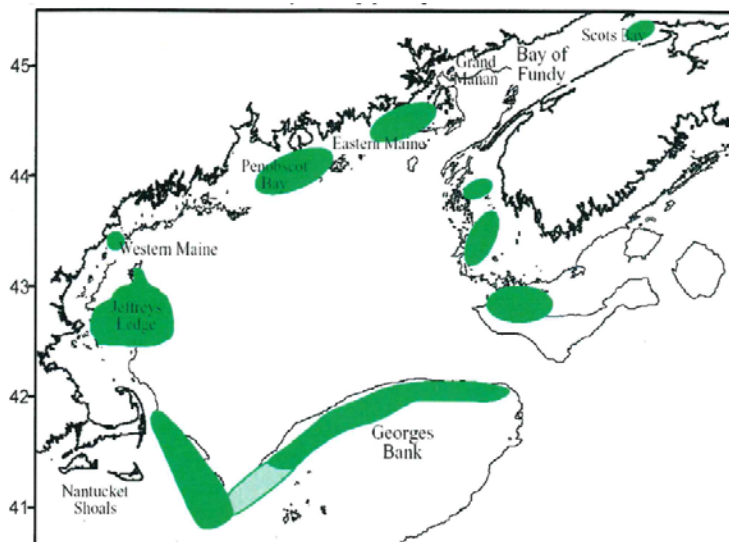


Atlantic Herring Fishery Management Plan

Framework Adjustment 7



DRAFT Discussion Document

June 3, 2022

Prepared by the
New England Fishery Management Council
In consultation with the
National Marine Fisheries Service and the
Mid-Atlantic Fishery Management Council



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Cover image

Generalized view of major herring spawning areas in the Gulf of Maine and Georges Bank
(Overholtz *et al.* 2004)



**FRAMEWORK ADJUSTMENT 7 TO THE
ATLANTIC HERRING FISHERY MANAGEMENT PLAN**

Proposed Action: Propose measures to protect spawning of adult Atlantic herring on Georges Bank.

Type of Statement: Draft Environmental Assessment

Responsible Agencies: New England Fishery Management Council
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Abstract: The New England Fishery Management Council, in consultation with NOAA National Marine Fisheries Service, has prepared Framework Adjustment 7 to the Atlantic Herring Fishery Management Plan, which includes a draft environmental assessment that presents the range of alternatives to achieve the goals and objectives of the action. The proposed action focuses on measures to protect spawning adults of Atlantic herring on Georges Bank. The document describes the affected environment and valued ecosystem components and analyzes the impacts of the alternatives on both. It addresses the requirements of the National Environmental Policy Act, the Magnuson Stevens Fishery Conservation and Management Act, the Regulatory Flexibility Act, and other applicable laws.

1.0 EXECUTIVE SUMMARY

This document contains the New England Fishery Management Council (Council) recommendations for the protection of Atlantic herring spawning on Georges Bank, consistent with the Magnuson-Stevens Fishery Conservation and Management Act (MSA) and the Atlantic Herring Fishery Management Plan (FMP), approved by the National Marine Fisheries Service (NMFS) on October 27, 1999. In addition, this document includes information and supporting analyses required under other applicable law, including the National Environmental Policy Act (NEPA) and Regulatory Flexibility Act (RFA).

To be completed later as Council develops this action.

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2.4 ACRONYMS

ABC	Acceptable Biological Catch	NEFMC	New England Fishery Management Council
ACL	Annual Catch Limit	NEFOP	Northeast Fisheries Observer Program
ALWTRP	Atlantic Large Whale Take Reduction Plan	NEFSC	Northeast Fisheries Science Center
AM	Accountability Measure	NEPA	National Environmental Policy Act
AP	Advisory Panel	NLSA	Nantucket Lightship closed area
APA	Administrative Procedures Act	NMFS	National Marine Fisheries Service
ASMFC	Atlantic States Marine Fisheries Commission	NOAA	National Oceanic and Atmospheric Administration
B _{MSY}	Biomass that would allow for catches equal to Maximum Sustainable Yield when fished at the overfishing threshold (F _{MSY})	OBDBS	Observer database system
BiOp, BO	Biological Opinion, a result of a review of potential effects of a fishery on Protected Resource species	OY	Optimum yield
CEQ	Council on Environmental Quality	PDT	Plan Development Team
DFO	Department of Fisheries and Oceans (Canada)	PRA	Paperwork Reduction Act
DMF	Division of Marine Fisheries (Massachusetts)	RFA	Regulatory Flexibility Act
DMR	Department of Marine Resources (Maine)	RPA	Reasonable and Prudent Alternatives
DPWG	Data Poor Working Group	SA	Statistical Area
EA	Environmental Assessment	SARC	Stock Assessment Review Committee
EEZ	Exclusive economic zone	SAW	Stock Assessment Workshop
EFH	Essential fish habitat	SIA	Social Impact Assessment
ESA	Endangered Species Act	SMB	Squid Mackerel Butterfish FMP (MAFMC)
F	Fishing mortality rate	SNE	Southern New England
FEIS	Final Environmental Impact Statement	SNE/MA	Southern New England-Mid-Atlantic
FMP	Fishery management plan	SSB	Spawning stock biomass
FW	Framework	SSC	Scientific and Statistical Committee
FY	Fishing year	TEWG	Technical Expert Working Group
GARFO	Greater Atlantic Regional Fisheries Office	TRAC	Trans-boundary Resources Assessment Committee
GB	Georges Bank	VEC	Valued Ecosystem Component
GIS	Geographic Information System	VMS	Vessel monitoring system
GOM	Gulf of Maine	VTR	Vessel trip report
HAPC	Habitat area of particular concern		
HPTRP	Harbor Porpoise Take Reduction Plan		
IFM	Industry-funded monitoring		
LOA	Letter of authorization		
MA	Mid-Atlantic		
MAFMC	Mid-Atlantic Fishery Management Council		
MMPA	Marine Mammal Protection Act		
MPA	Marine protected area		

3.0 BACKGROUND AND PURPOSE

3.1 PURPOSE AND NEED

To be completed later as Council develops this action.

3.2 GOALS AND OBJECTIVES

The goal of this action is to protect spawning adults of Atlantic herring and/or Atlantic herring egg mats to increase overall herring biomass. The specific measurable action, or objective of this action is to consider similar measures to ones in place in Area 1A for other spawning components of this resource (i.e., Georges Bank and Nantucket Shoals).

The goal specifically includes the term “and/or” before herring egg mats to clarify that if there is not enough information to support measures to protect adult herring or herring egg mats, the action could focus on just one. During development, the Council clarified that the scope of this action is to minimize potential impacts of the herring fishery on adult spawning aggregations only. Therefore, the measures under consideration in this action are limited to the herring fishery only and will not include restrictions on other fisheries. The Council may consider other measures to protect spawning of Atlantic herring and/or Atlantic herring egg mats from other fisheries in a separate action in the future.

4.0 ALTERNATIVES UNDER CONSIDERATION

4.1 ACTION 1 – HERRING SPAWNING CLOSURE ON GEORGES BANK

4.1.1 Alternative 1 - No Action

Alternative 1 (No Action) is no specific measure to directly protect spawning of Atlantic herring on Georges Bank (GB). There are several measures in place for other purposes that likely have indirect benefits for spawning adults on Georges Bank.

Draft Rationale: There are several measures in place that likely have indirect benefits on spawning of Atlantic herring on Georges Bank. For example, when 90% of the herring sub-ACL in Area 3 is estimated to be caught, a herring possession limit is implemented (40,000 lb) essentially closing the area to directed herring fishing for the remainder of the year. Under low herring sub-ACLs in particular, the Area 3 sub-ACL that includes most of Georges Bank may be harvested before the fall spawning season begins. Also, there are bycatch catch caps in place for river herring/shad and GB haddock. If these area/gear catch caps are reached during the year, portions of GB could close to the herring fishery for the remainder of the year. Finally, there are three spawning closures within the Gulf of Maine that are implemented through the Atlantic States Marine Fisheries Commission (ASMFC). Because herring stock components are known to mix, and mixing rates are somewhat uncertain and variable, there may be indirect benefits on the GB sub-component if some fish remain mixed and stay within the Gulf of Maine (GOM) spawning closures during these seasonal closures. In summary, the measures currently in place would be considered adequate to minimize potential impacts of the herring fishery on spawning adults of Atlantic herring on Georges Bank.

4.1.2 Alternative 2 - Implement a Default Herring Spawning Closure on Georges Bank

Alternative 2 would implement a default spawning closure to all vessels on a declared herring trip to protect spawning adults of Atlantic herring on Georges Bank. Within each of the following sub-sections, the Council will identify the recommended default closure area and default season for spawning protection on Georges Bank.

Draft Rationale: Implementation of a spawning closure on Georges Bank is expected to improve overall herring biomass by reducing potentially negative impacts of herring fishing on spawning adults of this sub-component of the overall herring stock. This measure is primarily intended to protect spawning adults from harvest, as well as reduce disturbance/interaction of spawning activity, and potentially protect herring egg Essential Fish Habitat (EFH) from disturbance. Finally, these measures are intended to be a compliment to spawning closures that have been implemented under the ASMFC to protect spawning of sub-components of Atlantic herring known to occur in more inshore areas within the Gulf of Maine.

4.1.2.1 Spawning Closure Area

4.1.2.1.1 Spawning Closure Area Option 1

Spawning Closure Area Option 1 would close two separate areas to protect spawning of Atlantic herring, the two red polygons in Map 1. One area is about 20 nautical miles southeast of Cape Cod and the other area is on the northeast peak of Georges Bank (specific coordinates in Table 1). In combination, the closure would be about 3,500 km². The spawning closure season that would have restrictions are included in Section 4.1.2.2.

Draft Rationale: Option 1 includes areas where three or more data layers overlap from an analysis of six existing data sets of Atlantic herring spawning information. This analysis occurred during a Council review and analysis of Atlantic herring spawning on Georges Bank before this action was developed (Appendix I, NEFMC 2019). The datasets evaluated include: the food habits database, larval monitoring dataset, Atlantic herring egg EFH, historical spawning grounds, portside monitoring (maturity stage U) from Maine Department of Marine Resources (DMR), and the NEFSC fall trawl survey (maturity stage U). Straight lines were drawn around the core areas of overlap to define the boundaries of this option.

Table 1. Coordinates of spawning closure under consideration for Spawning Area Option 1

Sub-area	Point	Longitude	Latitude
WGB	1	-69° 36'	40° 54'
	2	-69° 36'	41° 20'
	3	-69° 5'	41° 20'
	4	-69° 5'	40° 54'
	5	-69° 36'	40° 54'
EGB	1	-67° 32.5'	41° 49'
	2	-67° 31.5'	42° 10.5'
	3	-67° 9.78'	42° 10.47'
	4	-67° 4.6'	42° 4.5'
	5	-67° 5'	41° 49'
	6	-67° 32.5'	41° 49'

4.1.2.1.2 Spawning Closure Area Option 2

Spawning Closure Area Option 2 would close two separate areas to protect spawning of Atlantic herring, the areas in green in Map 1. One area encompasses most of the Great South Channel east of Cape Cod and the other area is on the northeast peak of Georges Bank that extends farther west than Option 1 (specific coordinates in Table 2). In combination, the closure would be about 5,500 km². The spawning closure season that would have restrictions are included in Sections 4.1.2.2.

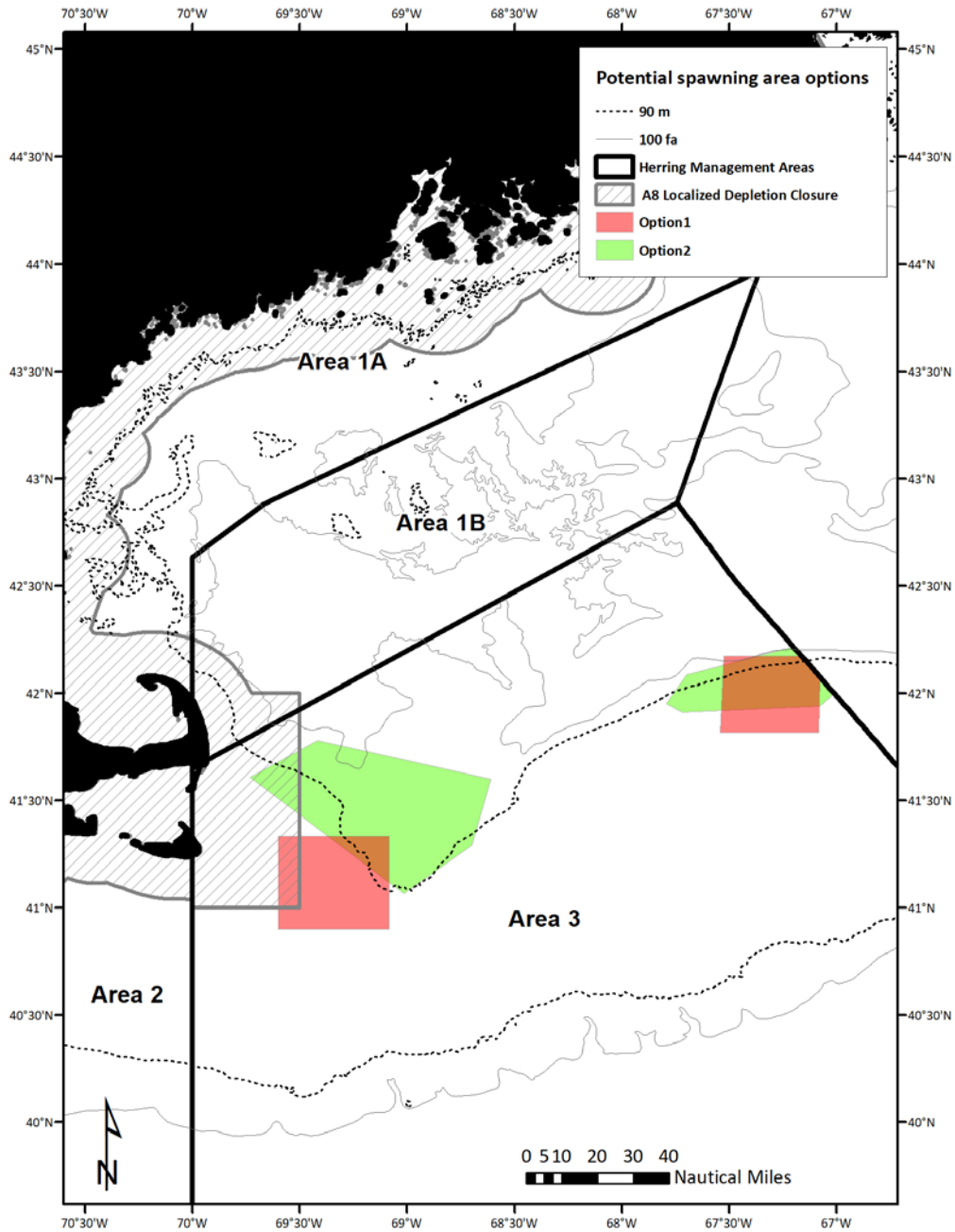
Draft Rationale: Option 2 also uses analyses from the GB Spawning Discussion Document, but is more focused on identifying the location of spawning adults from both the NEFSC bottom trawl fall survey as well as Maine DMR portside samples of spawning adults by decade (1981-2018; Appendix I, NEFMC 2019). Option 2 focuses on locations of adult spawning herring and recognizes spatial variation by decade, compared to the previous option which includes additional datasets including location of herring larvae, herring egg EFH, etc. Option 2 also identifies areas in eastern and western GB; the eastern GB area is very similar to the eastern GB in Option 1 (both about 1,500 km²); however, the western GB areas are quite different.

The PDT plans to calculate the degree of overlap of these two areas during development of this action.

Table 2. Coordinates of spawning closure under consideration for Spawning Area Option 2

Sub-area	Point	Longitude	Latitude
WGB	1	-69° 25.04'	41° 46.83'
	2	-68° 36.59'	41° 36'
	3	-68° 41.99'	41° 17.54'
	4	-69° 1'	41° 4'
	5	-69° 43.98'	41° 36.5'
	6	-69° 25.04'	41° 46.83'
EGB	1	-67° 41.95'	42° 5.2'
	2	-67° 12.07'	42° 13.07'
	3	-67° 0.5'	42° 0'
	4	-67° 4.55'	41° 56.45'
	5	-67° 43.22'	41° 54.68'
	6	-67° 45.32'	41° 55.83'
	7	-67° 47.55'	41° 57.17'
	8	-67° 41.95'	42° 5.2'

Map 1. Potential options for GB spawning closure areas (Option 1 in red and Option 2 in green).
Note: Grey hatched area is the MWT gear prohibition area approved in Amendment 8.



4.1.2.2 Spawning Closure Season

The spawning closure season selected in this section may be revised in a future action based on new data. In addition, if a more detailed real-time monitoring program is implemented like the one used by ASMFC for the spawning closures in the Gulf of Maine, this closure season could be modified based on real-time samples of spawning condition.

Georges Bank does not receive the same level of consistent pre-spawning fishing activity as in the GOM, making in-season monitoring and adaptive closures currently infeasible. Unless real-time monitoring of spawning on Georges Bank is developed (Section 4.3), spawning closure seasons would likely use a fixed starting date and length.

4.1.2.2.1 Spawning Closure Season Option 1 (six-week closure starting Sept 14)

Closure Season Option 1 would close the default spawning closure area selected in Section 4.1.2.1 for six weeks, September 14 through October 25 each year. Vessels could transit the area with all fishing gear stowed but could not fish on a declared herring trip within the boundary selected during these six weeks.

Draft Rationale: Option 1 is consistent with approaches used in the Gulf of Maine by ASMFC when spawning closures were recently updated in Addendum II (ASMFC 2019). Analyses of spawning herring samples from the GOM show that 25% of fish have begun to spawn when mean GSI equals 30, and for Atlantic herring that is when fish are about 23 cm. The length of time between when 25% of fish have begun to spawn and 25% have yet to spawn takes about 2.5 to 5 weeks. Based on these analyses, ASMFC implemented a default closure of six weeks to ensure low probability of fishery interaction with spawning.

While real-time data are not available, there are sufficient GSI samples from GB to inform the calculation of a closure date. The Herring PDT replicated the gonadal somatic index (GSI) timing analysis used in Addendum II using over 7,000 fish samples from over 270 herring trips on Georges Bank from 1998-2019 (Appendix II for details). Based on these analyses, September 14 is the predicted mean date that 25% of fish on Georges Bank will reach a GSI of 30, be in spawning condition.

4.1.2.2.2 Spawning Closure Season Option 2 (eight-week closure starting Sept 7)

Closure Season Option 2 would close the default spawning closure area to all vessels selected in Section 4.1.2.1 for eight weeks, September 7 through November 1 each year. Vessels could transit the area with all fishing gear stowed but could not fish within the boundary selected during these eight weeks.

Draft Rationale: This eight-week option better accounts for interannual variability and the inability to conduct in-season adaptive closures (Figure 2.3.1 in Appendix II). Option 1 is based on means, but there is variation from year to year and Option 2 would be more precautionary since in-season monitoring of GSI is not currently available for trips throughout the range of the fishery, as it currently is in the Gulf of Maine. Further, herring egg mats are thought to remain on the ocean floor for about 15 days after spawning. The additional two weeks could increase protection of herring eggs from impacts of any fishing gear used on herring trips that may encounter the seafloor during normal fishing activity.

4.2 ACTION 2 - POSSESSION OF SPAWNING ADULT ATLANTIC HERRING

4.2.1 Alternative 1 - No Action

Alternative 1 (No Action) would have no limit on possessing or landing herring that are in spawning condition. Many vessels avoid spawning fish for a variety of reasons, but there are no restrictions on possessing or landing herring that are in spawning condition. Alternative 1 would continue to allow vessels to possess and land herring in spawning condition.

Draft Rationale: Most vessels avoid landing spawning herring; they are generally lower quality and less desirable for the bait market. Therefore, the need to prohibit possession or landing of spawning fish has not been necessary. Catch data show that less than 3% of all mid-water trawl (MWT) catch sampled on Georges Bank from 1971-2018 was in spawning condition, adult herring with GSI values greater than Stage 3 (NEFMC 2019). Stage 4 herring are considered maturing, and herring in Stages 5 and 6 are considered mature, ripe, and running adults. Historically, spawning tolerances were used in this fishery through the ASMFC management plan, with some undesirable impacts such as increased regulatory discards and enforcement and monitoring challenges.

4.2.2 Alternative 2 - Implement an individual herring spawning tolerance possession limit per vessel

Questions/Considerations for the Committee:

- Alternative 2 is still under development. Requires more discussion
- The Committee has not defined what the “spawning tolerance area” would be yet. Same as the spawning closure options in Action 1? Larger area?
- In May 2021, the PDT recommended this alternative *not* be included in this action. There are multiple concerns raised about the feasibility of monitoring and enforcing an individual spawning possession limit.
- In May 2022, PDT members that monitoring may occur by random sampling of vessels upon return to port, but the monitoring program would need further development (e.g., threshold, area(s) to be closed, protocols of how much sampling would be required).
- In May 2022, several advisors (no motions of FW7) felt that if FW7 moves forward, Alternative 2 would effectively incentivize boats to stay away from ripe/running fish.
- The Committee had suggested that fishing in the specified area be allowed if an observer is onboard to ensure the vessel is not interacting with spawning herring. In May 2022, some advisors disagreed with this idea, noting it is already difficult to get an observer to be able to access closed areas. Instead, there was a suggestion that boats notify if they plan to fish in a spawning tolerance area and then be subject to dockside sampling.

Under Alternative 2, any vessel may fish for, take, land, or possess “spawn” herring (defined as Atlantic herring in ICNAF gonadal Stages 5 and 6) from or within the spawning tolerance area defined below if such herring comprise less than 20% (by volume) of the herring possessed onboard at any time.

The spawning tolerance area is defined as ???.....

Any herring vessel having onboard spawn herring $\geq 20\%$, which were caught outside of a spawning tolerance area, may transit the area only if all its fishing gear has been stowed.

An incidental bycatch allowance of up to 2,000 pounds of herring per trip for non-directed fisheries shall be in place in the spawning tolerance area. This bycatch allowance will not be subject to the tolerance provision, i.e., vessels may land “spawn” herring if said vessel lands no more than 2,000 pounds. The amount of herring landed by one vessel in a day, as a bycatch allowance, shall not exceed 2,000 pounds (this prohibits a vessel from making multiple trips in one day to land more than the bycatch allowance). A trip shall be based on a calendar day basis.

Draft Rationale: A spawning tolerance less than 20% of total catch may provide more flexibility for the industry than a spawning closure if vessels can successfully target non-spawning fish from areas within the closures. Furthermore, once an area closes, there is no data from that space and time, no trips would be sampled from within a spawning closure area to provide a full picture of spawning activity on Georges Bank, while a trip under a spawning tolerance could still be sampled and provide more data about spawning activity on Georges Bank. A similar tolerance program was in place by ASMFC preceding the spawning closures that are now in effect. There is no scientific rationale for 20%, it is the value that was used in the past and likely represents a reasonable threshold for vessels to practically stay under in a high-volume fishery. This value is expected to incentivize fishing behavior that will discourage fishing in areas with spawning adults but provides some tolerance that is needed in higher volume fisheries.

4.2.3 Alternative 3 - Implement a herring spawning tolerance possession limit that triggers a fleetwide spawning closure

Questions/Considerations for the Committee:

- Alternative 3 is still under development. Requires more discussion.
 - What area(s) and seasons(s)? Same as options already developed?
 - What is the most appropriate threshold, three trips? Maybe 20% threshold is not the best trigger to use here?
 - What would the monitoring program look like? Would it have to be fleetwide, is it ok if all vessels and/or trips are not monitored?
 - Could the IFM program be expanded to include biological sampling of catch to estimate spawning condition? Could the federal port sampling program be expanded to monitor spawning condition of commercial catch? What is status of state funded monitoring program?
- The PDT recommends that if in-season monitoring is feasible in the near term, the trigger should be modeled after the in-season spawning closure program used in the GOM, not based on 20% tolerance. The program used in the GOM is based on measuring gonad mass of female herring (GSI30 protocol); it has been tested and adjusted over time. The GSI30 protocol is likely more feasible and less expensive compared to monitoring a 20% tolerance per trip for the entire fishery.
- Advisors suggested FW7 analyze the current areas in the document (Option 1 or Option 2) as the spawning tolerance areas and 20 – 25% of herring in spawning condition from three or more offloads as the closure trigger.

Under Alternative 3, herring trips would be monitored in season and once NMFS determines that **???** **[three or more offloads]** have more than **???** **[20%]** of total herring in spawning condition, an area **[defined as...]** will close to the herring fishery for the remainder of the spawning season **[defined as...]**.

An incidental bycatch allowance of up to 2,000 pounds of herring per trip for non-directed fisheries shall remain in place if a spawning tolerance closure is implemented. This bycatch allowance will not be subject to the tolerance provision, i.e. vessels may land “spawn” herring as long as said vessel lands no more than 2,000 pounds. The amount of herring landed by one vessel in a day, as a bycatch allowance, shall not exceed 2,000 pounds (this prohibits a vessel from making multiple trips in one day to land more than the bycatch allowance). A trip shall be based on a calendar day basis.

4.3 ACTION 3 – SPAWNING AVOIDANCE PROGRAM / IN-SEASON MONITORING WITH TRIGGER BASED SPAWNING CLOSURE

Questions/Considerations for the Committee:

- The Committee has not developed alternatives for this action. Requires more discussion.
- How would this be different than Action 2?

Committee input, February 2021: The Committee tasked the PDT to explore an alternative that would implement a portside sampling program that would monitor catch. If catch exceeds a certain threshold, a specified area closes to the herring fishery.

NOAA Fisheries Enforcement input, April 2021: Multiple concerns raised: resources involved, logistics of monitoring long offloads, training needs for gonad sampling, etc.

PDT input, May 2021:

- The PDT discussed potential use of NMFS federal biological sampling program (contracted port agents) vs. dockside samplers that are part of new IFM program (EFP for part of fishery only).
 - If goal is to protect spawning adults – closing areas in real time likely more effective and in-line with objective compared to an individual spawning possession limit on every trip. Program should be designed to promote compliance and fishing behavior change to avoid spawning fish.
 - If in-season monitoring feasible, fleetwide trigger of area closure should be based on GSI samples, not a possession limit threshold (20%).

Committee input, June 2021: The Committee requested a joint meeting of the Herring AP and Herring PDT to further develop alternatives for this action. Specifically, the group should discuss feasibility of in-season monitoring as it relates to development of a potential spawning tolerance alternative for consideration in Framework 7. The Committee discussed that more time is needed to explore these complex questions. With low quotas expected in the near term there will likely be very little fishing activity offshore, especially later in the year during spawning season.

One suggestion was allowing vessels to fish in predefined spawning areas but require human observers to access the area during spawning (Sept 1 – October 31). During the fishing season, if a specified number of trips are observed over the acceptable tolerance level, then predefined spawning areas would close to the fishery for the remainder of the spawning season.

Advisory Panel and PDT input, May 2022: There were no AP motion on FW7.

- Several advisors felt that FW7 should be set aside until the stock is rebuilt, there has not been enough new information that would now result in NMFS approving a GB spawning closure and noted a lack of funds and low quotas in the fishery.
- If FW7 moves forward, several advisors supported keeping in all the current alternatives and further developing them.
- PDT notes gonad sampling to calculate GSI is done dockside in the GOM (difficult to do at sea).
- Observers are not currently trained to determine GSI.
- The IFM program is limited in how much portside sampling can be conducted.

