Fisheries Research 141 (2013) 88–94

Contents lists available at SciVerse ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Spatial and temporal patterns of anadromous alosine bycatch in the US Atlantic herring fishery

Jamie M. Cournane [a,*], Jacob P. Kritzer [b], Steven J. Correia [c]

[a] University of New Hampshire, Institute for the Study of Earth, Oceans, and Space, Ocean Process Analysis Laboratory, 8 College Road, Durham, NH 03824-2600, USA
[b] Environmental Defense Fund, 18 Tremont Street, Suite 850, Boston, MA 02108, USA
[c] Massachusetts Division of Marine Fisheries, 838 South Rodney French Blvd., Suite 850, New Bedford, MA 02744, USA

ARTICLE INFO

Keywords:
Alewife
Anadromous alosine
Atlantic herring
Blueback herring
Bycatch management

ABSTRACT

River herring, which comprise two species of anadromous alosines (alewife, *Alosa pseudoharengus*, and blueback herring, *Alosa aestivalis*), are under consideration for listing under the US Endangered Species Act. River herring populations have not rebounded despite reductions in directed fishing on these species and improvements in their freshwater and estuarine habitats. We examined recent (2005–2009) spatial and temporal patterns of fishing effort in the US fishery for Atlantic herring, *Clupea harengus*, and river herring bycatch patterns in this fishery. During the year, Atlantic herring fishing activity shifts spatially and temporally from the Northern Mid-Atlantic Bight and Southern New England waters in January–February, to Southern New England waters in March–April, to the Gulf of Maine in May–June, expanding to the Gulf of Maine and Georges Bank in July–August and September–October, respectively, and then contracting to the Gulf of Maine and Southern New England waters in November–December. At-sea fisheries observer data indicate that river herring bycatches in the Atlantic herring fishery occur mostly during January–April and September–December, primarily in Southern New England and the Northern Mid-Atlantic Bight waters. We discuss possible management measure to reduce these bycatches. Similar size, shape, and schooling behaviors between river herring and other pelagic species—and the high volume nature of the Atlantic herring fishery—limit the potential efficacy of gear-based bycatch mitigation measures. Hence, approaches such as regulatory management measures (e.g., time–area closures and catch caps) and improved fleet communication strategies (e.g., "move-on" rules) may be more practical and effective in minimizing river herring bycatch in the Atlantic herring fishery.

1. Introduction

1.1. Oceanic impacts on anadromous fishes

Most research and management activity on anadromous fishes has been focused on freshwater life stages (spawning adults, eggs, larvae, and young-of-year). These stages are generally the easiest to observe and sample, and frequently represent demographic bottlenecks to population growth because of habitat and food limitations. In contrast, the oceanic life stages of anadromous species typically experience density-independent growth and mortality, although the much greater duration of the oceanic phase can induce cumulative effects that substantially affect population abundance. Consequently, attention to oceanic life stages of anadromous fish is increasing. Effects of environmental factors such as temperature and other physical parameters (e.g., Friedland et al., 2009), diet (e.g., Haugland et al., 2006), parasites (e.g., McVicar, 1997), and benthic habitat features (e.g., Stein et al., 2004b) have been described for several anadromous species.

Fisheries for anadromous species are typically prosecuted within river systems and also along coastal migration routes. Managing oceanic bycatch of anadromous species is challenging because different management agencies have jurisdiction in freshwater and marine systems, and because some species cross national boundaries and leave territorial waters altogether during their ocean migrations. Although managing bycatch of anadromous species has primarily focused on salmon (e.g., Witherell et al., 2002) and sturgeon (e.g., Stein et al., 2004a), the problem is not unique to these species.

1.2. River herring stock status and recent management

Runs of many anadromous alosines have declined so markedly along the East coast of the United States that coast-wide stock collapses are feared to be underway (Limburg and Waldman, 2009). Commercial landings of river herring in US state-managed

* Corresponding author. Tel.: +1 603 862 2376; fax: +1 603 862 0243.
E-mail address: Jamie.Cournane@unh.edu (J.M. Cournane).

0165-7836/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.fishres.2012.08.001

waters declined from 31,750 mt in 1957 to 454 mt in 2007, with annual landings subsequently remaining relatively stable at the low 2007 level (ASMFC, 2009). The current status of US river herring stocks is depleted, and mitigation of negative impacts on river herring populations has been recommended (ASMFC, 2012). In 2006, the National Oceanic and Atmospheric Administration (NOAA) declared alewife and blueback herring to be "species of concern" and is currently investigating whether to list these two species under the Endangered Species Act (ESA).

Moratoria on directed fisheries for river herring in individual US state managed waters (inland waters to 3 NM) began 10 years ago, and were extended coast-wide in 2012 through a default closure in those directed river herring fisheries lacking an approved sustainable harvest plan by the Atlantic States Marine Fisheries Commission (ASMFC, 2009). River herring fishery moratoria have been in place in Connecticut since 2002, in Massachusetts since 2005, in Rhode Island since 2006, and in North Carolina since 2007. To date, Maine, New Hampshire, New York, North Carolina, and South Carolina have had sustainable harvest plans approved by the ASMFC.

