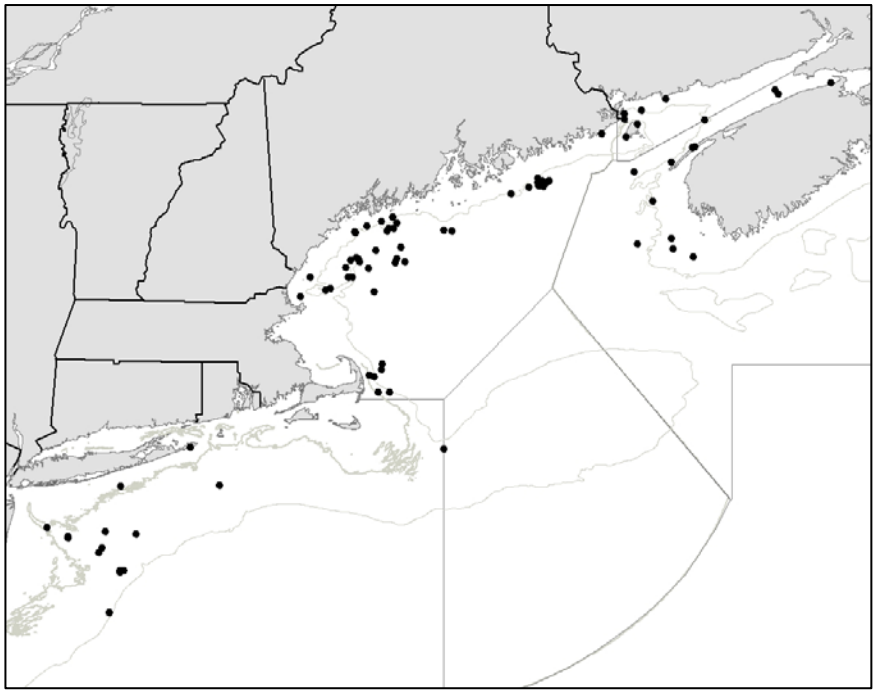
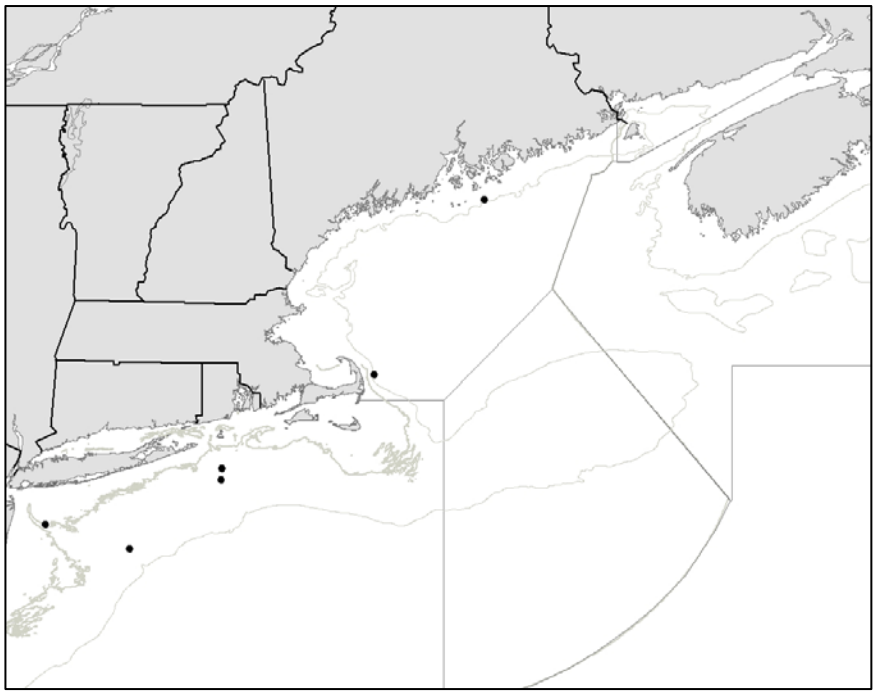


Figure 6: Tag returns from fish released in the GB stratum



Seasonal Movement

Atlantic herring exhibit highly seasonal migrations so it is important to consider the tagging data in a temporal context. Figure 7 plots the distance traveled from the original tagging location in the GOM stratum against the time at large for individual fish. Recoveries show a clear pattern of short term residency during the SFS stratum (<100 days), followed by longer distance migrations in the FM, WF and SM strata. After one year at large, recoveries of fish tagged in the GOM were made close to the original tagging location. Sixty percent of the tags returned after one year were made within 100 nmi of the tagging location. However, due to the limited number of tag returns after one year at large, small-scale site fidelity was impossible to assess. Additionally, fish recovered in the WF stratum of the following year showed long-distance migrations similar to results from their first year at-large.

Fish released in SNE during the WF stratum left the area quickly (300 nmi in <100 days). Recaptures made 200+ days after the initial tagging were generally near the original release site (Figure 8). Additional recoveries, exceeding 400 days at large were made more than 350 nmi from the release location. Only three tags were returned with adequate recovery information one year or more after release.