4.4 BACKGROUND INFORMATION FOR DEVELOPMENT OF ALTERNATIVES

4.4.1 Gulf of Maine spawning closures

Under ASMFC Amendment 3, spawning aggregations in the Gulf of Maine are protected using spawning closures. These closures prohibit directed fishing during specific times of the year in three distinct areas: Eastern Maine, Western Maine, and Massachusetts/New Hampshire (ASMFC 2016) (Map 2). The implementation of the spawning closures is determined by the GSI30 protocol. For female herring, GSI is a calculation of the gonad (ovary) mass as a proportion of the total body mass, and it is used to measure herring maturity. Per the GSI30 protocol, three or more samples of herring, either from fishery independent or dependent sources, are used to model the relationship between GSI and date and forecast the timing of spawning. Given larger herring spawn first, the GSI values are standardized to a 30 cm fish to ensure protection of most of the population. If there are insufficient samples in a given year and area to forecast the timing of spawning, a default closure date is used. This default date is derived from historical GSI samples over the last decade as well as applicable literature. The initiation of a spawning closure is determined by a trigger value established in Amendment 3 to the ASMFC Herring plan.

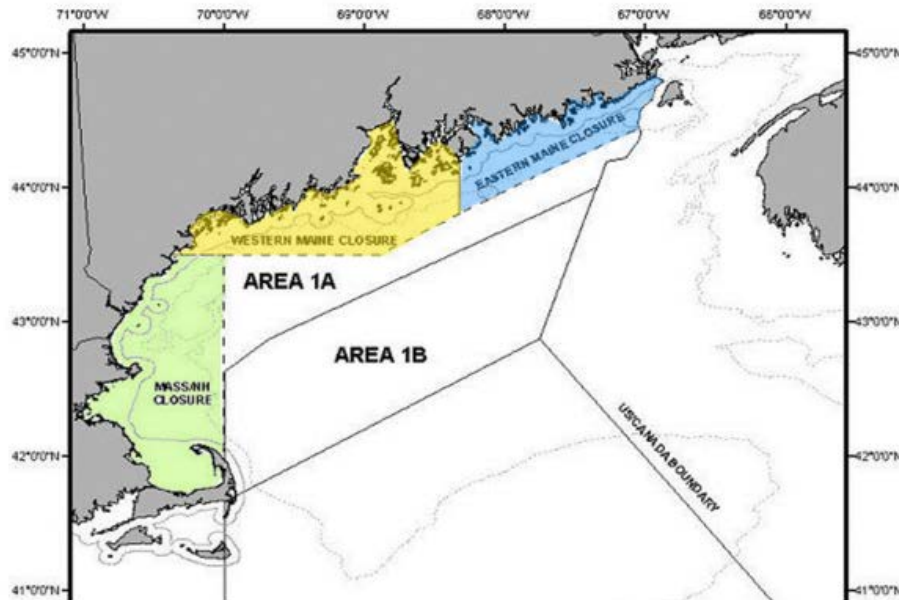
The relationship between GSI and the date is monitored as the season progresses and compared to the trigger value; when GSI is projected to exceed the trigger value, a spawning closure is implemented. Generally, a higher trigger value closes the fishery later and closer to spawning while a lower trigger value provides additional protection to maturing fish by encompassing time before the spawning season begins. Through Amendment 3, the Section implemented a GSI trigger value of 25 which sought to close the fishery in the later stages of maturity but just before spawning. Under Amendment 3, the length of a spawning closure is initially set at four weeks. A closure can be extended by two weeks if a sample taken from the area indicates a significant number of spawning herring. A ‘significant number’ of spawn herring is defined as 25% or more mature herring, by number in a sample, that have yet to spawn. To qualify, a sample must have a minimum of 80 randomly selected adult sized fish. A full copy of the spawning closure protocol can be found in Section 4.2.6 of Amendment 3.

In April 2019, the ASMFC Herring Board approved Addendum II to strengthen spawning protections in Area 1A by initiating a closure when a lower percentage of the population is spawning (from about 25% to 20%) and extending the closure for a longer time (from four weeks to six weeks; ASMFC 2019). The Addendum also modified the trigger level necessary to reclose the fishery, with the fishery reclosing when 20% or more of the sampled herring are mature but have not yet spawned. These changes to spawning protections were implemented in response to the results of the 2018 Benchmark Stock Assessment which showed reduced levels of recruitment and spawning stock biomass (NEFSC 2018).

The modeling effort behind the in-season GOM spawning closures is at:

<http://www.massmarinefisheries.net/herring/>.

Map 2. Spawning areas in the Gulf of Maine, implemented through ASMFC Herring plan.



4.4.2 Spawning closures developed and recommended by NEFMC in the Atlantic Herring FMP (1999), but disapproved by NOAA Fisheries

The Council recommended spawning closures in the original Atlantic Herring FMP, but they were disapproved by NOAA Fisheries and not implemented through the federal FMP. The description of the alternatives is pasted below with Council rationale, and an explanation of why the measures were disapproved.

Management Area 1

NEFMC recommended alternative: Spawning closures are proposed for Management Area 1 (in both subareas 1A and 1B). These areas are modified from the spawning closures implemented by the Commission in its 1994 management plan. Spawning closure dates are fixed. In an area closed to protect spawning, fishing for, harvesting, or *possessing* herring will not be allowed except for the following exception: vessels will be allowed to catch and possess up to 2,000 pounds of herring per trip. The amount of herring landed from a closed spawning area by one vessel in a day cannot exceed 2,000 pounds (this prohibits a vessel from making multiple trips in one day to exceed the 2,000 pound trip limit). This limit will be enforced based on calendar days and not on the basis of days-at sea used in any other management plan (for example, a groundfish days at sea running clock cannot be used to land more than 2,000 pounds of herring in one calendar day). Any fishing vessel transiting a closed spawning area and possessing more than 2,000 pounds of herring must have all fishing gear stowed as specified by the Regional Administrator.

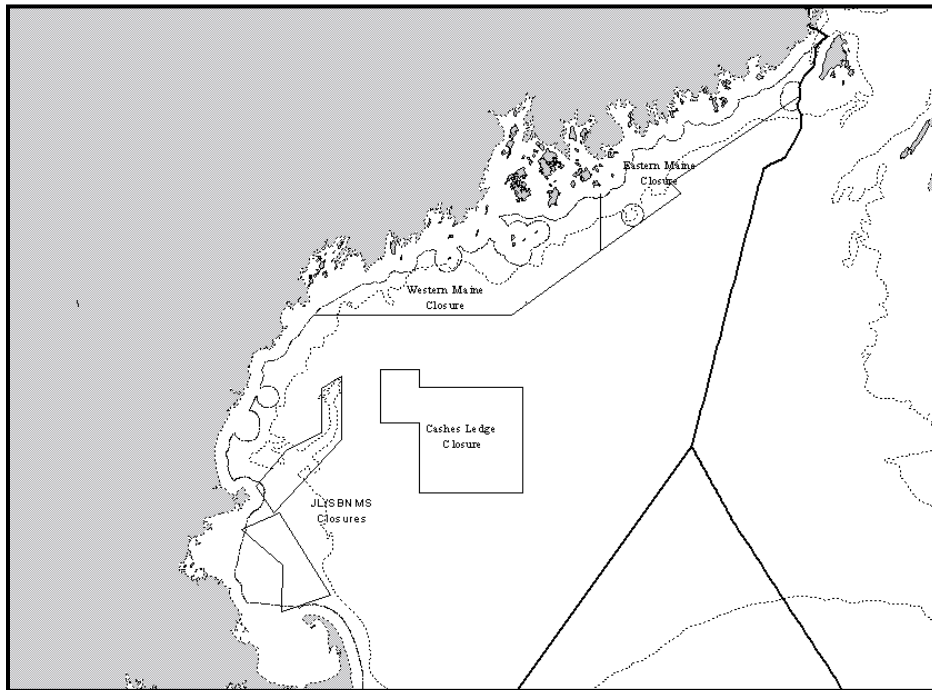
The boundaries of the spawning closures, and the dates the areas are closed, may be adjusted through framework action (see Section 3.3.6). Additional area closures may also be adopted through framework

action. The spawning closure areas in Management Area 1 are defined in Map 3. Herring Management Area 1 spawning closures (with approximate territorial sea boundary shown).

The closure dates will be:

Eastern Maine	August 15 – September 11
Western Maine	September 1 – September 28
Jeffreys Ledge/Stellwagen Bank	September 15 – October 12
Cashes Ledge	August 1 – September 25

Map 3. Herring Management Area 1 spawning closures (with approximate territorial sea boundary shown)



Rationale: Herring schools are especially susceptible to fishing when they aggregate for spawning. This is also when herring are at their most valuable, as fat content is generally at its peak. These economic reasons to allow fishing on spawning herring, however, are opposed by conservation concerns. Herring in the latter stages of spawning are not fit for some markets, resulting in the loss of spawning aggregations not only results in high catch rates, but it interferes with the spawning behavior of those herring not caught. There is evidence that part of the reason for the collapse of the Georges Bank fishery in the late 1970's was not only due to high overall mortality, but because sequential fishing on spawning herring reduced the resiliency of the stock to survive the increased fishing pressure (Anthony and Waring, 1980). Spawning closures provide the maximum opportunity for successful spawning.

The spawning closures adopted by this plan are also intended to complement the spawning area restrictions contained in the Commission's amended management plan for Atlantic herring. The Commission's measures apply a "tolerance" provision to fishing for Atlantic herring in state waters of the Gulf of Maine for the period August 1 through October 31. This "tolerance" allows the catching of herring as long as no more than a certain percentage consist of spawn fish. As the Commission and the

Council discussed measures to protect spawning aggregations of herring, one of the options considered by the Council was to leave the protection of spawning herring to the Commission. Under this concept, the only protection for spawning fish would have been through any landing regulations implemented by the states in accordance with the Commission's plan. Some states, however, do not have the resources to implement and enforce the tolerance provision. As a result, if the Council did not adopt any spawning closures, it is possible that vessels could catch spawn herring in federal waters and land them in a state that is unable to enforce the Commission's provisions, preventing effective spawning protection. By adopting spawning closures in federal waters for the key areas and times of spawning activity, the Council's closures augment the efforts of the states to protect spawning herring.

Management Areas 2 and 3

NEFMC recommended alternative: Because of the robust condition of the herring resource and interest in developing the offshore fishery, spawning closures will not be established in these areas when the plan is implemented. Closures may be established in the future as information is obtained on the appropriate times and areas to be closed and the industry develops the ability to harvest herring offshore. Closures may also be adopted if it is determined a developing roe fishery needs to be limited to protect the resource.

NMFS letter to partially approve the Herring FMP, 1999

“I disapproved the spawning area closures because it was not demonstrated that the costs of imposing the closures outweigh the benefits, and the measure appears to be inconsistent with National Standard 7 in that conservation benefits are uncertain. The measure also appears to contravene the M-SFCMA, Sec. 303(a) (1) (A). Further, the spawning closures would not apply to mobile, bottom-tending vessels, just to purse seiners and midwater trawlers. Such fishing gear may also disturb spawning herring. Also, the Northeast Region Office of Law Enforcement stated that spawning area closures that allow the possession of herring on board pose enforcement problems. In consideration of the aforementioned and of concerns raised by commentators, and given the uncertainty of conservation benefits to be realized, a spawning closure at this time does not appear to be a necessary and appropriate conservation and management measure.”

4.5 ACTION 4 - REQUIRED REVIEW PROGRAM

4.5.1 Required Review Alternative 1 - No Action

Alternative 1 (No Action) would not require the Council to complete a specific review of any measures implemented by this action to protect spawning of Atlantic herring on Georges Bank.

Draft Rationale: If any measures to protect Atlantic herring spawning on Georges Bank are implemented by this action, the Council would always have the flexibility to complete a review, but a review would not be required within a specific timeframe or for a stated purpose.

4.5.2 Required Review Alternative 2 - Implement a required review of the measures implemented in this action

4.5.2.1 Required review of spawning closure areas

Alternative 2 would develop a regular, strategic process to review the effectiveness of any spatial spawning closure areas that may be adopted in this action. The boundaries, scope, characteristics, and timing of spawning protection areas would be evaluated. The PDT would prepare a technical review that evaluates the performance of spawning protection areas. This review will be completed at either:

Option A: 10-year intervals following implementation of spawning protection areas; or

Option B: several years (<5 years) after herring biomass is declared rebuilt (biomass above B_{MSY}).

The review and associated written report would be prepared using relevant available science and data to show whether the areas are meeting the objectives and advise the Council whether changes are warranted. Development of this technical review and report may be aided through review of new research and data, independent evaluation, a workshop convened by the Council, consultation with Council technical teams, and/or peer review by the Council's Scientific and Statistical Committee or the Center for Independent Experts. The review process is intended to be flexible and somewhat general but would include establishing metrics and indicators of how effective the spawning protection areas are.

This review should consider but is not limited to the following questions:

- How well does the timing of spawning coincide with the spawning closure areas?
- Does fishing disrupt spawning activity (apart from the effect of removing spawners)?
- Have the closed areas improved stock-wide recruitment?
- What is the variability of spawning activity (location and timing) over time?
- Are spawning closures as configured able to protect spawning activity, given this variability?
- Have new sub-populations of spawners been identified that require specific protection?
- Has the fishery changed behavior because of these measures? Has that had any biological or economic impacts? Have there been any unintended consequences?
- Has the monitoring and enforcement of the spawning protection area been adequate?

Based on this review, the Council may choose to initiate a framework adjustment to change spatial spawning protections. In addition, the Council could identify and periodically revise research priorities to improve spawning area monitoring.

Draft Rationale: Alternative 2 would require the Council complete a review of any spawning closure area measures adopted in this action. At some point in the future, the Council is committing to reviewing and evaluating the effectiveness of any spawning closure areas approved in this action. This review could serve as the basis for future revisions.

4.5.2.2 Required review of spawning tolerance measure

Alternative 2 would develop a regular, strategic process to review the effectiveness of a spawning tolerance measure, if adopted in this action. The PDT would prepare a technical review that evaluates the performance of the spawning tolerance measures. This review will be completed at either:

- Option A:** 10-year intervals following implementation of the spawning tolerance measures; or
- Option B:** several years after herring biomass rebuilds above B_{MSY} (< 5 years after $B > B_{MSY}$).

The review and associated written report will be prepared using relevant available science and data to show whether the measure is the objectives and advise the Council whether changes are warranted. Development of this technical review and report may be aided through review of new research and data, independent evaluation, a workshop convened by the Council, consultation with Council technical teams, and/or peer review by the Council's Scientific and Statistical Committee or the Center for Independent Experts. The review process is intended to be flexible and somewhat general but would include establishing metrics and indicators of how effective the spawning tolerance measure is.

This review should consider but is not limited to the following questions:

- Has the monitoring and enforcement of the spawning tolerance measure been adequate?
- How has compliance been with the spawning tolerance measure?
- Are there noticeable differences in proportion of catch with spawning fish by gear, area and season?
- Does fishing disrupt spawning activity (apart from the effect of removing spawners)?
- Has stock-wide recruitment improved since adoption of this measure?
- Has the fishery changed behavior as a result of these measures? Has that had any biological or economic impacts? Have there been any unintended consequences?

Based on this review, the Council may choose to initiate a framework adjustment to change the spawning tolerance measure. In addition, the Council could identify and periodically revise research priorities to improve monitoring of Atlantic herring spawning.

Draft Rationale: Alternative 2 would require the Council complete a review of any spawning tolerance measure adopted in this action. At some point in the future, the Council is committing to reviewing and evaluating the effectiveness of any spawning tolerance measure approved in this action. This review could serve as the basis for future revisions.

5.0 REFERENCES

- ASMFC (2016). *Amendment 3 to the Interstate Fishery Management Plan for Atlantic Herring*. Alexandria, VA: Atlantic States Marine Fisheries Commission. 117 p.
http://www.asafc.org/uploads/file/57042f26Amendment3_RevisedApril2016.pdf.
- ASMFC (2019). *Addendum 2 to Amendment 3 to the Atlantic Herring Interstate Fishery Management Plan*. Arlington, VA: Atlantic States Marine Fisheries Commission. 29 p.
<http://www.asafc.org/uploads/file/5cddb296Atl.HerringDraftAddendumIIFinalApprovedRevised.pdf>.
- NEFMC (2019). *Review and analysis of Atlantic herring (Clupea harengus) spawning on Georges Bank, 2019 Discussion Document for the New England Fishery Management Council*. Newburyport, MA: New England Fishery Management Council. 92 p.
https://s3.amazonaws.com/nefmc.org/2_Herring-Spawning-Review-191122.final.pdf.
- NEFSC (2018). *65th Northeast Regional Stock Assessment Workshop (65th SAW) Assessment Summary Report*. Woods Hole, MA: U.S. Department of Commerce. NEFSC Reference Document 18-08. 38 p. <http://www.nefsc.noaa.gov/publications/>.
- Overholtz W.J., L.D. Jacobson, G.D. Melvin, M. Cieri, M. Power, D.A. Libby & K. Clark (2004). *Stock assessment of the Gulf of Maine – Georges Bank Atlantic herring complex, 2003*. U.S. Department of Commerce. NEFSC Reference Document 04-06. p.

Review and analysis of Atlantic herring (*Clupea harengus*) spawning on Georges Bank
2019 Discussion Document for the New England Fishery Management Council

Prepared by Dr. Graham Sherwood, Ashley Weston, and Aaron Whitman in consultation with
the Herring Plan Development Team

Final Report (November 22, 2019)



**New England
Fishery Management
Council**

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List of Acronyms

ASM – At Sea Monitoring

ASMFC – Atlantic States Marine Fisheries Commission

DFO – Department of Fisheries and Oceans (Canada)

DMF – Division of Marine Fisheries (Massachusetts)

DMR – Department of Marine Resources (Maine)

EFH – Essential Fish Habitat

EGOM – Eastern Gulf of Maine

EU – European Union

FMP – Fishery Management Plan

FSB – Fisheries Sampling Branch

GB – Georges Bank

GMRI – Gulf of Maine Research Institute

GOM – Gulf of Maine

GS – Great South Channel

GSI – Gonadal Somatic Index

ICES – International Council for the Exploration of the Sea

ICNAF – International Commission for the Northwest Atlantic Fisheries

LEC – Law Enforcement Committee

NAFO – Northwest Atlantic Fisheries Organization

NEFMC – New England Fisheries Management Council

NEFOP – Northeast Fisheries Observer Program

NEFSC – Northeast Fisheries Science Center

NEP – Northeast Peak

NF – Northern Flank

NMFS – National Marine Fisheries Service

OHA2 – Omnibus Habitat Amendment 2 (NEFMC)

PPI – Predation Pressure Index

SST – Sea Surface Temperature

TAC – Total Allowable Catch

VMS – Vessel Monitoring System

WGB – Western Georges Bank

I. Executive Summary

This document contains an analysis of Atlantic herring spawning on Georges Bank and provides an overview of management decisions leading to spawning protections in the nearby Gulf of Maine. It also includes a review of spawning protection strategies used in other parts of the north Atlantic. The purpose of this review is to provide up-to-date information on Georges Bank spawning dynamics (location and timing) and spawning protection strategies that may be considered by the New England Fishery Management Council (NEFMC) in future management actions regarding herring spawning protection on Georges Bank.

The bulk of this review involves new analyses of existing datasets, most of which have not been considered together in the context of herring spawning. The existing data sets considered here include: portside monitoring data, trawl survey data, and ichthyoplankton data (larvae). We also considered diet data from the National Marine Fisheries Service's (NMFS) Food Habits database and at-sea observer data. Finally, industry members were consulted for their input.

The portside monitoring data came from two sources (the Maine Department of Marine Resources, DMR and the Massachusetts Division of Marine Fisheries, DMF). This data covered the period 1971 – 2018 and included data on location, date, maturity stage and gonadal somatic index (GSI, used in the Gulf of Maine to determine timing of spawning closures). Trawl survey data came from the Northeast Fisheries Science Center's (NEFSC) trawl survey database and covered the period 1987 – 2018. Trawl survey data considered for this review included location, date, and maturity stage. Larval data came from the NEFSC ichthyoplankton surveys (1971 – 2017) and spawning locations were inferred from the distribution of early stage (< 9 mm) herring larvae.

Where possible, data/information sources were used to map the distribution of spawning herring and these were compared to existing/historical maps of herring spawning areas, as well as egg essential fish habitat. Maps from all data/information sources were then overlain to examine areas of overlap in a manner that has been used before to determine 'consensus' cod (*Gadus morhua*) spawning locations on Georges Bank (DeCelles et al 2017). This was done for the full range of years represented by each dataset as well as by decade. Resulting consensus herring spawning areas, one near the Great South Channel and the other on the Northern Flank of Georges Bank, were then compared to herring fishing effort. The analysis suggests that most of the herring fishing effort takes place outside of consensus spawning areas with the exception of some fishing effort in the eastern spawning area (Northern Flank) in some decades. For the portside monitoring data, GSI data taken throughout the year since the early 1990s allowed for an examination of seasonal trends in spawning across Georges Bank and areas further south. This analysis showed that spawning takes place primarily in September and October and has no directional trend among years or areas. This document ends with a consideration of how consensus herring spawning areas may overlap with other fishing activities (herring and non-herring) and how spawning may be affected by non-fishing drivers such as climate change and predators. The NEFMC Atlantic Herring Plan Development Team was consulted during development of these analyses and the PDT drafted research priorities for future survey work on this topic.

1. Background

1.1. Purpose and Structure of Review

In 2019 the New England Fishery Management Council (NEFMC) committed resources to develop a discussion document that would review historical and current scientific research and other relevant information about offshore spawning of Atlantic herring. The intent of this discussion document is to summarize all pertinent information in one place to support future Council deliberations about potential management measures to protect spawning of Atlantic herring on Georges Bank and Nantucket Shoals.

The Gulf of Maine Research Institute (GMRI) was awarded a contract to carry out this review of herring spawning on Georges Bank. In addition to reviewing and reproducing (from previous council documents) existing information on herring biology and spawning on Georges Bank and reviewing spawning protections in other locations (contained in sections 1.2 – 1.4), the bulk of this document is focused on examining sources of data that can be used to newly infer spawning timing and location on Georges Bank. This included analyses of larval distributions from NEFSC ichthyoplankton surveys (EcoMon; 1971 – 2017), and distributions of spawning stage (mature) herring from portside monitoring programs (DMR and DMF; 1971 – 2018) and trawl surveys (NEFSC spring and fall bottom trawl surveys; 1987 - 2018). Additional information included data from the NEFSC Food Habits Database as well as input from fishing industry members. Table 1.1 is a summary of data sets used in this analysis.

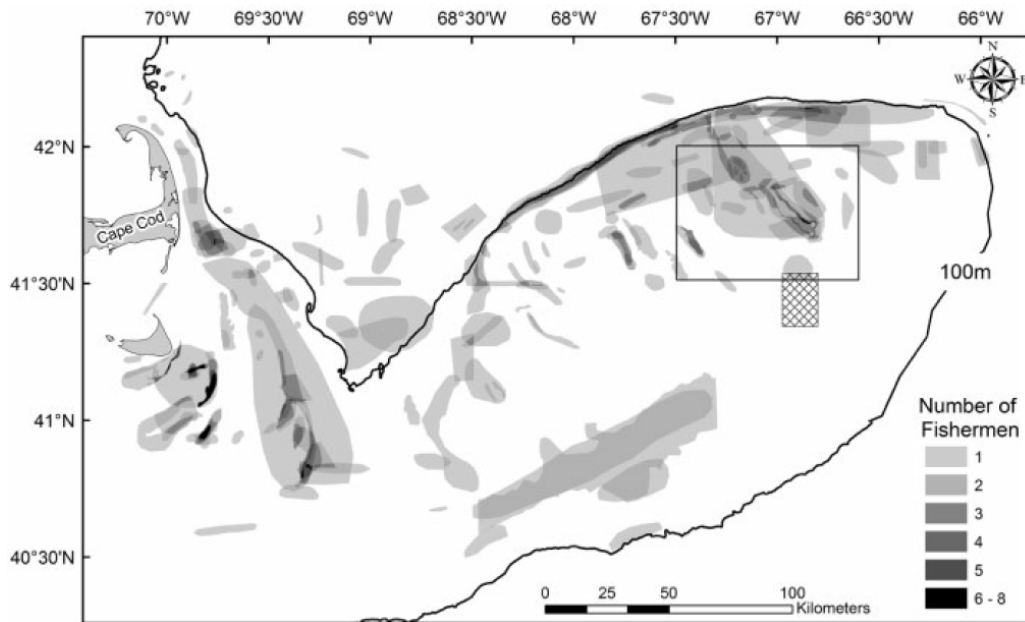
Table 1.1.1. Summary of time span of various data sources used in this review as well as data type and samples sizes.

Data Source	1970s			1980s			1990s			2000s			2010s																																		
	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
ME DMR portside monitoring	17,529 (from 583 trips) - location, date, maturity stage, GSI (Areas 1B, 2 and 3 only)																																														
Mass DMF portside monitoring																												2,725 - location, date, maturity stage, GSI																			
Trawl surveys																46,242 - location, date, maturity stage (focus on fall survey)																															
Larval surveys	6,446 tows with herring larvae - location, date, size (2,371 samples with larvae < 9mm)																																														
Food Habits Database	>650,000 stomachs - location, date, presence of herring eggs (113 positive for herring eggs)																																														

The approach used for identifying herring spawning areas in this document was modified from DeCelles et al (2017) who examined Atlantic cod (*Gadus morhua*) spawning on Georges Bank using a ‘consensus’ approach (Figure 1.1.1). This involved interviewing fishermen and asking them to identify cod spawning locations. Each of these was mapped and areas of overlap were determined. The resultant ‘consensus’ areas, where three or more sources agreed, were

given greater weight in the final representation of cod spawning. A similar method was used here. However, in our case, maps were derived from various data sources described above and groundtruthed with input from members of the mid-water trawl fishery.