In 2009, the ASMFC and the Mid-Atlantic Fishery Management Council (MAFMC) requested emergency action from the US Secretary of Commerce to protect river herring at sea, while the New England Fishery Management Council (NEFMC) requested additional information collection through increased monitoring. These requests were ultimately denied citing ongoing activities by the two Councils (which manage fisheries in the USA EEZ off the Atlantic coast) to address river herring bycatch. During 2009, the NEFMC tasked its Atlantic Herring Plan Development Team (PDT) to develop alternatives for mitigating river herring bycatch in the Atlantic herring fishery. Currently, NEFMC and MAFMC are discussing strategies to reduce the marine bycatch of river herring through amendments to the Atlantic herring fishery management plan and the Atlantic mackerel (*Scomber scombrus*) fishery management plan, respectively (NEFMC, 2012; MAFMC, 2012). Much of the work presented here informed NEFMC and MAFMC during the development of these amendments.

1.3. River herring bycatch in ocean fisheries

Bycatch of river herring in oceanic fisheries was recognized as early as the 1980s during Soviet-US joint-venture Atlantic mackerel fisheries (Chuksin, 2006; Shepherd, 1986) and subsequently in the 1990s in trawl fisheries in Canadian waters (Stone and Jessop, 1992). The impacts of oceanic bycatch on alewife and blueback herring populations differ, in part, because of migration patterns (Collette and Klein-MacPhee, 2002; Neves, 1981; Stone and Jessop, 1992).

Cieri et al. (2008) estimated river herring bycatch (kept and discarded) in the U.S. directed Atlantic herring fishery. Yearly bycatch estimates vary from 78 mt (60% CV) in 2006 to 765 mt in 2007 (50% CV) (see Table 2 in Cieri et al., 2008).

Wigley et al. (2009) estimated that oceanic river herring discards in US Atlantic coast fisheries totaled 48 mt (149% CV) between June 2008 and July 2009. River herring discards were highest in the New England small mesh otter trawl fishery, and to a lesser degree in the New England shrimp trawl fishery, the New England large mesh trawl fishery, and the Mid-Atlantic small mesh otter trawl fisheries. Wigley et al. (2009) note that fishing practices in high volume fisheries, such as those for Atlantic herring and Atlantic mackerel, limited the observation of all discards.

Using a combination of the above two approaches, the 2012 ASMFC river herring stock assessment includes estimates of oceanic river herring bycatch, both the kept and discarded components of this catch. The bycatch estimates are summarized by year, major gear type, and port location, but not by fishery such as the Atlantic herring fishery (ASMFC, 2012). The assessment results reveal that annual oceanic river herring bycatches have often been as high as the river herring landings in directed state waters fisheries, and sometimes even greater (ASMFC, 2012).

1.4. Current management of the Atlantic herring fishery

The Atlantic herring fishery primarily supplies a source of bait, especially for the American lobster, *Homarus americanus*, fishery (NEFMC, 2012). The Atlantic herring fishery is managed through a fleet-wide hard total allowable catch (TAC) allocated to each of the fishery management plan (FMP) areas (1A, 1B, 2, and 3; Fig. 1) (NEFMC, 2006). The fishery is closed in a given area when its sub-TAC is reached. The three main gear types, mid-water trawls (single and paired), purse seines, and otter bottom-trawls, account for approximately 1000 permits. In 2009, roughly 4% (104 out of 2498) of the permit holders (i.e., primarily those fishing by mid-water trawling and purse seining) harvested greater than 99% of Atlantic herring landings (NEFMC, 2012). The fishery is subject to spatial closures in area 1A during times when Atlantic herring spawn inshore and in sub-areas of the Gulf of Maine and Georges Bank if 1% of the haddock, *Melanogrammus aeglefinus*, TAC is projected to be exceeded by haddock stock area as bycatch in the fishery (NEFMC, 2011, 2012). Haddock bycatch occurs primarily on Georges Bank, where the Atlantic herring fishery operates during the summer and fall (see Appendix I of NEFMC, 2011).

Bycatch of river herring is currently unmanaged in the Atlantic herring fishery. The high volume nature of the Atlantic herring fishery limits the potential effectiveness of gear-based bycatch mitigation measures. Alternate approaches such as regulatory management measures (e.g., time–area closures and catch caps) or improved fleet communication strategies (e.g., "move-on" rules) are likely to be more practical and effective in minimizing river herring bycatch in the Atlantic herring fishery. In fact, the Atlantic herring fishery is currently exploring a "move-on" approach (outside of the regulatory framework) through a pilot voluntary river herring bycatch avoidance program (NEFMC, 2012).

1.5. Research objectives

The objectives of our research were to: (1) identify the times and areas that river herring bycatch occurred in the Atlantic herring fishery; and (2) compare river herring bycatch patterns to effort patterns in the US Atlantic herring fishery.