Days at large and distance traveled plots were not made for GB because of the small number of recoveries.

Figure 7: Days at large and distance traveled for fish released in the GOM

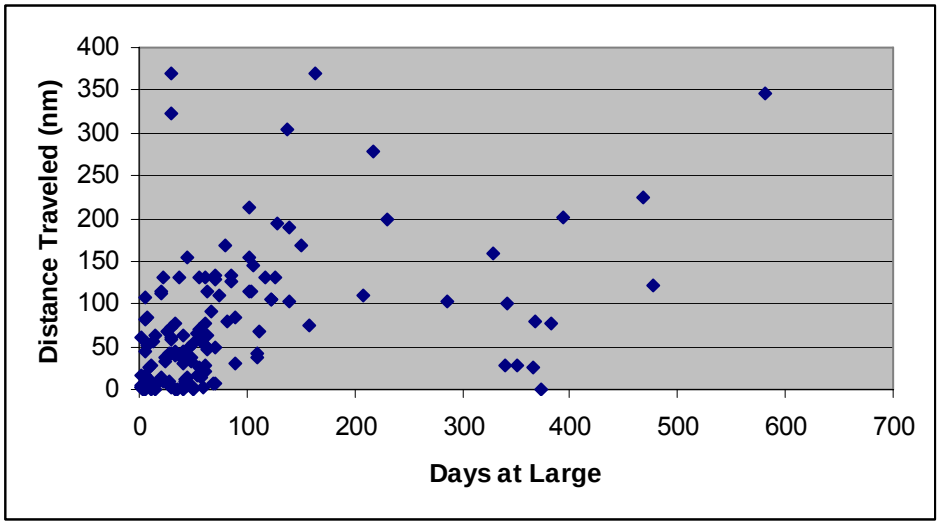
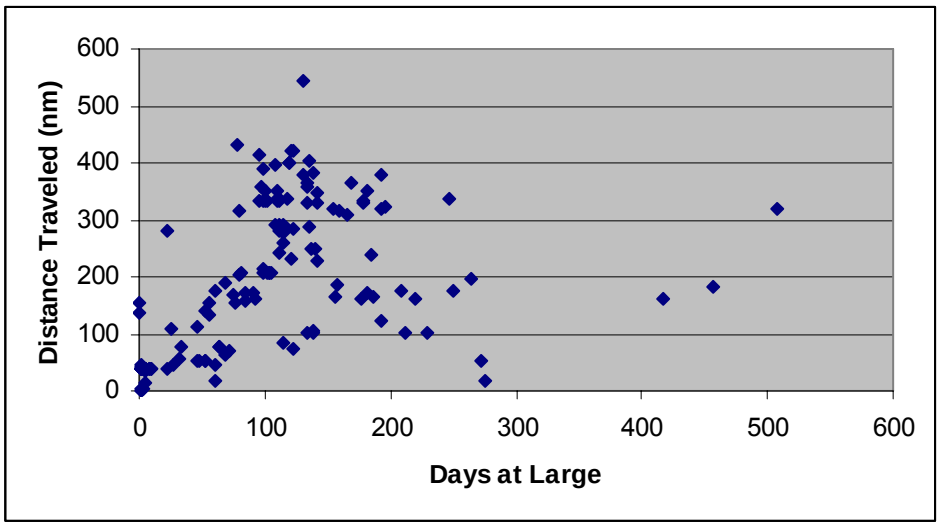


Figure 8: Days at large and distance traveled for fish released in SNE



DISCUSSION

Results from this study reveal two major findings; Atlantic herring can be tagged and recovered in meaningful numbers in the context of a modern, mobile gear pelagic fishery pursued offshore and there is apparent and appreciable intermixing of the western portion of the Nova Scotian herring stock (4X) in both the Gulf of Maine and Southern New England. The first point is noteworthy because tagging studies on the US coastal complex of Atlantic herring using anything but weir caught fish have only realized limited results mostly related to short-term and short-distance migration patterns. The second point is an

important finding because the US coastal complex and the Nova Scotian complex are currently assessed separately and any intermixing or straying between stocks is considered minimal and insignificant.

Obtaining healthy herring has been a major challenge for previous tagging projects. In the past, many herring tagging projects relied on fish caught by weirs and stop seines. These gear types were ideal for tagging because they were fished close to shore and the herring were allowed to school freely within the enclosure until the catch was harvested. Historically, this provided an opportunity for researchers to apply tags on healthy fish, near shore in a relatively controlled environment. Unfortunately, there is virtually no fixed gear fishery for Atlantic herring in US waters anymore. The herring fishery is now dominated by mobile gear fishing vessels employing purse seines and midwater trawls. These gear types are much more difficult to obtain healthy herring from because they are used offshore in more variable conditions. Purse seined herring can only be accessed by tagging personnel if the school circles around the perimeter of the seine within reach of dip nets deployed from the fishing vessel. Stress induced mortality is extremely high with Atlantic herring so each tagging event was limited to the number of fish that could be held and tagged in approximately one hour. Using midwater trawls to obtain live herring posed a unique challenge because the commercial nets are large, the twine is abrasive and the herring are pushed into the codend during the capture process and dragged through the water. The aquarium codend basically provided a contained, still pocket of water where the herring could collect while the net was being fished. This development was critical to the future of herring tagging because there are certain areas and times of year when herring can only be captured with a midwater trawl net (e.g. SNE during the WF period).