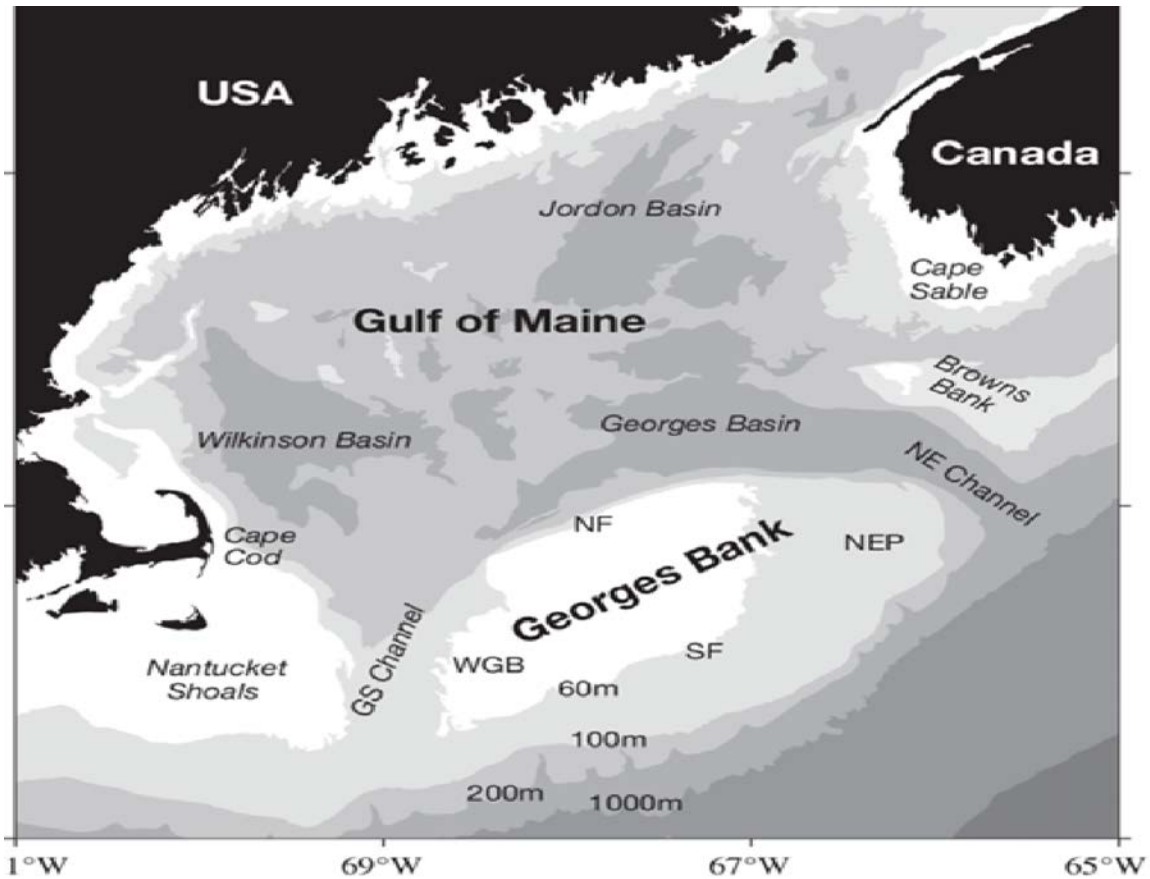
Figure 1.1.1. From DeCelles et al (2017). “Cod spawning grounds that were identified by fishermen. Each polygon represents a spawning ground that was identified by a single fisherman. The shading is used to identify areas where there is overlap in the spawning locations reported by multiple fishermen. The rectangle outlined in black depicts the “Winter Fishing Grounds” that were described by Goode (1884) and Rich (1929). The hashed rectangle represents the cod spawning grounds that were reported by Bigelow and Schroeder (1953).”



This document first outlines the results from each data source independently in section 2. Spatial patterns are explored using interpolation and density mapping techniques where the distribution of spawning adult herring or larvae can be visualized. Section 2 also contains an analysis of the seasonal trends in GSI values from portside monitoring data.

Section 3 of this document collates all of the maps generated from consideration of the different data sets. A consensus approach similar to that of DeCelles et al (2017) is used to look for areas of overlap between the different data sets. Consensus areas are then compared to herring fishing effort distribution to examine potential areas of overlap in section 4 which also considers previous, current and planned management boundaries that may overlap herring spawning. Consensus herring spawning areas are also compared to the footprint of other fisheries in section 5 which also considers potential threats to spawning from other sources including climate change and predators. Finally, future research recommendation from the herring Plan Development Team are included in section 6. Throughout the document, a number of different areas throughout the Georges Bank region are referred to. These areas are shown in Figure 1.1.2.

Figure 1.1.2. Map of Gulf of Maine and Georges Bank showing place names referred to in this document: Nantucket Shoals, Great South Channel (GS Channel), Western Georges Bank (WGB), Northern Flank (NF), and Northeast Peak (NEP). From Lough et al. (2006).



1.2. Herring Spawning Biology

Herring spawning biology is described in Amendment 8 to the Atlantic Herring Fishery Management Plan (NEFMC 2019). The description is reproduced here (in italics).

While Atlantic herring reproduce in the same general season each year, the onset, peak and duration of spawning may vary by several weeks annually (Winters & Wheeler 1996) due to changing oceanographic conditions (e.g., temperature, plankton availability, etc.). Atlantic herring are believed to return to natal spawning grounds (Map 9) throughout their lifetime to spawn (NEFMC 2006; Ridgeway 1975; Sinderman & Iles 1985).

Spawning occurs at specific locations in the Gulf of Maine in depths of 20-50 m (about 60-160 feet), on coastal banks such as Jeffreys Ledge and Stellwagen Bank located 8-40 km offshore, along the eastern Maine coast between the U.S.-Canada border and at other locations along the western Gulf of Maine (Figure 1.2.1). Some spawning sites are used repeatedly, sometimes more than once a year (NEFMC 2006; Stevenson 1989). Jeffreys Ledge

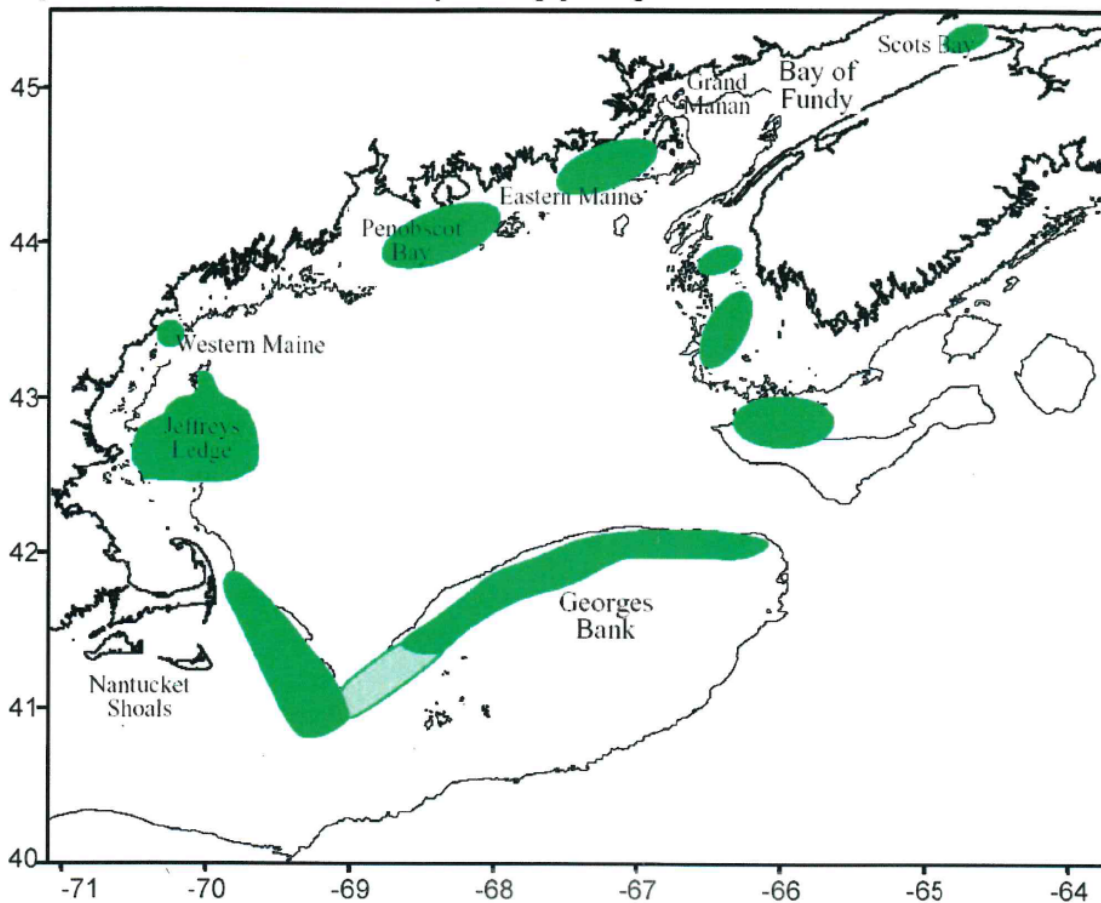
may be the most important spawning ground in the Gulf of Maine based on the number of spawning and near-spawning adults found there (Boyar et al. 1973). Figure 1.2.1 summarizes the general locations of major herring spawning areas in the GOM and GB.

Herring also spawn on Nantucket Shoals and Georges Bank, but not further south. In Canada, spawning occurs south of Grand Manan Island (in the entrance of the Bay of Fundy) and on various banks and shoals south of Nova Scotia (Figure 1.2.1). Spawning occurs in the summer and fall, starting earlier along the eastern Maine coast and southwest Nova Scotia (August-September) than in the southwestern Gulf of Maine (early to mid-October in the Jeffreys Ledge area and as late as November-December on Georges Bank; NEFMC 2006; Reid et al. 1999). Eggs are laid in layers and form mats as thick as 4-5 cm. Herring in the Gulf of Maine region usually reproduce at relatively high temperatures (10-15°C) and at high salinities (NEFMC 2006). Herring do not spawn in brackish water.

Atlantic herring spawn on the bottom in discrete locations by depositing adhesive eggs that stick to any stable bottom substrate, including lobster pots and anchor lines. Eggs are laid in layers and form mats or carpets. In the Gulf of Maine, egg mats as thick as 4-5 cm have been observed in discrete egg beds that have varied in size from 0.3-1.4 km². One very large egg bed surveyed on Georges Bank in 1964 covered an area of about 65 km² (Noskov & Zinkevich 1967).

Atlantic herring are synchronous spawners, producing eggs once annually upon reaching maturity. Depending on their size and age, female herring can produce 55,000-210,000 eggs (Kelly & Stevenson 1983). Once they are laid on the bottom, herring eggs are preyed upon by a number of fish species, including cod, haddock, red hake, sand lance, winter flounder, smelt, tomcod, cunner, pollock, sculpins, skates, mackerel and even herring themselves (Munroe 2002; NEFMC 2006). Egg predation and adverse environmental conditions often result in high egg mortalities.

Figure 1.2.1. Generalized view of the current major herring spawning areas in the GOM and on GB (from Overholtz et al. 2004).



1.3. Spawning Closures as a Fisheries Management Tool

Spawning closures are used throughout the world to protect this vulnerable stage of a fish's life-cycle. Spawning closures may be designed to account for the fact that spawning may make fish more susceptible to overfishing since fish are highly aggregated during this time. In this sense, spawning closures may be considered as an effort control measure. Alternatively, fishing may disrupt spawning behavior (e.g., formation of schools) that may lead to missed spawning potential, which could ultimately affect recruitment. Finally, spawning closures may be designed to protect habitat over which fish may spawn. This is particularly important for fish that deposit eggs over specific habitats including certain bottom types and structures (e.g., macroalgae). Additionally, spawning closures may be designed in a network fashion to avoid overexploitation of specific spawning components. van Overzee and Rijnsdorp (2015) provided a review of the various goals and benefits of spawning closures for a range of species and considered a semi-quantitative assessment of the potential for disruption to spawning by fishing for different aspects of spawning: aggregation during spawning, spawning behavior complexity, and spawning habitat. Different species were more or less vulnerable for different aspects. For

example, bivalves have a low vulnerability across all aspects of spawning as considered by van Overzee and Rijnsdorp (2015); they do not form spawning aggregations, they broadcast their spawn with no courtship behavior and their spawning habitat is pelagic. Herring, on the other hand, were scored intermediate for their vulnerability to fishing during aggregation and during the act of spawning since they do form spawning aggregations and they do have some level of courtship behavior that can be disrupted. Herring were scored high in their vulnerability to fishing effects with respect to habitat since their eggs are attached and aggregated on the bottom, thus making them vulnerable to various bottom tending gears. In terms of the assessment of van Overzee and Rijnsdorp (2015), herring were among the most vulnerable species considered to fishing effects during all aspects of spawning and would therefore be expected to benefit from some sort or range of spawning protection(s).

1.4. History of Spawning Closures in the Gulf of Maine

Perhaps the most relevant example of spawning protections being implemented for Atlantic herring comes from the Gulf of Maine. The discussion document from Appendix VIII to Amendment 5 to the Atlantic herring Fishery Management Plan (FMP, NEFMC 2013) outlines the timeline of implementation of spawning closures in the Gulf of Maine (up until 2013) and is reproduced below (in italics).

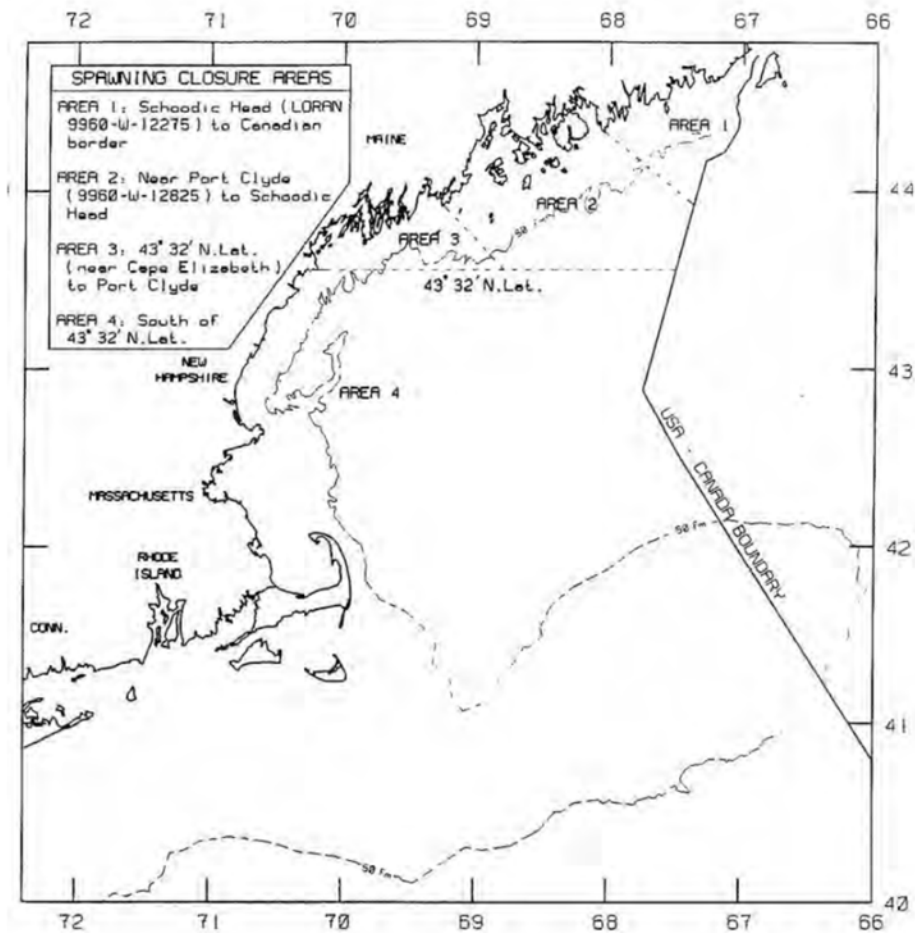
The Atlantic States Marine Fisheries Commission (ASMFC) began formal spawning closures in 1994 as part of the 1993 Atlantic Herring Fishery Management Plan (FMP). These spawning closures were a continuation of an agreement among Maine, New Hampshire, Massachusetts, and Rhode Island, who had adopted a series of spawning closures in November 1983 as part of their Interstate Herring Management Plan. The 1993 FMP included spawning protection for the entire range of Atlantic herring, including offshore areas such as Georges Bank. Foreign fishing from the late-1960s to the mid-1970s had depleted the offshore stock. Consequently, there were few spawning females in offshore areas. States sought to protect the new abundance of offshore spawning females when the population rebounded in the late 1980s and included offshore spawning restrictions.

The goals of the ASMFC FMP relating to the spawning closures were “to maintain the U.S. northwest Atlantic sea herring resource at or above 20% of its maximum spawning potential for optimal utilization while reducing the risk of stock collapse” and “to provide adequate protection for spawning herring and prevent damage to herring egg beds”.

The 1993 ASMFC FMP required states to monitor the spawning closures by sampling commercial catch just prior to the automatic closure dates. Closures were delayed for one week if the average gonad somatic index (GSI) of mature females (International Convention for the Northwest Atlantic Fisheries [ICNAF] gonadal stages III – V) was below the threshold value for either size class (18% for fish ≥ 28 cm total length and 10% for fish between 24 and 28 cm total length). Additional one week delays were implemented if sampling indicated that at least one size class had not yet reached the threshold value. The FMP allowed some landing of spawning fish (tolerances). Tolerances varied between closure areas with a 25% spawn allowance by number in the eastern, central, and western Maine spawning areas and a 5% or

1,000 pound (whichever is greater) spawn allowance in New Hampshire and Massachusetts. Vessels were prohibited from fishing for, possessing, or landing any Atlantic herring containing spawn in all other areas. Spawning closures boundaries are shown in Figure 1.4.1 and language specific to the 1993 ASMFC FMP follows:

Figure 1.4.1. Spawning closure areas from 1993 Atlantic Herring Fishery Management Plan. Note that figure is renumbered from original document.



From Section 6.2.3 Spawning Closures of 1993 ASMFC FMP:

1. A four week closure in eastern Maine beginning August 15 (unless samples of the commercial catch taken prior to the closure date indicate that females are delayed in reaching full maturity) during which time it is unlawful to fish for or take herring containing spawn (milt or roe) when they make up more than 25% by number of any load.
2. A four week closure in two additional areas in central and western Maine beginning September 1 subject to the same monitoring or maturity and 25% tolerance exceptions.
3. A three week closure beginning October 1 for the area south of 43° 32' N (Cape Elizabeth) that is not subject to any tolerance exceptions. The closure date in this area

is subject, however, to successive one week delays if sampling indicates that spawning will be delayed (identical to provisions which apply in the three areas north of 43° 32' N). This closure is enforced jointly by the four states which are party to the Interstate Herring Management Plan.

- *Area 1 (eastern Maine) : area northeast of Loran C 9960-W-12275 (Schoodic Point) to the U.S.-Canadian border.*
- *Area 2 (central Maine) : area east (or north) of Loran C 9960-W-12825 (Small Point) to Loran C 9960-W-12275 and north of 43° 32' N. Amendment 5 Volume II Appendix VIII Discussion Document: Spawning Atlantic Herring 4*
- *Area 3 (western Maine) : area bounded by 43° 32' N (Cape Elisabeth) on the south and by Loran C 9960-W-12825 on the east (or north).*
- *Area 4 : area south of 43° 32' N, including state and federal waters adjacent to Maine, New Hampshire and Massachusetts and the southern New England area.*

The New England Fishery Management Council (NEFMC) first proposed spawning area closures as a part of its Atlantic Herring FMP in 1998. The measures were intended to be adjusted through framework actions which could be initiated when additional information on the timing and locations of spawning became available. Additional closures were also a possibility through a framework action, particularly in the lesser known offshore areas. The proposed closures in the 1998 NEFMC FMP were considered necessary to ensure adequate protection of the herring resource. Herring fat content is at its peak during spawning, making them more economically valuable for human consumption, while concentrated spawning aggregations make herring susceptible to harvesting.

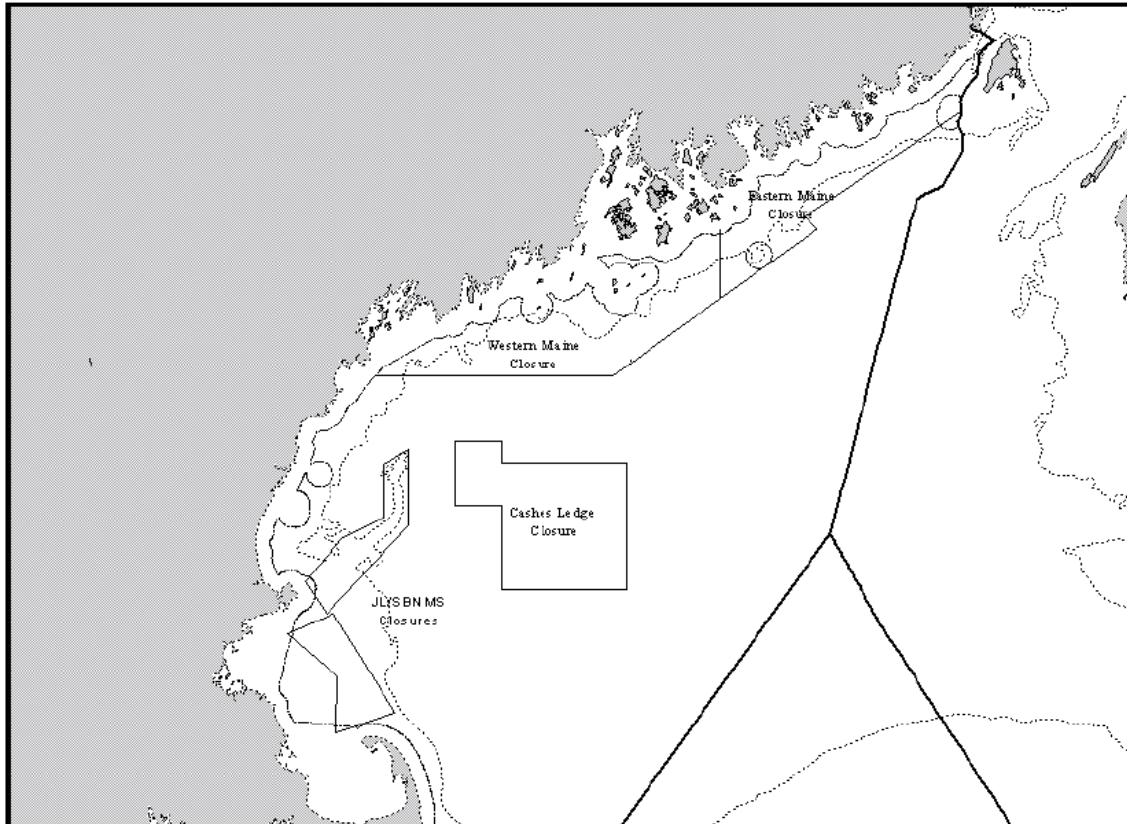
In addition, spawning behavior of the uncaught herring was believed to be influenced by harvesting operations. At the time that the spawning closures were being considered, it was believed that protection of individual spawning populations would ensure successful recruitment across the entire stock complex. It was also believed that removal of fishing pressure during spawning would relieve the aforementioned stresses while also making it easier to accurately assess the extent and size of the spawning populations, as they would not be disturbed by fishing pressure. The closures proposed by the NEFMC are shown in Figure 1.4.2. These areas were modified from the spawning closures implemented by the ASMFC 1993 Atlantic Herring FMP. Language specific to the proposed NEFMC FMP follows. The spawning closure dates in Management Area 1 were defined as:

- *Eastern Maine August 15 – September 11*
- *Western Maine September 1 – September 28*
- *Jeffreys Ledge/Stellwagen Bank September 15 – October 12*
- *Cashes Ledge August 1 – September 25*

The spawning closure dates proposed were fixed. In an area closed to protect spawning, fishing for, harvesting, or possessing herring would not be allowed except for the following exception: vessels will be allowed to catch and possess up to 2,000 pounds of herring per trip. The amount of herring landed from a closed spawning area by one vessel in a day could not

exceed 2,000 pounds (this prohibits a vessel from making multiple trips in one day to exceed the 2,000 pound trip limit).

Figure 1.4.2. Herring Management Area 1 spawning closures (with approximate territorial sea boundary shown) proposed in the 1998 NEFMC Atlantic Herring FMP. Note that figure is renumbered from original document. From south to north, Stellwagen Bank National Marine Sanctuary Closure, Jeffreys Ledge Closure, Cashes Ledge Closure, Western Maine Closure, Eastern Maine Closure.



Management Areas 2 and 3 were not considered for closures in the proposed measures of the NEFMC FMP because the offshore herring resource was considered robust and there was interest in developing the offshore fishery.

The proposed NEFMC closures in federal waters were also intended to complement the efforts of the ASMFC Amendment 1 (1999) measures (see below). The tolerance measures enacted by ASMFC allowed for some landing of spawn fish but enforcement was limited to landing regulations implemented by the individual States within ASMFC. The NEFMC developed its proposed measures out of concern that some states did not have the resources to implement and enforce the measures, which would have negated the spawning protection. The NEFMC's intention was to augment the efforts of the ASMFC by preventing the catch of spawn herring in federal waters.

In the proposed NEFMC FMP, the spawning area closures were predicted to increase cost and decrease revenue for the herring industry. Effort would have been shifted to where and when herring would be less aggregated and contain less fat. It was projected that one-third of the landings of the year prior to the proposed measures (1997) would have been closed to fishing in subsequent years as a result of the proposed action. This analysis was based on only one year of data, however, and may not have represented average fishing. A shift in effort as a result of the measures also was not considered. However, community impacts were projected to be minimal to non-existent because the NEFMC's proposed closures were smaller than those in the Amendment 5 Volume II Appendix VIII Discussion Document: Spawning Atlantic Herring 6 ASMFC's 1993 plan, and other open areas closer to shore were made available for fishing to the potentially affected boats.

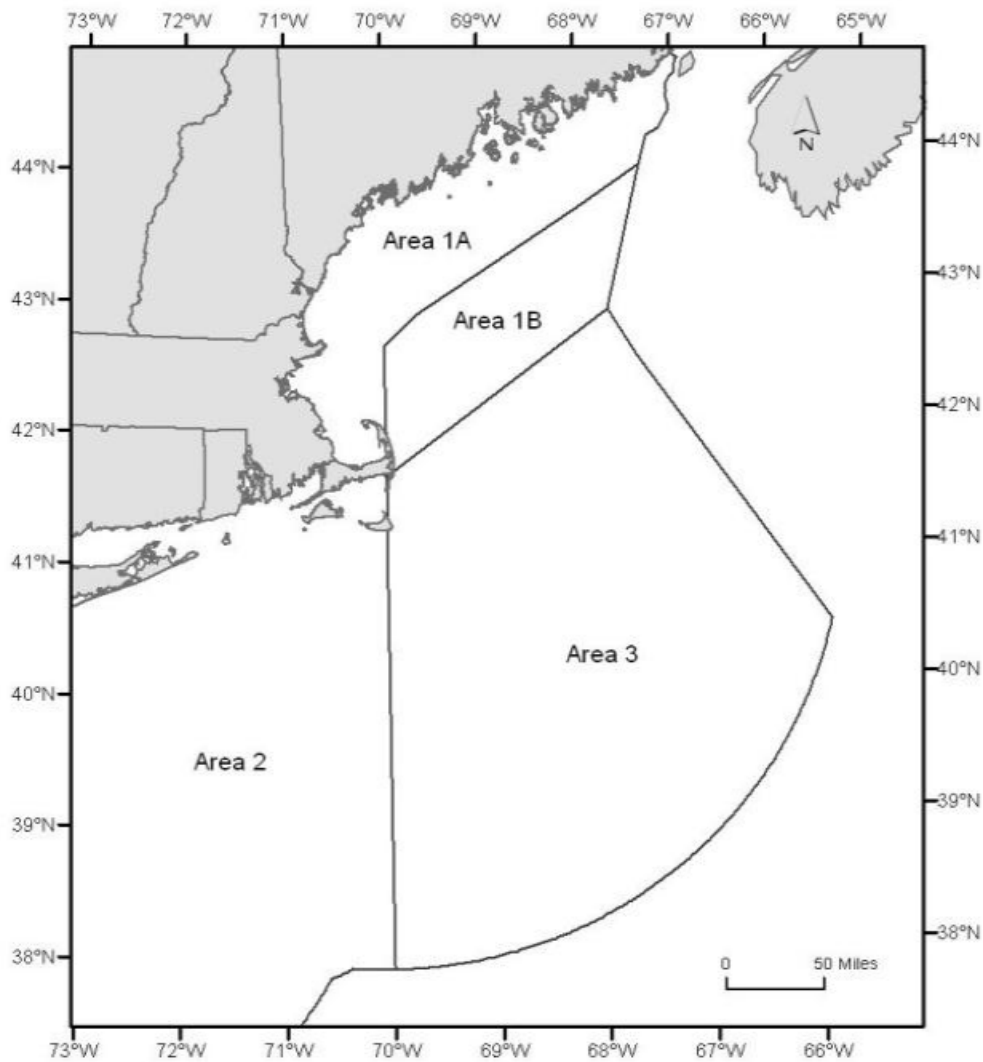
On October 27, 1999, the NEFMC received notification that the National Marine Fisheries Service (NMFS) Regional Administrator rejected the measures that would have created spawning area closures:

"I disapproved the spawning area closures because it was not demonstrated that the costs of imposing the closures outweigh the benefits, and the measure appears to be inconsistent with National Standard 7 in that conservation benefits are uncertain. The measure also appears to contravene the M-SFCMA, Sec. 303 (a)(1)(A). Further, the spawning closures would not apply to mobile, bottom-tending vessels, just to purse seiners and mid-water trawlers. Such fishing gear may also disturb spawning herring. Also, the Northeast Region Office of Law Enforcement stated that spawning area closures that allow the possession of herring on board pose enforcement problems. In consideration of the aforementioned and of concerns raised by commenters, and given the uncertainty of conservation benefits to be realized, a spawning closure at this time does not appear to be a necessary and appropriate conservation and management measure."