2. Materials and methods

2.1. Study area

The study area includes the Atlantic herring FMP areas (Fig. 1). These areas are located on the Eastern US Continental shelf, encompassing portions of the Gulf of Maine, Georges Bank, and the Mid-Atlantic Bight (Fig. 1). The shelf is highly productive and supports many commercially valuable marine species, including lobster, Atlantic cod, haddock, and Atlantic herring. The oceanography of the region is well understood (e.g., Beardsley et al., 1997; Churchill et al., 1993; Ji et al., 2006; Lynch et al., 1997; Mountain and Kane, 2010; Townsend et al., 2006).

2.2. Datasets

Directed Atlantic herring fishery effort and catch data for 2005–2009 were available from self-reported (vessel trip reports, VTRs) and at-sea fishery observer (the Northeast Fisheries Observer Program, NEFOP) records. These records are only from federal waters, those waters from 3 NM to the edge of the EEZ (200 NM).

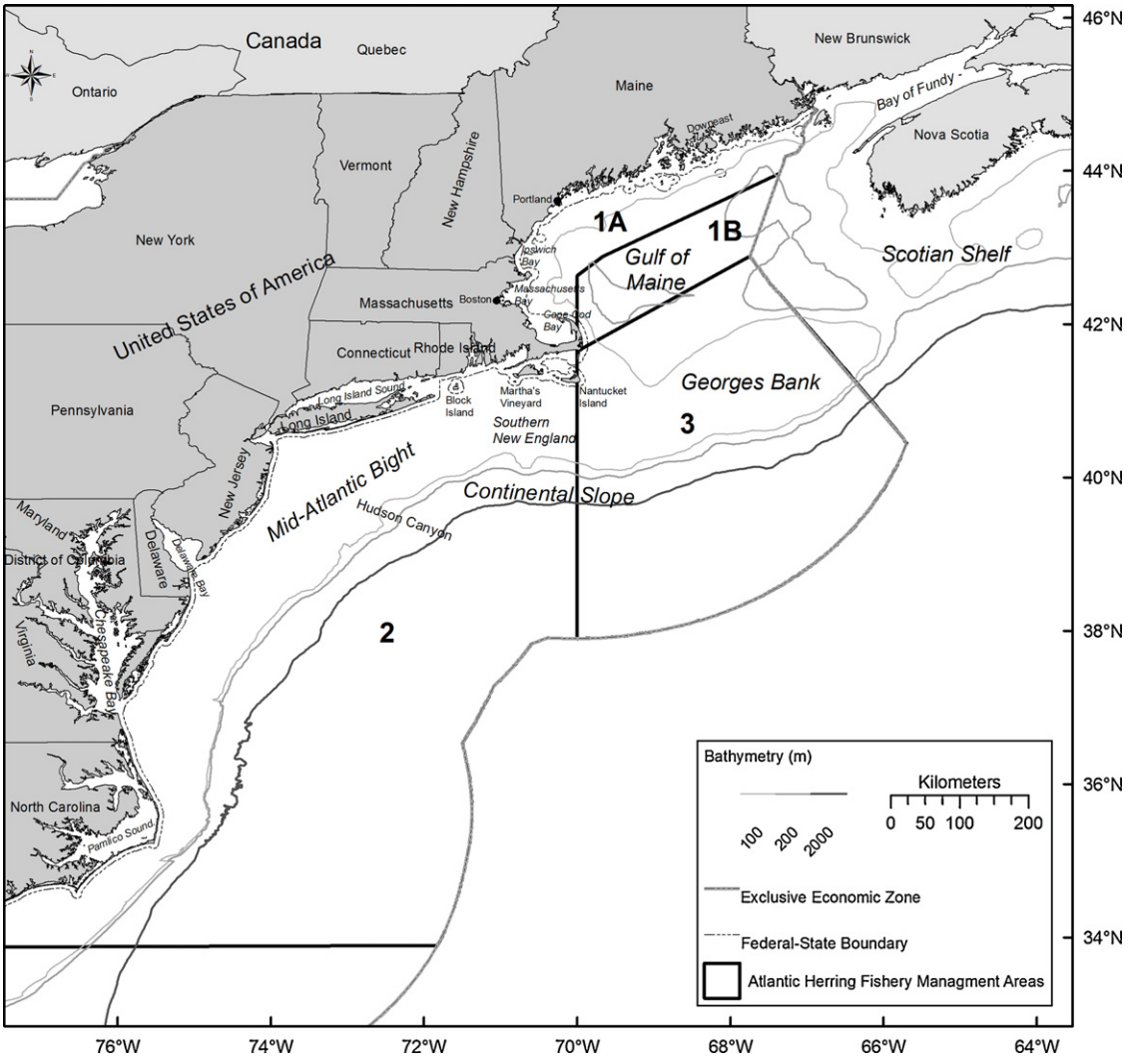

Fig. 1. Study area of the Eastern US Continental Shelf overlapped with Atlantic herring fishery management plan areas (1A, 1B, 2, and 3) indicated.

We defined a directed herring fishery trip as a trip with greater than 907 kg of kept Atlantic herring (following Cieri et al., 2008). Data from non-directed trips were not analyzed. The directed herring fishery comprises three gear types: bottom otter-trawls, purse seines, and mid-water trawls (consisting of either single or paired mid-water trawls).