Achieving adequate return rates in any tagging project on an open population is difficult, but particularly so in the context of the modern Atlantic herring fishery. Past tagging studies reported return rates occasionally as high as six percent, but averaged between one and three percent. These high return rates were likely a result of several factors such as; the fixed gear fishery targeted juveniles which appear to be hardier than larger adults, fish were in excellent condition prior to tagging due to the capture method employed, the vast majority of recaptures were made shortly after the fish were released and in the same geographic vicinity, and the overall herring population was in a depressed state with the collapse of the Georges Bank component. Finally, these studies were all conducted at a time when 80% of the herring catch went to canneries. The processing facilities provided an increased opportunity for the tagged fish to be seen because every herring was handled by a plant worker while they were sorted, cut and packed.

In contrast, the current tagging project occurs in the context of an entirely changed fishery and recovered stock status. The last sizeable catches of herring by the US fixed gear fishery were in the early 1980s. The mobile gear fishing fleet

has dominated the fishery ever since and occurs increasingly farther from shore, covering a broader geographic area and operating throughout the year. This means that short term recaptures within a small geographic area are less likely resulting in lower unadjusted return rates. In addition to the changes in the fishery, the population of herring on Georges Bank has recovered. To realize adequate return rates the numbers of fish that have to be tagged and released increases dramatically, especially in SNE during the WF stratum when it is assumed that all of the spawning components intermix. Finally, the market structure of the herring fishery has changed from processor dominated to the majority of landings going to the lobster bait industry. In 2006, about 60% of the catch went to lobster bait dealers. Tagged herring are difficult to recover from lobster bait because the first opportunity to see a tagged fish is when a sternman is stuffing bait bags between hauling strings of traps. In essence, recoveries are reliant on non-herring fishermen to see the tag, know about the project, and be motivated to report the recovery. On top of this shift in market distribution of the catch, both sectors and the catcher vessels themselves employ modern mass handling techniques (fish pumps) that provide only limited opportunities to see tagged fish.

The second major finding of this study is that herring move between all five spatial strata and that there is appreciable intermixing of herring from the GOM and SNE in the waters to the south-west of NS. Several recaptures of spawning herring originally tagged in the GOM were made in all years of the study on the grounds of the Nova Scotia roe fishery (Scots Bay and/or German Bank). These results are noteworthy, apparently indicating that some amount of herring that eventually spawned in NS migrated through the GOM in the summer. These results coupled with data from SNE tagged fish would logically imply that herring are migrating through the GOM to NS after spending the WF period in SNE.

The returns from SNE also indicated similar movement patterns and possible stock intermixing. Predictably, a large proportion of the returns came from the GOM where the bulk of fishing activity occurs. The results also indicated a large number of fish remained or returned to the SNE stratum. However, the most important finding was the apparent intermixing of fish from SNE in NS. Tag returns from the mobile gear fishery in NB also imply intermixing between the NS stock and the US coastal complex. This is explained by the fact that fish caught by mobile gear in NB are considered part of the NS stock component. The results of this study call into question the long standing assumption that the US coastal complex does not intermix to any measurable extent with the NS stock.

An additional analysis was done on the 2003 and 2004 data that weighted the actual return numbers by catch and effort. A manuscript is currently being prepared presenting the results of this analysis and updating it with results from 2005 and 2006. To summarize the findings, the weighted tag return data were comparable to the actual return numbers. Interestingly, the tag returns from Nova Scotia accounted for almost 10% of the GOM returns and almost 20% of the SNE returns in 2003 and 2004 (please refer to the DMR website for a power point

presentation on these results:
http://www.maine.gov/dmr/rm/herring/herring_project.htm.

The significance of this tagging study is not that a high return rate was achieved, but that herring can be effectively tagged and long-term, long-distance recoveries made. The actual return rate from this study is low, but the percent of returns after two weeks at large is high. These results have indicated connections between different herring stock components in the US and Canada. Although these returns are very limited in scope they do provide intriguing results and warrant continued study.

APPENDIX A: Abbreviations for spatial and temporal strata

SPATIAL STRATA	ABBREVIATION
NEW BRUNSWICK	NB
NOVA SCOTIA	NS
GULF OF MAINE	GOM
GEORGES BANK	GB
SOUTHERN NEW ENGLAND	SNE

TEMPORAL STRATA	ABBREVIATION	TIME PERIOD
SPRING MIGRATION	SM	MAY-JUNE
SUMMER FEEDING/SPAWNING	SFS	JULY-OCTOBER
FALL MIGRATION	FM	NOVEMBER-DECEMBER
WINTER FEEDING	WF	JANUARY-APRIL

Appendix B: Length frequency plots by spatial strata