The ASMFC developed Addendum I as a result of NMFS disapproval to readdress the spawning measures that had been defined in ASMFC Amendment 1 (see following).

Amendment 1 (1999) to the ASMFC Atlantic Herring FMP replaced all previous ASMFC Atlantic herring measures including spawning closures. The goal of the new spawning measures was to protect distinct spawning units that are especially susceptible to fishing when they aggregate for spawning. The new spawning measures applied only to state waters within Management Area 1A (Figure 1.4.3) and did not include any measures to protect spawning fish in offshore areas such as Georges Bank. From August 1 through October 31, vessels were prohibited from taking, landing, or possessing more than 20% (by number) "spawn" herring containing roe or milt from state waters within Management Area 1A. Amendment 1 (1999) defined spawn herring as "ICNAF gonadal stages 4, 5, & 6."

Figure 1.4.3. Management areas under ASMFC Amendment 1. Note that figure is renumbered from original document.

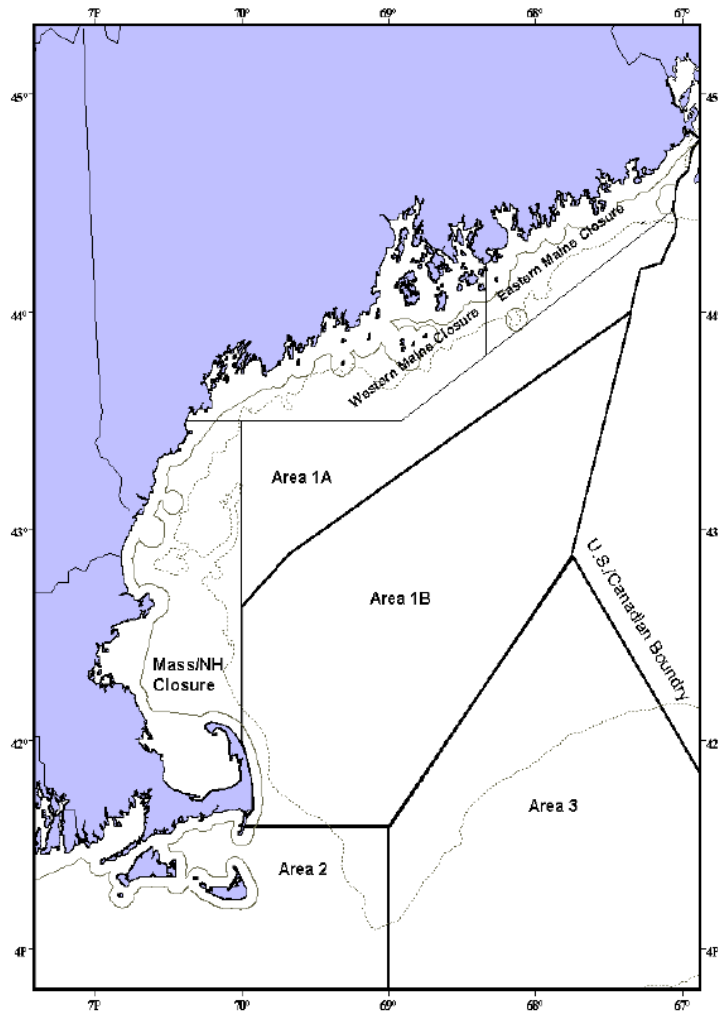


Addendum I (2000) to Amendment 1 of the ASMFC Atlantic herring FMP was developed to readdress the protection of spawning areas because NMFS rejected the NEFMC’s proposed Area 1A spawning closures in federal waters (see above). Under Addendum I, three spawning management areas were created (Figure 1.4.4) – Eastern Gulf of Maine (EGOM), Western Gulf of Maine (WGOM), and Massachusetts/New Hampshire (MA/NH), all of which are in Management Area 1A. These spawning areas extended into federal waters and had distinct start dates of August 15 (EGOM), September 1 (WGOM), and September 21 (MA/NH). Closures lasted 4 weeks by default, but would be extended 2 weeks if commercial catch sampling found that 25% or more mature herring, by number, had yet to spawn. Mature or “spawn” herring were defined as Atlantic herring in ICNAF gonadal stages V & VI. The

definition remained "ICNAF gonadal stages V & VI" in all subsequent management documents.

In 2000, members of the public, herring fishermen, and Maine Department of Marine Fisheries personnel all noted a significant take of spawn herring from the area just outside the EGOM area during the closure. Consequently, Technical Addendum 1A (2001) was created to expand the EGOM spawning area to protect spawning females inside the eastern tip of Inner Schoodic Ridge (Figure 1.4.4).

Figure 1.4.4. Spawning closure boundaries under Technical Addendum 1A to ASMFC Amendment 1. Note that figure is renumbered from original document.



Today [note that 'today' refers to 2013 when document was written], ASMFC spawning regulations are specified through Amendment 2 and Technical Addendum I (2006), which continue with the three spawning areas and default dates established by Addendum 1 and Technical Addendum 1A (Figure 1.4.4). Spawning closures begin on the default start date

unless commercial catch samples show significant amounts of spawn herring, defined as 25% or more in ICNAF gonadal stages V & VI. By default, closures last 4 weeks, at which point fishing is allowed. If a significant amount of spawn herring are found in the commercial catch samples after the closure, an additional 2 week closure is triggered. Fishermen are notified of the additional closure by the states, which use a distribution list that includes the ASMFC. The ASFMC will then place notice of the closure on their website.

Amendment 2 contains a “zero tolerance” provision that prohibits vessels from fishing for, taking, landing, or possessing “spawn” herring (ICNAF gonadal stages V & VI) in a spawning area during a closure. Some states interpreted zero tolerance to allow fishing in a closed area as long as no spawn herring are caught. Upon review of the loose interpretation of zero tolerance, and based on input from the Atlantic Herring Law Enforcement Committee (LEC), ASMFC developed Technical Addendum I to Amendment 2 to clarify that vessels are prohibited from fishing for, taking, or possessing herring within a restricted spawning area. The LEC was concerned that tolerances are difficult to enforce while prohibiting fishing in a closed area is easily enforceable.

Vessels on non-directed herring trips are allowed an incidental catch of 2,000 pounds from a restricted spawning area as a bycatch allowance. Any herring vessel that has more than 2,000 pounds of herring onboard that were caught outside an area under a spawning closure must have all of its fishing gear stowed as it travels through the closure area. Fixed gear fishermen east of Cutler, ME, are exempt from spawning closures and are not limited to the 2,000 pound bycatch allowance.

Amendment 2 does not include spawning restrictions for any offshore areas, although enforcement is by possession, not location of fishing. Its measures are designed to protect the inshore component of the stock by moving effort to offshore areas where the total allowable catch was historically not fully harvested. Section 4.3.2 Spawning Restrictions states that “protection to the offshore spawning component would come at the expense of putting more pressure on the inshore component of the stock complex.”

1.5. Current Approach for Managing Spawning Closures in the Gulf of Maine

The current approach for managing spawning closures in the Gulf of Maine is outlined in Amendment 3 to the Atlantic Herring Interstate Fishery Management Plan (ASMFC). This approach, launched in 2015, utilizes what is known as the GSI30 protocol. GSI, or gonadal somatic index (percent of gonad weight to whole body weight), is calculated for females sampled from portside monitoring programs or other fishery independent sources. Three or more samples are required to model the relationship between GSI and date. If a significant relationship exists between GSI and date, the trend can be extrapolated to forecast the date at which GSI will cross a threshold value – established as 25% in Amendment 3, but reduced to 23% in Addendum II to Amendment 3; the lower value ensures that pre-spawning fish are protected earlier in the spawning season. While previous schemes used different GSI trigger values in different length classes to determine closures, the GSI30 method standardizes GSI values to a 30 cm fish to ensure protection of the whole population (i.e., all sizes). If insufficient data exists to model the

relationship between GSI and date, default closure dates are used. Default dates are derived from historical GSI samples over the last decade as well as from the literature. The following default dates were derived from spawning samples collected between 2005-2017 and using a trigger value of 23%.

- Eastern Maine – August 28
- Western Maine – September 23
- Massachusetts/New Hampshire – September 23

The duration of spawning closures was initially set at 4 weeks under Amendment 3 but raised to 6 weeks in Addendum II to Amendment 3, based on an analysis by Dean et al (2018) which showed that spawning season often exceeds 4 weeks. Amendment 3 specified the following reclosure protocol: If a significant number of spawning herring (25% or more mature herring in the sample; sample must contain at least 80 randomly sampled adult sized fish) are observed at the end of the initial closure, the closure can be extended another 2 weeks. Addendum II refined this protocol such that ‘significant number of spawn herring’ now means 20%. Mature herring in both case means herring in ICNAF gonadal stages V and VI. Samples should be taken in final week of the initial closure or at the end of the initial closure period.

Figure 1.5.1. Real output from GSI30 forecast method for Mass/NH Spawning Area. In this case, 4 samples were taken prior to spawning closure. The trend (black line) showed that forecast mean GSI would not reach the threshold value of 23 (blue line) before the default date (red line). In this case the closure was triggered by the default date of September 23rd.

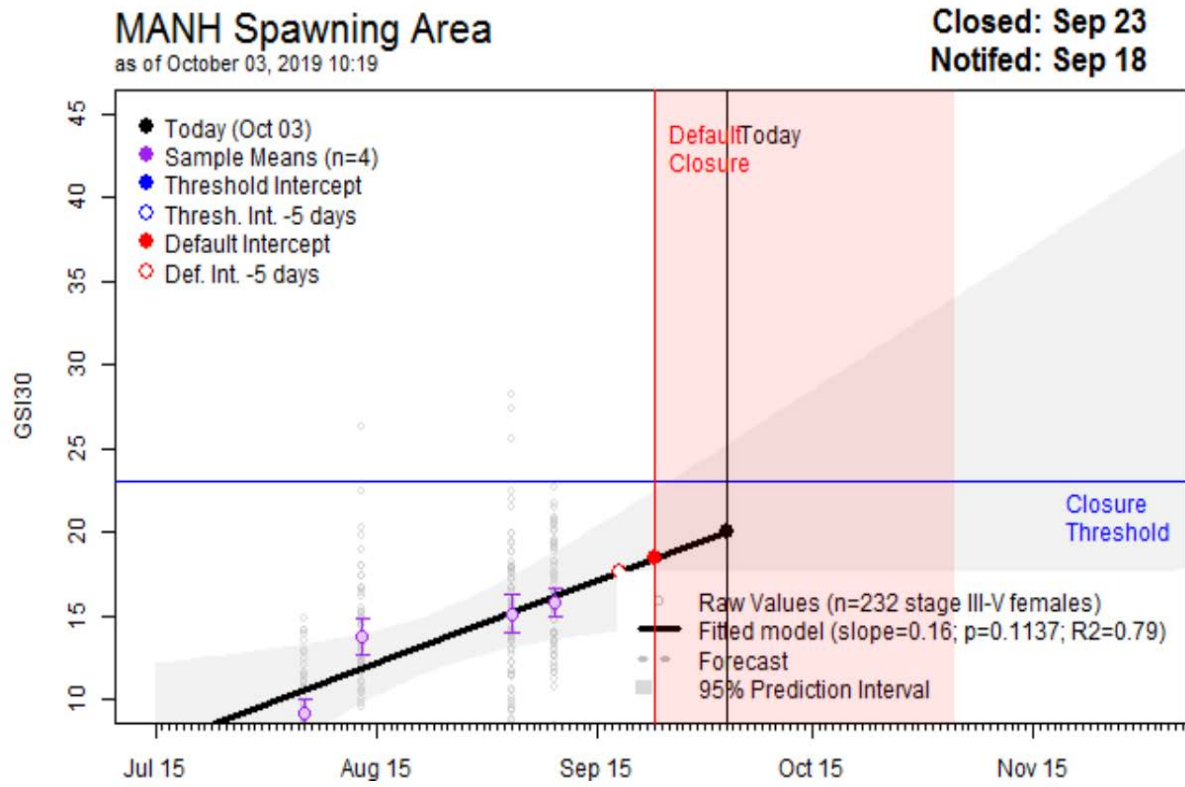
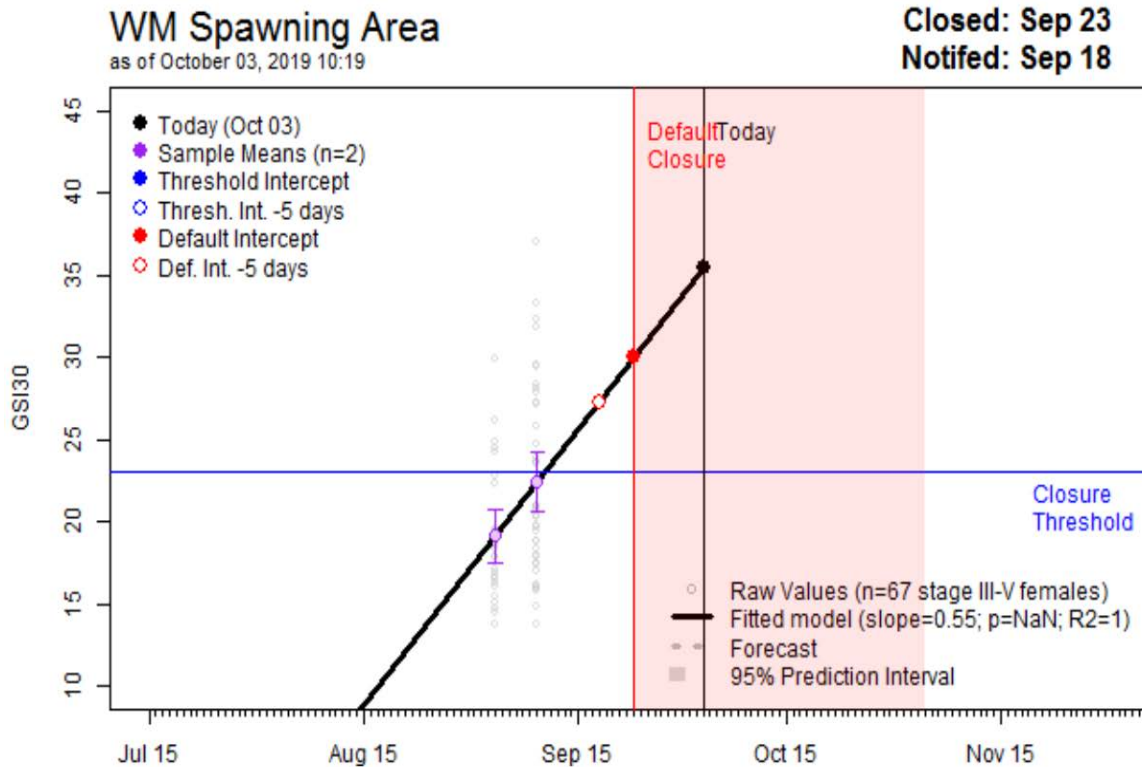


Figure 1.5.2. Real output from GSI30 forecast method for Western Maine Spawning Area. In this case, only 2 samples were taken prior to spawning closure. The trend (black line) showed that forecast mean GSI would cross the threshold value of 23 (blue line) before the default date (red line). However, since only 2 samples were taken (short of the required 3), the default date of September 23rd was used. Note that no samples were available from the Eastern Maine Spawning Area this year (2019).



1.6. Examples of Herring Spawning Protections in Other Areas of the World

An exhaustive review of management measures in other parts of the world intended to directly or indirectly protect spawning herring is beyond the scope of this document. However, some examples from different fishery management plans, with different objectives with respect to spawning protections, are provided for reference.

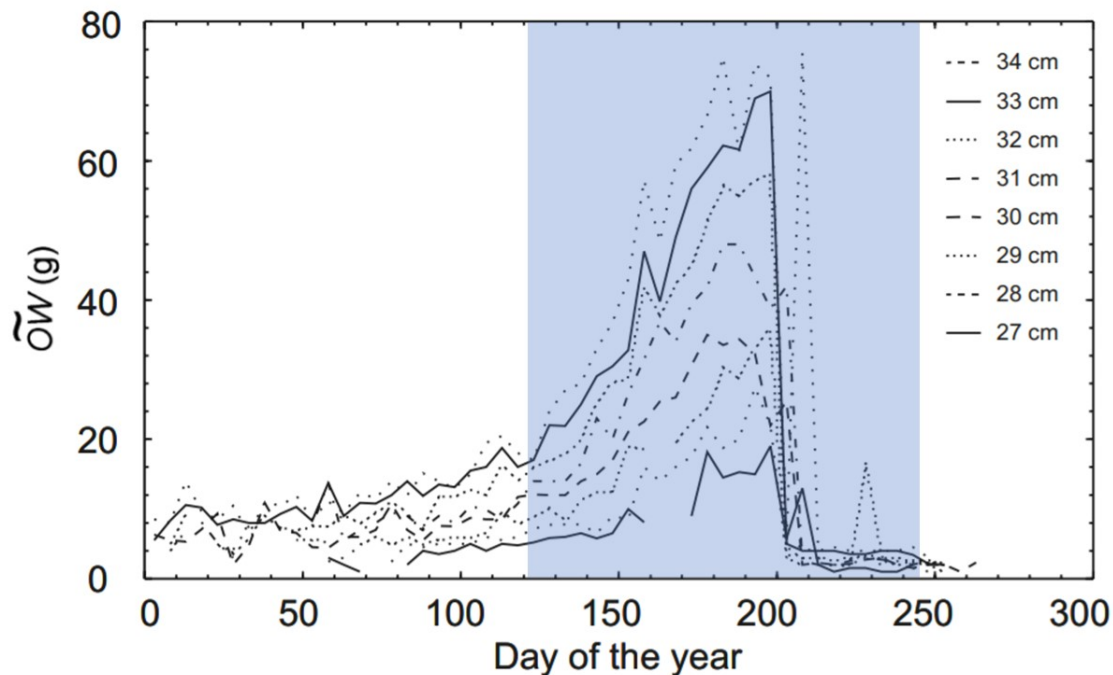
Closest to home, the management plan for herring in the southwest Nova Scotia/Bay of Fundy region includes a number of measures to reduce mortality and encourage stock growth. With respect to spawning, the main strategy is to maintain biomass of each spawning component of which there are four main grounds: Scots Bay, German Bank, Trinity Ledge and Seal Island. Fishing on spawning aggregations is part of the management plan and thus the goal of maintaining each spawning component above limit reference points is achieved via TACs informed by acoustic surveys and fishermen input. The management plan also includes a range of size limits, seasonal closures and area-based TACs all which address the strategy of maintaining biomass of each spawning component (DFO 2014).

In the Gulf of St. Lawrence, the bottom of Bay St. George (in western Newfoundland) has been identified as a major spawning area for spring spawning herring in NAFO Divisions 4R3Pn. In order to protect the spawning ground, a portion of the bottom of Bay St. George was closed to fishing for all gear types (DFO 2017). Thus, in contrast to the previous example, which was focused on maintaining reproductive capacity of herring in each management unit, the focus in western Newfoundland was on protecting habitat.

In northeastern Newfoundland (NAFO Divisions 2J3KLPs), while there are currently no explicit protections for spawning herring, an important future objective for DFO is to “work with stakeholders to ensure that migrating and spawning herring are not adversely impacted. This may necessitate additional closed areas and times.”

In Iceland, a number of measures are in place to protect summer-spawning herring. Most notably, fishing is limited to the period September 1st to May 1st, outside of the spawning season (Figure 1.6.1). While not spawning protections, there are also regulations to protect juvenile herring (27 cm and smaller). In this case, a series of closures are enforced when the proportion of juveniles in the catch exceeds 25% in number (ICES 2017a).

Figure 1.6.1. Time series of median ovarian weight (OW) by size class (27-34 cm) in Icelandic summer-spawning herring aggregated over period 1953-2000. Blue shading represents closed season. Modified from Óskarsson and Taggart (2009).

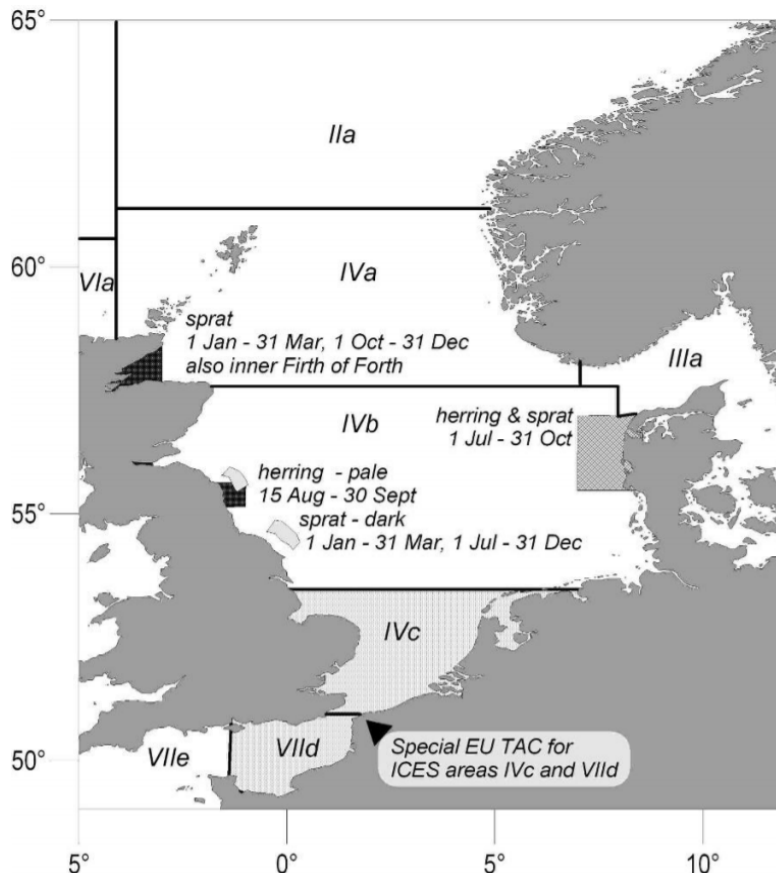


A series of herring spawning closures have been used around the United Kingdom over the last several decades. These are outlined and evaluated in a working document commissioned by the European Commission (STECF 2007). The general takeaway from this analysis is that spawning closures were implemented during periods of herring stock declines and heavy

exploitation to limit overexploitation of herring when they are highly aggregated and when roe fisheries are most valuable. The group recommended that herring spawning closures could be lifted when stocks are healthy. They also argued that spawning closures can be an effective way of controlling fishing mortality when there is little confidence in management being able to maintain F at desired levels.

Clarke and Egan (2017) describe the role of spawning closures in the recovery of Celtic Sea herring between 2000 and 2012. The Celtic Sea herring stock collapsed first in the 1970s and again in the early 2000s. Following the first collapse, the stock was managed by TACs and with input from stakeholders, efforts to reduce fishing mortality were increased including the establishment of box closures in the 1980s that still exist. Following the second collapse, a number of actions were taken to rebuild the fishery including the closure of the ‘recruit-spawner’ box which varied in temporal duration each season. In concert with other management measures, including time/area allocations of TACs to shift effort away from dense spawning aggregations and the removal of a “use it or lose it” provision for license holders, the stock recovered by 2012.

Figure 1.6.2. ICES areas and areas closed to fishing on herring and sprat under EU legislation. Black areas denote three small sprat closures to protect juvenile herring. Pale areas denote two closures on the herring fisheries to protect spawning herring around the Banks spawning ground. The shaded area to the west of Denmark is closed to the juvenile herring and the sprat fishery (although there is no targeted juvenile herring fishery). Figure and caption from ICES (2017b).



There has been a history of spawning closures for North Sea autumn spawning herring in ICES subarea 4, divisions 3.a and 7.d which consists of four major spawning components. This Fishery involves Norway, Denmark, Sweden, Germany, The Netherlands, Belgium, France, UK, Faroe Islands and Ireland. Two different types of closures are used: sprat closures to protect juveniles and spawning closures to protect spawning herring (ICES 2017b). The closures with their respective closure dates are shown in Figure 1.6.2.

2. Analysis of Existing Data Sets

2.1. Larval Data

Fish larvae can be a valuable indicator of spawning locations in fish (Richardson et al. 2010), particularly for herring since eggs are demersal and not subject to dispersal. Thus, young larvae, within a short time frame of hatching, may be spatially associated with where they were spawned. Herring larval data from Georges Bank monitoring have been presented in numerous publications and assessments (e.g., 54th Northeast Regional Stock Assessment Workshop; NEFSC 2012). For this review, larval data were accessed (D. Richardson, pers. comm.) and explored from the Northeast Fisheries Science Center ichthyoplankton sampling program from 1971-2017 (see Richardson et al. 2010 for description of monitoring program). Sampling was not conducted in every region every year during sampling cruises. During some sampling trips, there were ship time limitations, inclement weather, and other unforeseen circumstances leaving gaps in sampling. For this analysis, abundance of Atlantic herring <9mm was summed for each sample with unique locations. Larvae less than 9mm length are typically 10-15 days old (Richardson et al. 2010).

Larval distribution was visualized using the ‘MASS’ package in R where data was plotted by 2-dimensional kernel density estimation (Venables and Ripley 2002). Most larval herring were observed in October and November. Over the entire time series, highest densities of larval herring occurred on the northeast section of Georges Bank and Nantucket Shoals (Figure 2.1.1). These two areas had high densities in the 1970s and again in the 1990s, while Nantucket Shoals and Stellwagen Bank were prominent in the 1980s (Figure 2.1.2). Smith and Morse (1993) similarly found that the full extent of larval herring contracted to only Nantucket Shoals and Stellwagen Bank after the fishery collapsed in 1976, but then expanded eastward on Georges Bank through 1990. Between 2000 and 2017 larval herring density has concentrated to the Northeast section of Georges Bank (Figure 2.1.2).