VTRs are self-reported and mandatory for commercial fishing trips. VTRs provide information on the starting location of fishing within a single statistical reporting area (SRA). Captains are required to complete and submit a new VTR once a vessel moves and fishes in another SRA. The total number of VTR reported trips is therefore higher than the number of actual fishing trips, and should provide more detailed information on the spatial distribution of fishing effort. We examined a total of 4776 VTRs (Table 1).

A total of 1775 observed hauls or sets in the directed Atlantic herring fishery were analyzed from the records in the NEFOP database (Table 2). These records include the presence or absence and total weight (kg) of river herring from each haul or set observed, and the actual (or estimated) kept and discarded alewife and blueback herring. In our analysis, we pooled the kept and discarded components of alewife and blueback herring, and refer to the total catch of both species as 'river herring' bycatch. In 2006, no purse seines were observed by NEFOP staff (Table 2).

Observers use different sampling protocols for the three gear types (NEFOP, 2010). For bottom otter-trawls, a census of all kept and discarded fish is taken after on-deck sorting. A census of river herring bycatch for purse seines and mid-water trawls remains problematic due to the high-volume nature of these gears (NEFOP, 2010; Wigley et al., 2009). Therefore, observers cluster sample the catch, on average taking 10 standard orange bushel baskets (with a NEFOP standard volume of 1.47 $ft^3 \sim 0.0416\ m^3$), equally spaced in time relative to the captain's best estimate of the time taken to pump the fish into the hold. The captain provides a total hail weight and the total river herring bycatch is extrapolated by the observer from the basket samples, using the ratio of river herring weight to total species weight in the basket samples. The river herring bycatch estimates in purse seines and mid-water trawls might therefore be biased if the captain's hail weight varies from the actual total catch weight or if the basket samples are not representative of the river herring bycatch.

2.3. Data analysis

Spatial analysis, using Arc GIS 9.3.1, included mapping patterns of river herring bycatch and Atlantic herring fishing effort. Due to data confidentially requirements, limited data prior to 2005, and variable observer coverage rates year to year by gear type, all years and gear types were combined in the spatial analysis.

Table 1
Number of directed Atlantic herring trips (reported VTR trips) separated by gear, year, and bimonthly groupings used in the analysis. Gear categories include bottom otter-trawls (OT), mid-water trawls-single and paired (PR), and purse seines (PS).

Year	Gear category			All
	OT	PR	PS	
January–December				
2005	77	774	200	1051
2006	150	739	175	1064
2007	414	389	365	1168
2008	109	304	246	659
2009	203	406	225	834
All	953	2612	1211	4776
January–February				
2005	10	89	0	99
2006	52	108	0	160
2007	140	141	0	281
2008	56	101	0	157
2009	79	128	0	207
All	337	567	0	904
March–April				
2005	5	48	0	53
2006	19	71	0	90
2007	15	65	0	80
2008	7	44	0	51
2009	26	55	0	81
All	72	283	0	355
May–June				
2005	7	151	25	183
2006	0	158	27	185
2007	0	75	52	127
2008	0	25	53	78
2009	1	18	53	72
All	8	427	210	645
June–August				
2005	7	182	88	277
2006	12	202	94	308
2007	163	0	187	350
2008	17	12	177	206
2009	27	9	121	157
All	226	405	667	1298
September–October				
2005	20	195	82	297
2006	25	143	54	222
2007	64	52	126	242
2008	10	68	16	94
2009	25	128	45	198
All	144	586	323	1053
November–December				
2005	28	109	5	142
2006	42	57	0	99
2007	32	56	0	88
2008	19	54	0	73
2009	45	68	6	119
All	166	344	11	521

Source: Vessel Trip Report Database 2005–2009.

Table 2
Number of observed directed Atlantic herring fishing hauls or sets separated by gear, year and bimonthly groupings used in the analysis. Gear categories include bottom otter-trawls (OT), mid-water trawls-single and paired (PR), and purse seines (PS).

Year	Gear category			All
	OT	PR	PS	
January–February				
2005	0	39	0	39
2006	36	72	0	108
2007	37	19	0	56
2008	4	44	0	48
2009	23	76	0	99
All	100	250	0	350
March–April				
2005	0	21	0	21
2006	0	3	0	3
2007	0	22	0	22
2008	0	41	0	41
2009	4	34	0	38
All	4	121	0	125
May–June				
2005	0	64	5	69
2006	0	6	0	6
2007	0	3	0	3
2008	0	28	25	53
2009	0	37	39	76
All	0	138	69	207
July–August				
2005	3	112	47	162
2006	16	17	0	33
2007	11	0	18	29
2008	4	15	36	55
2009	0	11	51	62
All	34	155	152	341
September–October				
2005	12	111	43	166
2006	8	20	0	28
2007	3	15	9	27
2008	0	42	8	50
2009	4	194	3	201
All	27	382	63	472
November–December				
2005	0	118	0	118
2006	4	2	0	6
2007	8	16	0	24
2008	0	39	0	39
2009	4	85	4	93
All	16	260	4	280

Source: NEFOP Database 2005–2009.