Figure 2.1.1. 2-dimensional kernel density estimates of larval herring (<9 mm) abundance per sample 1971-2017 with all sample location points overlaid. Red areas indicate higher densities. Total sample size = 2,371. 100 m isobath is shown. Points are sample locations.

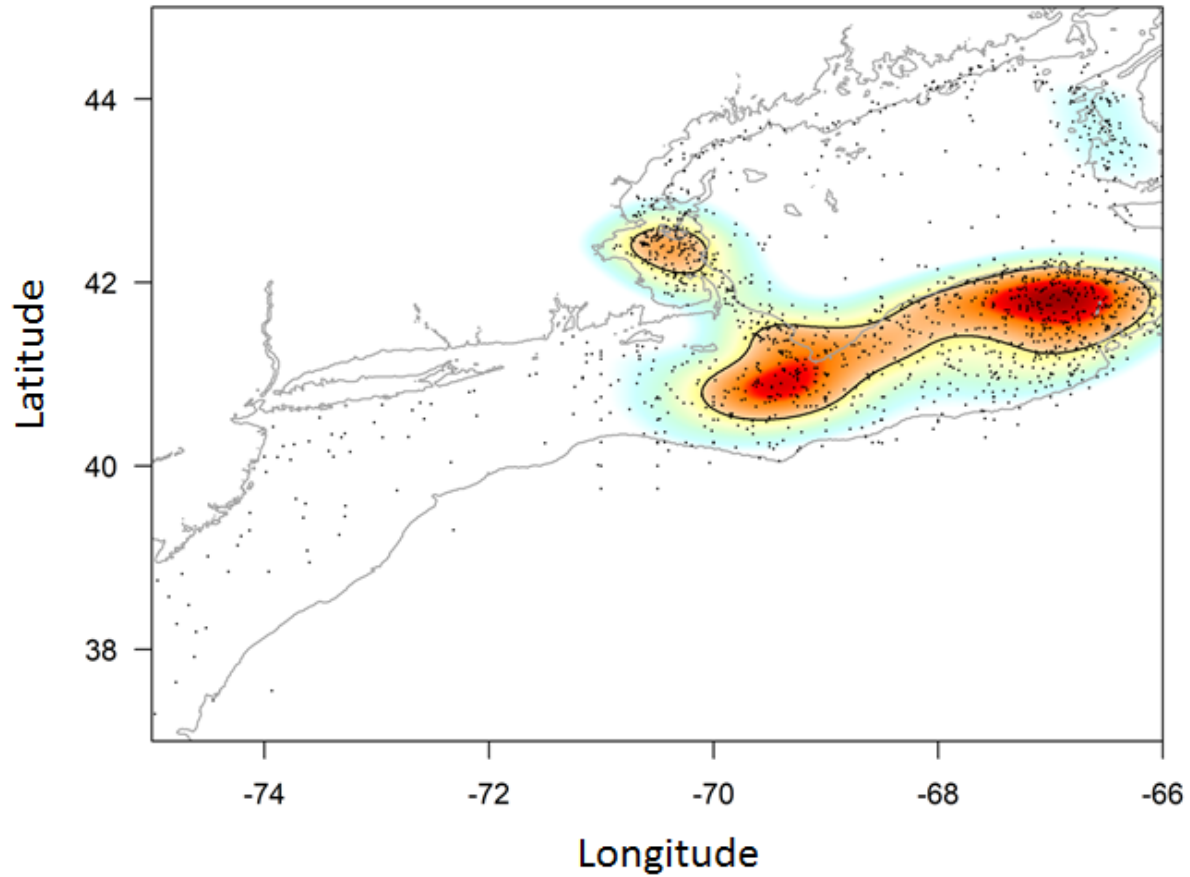
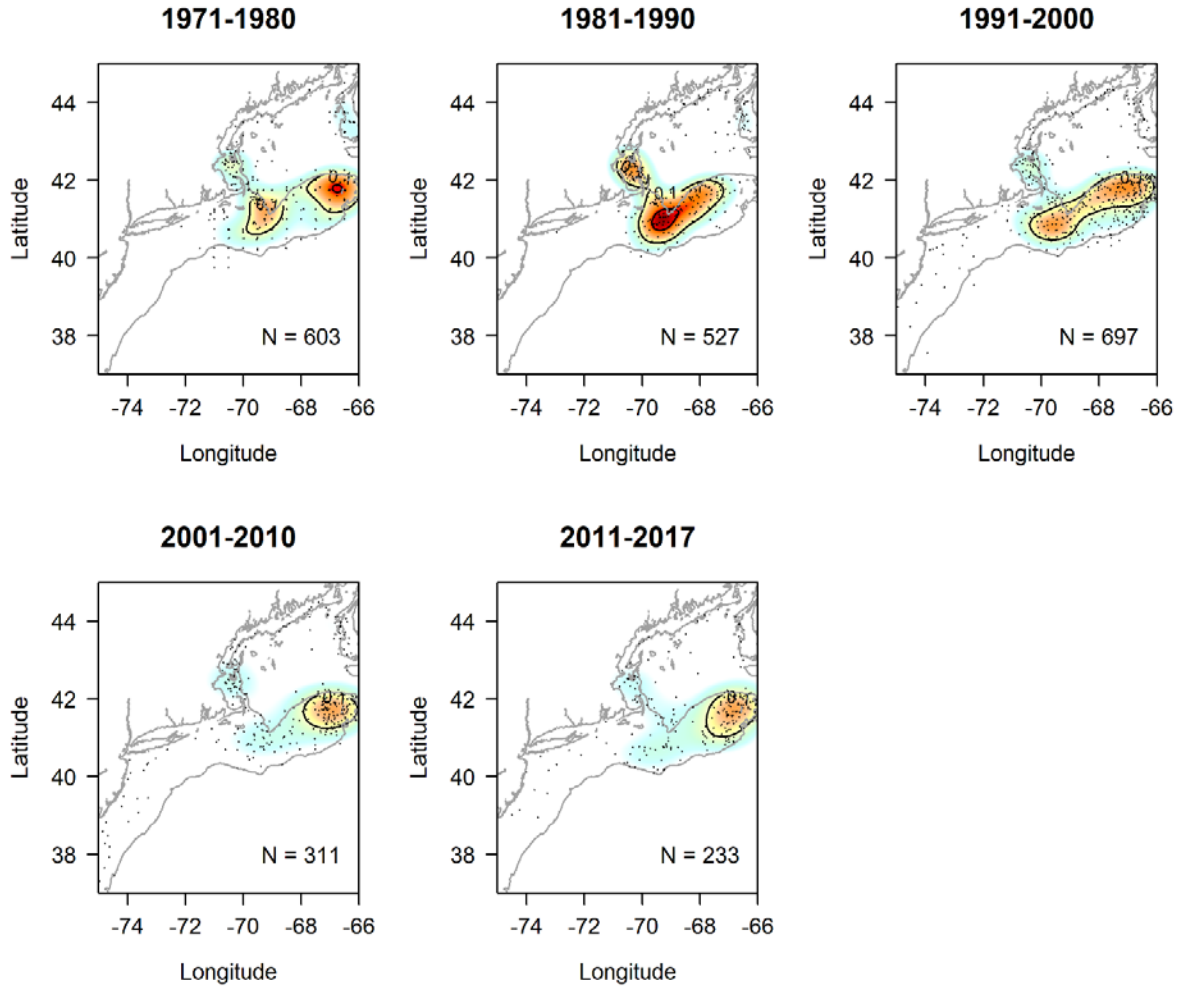


Figure 2.1.2. 2-dimensional kernel density estimates of larval herring (<9mm) per sample by decade with all sample location points overlaid. N = sample size and red areas indicate higher densities. 100 m isobath is shown. Points are sample locations.



2.2. Adult Data: DMR and Mass DMF Portside Monitoring Data (spatial patterns)

The Maine Department of Marine Resources (DMR) has administered a portside monitoring program for the US Atlantic herring fishery and has collected and processed commercial catch samples using a consistent methodology since 1971. Herring samples are collected from all commercial gear types; purse seine, single midwater trawl, pair midwater trawl, small mesh bottom trawl, and fixed gear. Two types of samples are collected, catch-at-age and spawn samples. Catch-at-age samples are collected throughout the entire range of the US fishery, year-round, including all four management areas, 1A, 1B, 2, and 3. Ports used for sample collection are from north to south: Jonesport ME, Prospect Harbor ME, Stonington ME, Rockland ME, New Harbor ME, Boothbay Harbor ME, Portland ME, Portsmouth NH, Newington NH, Seabrook NH, Gloucester MA, Fall River MA, New Bedford MA, Point Judith RI, Davisville RI,

Newport RI, and Cape May NJ. Catch-at-age sampling requires n=50 randomly selected herring per gear type, per NMFS statistical area, per week. Spawn samples require n=150, adult sized herring per sample (≥ 23 cm) during the spawn season (August – October) per week from all three spawn areas within Area 1A, only. Whole lengths, weights, age via otoliths, gender, spawn condition via staging (see Table 2.2.1) and stomach fullness, and additionally, GSI calculation for spawn samples are collected (J. Becker, Maine DMR, pers. comm.). The Massachusetts Department of Marine Fisheries (DMF) has collected additional data from 1998 – 2018 which were also included in this review.

Table 2.2.1. Maturity stages/codes used in DMR portside monitoring and NMFS trawl surveys. Rows in bold are stages of interest for this review (i.e., closest to spawning condition).

DMR	Description	NMFS	Description
1	immature	I	immature
2	starting		
3	developing	D	developing
4	maturing		
5	mature	R	ripe
6	ripe/running	U	ripe/running
7	spent	S	spent
8	resting	T	resting
		X	unknown

The DMR data set included 17,529 samples from Areas 1B, 2 and 3. Additional samples for Area 1A exist but were not included in this review. Other data included length, weight and sex. This rich data set allowed for explorations of spatial and temporal patterns in maturity and GSI, both of which can be used to infer location of spawning. In other words, spawning could be assumed to occur at or near areas with high mean GSI values or high densities of later stage maturity fish (i.e., stages 5 and 6; Table 2.2.1).

Spatial patterns using both GSI and maturity stage were examined. For GSI, the ‘MBA’ and ‘fields’ packages in R (Finley et al. 2017, Nychka et al. 2019) were used to interpolate mean GSI per sample using multilevel B-spline approximation. This was done for the entire data set (all years and sexes combined) as well as by decade and with just females (Figures 2.2.1 to 2.2.7). The progression of GSI figures is as follows. Figure 2.2.1 shows mean GSI over the sample area (Areas 1B, 2 and 3) for all years.

Overall, the highest GSI values tended to follow the northern edge of Georges Bank from Cape Cod to off of the bank near the Northern Flank. Some higher values were also associated with on the Bank (between Northern Flank and Southern Flank) but were associated with only 2 sample locations. The highest density of fishing locations was along the northern edge and was associated with relatively low GSI values. Figure 2.2.2 is the same as the previous but includes only females. The spatial pattern in GSI is similar with slightly higher mean GSI values (i.e.,

darker reds). Two areas in particular stand out as having higher GSI values: the Great South Channel and to the north of the Northern Flank. Figure 2.2.3 is the same as figure 2.2.1 except that instead of applying the spline to the raw data (with multiple individuals per sample), the spline was applied to summarized data per sample (i.e., mean GSI per sample). The spatial pattern was again the same as in previous figures. Since spatial patterns were relatively consistent regardless of sex or whether samples were averaged or not, the following are both sexes and for whole data set (i.e., not averaged by sample).

Figure 2.2.4 shows mean GSI over sample area by decade. Note that there was not continuous sampling between 1971 and 2018. There was a major gap in sampling between 1983 and 1995. As such data was pooled between 1971 and 2000, whereas the last two decades had relatively complete sampling and therefore were considered separately. The spatial pattern among decades/time periods was relatively consistent with previous figures. Figure 2.2.5 shows the Mass DMF data separately. This figure shows that the Mass DMF data set is relatively limited compared to the DMR data set. Finally, for the splines, figures 2.2.6 and 2.2.7 show the DMR and Mass DMF data combined for both sexes and for females alone. Given the limited size of the Mass DMF data the figures are not different than Figures 2.2.1 and 2.2.2.

Figures 2.2.8 and 2.2.9 show 2-D kernel density estimates of the distribution of ripe and ripe and running herring, respectively (maturity stages 5 and 6 or R + U; see Table 2.2.1). In this case, ripe herring are most associated with the Northern Flank for the entire data set, whereas ripe and running herring are associated with both the Great South Channel and the Northern Flank. Figure 2.2.10 shows the distribution of female herring with GSI30 values greater than or equal to 0.23 (see section 1.5 for explanation of GSI30 method and threshold values). In this case, the highest density of high GSI female herring, with values that would trigger closures in the Gulf of Maine, is at the Northern Flank.

Figures 2.2.11 to 2.2.13 show 2-D kernel density estimates of ripe + ripe/running (R + U), ripe/running only (U), and GSI30female ≥ 0.23 herring, respectively by decade. Densities of R + U stage herring were relatively high at both the Northern Flank and Great South Channel in all decades. Densities of U stage herring were high in both Northern Flank and Great South Channel in 1991 – 2000 and were highest in the Great South Channel in the decade 2001 – 2010. No ripe and running herring were sampled in the decade 2011 – 2018. Finally, densities of high GSI female herring (GSI30 ≥ 0.23) were generally highest at the Northern Flank for all decades but areas of high density also existed at the Great South Channel. Consistent with all of these depictions of spawning (Figures 2.2.1 to 2.2.13) is the relatively high importance of the Northern Flank and Great South Channel for harboring spawning condition (or near spawning condition) herring.

Figure 2.2.1. Surface spline interpolation of mean male and female GSI from DMR portside monitoring data (1971-2018). 100 m isobath is shown. Faint lines are boundaries of herring management areas (see figure 1.4.3). Points are sample locations.

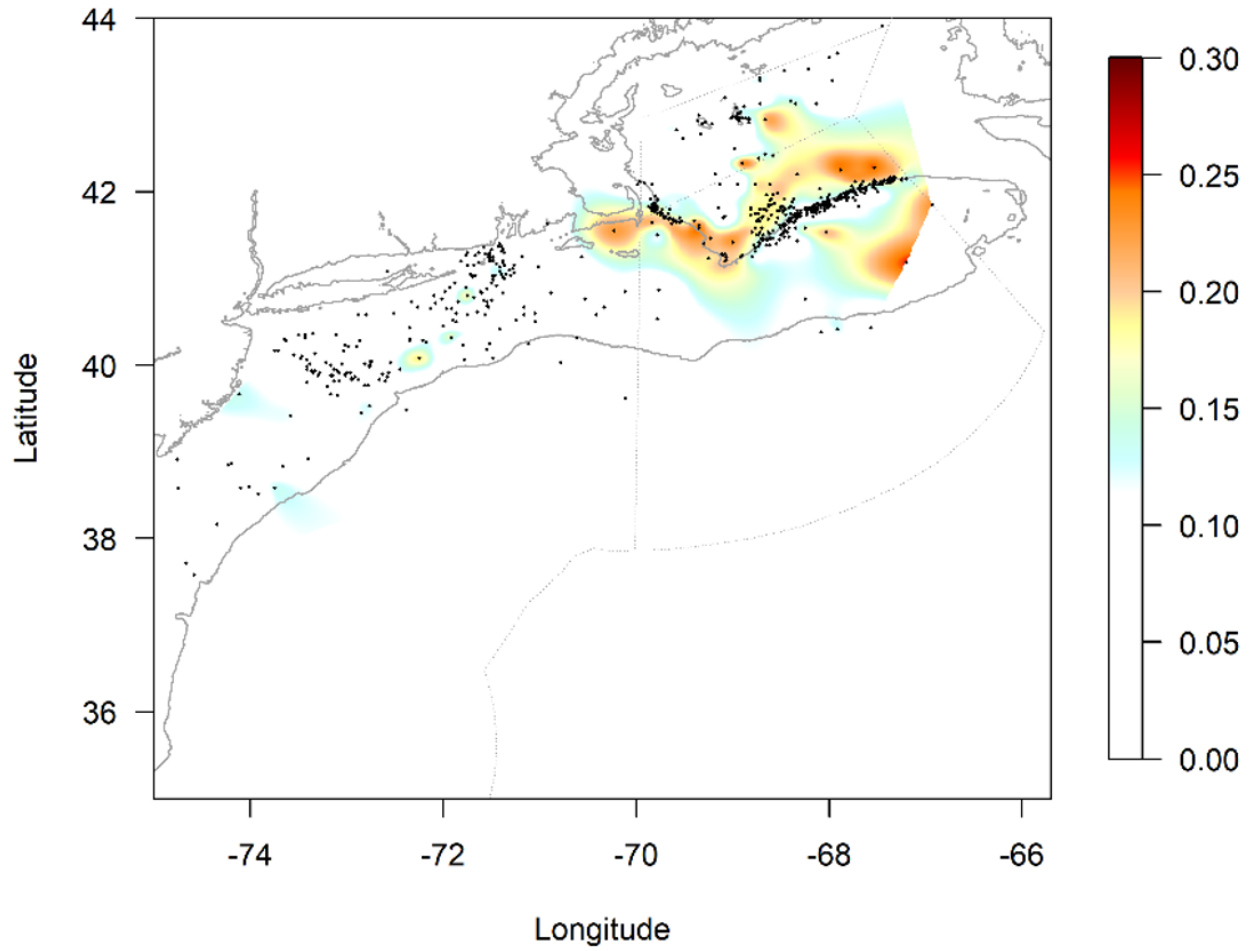


Figure 2.2.2. Surface spline interpolation of mean female GSI from DMR portside monitoring data (1971-2018). 100 m isobath is shown. Faint lines are boundaries of herring management areas (see figure 1.4.3). Points are sample locations.

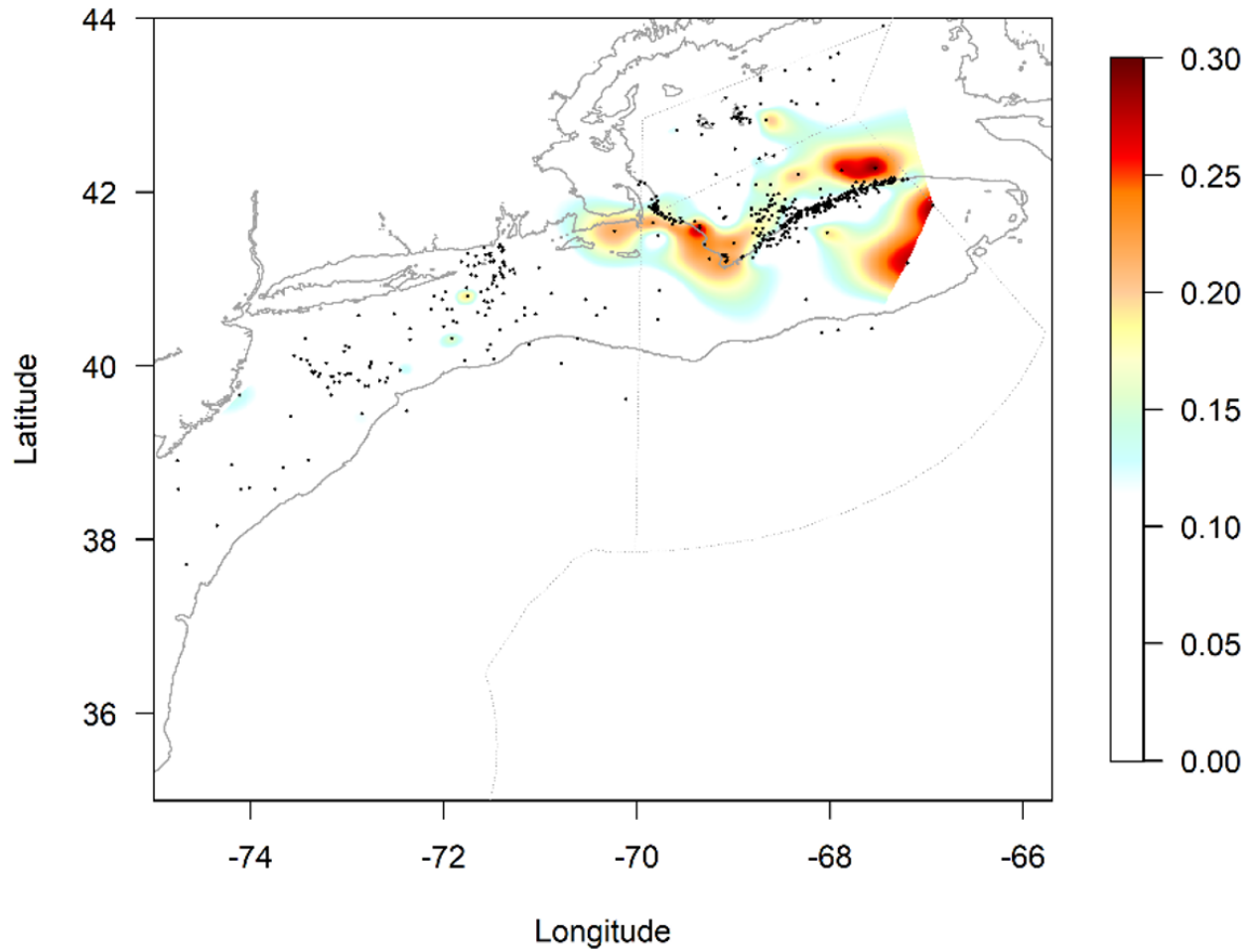


Figure 2.2.3. Surface spline interpolation of mean male and female GSI/sample from DMR portside monitoring data (1971-2018). Samples were defined as unique date/locations (i.e., values were averaged for each sample). 100 m isobath is shown. Faint lines are boundaries of herring management areas (see figure 1.4.3). Points are sample locations.

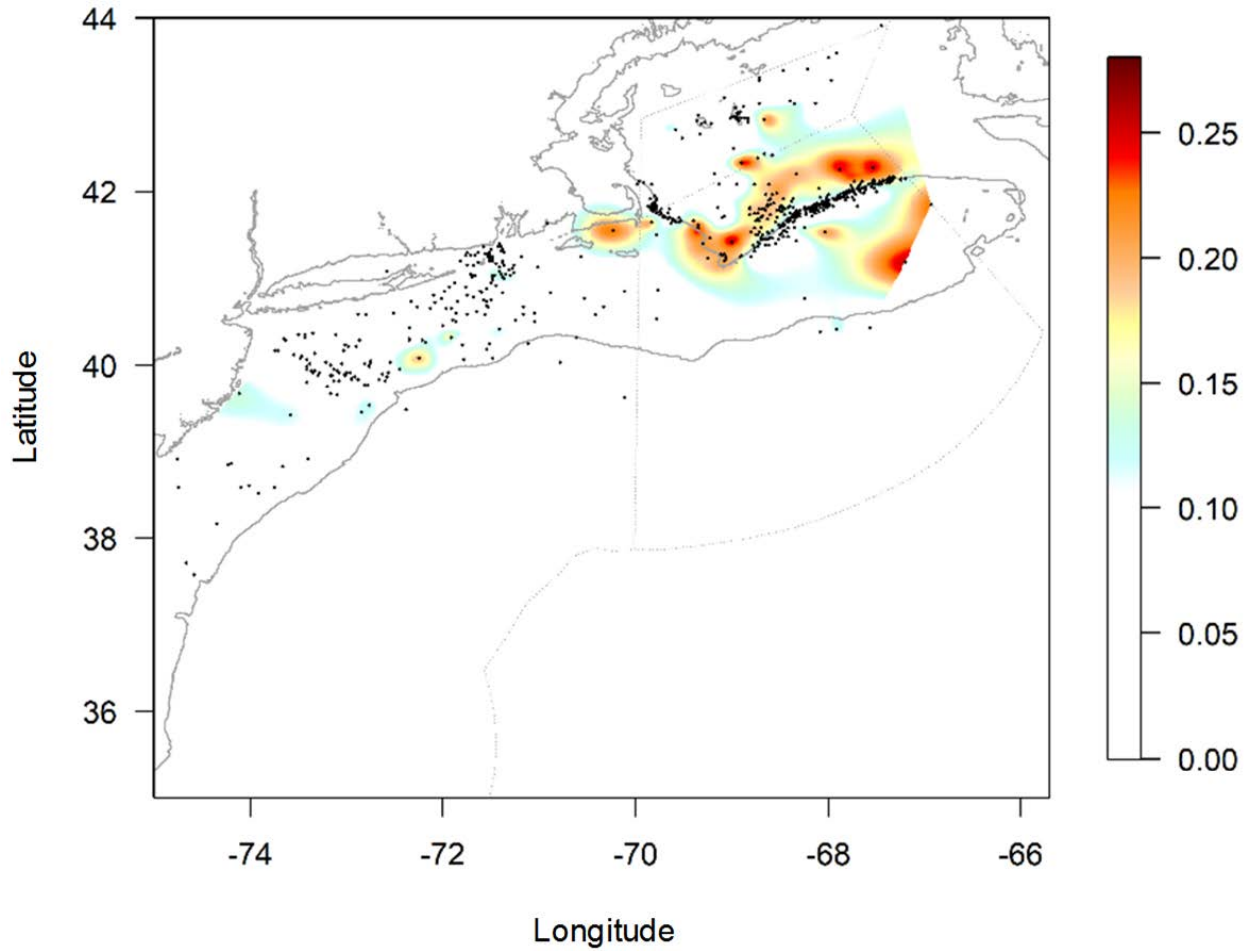


Figure 2.2.4. Surface spline interpolation of mean male and female GSI from DMR portside monitoring data by decade (1971-2018). Note that 1971 – 2001 was pooled due to data gaps. 100 m isobath is shown. Faint lines are boundaries of herring management areas (see figure 1.4.3). Points are sample locations.