2.3.1. Analysis of fishing effort

Bimonthly maps and tables of the number of fishing trips per SRA were constructed using the VTR data (Fig. 2). As a proxy for actual fishing effort, we estimated relative fishing effort using the number of VTR trips within a SRA.

We binned relative fishing effort into three categories: high (>69), medium (6–68) and low (1–5) effort concentration areas using natural breaks classification across SRAs and bimonthly groupings for all positive values. Natural breaks classification, a statistical approach that reduces the variance within classification bins and maximizes the variance among classification bins, was used to construct bimonthly maps of relative fishing effort by SRA. Within a bimonthly grouping, areas identified as "none" delineate potential fishing areas (i.e., classified as high, medium, or low fishing effort in another bimonthly grouping) that were not fished during that bimonthly period.

2.3.2. Analysis of river herring bycatch

We also binned bimonthly NEFOP river herring bycatch data using natural breaks classification. Six bins, based on river herring presence/absence and river herring catch weight, were developed: >559.28 kg; >162.39–559.28 kg; >58.51–162.39 kg;

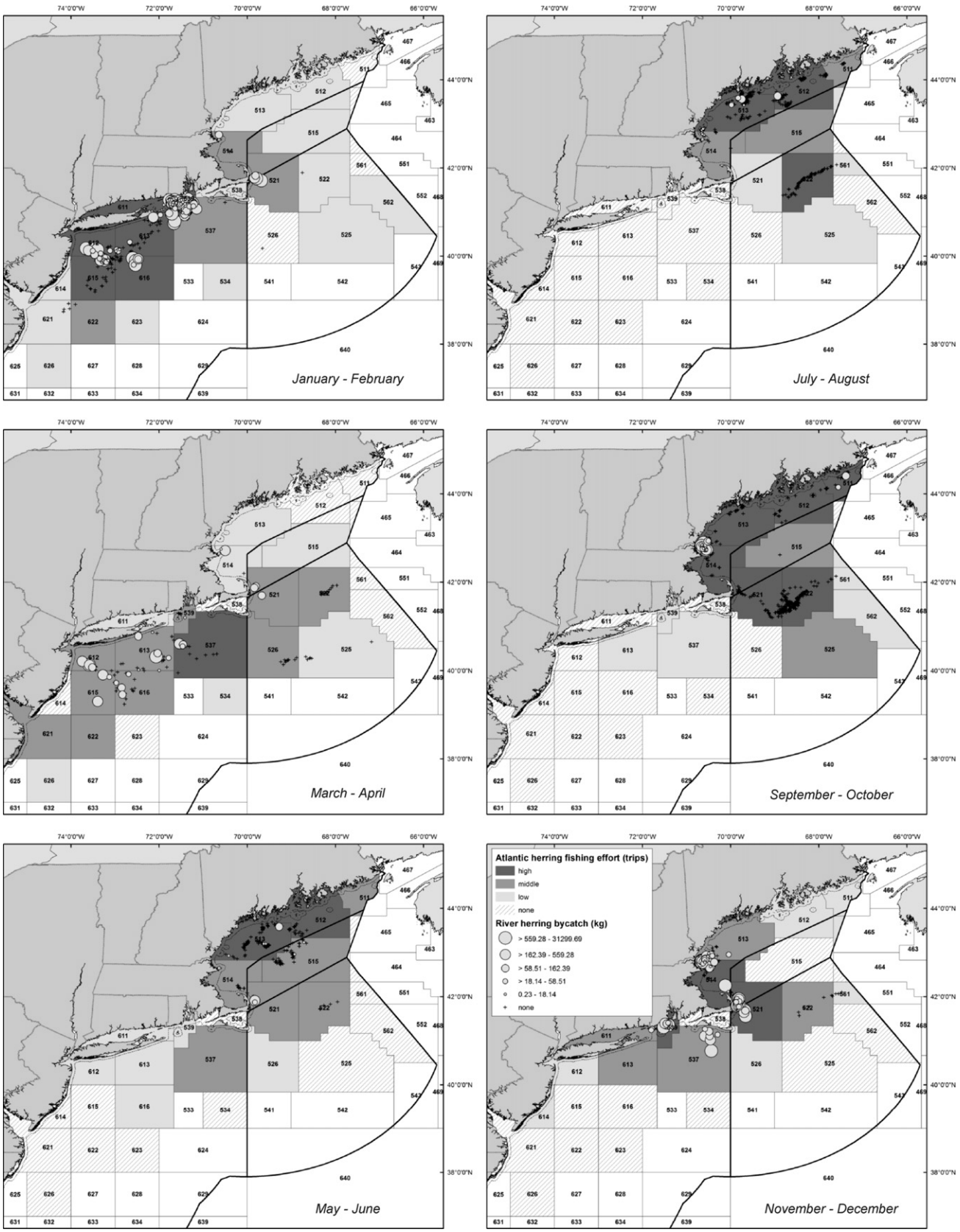

Fig. 2. Bimonthly Atlantic herring fishing effort and associated river herring bycatch patterns. Fishing effort (reported VTR trips) by SRA is grouped from high (>69), medium (6–68), low (1–5), and no (0) effort within the bimonthly grouping. White areas indicate statistical areas with no fishing effort at any time during the year. Scaled circles represent the relative magnitude of river herring bycatch (kg), see categories in Table 3. A "+" signifies no river herring catch.