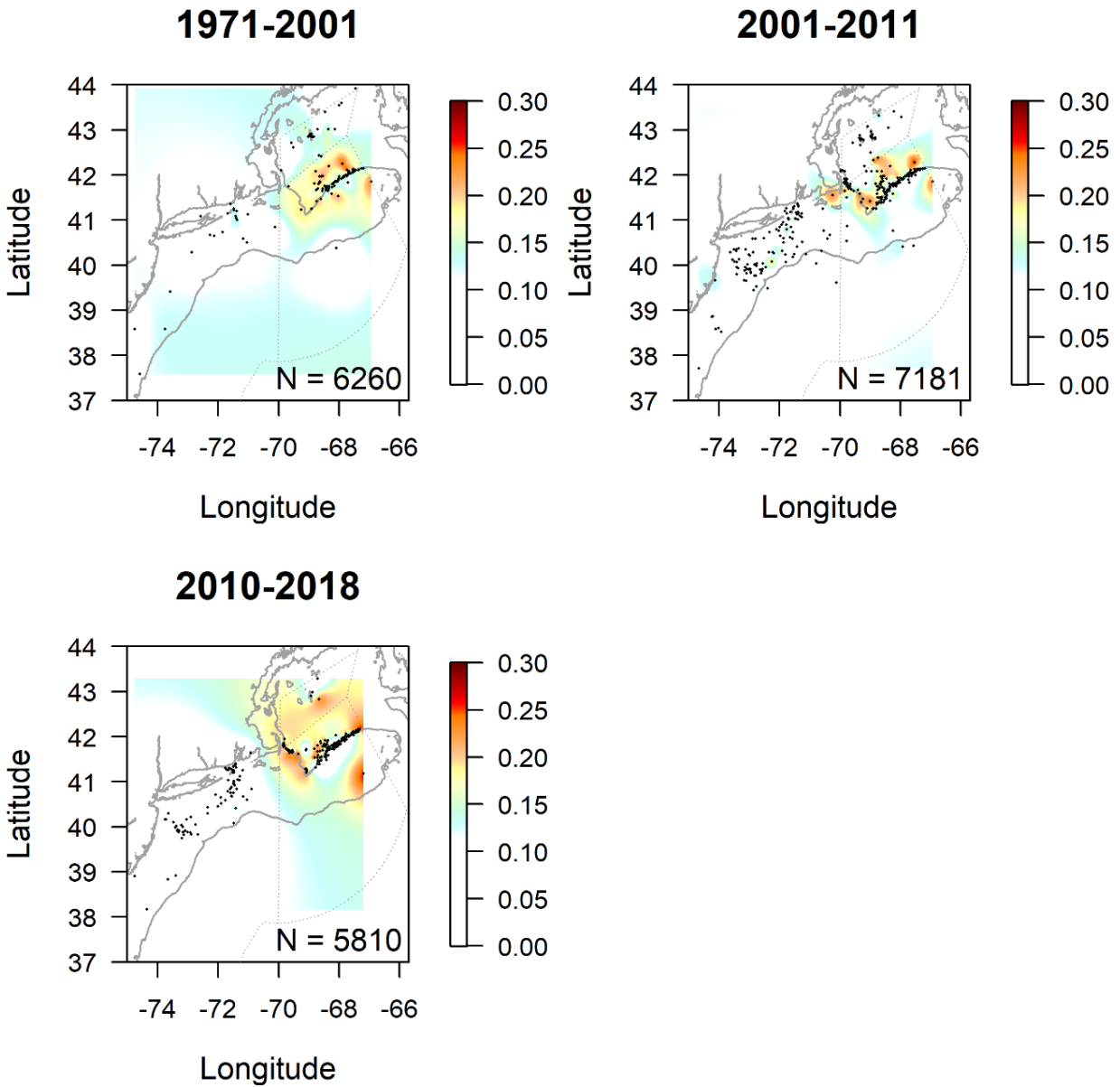


Figure 2.2.5. Surface spline interpolation of mean female GSI from Massachusetts Division of Marine Fisheries data (1998-2018); note: only female observations were available. 100 m isobath is shown. Faint lines are boundaries of herring management areas (see figure 1.4.3). Points are sample locations.

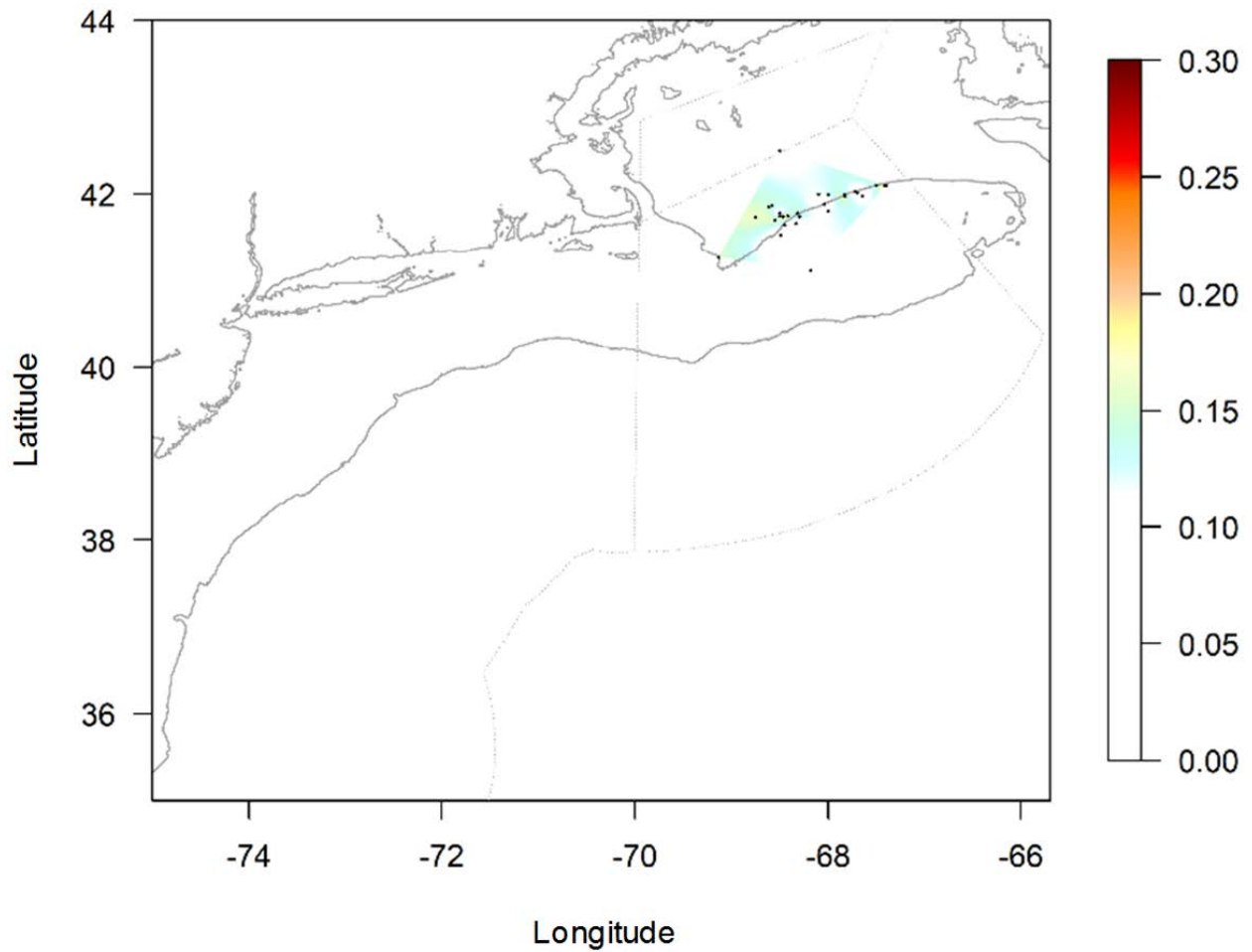


Figure 2.2.6. Surface spline interpolation of mean male and female GSI from combined DMR portside monitoring data (1971-2018) and Massachusetts DMF data (1998-2018). 100 m isobath is shown. Faint lines are boundaries of herring management areas (see figure 1.4.3). Points are sample locations.

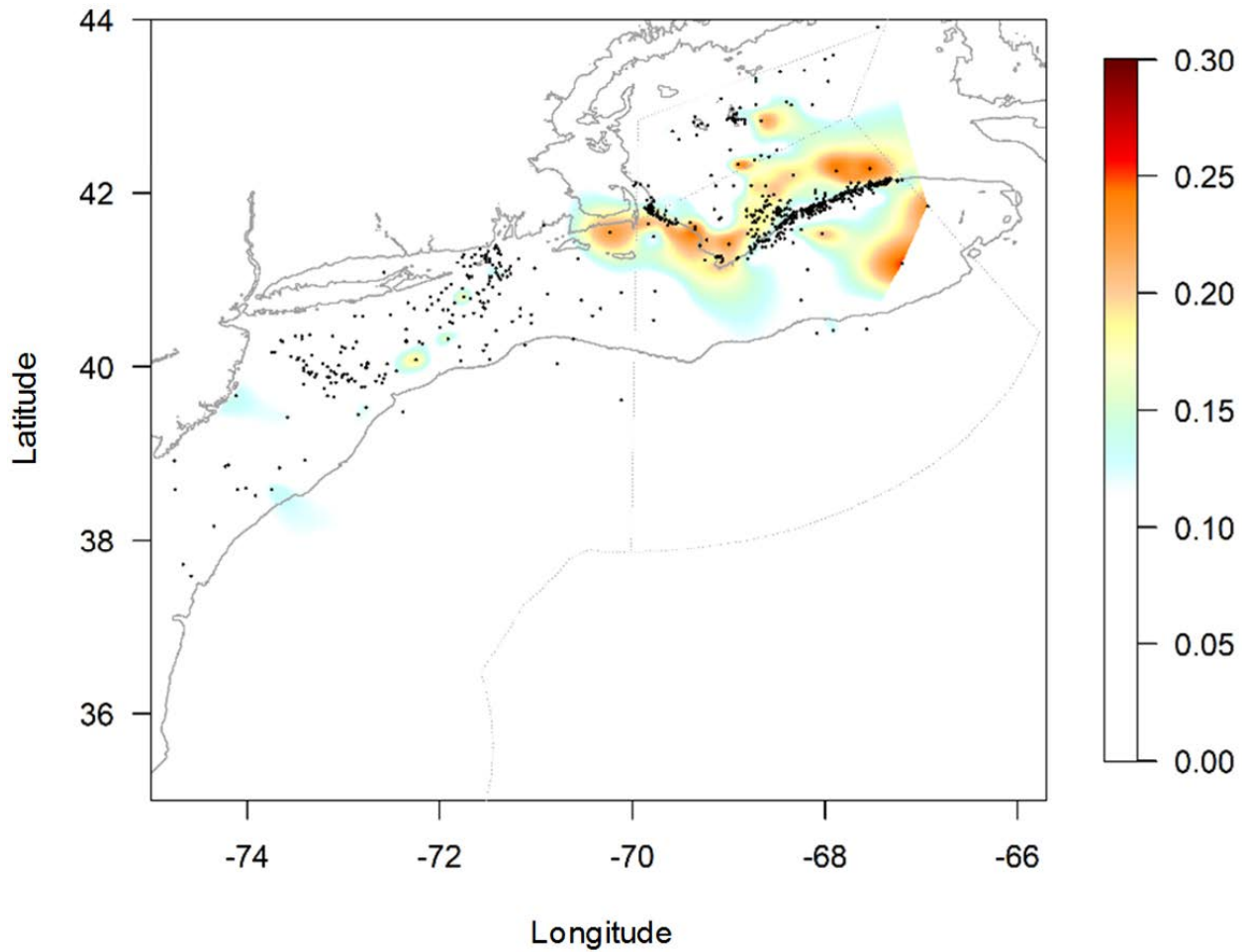


Figure 2.2.7. Surface spline interpolation of mean female GSI from combined DMR portside monitoring data (1971-2018) and Massachusetts DMF data (1998-2018). 100 m isobath is shown. Faint lines are boundaries of herring management areas (see figure 1.4.3). Points are sample locations.

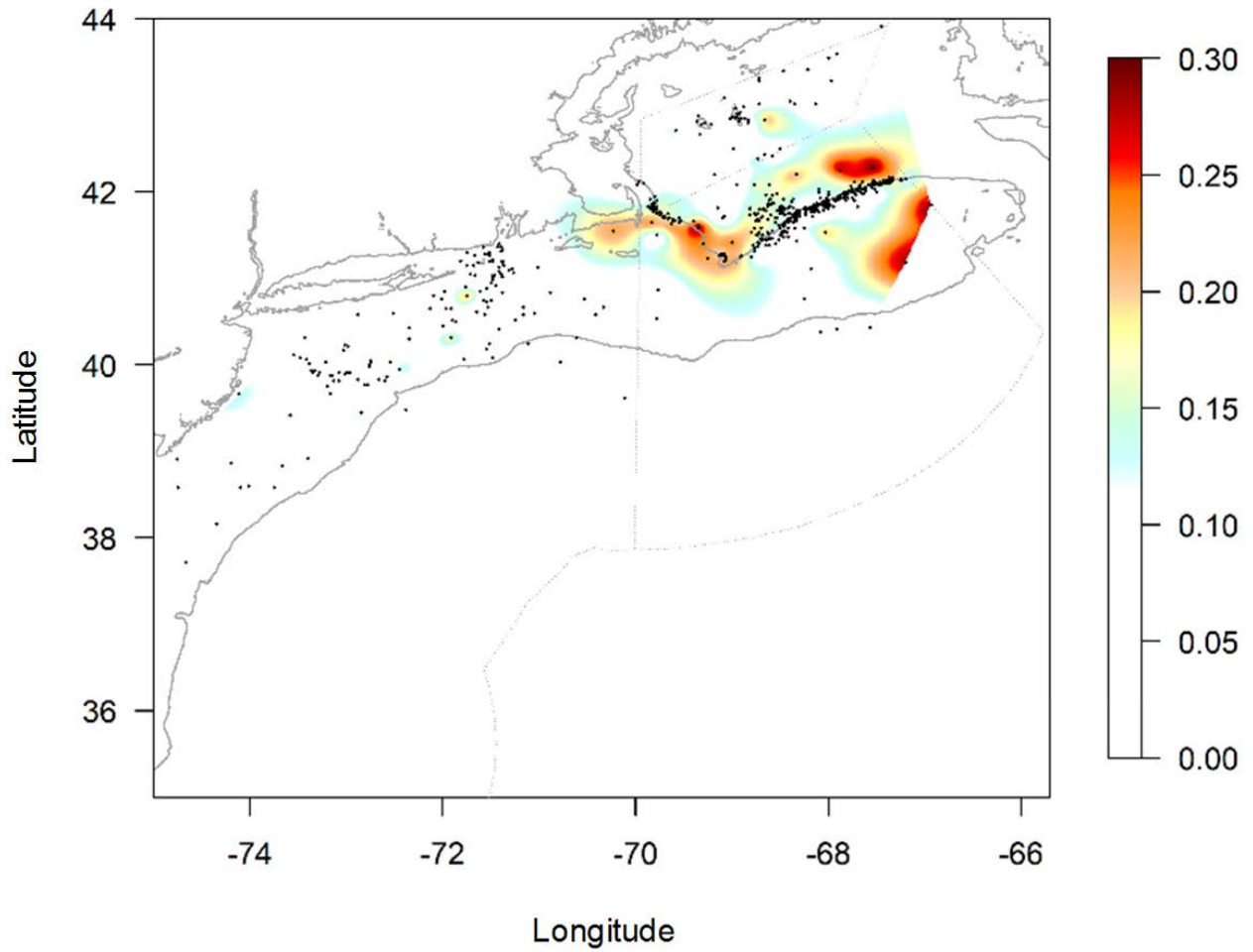


Figure 2.2.8. 2-dimensional kernel density estimates of DMR portside monitoring data (1971-2018) of male and female “ripe + ripe/running” herring. 100 m isobath is shown. Points are sample locations.

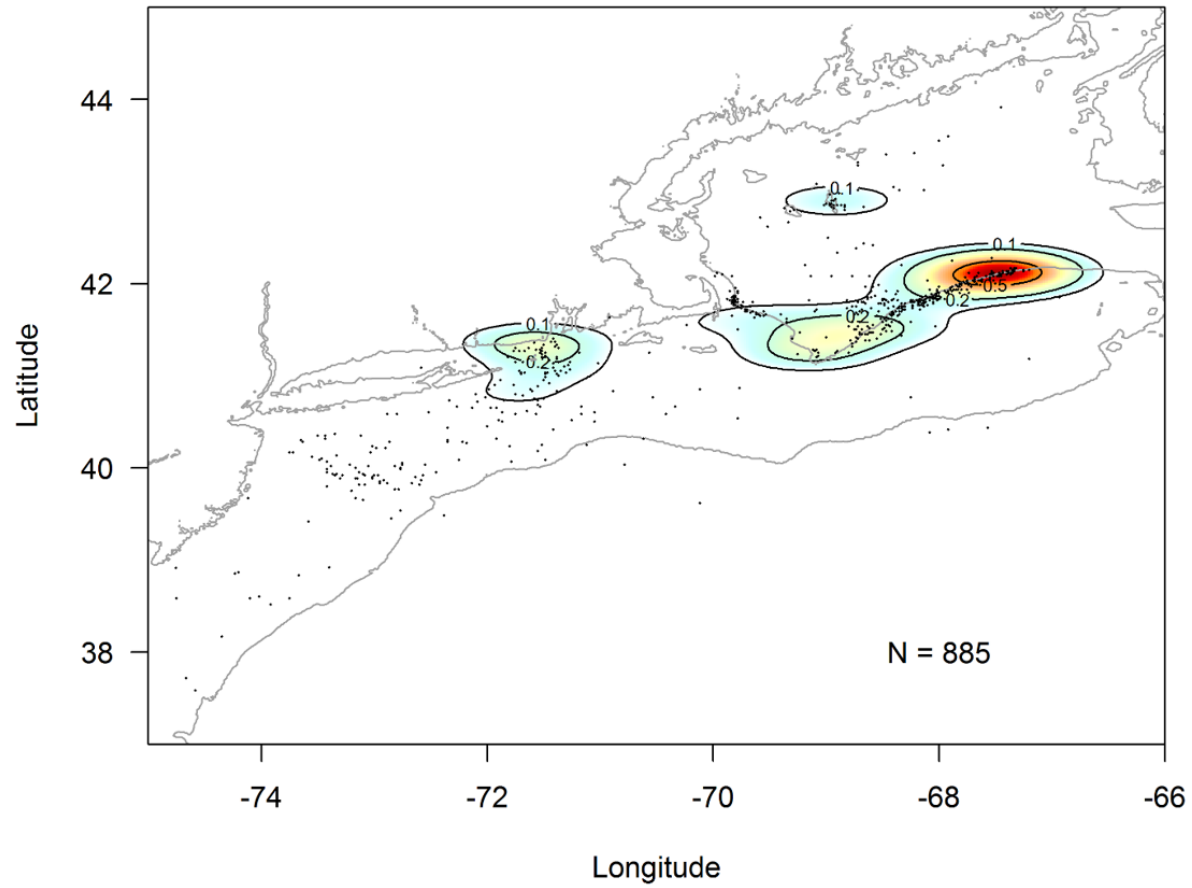


Figure 2.2.9. 2-dimensional kernel density estimates of DMR portside monitoring data (1971-2018) of male and female “ripe and running” herring. 100 m isobath is shown. Points are sample locations.

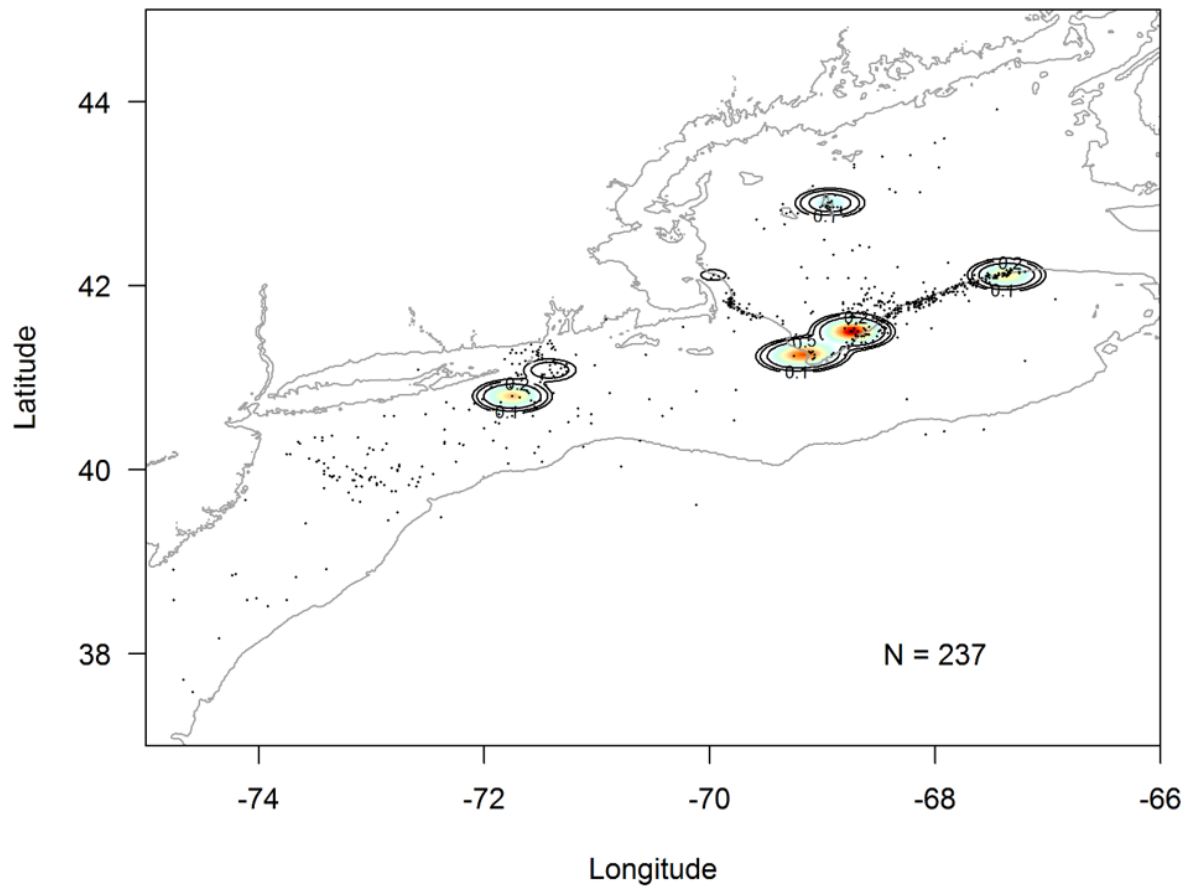


Figure 2.2.10. 2-dimensional kernel density estimates of DMR portside monitoring data (1971-2018) of female herring with GSI30 values ≥ 0.23 . 100 m isobath is shown. Points are sample locations.

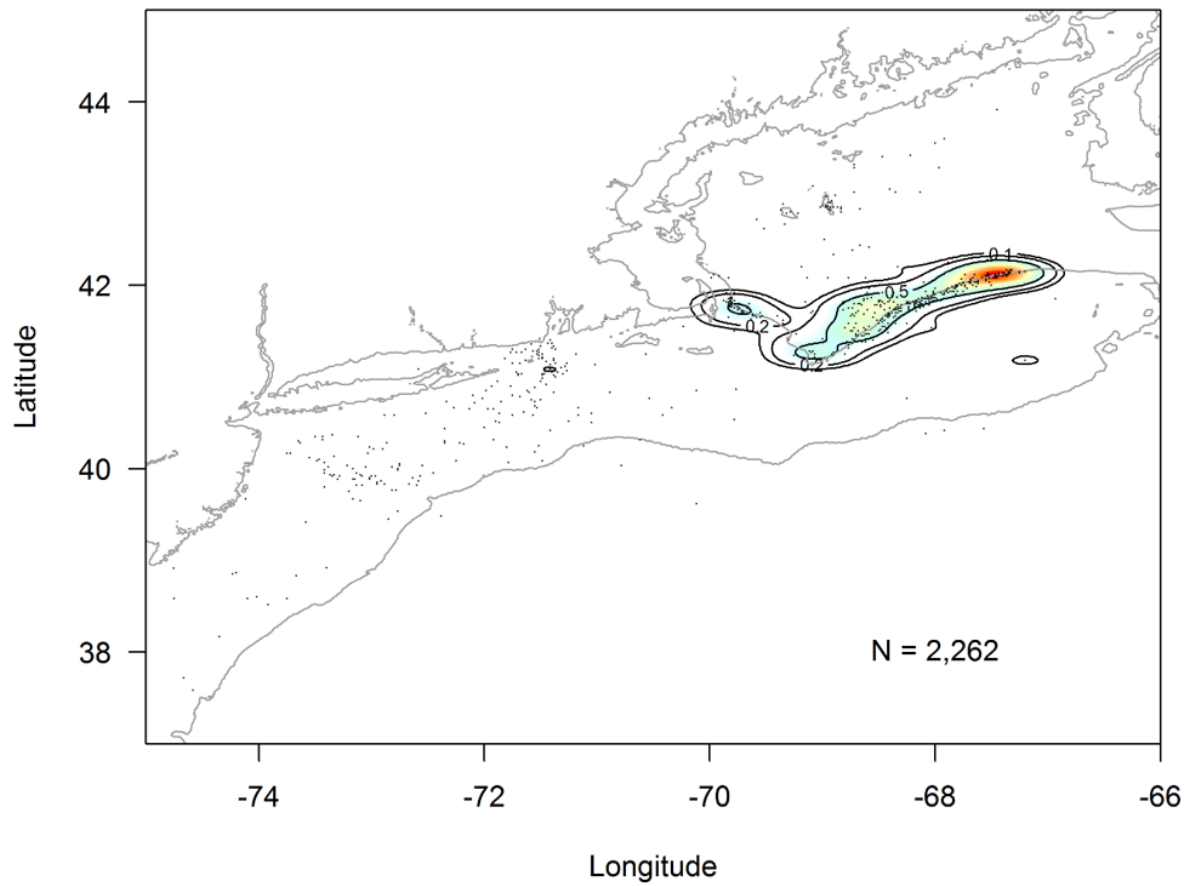


Figure 2.2.11. 2-dimensional kernel density estimates of DMR portside monitoring data by decade of male and female “ripe + ripe/running” herring. Decades began at 1991 because there were no observations of ripe + ripe/running fish prior to this. This was likely due to sampling timing during the year (see Figure 2.3.1). 100 m isobath is shown. Points are sample locations.

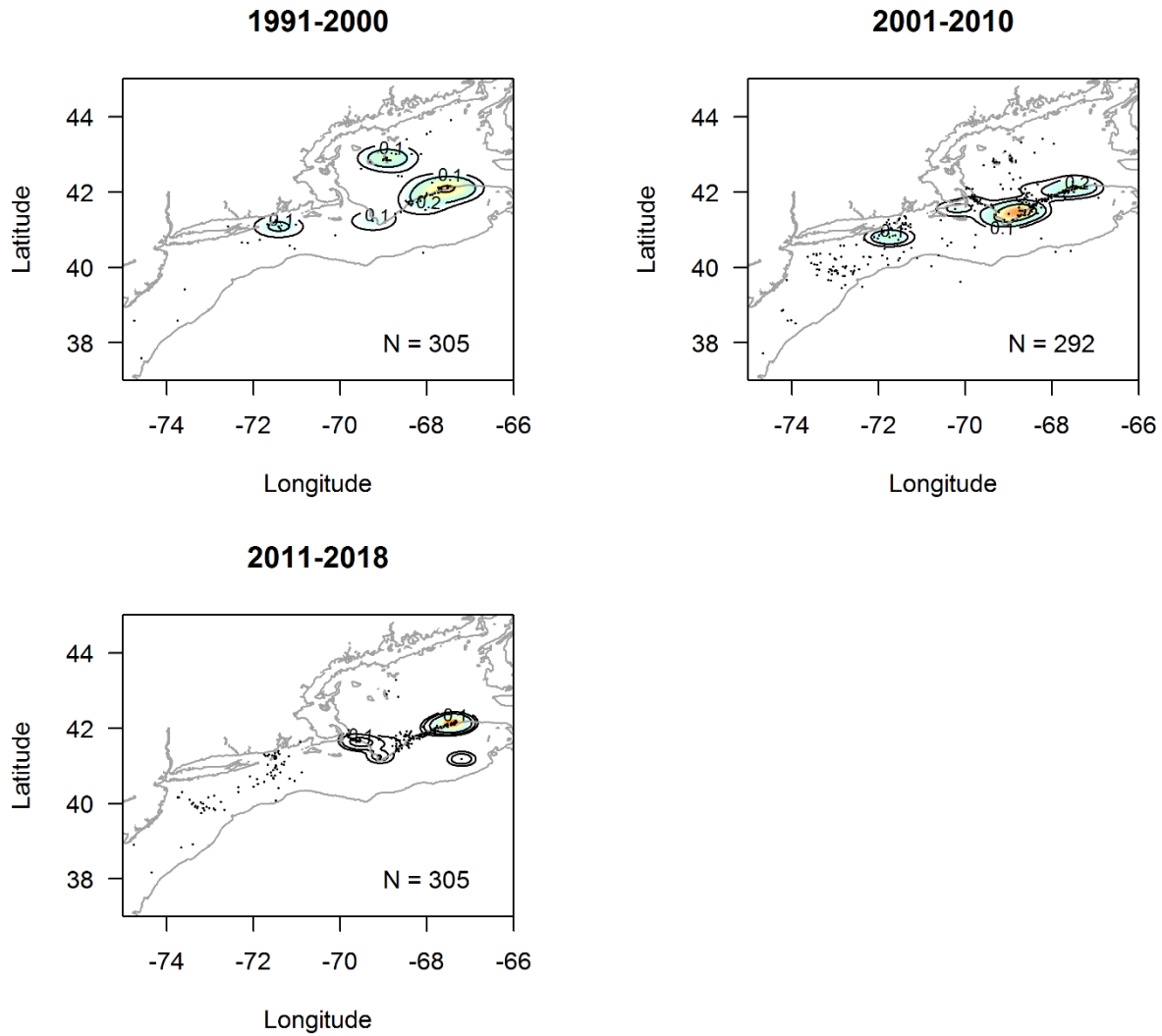


Figure 2.2.12. 2-dimensional kernel density estimates of DMR portside monitoring data by decade of male and female “ripe and running” herring. Decades cover only 1991-2010 because there were no observations of ripe and running fish outside of that time frame. 100 m isobath is shown. Points are sample locations.