Sources: VTR Database 2005–2009 and NEFOP Database 2005–2009.

>18.14–58.51 kg; 0.23–18.14 kg (presence); and none (absence). We then mapped binned bycatch events using bimonthly groupings, and overlaid these with maps of fishing effort (Fig. 2).

3. Results

3.1. Patterns of fishing effort and associated bycatch

During the first six months of the year, Atlantic herring fishing effort shifted from the Northern Mid-Atlantic Bight and Southern New England waters (January–February) to Southern New England waters (March–April), and subsequently to the Gulf of Maine (May–June) (Fig. 2). Fishing effort was concentrated in the Gulf of Maine and Georges Bank during July–August and September–October, before contracting to the Gulf of Maine and Southern New England waters during November–December. Presumably, some of the winter Atlantic herring fishery is a joint Atlantic mackerel fishery in which Atlantic herring are landed as bycatch.

River herring bycatch events occurred in 17.13% (304 out of 1775) of all observed fishing activities (Table 3). River herring bycatch events clustered in Ipswich Bay (SRA 513/514), off the back of Cape Cod (SRA 521), and in the Northern Mid-Atlantic Bight in January–February and in March–April (Fig. 2). In May–June, bycatch events clustered in the Northern Gulf of Maine and off the back of Cape Cod in May–June. Subsequent bycatch events occurred in the Northern Gulf of Maine in July–August and September–October, in Ipswich Bay in September–October and November–December, and in Massachusetts Bay, the back of Cape Cod, south of Martha's Vineyard, and near Block Island in November–December. These bycatch patterns roughly match the spatial distribution of Atlantic herring fishing effort, with the exception of summer and fall fishing (July–October) on Georges Bank (Table 3 and Fig. 2).

Table 3
Frequency table of river herring bycatch (kg) by gear type and bimonthly groupings for observed directed Atlantic herring fishing hauls or sets. Gear categories include bottom otter-trawls (OT), mid-water trawls-single and paired (PR), and purse seines (PS).

River herring weight (kg)	Gear Category			All
	OT	PR	PS	
January–February				
None	22	181	0	203
0.23–18.14	23	3	0	26
>18.14–58.51	15	16	0	31
>58.51–162.39	14	17	0	31
>162.39–559.28	16	12	0	28
>559.28–31,299.69	10	21	0	31
Maximum = 31,299.69, All	100	250	0	350
March–April				
None	4	94	0	98
0.23–18.14	0	5	0	5
>18.14–58.51	0	5	0	5
>58.51–162.39	0	9	0	9
>162.39–559.28	0	6	0	6
>559.28–31,299.69	0	2	0	2
Maximum = 5596.88, All	4	121	0	125
May–June				
None	0	132	67	199
0.23–18.14	0	4	1	5
>18.14–58.51	0	1	0	1
>58.51–162.39	0	0	1	1
>162.39–559.28	0	1	0	1
>559.28–31,299.69	0	0	0	0
Maximum = 174.18, All	0	138	69	207
July–August				
None	21	154	147	322
0.23–18.14	13	1	0	14
>18.14–58.51	0	0	3	3
>58.51–162.39	0	0	2	2
>162.39–559.28	0	0	0	0
>559.28–31,299.69	0	0	0	0
Maximum = 162.39, All	34	155	152	341
September–October				
None	22	365	63	450
0.23–18.14	3	2	0	5
>18.14–58.51	2	4	0	6
>58.51–162.39	0	2	0	2
>162.39–559.28	0	4	0	4
>559.28–31,299.69	0	5	0	5
Maximum = 6023.71, All	27	382	63	472
November–December				
None	11	184	4	199
0.23–18.14	0	6	0	6
>18.14–58.51	1	14	0	15
>58.51–162.39	1	15	0	16
>162.39–559.28	2	20	0	22
>559.28–31,299.69	1	21	0	22
Maximum = 8926.7, All	16	260	4	280

Source: NEFOP Database 2005–2009.

4. Discussion

4.1. Fishing effort and bycatch patterns

In general, areas with high directed Atlantic herring fishing effort in near-shore areas are associated with river herring bycatch. These areas include the northern Gulf of Maine, Ipswich Bay, southern New England waters (southeast of Cape Cod, south of Martha's Vineyard, and adjacent to Block Island) and Hudson Canyon. Bycatch variation throughout the year is likely due to the migratory behavior of river herring at sea and mixing with other pelagic species. In general, river herring move from southern to northern latitudes during spring through fall, presumably due to seasonal shifts in temperature, food availability, and timing of in-river spawning. River herring overwinter in southern latitudes. Therefore, river herring were more often encountered by the fishery in the winter in Southern New England waters and the Northern Mid-Atlantic Bight, and during the spring fishery in the Gulf of Maine, in Southern New England, and in the Northern Mid-Atlantic Bight.