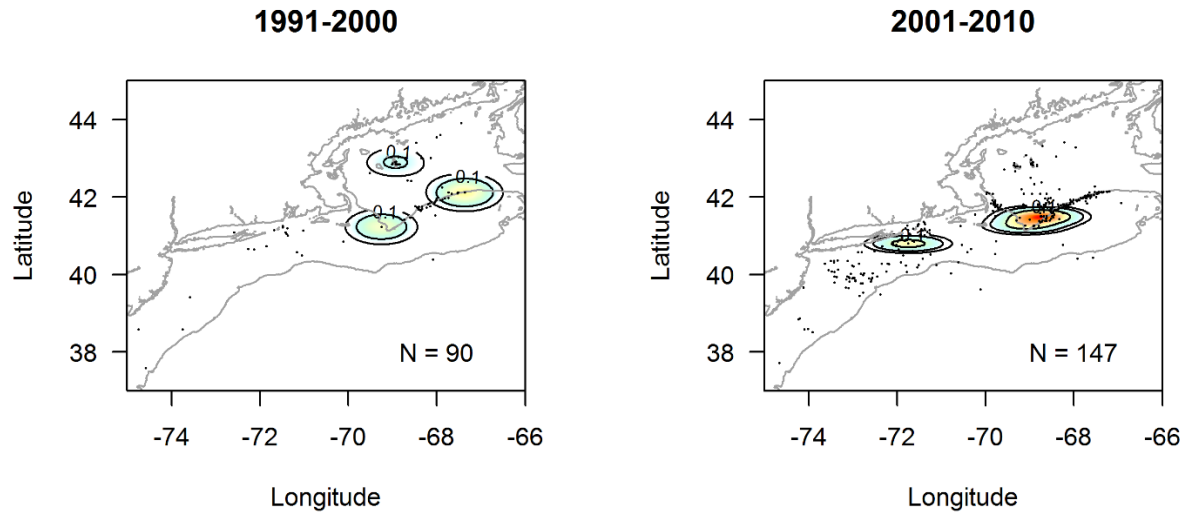
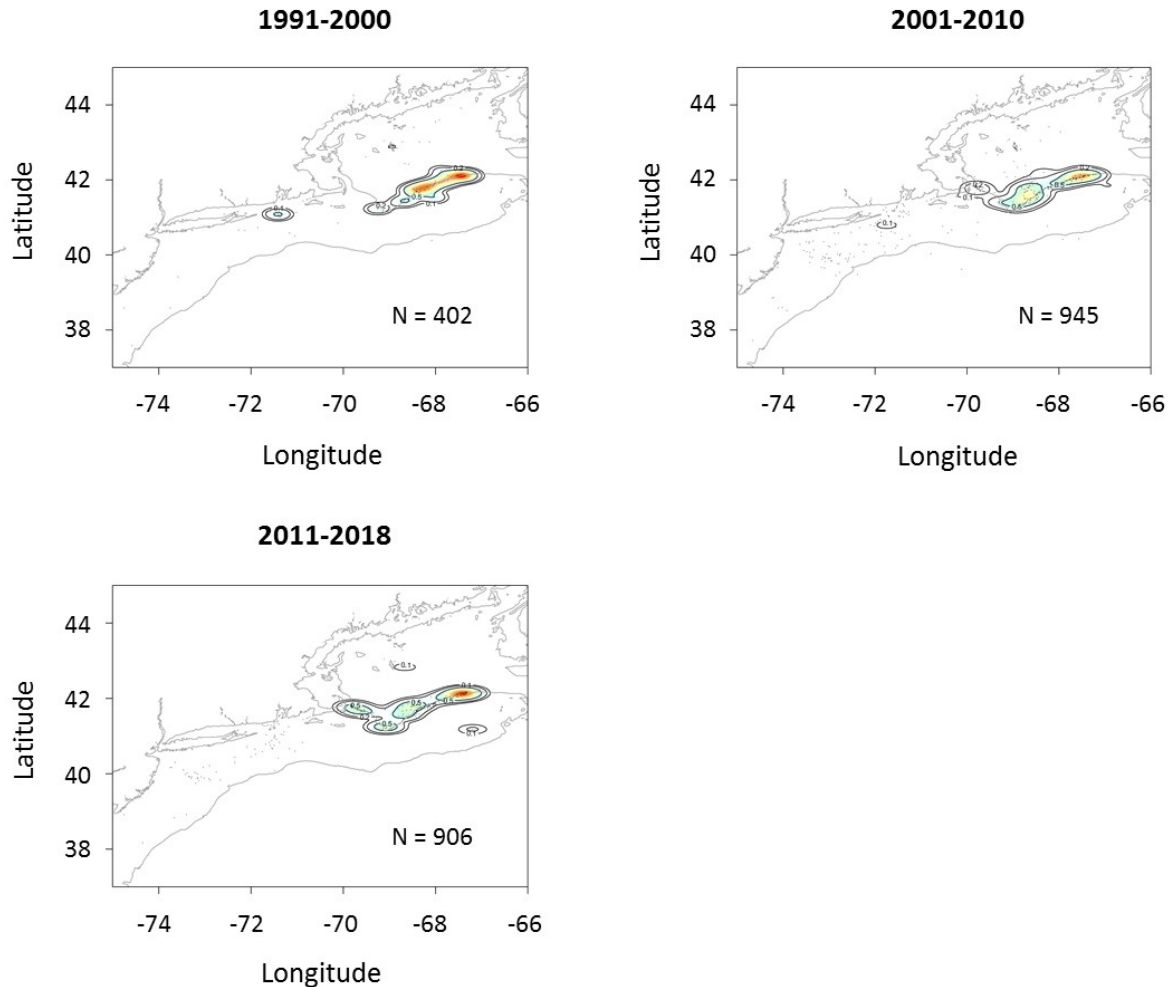


Figure 2.2.13. 2-dimensional kernel density estimates of DMR portside monitoring data by decade of female herring with GSI30 values ≥ 0.23 . 100 m isobath is shown. Points are sample locations.



2.3. Adult Data: DMR Portside Monitoring Data (temporal patterns)

The DMR portside monitoring data was comprehensive enough to allow for temporal comparisons using GSI values. Here, mean GSI values were calculated by month and by year and are presented as heat maps using the ‘ggplot2’ package in R (Wickam 2016). Figure 2.3.1 shows mean GSI by month and year for the entire data set. This figure shows the temporal distribution of sampling effort. Particularly, sampling was confined to the early months (January – April) for the first half of the data set. It was not until the mid to late 90s that sampling occurred year-round.

From the 1990s on, the highest mean GSI values were in September and October. The limited sampling that took place in November suggests that spawning was completed by October, although only three years had data for November. There did appear to be some higher GSI values in March in the early half of the data set. However, these values did not approach those seen in

the fall. Figures 2.3.2 and 2.3.3 show the same data separated by sex; females tended to have a more contracted period of higher GSI values than males.

Mean GSI values by month and year were also explored between different regions. The spatial analyses suggest that there are eastern and western components to spawning on Georges Bank (i.e., Northern Flank versus Great South Channel; previous section). We chose 68.7 degrees west longitude to divide eastern Georges Bank from western Georges Bank. We also considered Southern New England separately from these two. In this case, the cutoff between SNE and western Georges Bank was 70.5 degrees west longitude. There did not appear to be any difference between the timing of spawning between eastern Georges Bank western Georges Bank. Peak values for females were in September and October for both regions. Southern New England samples were clustered earlier in the year and showed no obvious sign of a spawning period; although higher GSI values in males in February and March in the 1970's may be indicative of spring spawning during this time.

Figure 2.3.1. Mean GSI by month and year for entire DMR data set (both sexes). GSI approaching 0.23 indicates fish that are spawning.

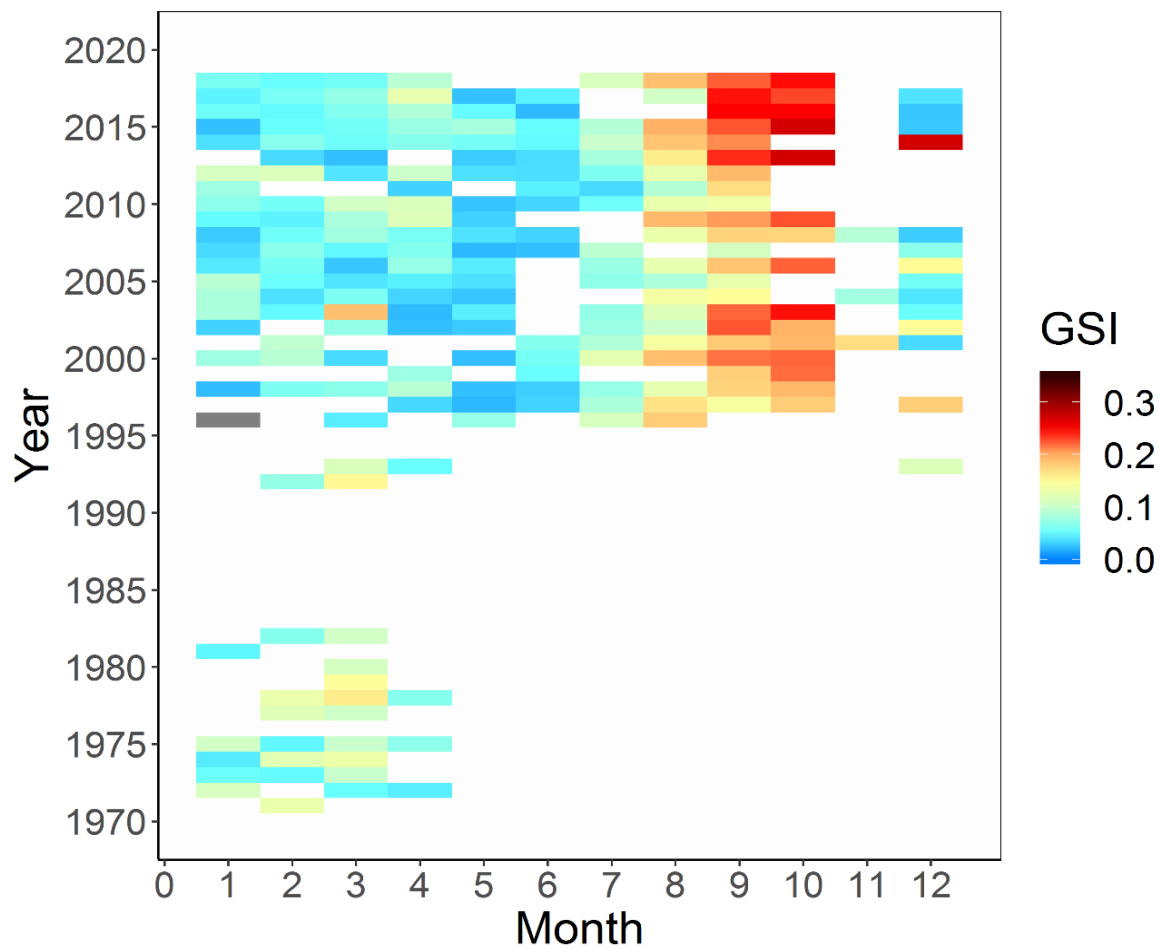


Figure 2.3.2. Mean GSI values by month and year for females. GSI approaching 0.23 indicates fish that are spawning.

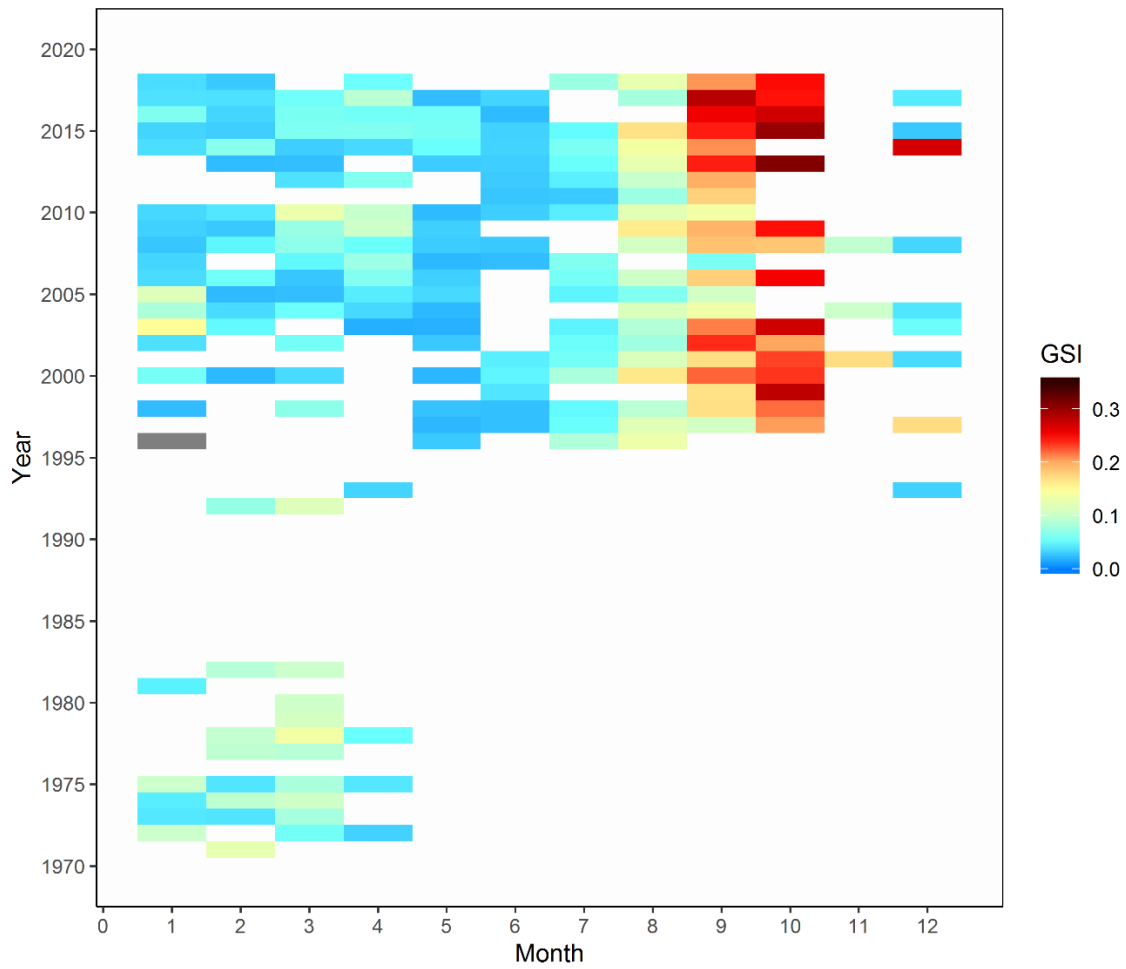


Figure 2.3.3. Mean GSI values by month and year for males. GSI approaching 0.23 indicates fish that are spawning.

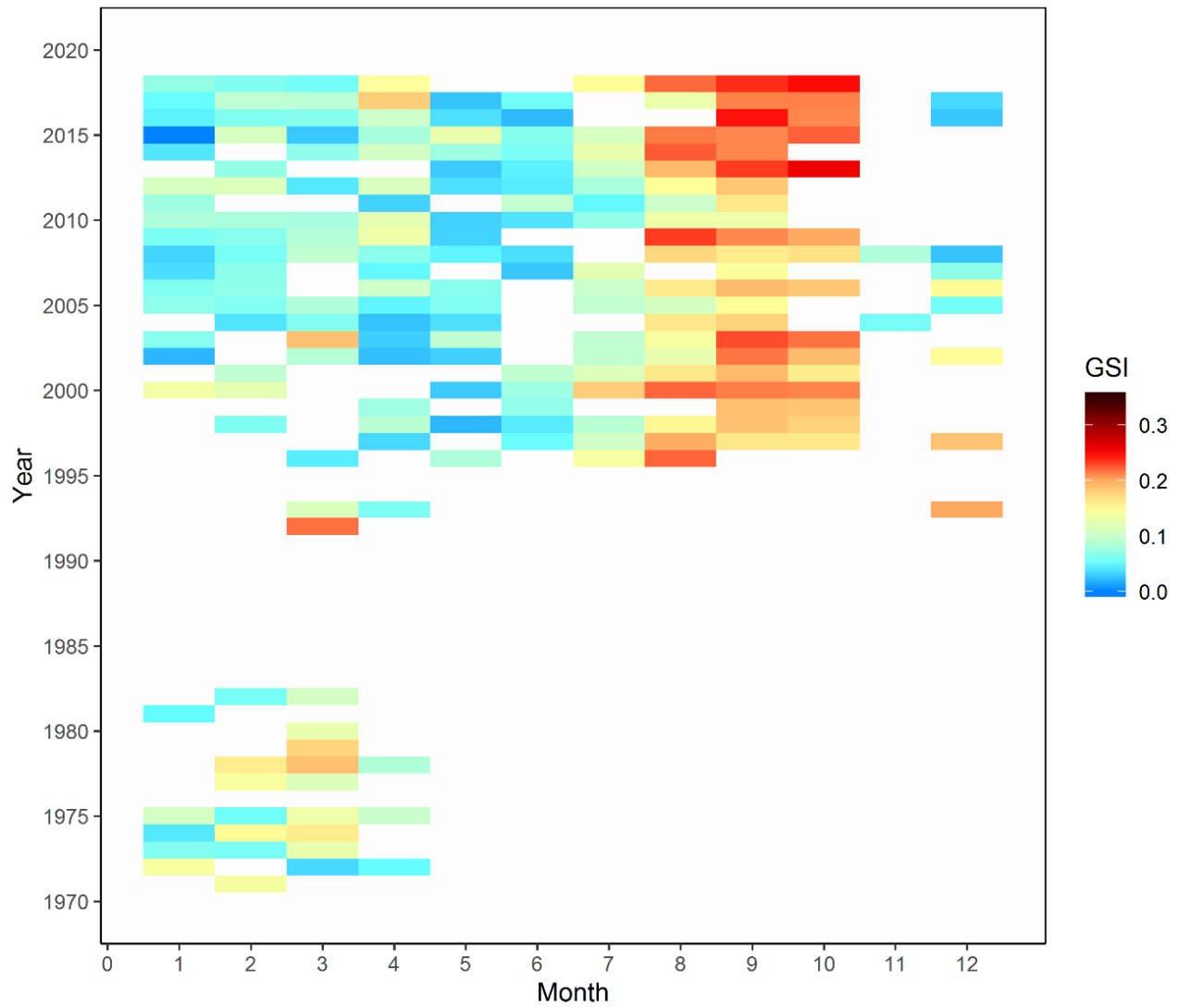


Figure 2.3.4. Same as figure 2.2.7 but with regions defined as southern New England (SNE), western Georges Bank (WGB) and Eastern Georges Bank (EGB). These regions were defined to explore spatial differences in temporal GSI patterns shown in figure 2.3.5. 100 m isobath is shown. Faint lines are boundaries of herring management areas (see figure 1.4.3). Points are sample locations.

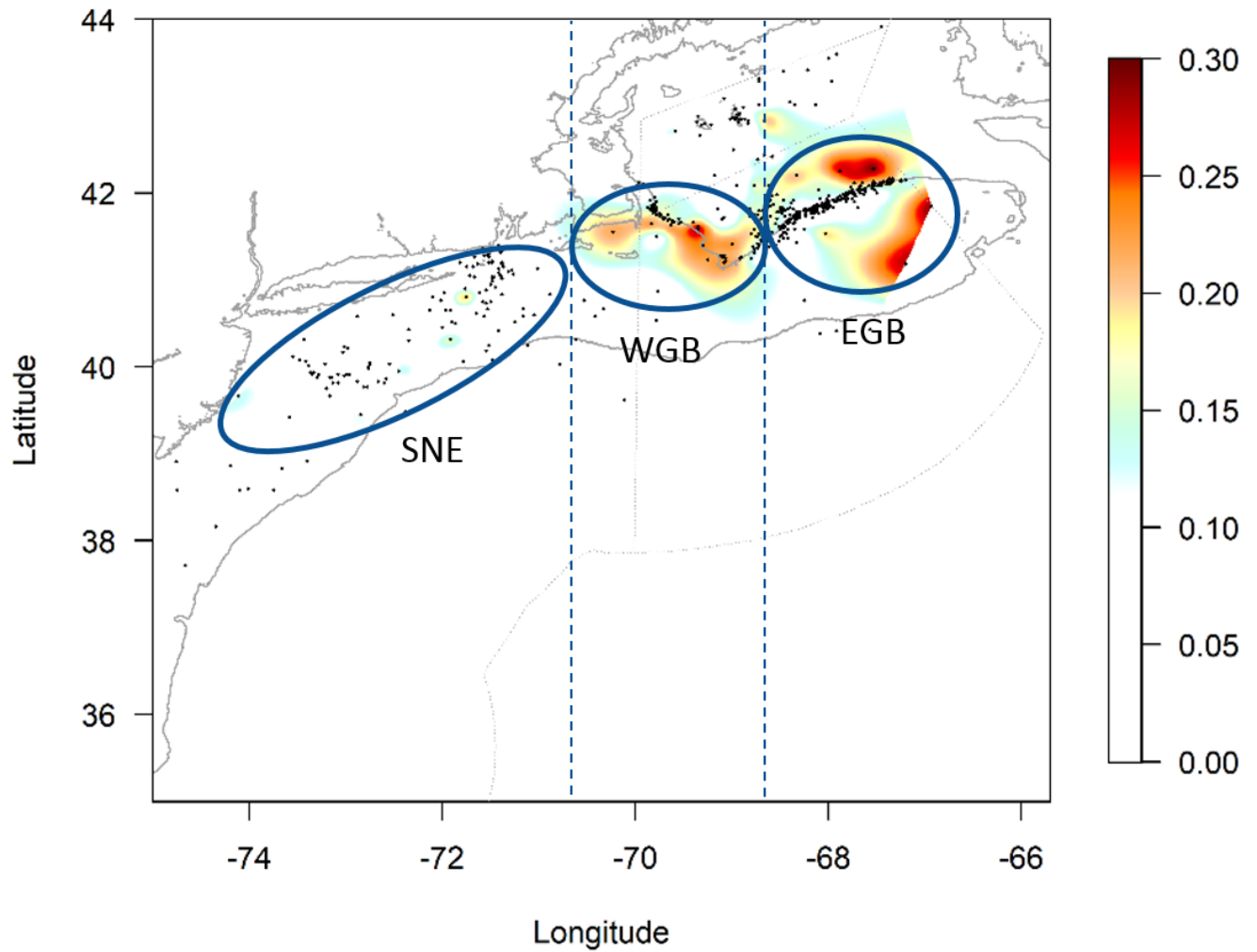
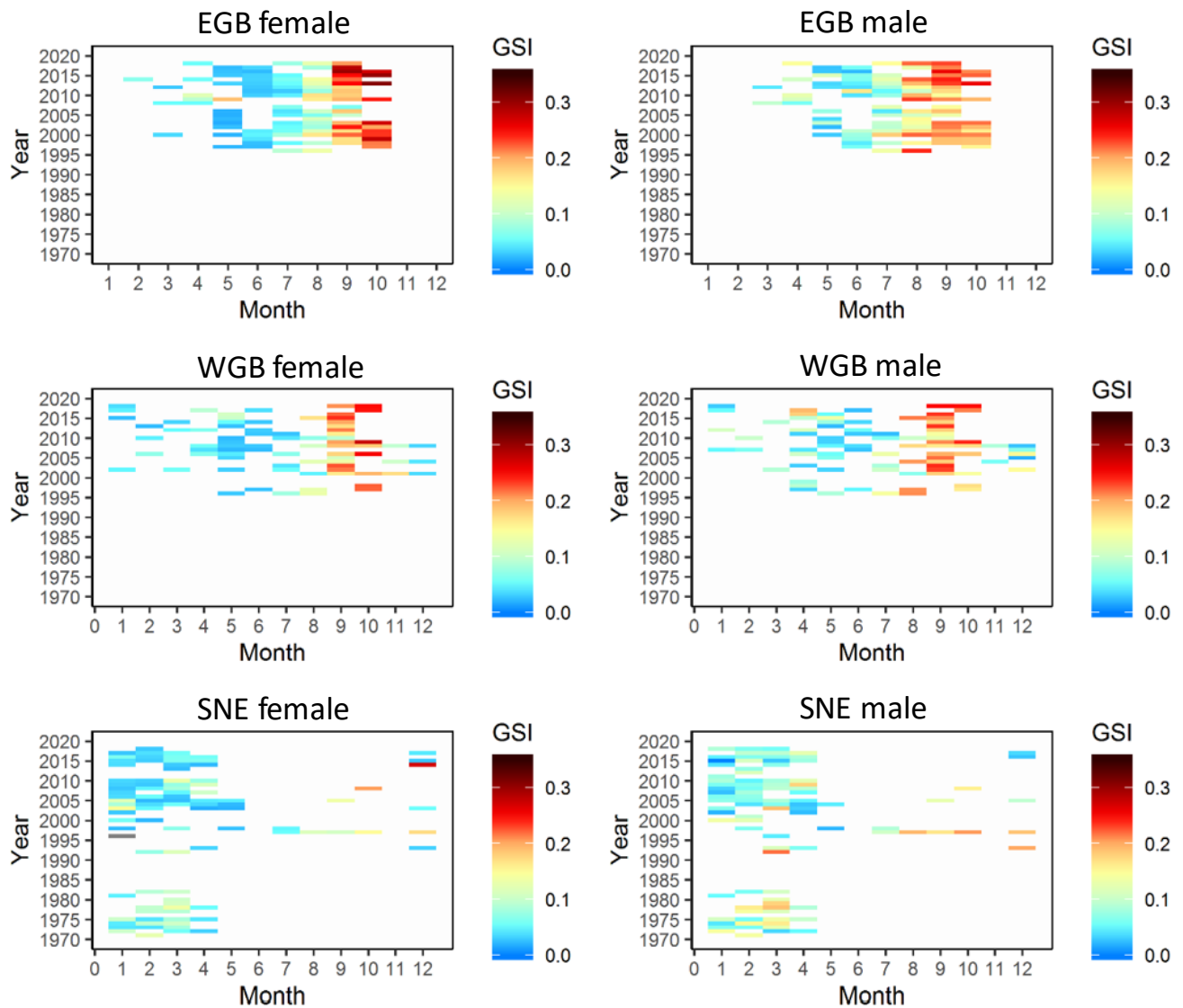


Figure 2.3.5. Mean GSI values by month and year and by location and sex. See text and figure 2.3.4 for description of locations. GSI approaching 0.23 indicates fish that are spawning.