4.2. Possible management strategies

Given the spatial and temporal patterns of river herring bycatch in the Atlantic herring fishery, area-based management measures (e.g., seasonal fishing closed areas) could potentially reduce these interactions. However, such measures would not provide river herring mortality protection outside of protection areas, and could lead to increased bycatch rates outside of such closed areas if fishing effort were to shift to areas with high river herring abundance not detected by our analyses. This is particularly true because our evaluation was conditioned on the seasonal distribution of Atlantic herring fishing effort. Clearly, more recent data (post-2009) needs to be analyzed to test the consistency of river herring abundance in any potential Atlantic herring fishery closure area.

Perversely, the current regulations in the Atlantic herring fishery may actually promote river herring bycatch by shifting effort into Southern New England and Mid-Atlantic waters in winter and early spring to try to reduce Atlantic herring catches in the Gulf of Maine

(1A in Fig. 1). Moreover, current management of the Atlantic herring fishery is not incentive-based. Due to the fleet-wide spatially allocated Atlantic herring quota, the fleet essentially operates during the fishing year under four fishing derbies, subject to area-based closures if a quota is reached. A system integrating Atlantic herring and bycatch species could result in changes to fishing behavior, ending the race to fish and also reducing non-targeted bycatch (Essington, 2009).

Several challenges exist to implementing incentive-based approaches to reduce bycatch in the Atlantic herring fishery. First, fishermen find the current haddock bycatch cap in the Atlantic herring fishery unduly restrictive, partly due to a mismatch between the fishery year for haddock (May–April) and Atlantic herring (January–December) and also because of an interaction with other indirect Atlantic herring measures (e.g., slowing down of fishing effort in area 1A, and Atlantic herring spawning closures in area 1A that make Atlantic herring fishing in the Gulf of Maine during the spring inefficient) (NEFMC, 2011, 2012). Therefore, Atlantic herring fishermen may not be receptive to another bycatch cap (for river herring). Second, the stock assessment for river herring did not determine an overall population estimate with which to set a bycatch cap or overfishing/overfished status of river herring. Therefore, the relationship between a river herring bycatch cap and river herring fishing mortality remains poorly understood. Finally, the effectiveness of other incentive-based approaches, like the catch share system in the New England groundfish fishery, has been the subject of intense debate among industry and politicians and attempting to apply such approaches in the Atlantic herring fishery is likely to encounter similar challenges. In the interim, spatial management offers a first-step approach.

5. Conclusions

These analyses informed the NEFMC in developing management options to address river herring bycatch. At-sea fisheries observer data showed that river herring bycatches were highest mostly during January–April and September–December when the Atlantic herring fishery primarily occurred in Southern New England and the Northern Mid-Atlantic Bight waters. The NEFMC is currently considering whether to use spatial management approaches or other approaches to address river herring bycatch in the Atlantic herring fishery.

Acknowledgements

We sincerely appreciate the valuable input of NEFMC's Atlantic herring PDT throughout development of our research. We thank the Atlantic herring fishery, NEFMC, and NEFOP for collecting and sharing the data used in this study. We are grateful for the support and advice of our colleagues during this research and wish to thank Karen Alexander, Teresa A'mar, Michael Armstrong, Pam Baker, Talia Bigelow, Merrick Burden, Mathew Cieri, John Crawford, Micah Dean, John Deroba, Jason Didden, Rod Fujita, Christopher Glass, Alan Haynie, Jim Ianelli, Les Kaufman, William Leavenworth, David Pierce, Doug Rader, Andrew Rosenberg, Lori Steele, and Kate Taylor. This research was supported by grants from the National Fish and Wildlife Foundation and the Gordon and Betty Moore Foundation and made possible by Massachusetts Division of Marine Fisheries Contribution No. 39.

References

ASMFC, 2009. Amendment 2 to the Interstate Fishery Management Plan for Shad and River Herring (River Herring Management). ASMFC, Washington, DC.
ASMFC, 2012. River Herring Benchmark Stock Assessment. Stock Assessment Report No. 12-02. ASMFC, Arlington, VA.
Beardsley, R.C., Butman, B., Geyer, W.R., Smith, P.C., 1997. Physical oceanography of the Gulf of Maine: an update. In: Wallace, G.T., Braasch, E.F. (Eds.), Proceedings of the Gulf of Maine Ecosystem Dynamics Scientific Symposium and Workshop, RARGOM Report 97-1. Regional Association for Research on the Gulf of Maine, Hanover, NH, pp. 39–52.
Chuksin, Y.V., 2006. From Cape Hatteras to Cabot Strait: the history of the Soviet fishery on the Atlantic Continental Shelf of the United States and Canada. NOAA Technical Memorandum, NMFS-F/SPO-71. US Department of Commerce.
Churchill, J.H., Levine, E.R., Connors, D.N., Cornillon, P.C., 1993. Mixing of shelf slope and Gulf Stream water over the continental slope of the Middle Atlantic Bight. Deep Sea Res. 40 (Pt I), 1063–1085.
Cieri, M., Nelson, G., Armstrong, M., 2008. Estimates of river herring bycatch in the directed Atlantic herring fishery. Report prepared for the Atlantic States Marine Fisheries Commission, Washington, DC.
Collette, B.B., Klein-MacPhee, G. (Eds.), 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine. , 3rd ed. Smithsonian Institution Press, Washington, DC.
Essington, T.E., 2009. Ecological indicators display reduced variation in North American catch share fisheries. Proc. Natl. Acad. Sci. U.S.A. 107, 754–759.
Friedland, K.D., MacLean, J.C., Hansen, L.P., Peyronnet, A.J., Karlsson, L., Reddin, D.G., Ó Maoiléidigh, N., McCarthy, J.L., 2009. The recruitment of Atlantic salmon in Europe. ICES J. Mar. Sci. 66, 289–304.
Haugland, M., Holst, J.C., Holm, M., Hansen, L.P., 2006. Feeding of Atlantic salmon (*Salmo salar* L.) post-smolts in the Northeast Atlantic. ICES J. Mar. Sci. 63, 1488–1500.
Ji, R., Chen, C., Franks, P.J.S., Townsend, D.W., Durbin, E.G., Beardsley, R.C., Lough, R.G., Houghton, R.W., 2006. The impact of Scotian Shelf Water cross-over on the plankton dynamics on Georges Bank: a 3-D experiment for the 1999 spring bloom. Deep Sea Res. 53 (Pt II), 2684–2707.
Limburg, K.E., Waldman, J.R., 2009. Dramatic declines in North American diadromous fishes. Bioscience 59, 955–965.
Lynch, D.R., Holboke, M.J., Naimie, C.E., 1997. The Maine coastal current: spring climatological circulation. Cont. Shelf. Res. 17, 605–634.
McVicar, A.H., 1997. Disease and parasite implications of the coexistence of wild and cultured Atlantic salmon populations. ICES J. Mar. Sci. 54, 1093–1103.
MAFMC, 2012. Draft Amendment 14 to the Atlantic mackerel, squid, and butterfish Fishery Management Plan (FMP) including a Draft Environmental Impact Statement (DEIS), April 2012. Mid-Atlantic Fishery Management Council, Dover, DE.
Mountain, D.G., Kane, J., 2010. Major changes in the Georges Bank ecosystem, 1980 to the 1990. Mar. Ecol. Prog. Ser. 398, 81–91.
Neves, R.J., 1981. Offshore distribution of alewife, *Alosa pseudoharengus*, and blueback herring, *Alosa aestivalis*, along the Atlantic Coast. Fish. Bull. 79, 473–485.
NEFMC, 2006. Final Amendment 1 to the Atlantic Herring Fishery Management Plan. Incorporating the supplemental environmental impact statement and regulatory impact review, vols. I and II. NEFMC in consultation with the ASMFC, MAFMC, and NMFS, May 2006. New England Fishery Management Council, Newburyport, MA.
NEFMC, 2011. Framework 46 to the Northeast Multispecies Fishery Management Plan, June 2011. New England Fishery Management Council, Newburyport, MA.
NEFMC, 2012. Draft Amendment 5 to the Fishery Management Plan (FMP) for Atlantic Herring including a Draft Environmental Impact Statement (DEIS), March 2012. New England Fishery Management Council, Newburyport, MA.
NEFOP, 2010. Northeast Fisheries Observer Program Biological Sampling Manual. NOAA Fisheries. US Department of Commerce.
Shepherd, G., 1986. Evaluation of the river herring by-catch in the mackerel fishery. Woods Hole Lab. Ref. Doc. 86-10. US Department of Commerce.
Stein, A.B., Friedland, K.D., Sutherland, M., 2004a. Atlantic sturgeon marine bycatch and 384 mortality on the Continental Shelf of the Northeast United States. N. Am. J. Fish. Manage. 385 (24), 171–183.
Stein, A.B., Friedland, K.D., Sutherland, M., 2004b. Atlantic sturgeon marine distribution and habitat use along the Northeastern Coast of the United States. Trans. Am. Fish. Soc. 133, 527–537.
Stone, H.H., Jessop, B.M., 1992. Seasonal distribution of river herring *Alosa pseudoharengus* and *A. aestivalis* off the Atlantic coast of Nova Scotia. Fish. Bull. 90, 376–389.
Townsend, D.W., Thomas, A.C., Mayer, L.M., Thomas, M., Quinlan, J., 2006. Oceanography of the northwest Atlantic continental shelf. In: Robinson, A.R., Brink, K.H. (Eds.), The Sea, vol. 14. Harvard University Press, Cambridge, MA, pp. 119–168.
Wigley, S.E., Blaylock, J., Rago, P.J., 2009. River herring discard estimation, precision and sample size analysis. U.S. Dept. Commer. Northeast Fish. Sci. Cent. Ref. Doc. 09-20. US Department of Commerce.
Witherell, D., Ackley, D., Coon, C., 2002. An overview of salmon bycatch in Alaska groundfish fisheries. Alaska Fish. Res. Bull. 9, 53–64.