2.4. Adult Data: Trawl Survey

Spatial and temporal patterns in maturity for herring sampled as part of biological processing during the Northeast Fisheries Science Center’s spring and fall trawl surveys were examined. While the trawl surveys have been operating since the 1960’s, biological sampling for herring did not begin until 1987. Thus, the sample period includes the years 1987 – 2018. During this time, a total of 46,242 (28,878 spring and 17,364 fall survey) herring were sampled for length, weight, age, sex and maturity from 6,650 trawl tows. Thus, an average of 7.0 herring were sampled per tow. Sampling intensity was higher in the spring than in the fall (8.5 versus 5.4 herring per tow). The parameter of interest for this review was maturity stage. Maturity stages were as follows: immature (I), developing (D), ripe (R), ripe and running (U), spent (S), and

resting (T). See table 2.2.1 for how these codes translate to DMR codes. We considered two stages as potentially indicative of spawning locations. That is, if herring in spawning stages R or U were captured, they were inferred as being close to spawning grounds since they were in near or actual spawning condition. In reality, herring in maturity stage U would be the closest to spawning and therefore most likely to be near spawning grounds.

The location of herring in maturity stages R and U were mapped using a 2-D kernel density estimator in the package ‘MASS’ (Ripley et al. 2019) in R (R Core Team 2019). This was done for all samples combined by season (i.e., spring and fall separately), and for different decades (by season). In this case, ‘decades’ were as follows: 1987 – 1990, 1991 – 2000, 2001 – 2010, and 2011 – 2018. For eventual incorporation of spatial depictions of spawning condition herring as layers in our consensus figures (see section 3), we considered polygons containing density values of 0.2 or greater (arbitrary).

For all the fall data combined, the location of ripe and ripe/running (R + U) herring was throughout the northern edge of Georges Bank with higher densities near the Great South Channel and the Northern Flank (Figure 2.4.1). Figure 2.4.2 shows the same data over different decades. Higher densities of R and U herring were found primarily on the western side of Georges Bank in the 1980’s and 1990’s. The distribution of R and U herring appeared to shift to the eastern side in the 2000’s and in the most recent decade there are two areas of high density in both the east and the west. Figure 2.4.3 shows just maturity stage U herring from the fall survey from all years. Two areas of high density are evident in the Great South Channel (western side) and the Northern Flank (eastern Georges). The areas of high density of U stage herring shifts from decade to decade. It was highest in the west in the 1980’s and 1990’s, highest in the east in the 2000’s and in the most recent decade it appears to have shifted back to the west, although densities were quite low. The density of spawning herring (maturity stage U) from the spring trawl survey are shown in Figure 2.4.5. Only 9 of 28,878 samples were in maturity stage U confirming that spawning does not take place on Georges Bank in the spring. Similarly, only 179 herring were in maturity stage R in the spring (all years combined; not plotted).

Figure 2.4.1. 2-dimensional kernel density estimates of ripe (mat stage R) and ripe/running (mat stage U) herring from fall trawl survey. Sample size is indicated; smaller number for samples in mat stage R + U and larger number for total sample size. 100 m isobath is shown. Points are sample (tow) locations.

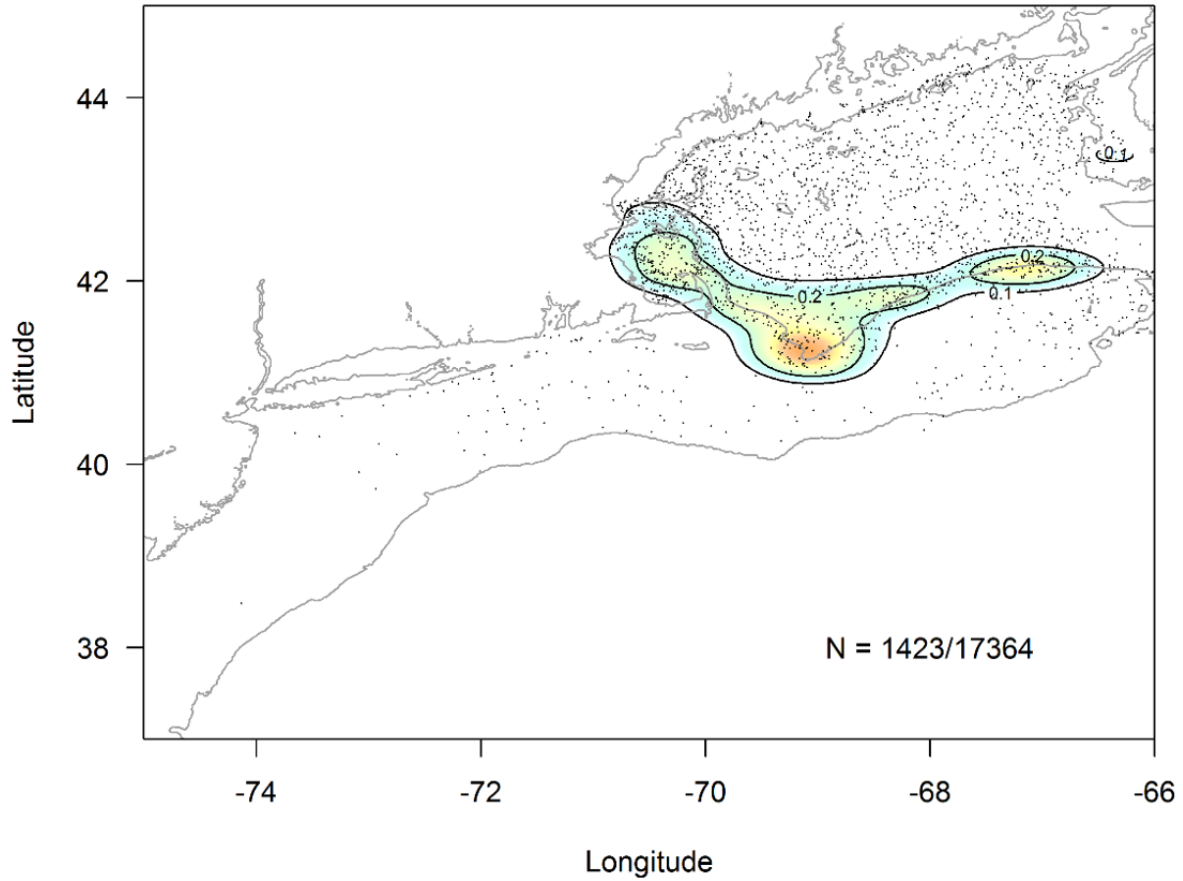


Figure 2.4.2. 2-dimensional kernel density estimates of ripe (mat stage R) and ripe/running (mat stage U) herring from fall trawl survey by decade. Sample size is indicated; smaller number for samples in mat stage R + U and larger number for total sample size by decade. 100 m isobath is shown. Points are sample (tow) locations.

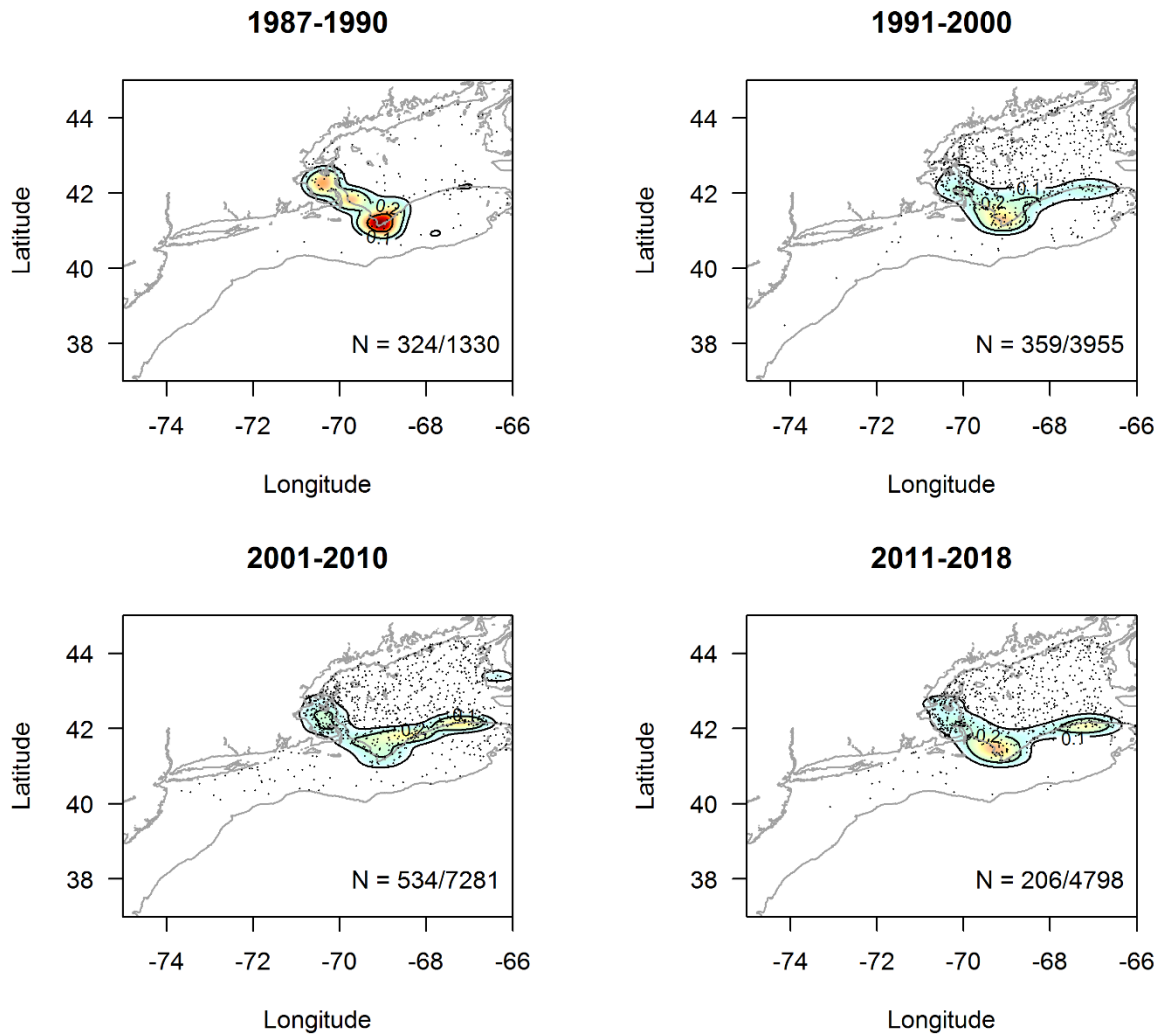


Figure 2.4.3. 2-dimensional kernel density estimates of ripe/running (mat stage U) herring from fall trawl survey. Sample size is indicated; smaller number for samples in mat stage U and larger number for total sample size. 100 m isobath is shown. Points are sample (tow) locations.

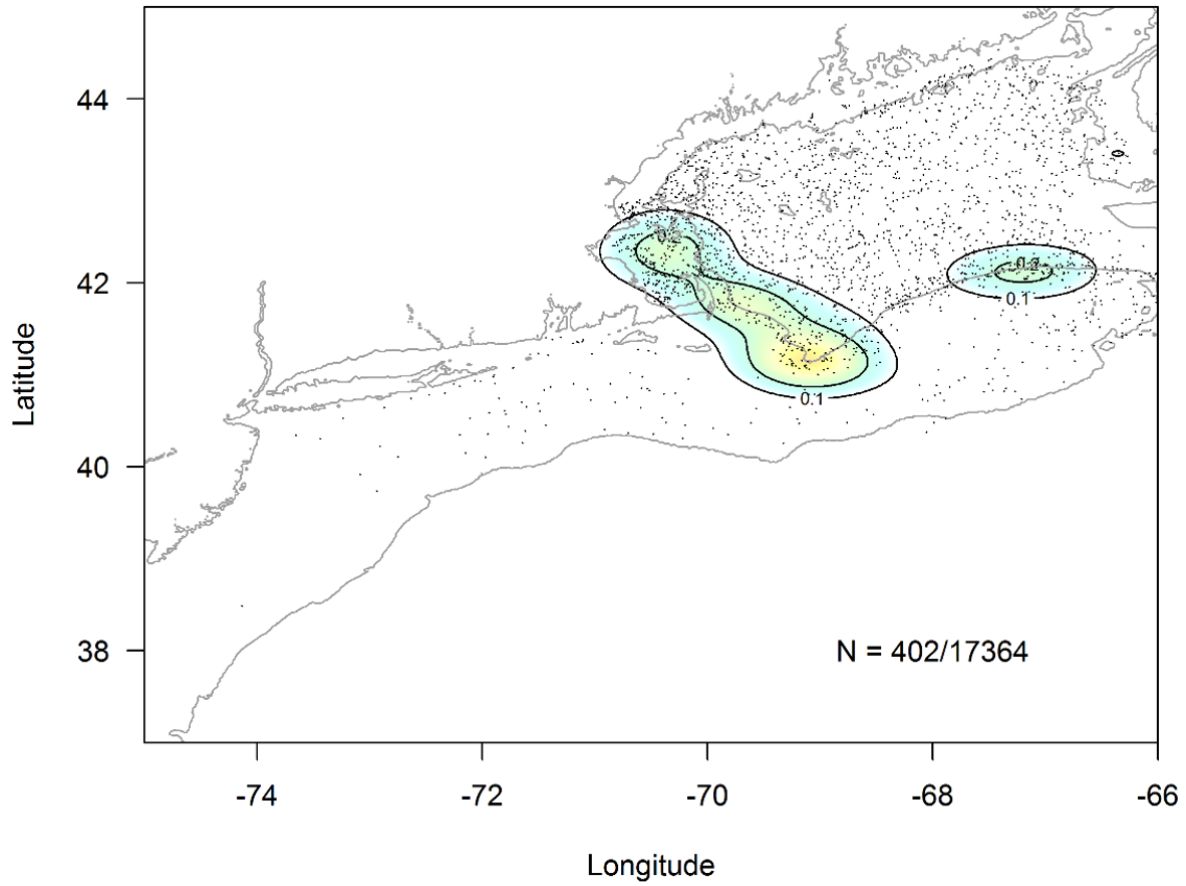


Figure 2.4.4. 2-dimensional kernel density estimates of ripe/running (mat stage U) herring from fall trawl survey by decade. Sample size is indicated; smaller number for samples in mat stage U and larger number for total sample size by decade. 100 m isobath is shown. Points are sample (tow) locations.

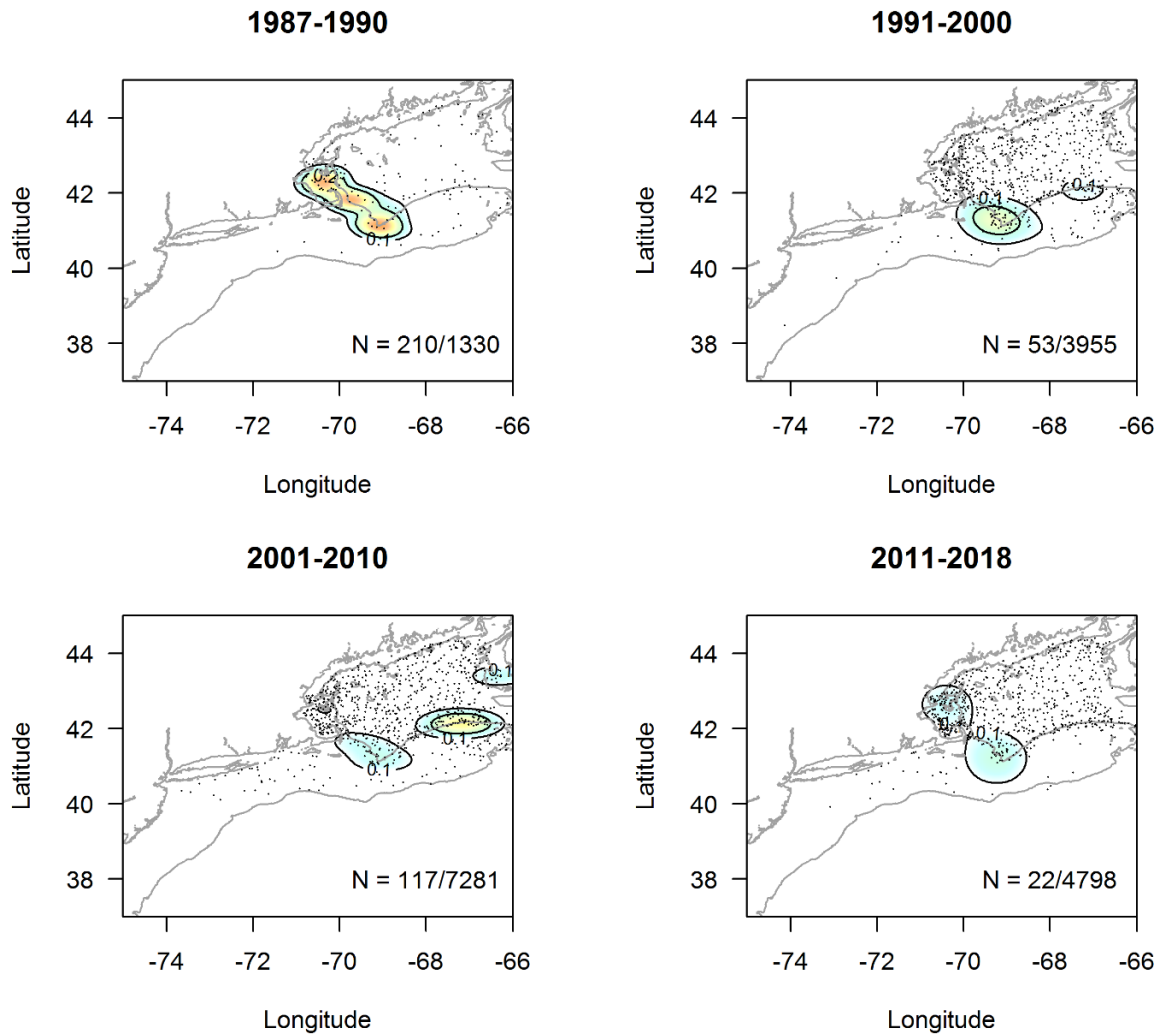
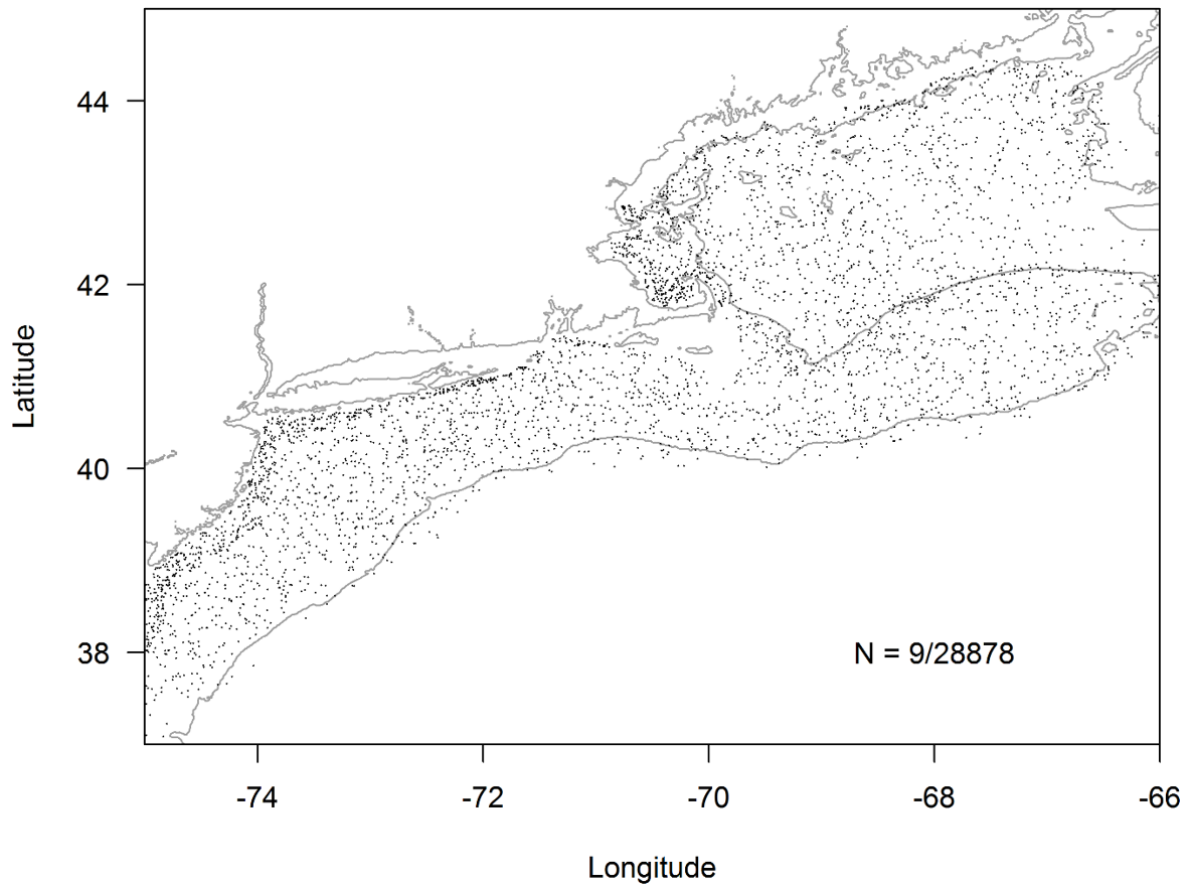


Figure 2.4.5. 2-dimensional kernel density estimates of ripe/running (mat stage U) herring from spring trawl survey (all years combined). Sample size is indicated; smaller number for samples in mat stage U and larger number for total sample size. No areas were indicated (i.e., coloring as in other figures) since there were no dense areas of ripe/running fish. 100 m isobath is shown. Points are sample (tow) locations.

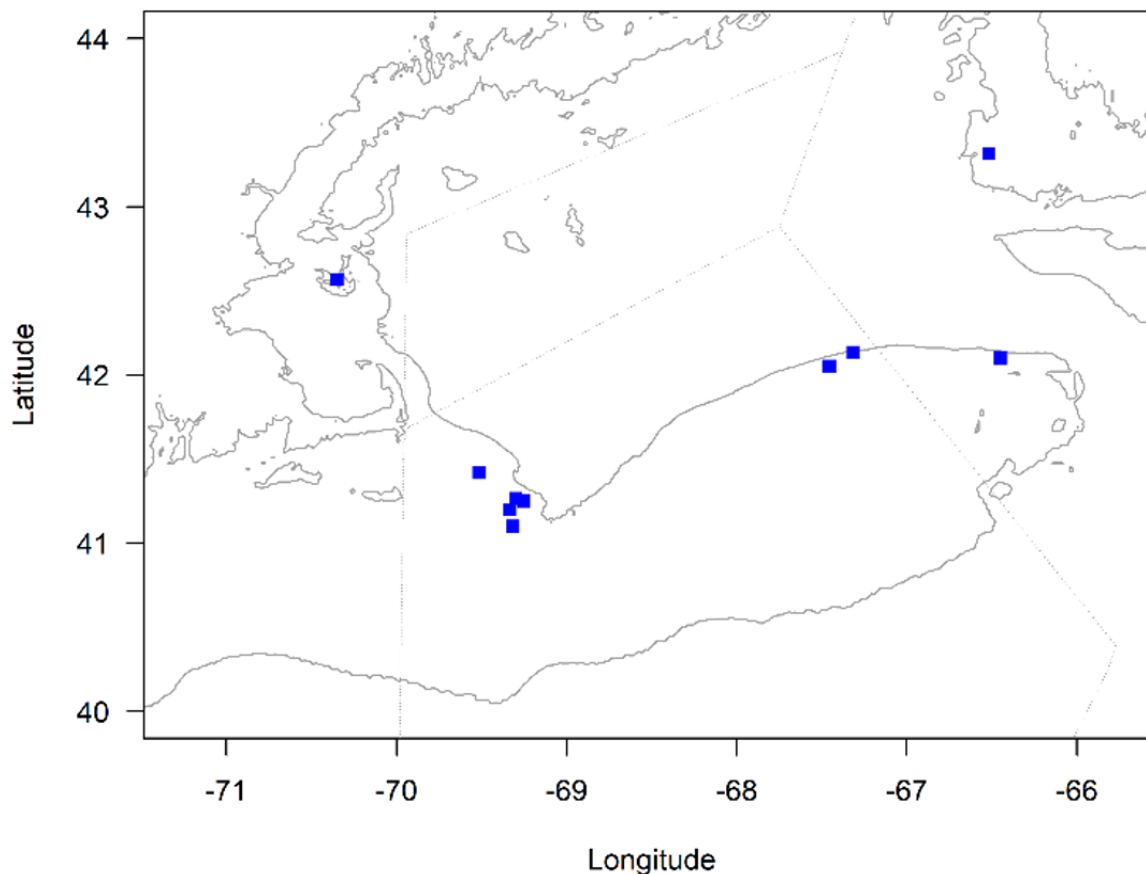


2.5. Food Habits Database (*Herring Eggs in Diet of Groundfish*)

Food habits data from the Northeast Fisheries Science Center Food Web Dynamics Program were explored for occurrences of Clupeidae eggs and Atlantic herring (*Clupea harengus*) eggs as prey between 1973 and 2017 (B. Smith, pers. comm.). These data covered the entire Northeast US continental shelf. Of the 650,000 samples, only 113 observations (0.02%; from 10 hauls) contained herring eggs. Most of these samples were Clupeidae eggs and only a few were identified to the level of *Clupea harengus* eggs. All observations with eggs occurred between late September and early November and in the years 1989, 1993, 1994, 1995, 1997, 1998, and 2005. Due to the limited amount of data, we only examined the locations where these herring eggs were present, most of which were in the northeast section of Nantucket Shoals and a few occurrences on the northeast edge of Georges Bank (Figure 2.5.1). These locations are generally

consistent with herring egg essential fish habitat identified in Ammendment 5 to the Atlantic Herring Fishery Management Plan (Figure 2.3).

Figure 2.5.1. Locations of herring eggs observed in 113 NEFSC diet samples from 10 hauls (1989, 1993, 1994, 1995, 1997, 1998, 2005). 100 m isobath is shown. Faint lines are boundaries of herring management areas (see figure 1.4.3).



2.6. Industry Interviews

Representatives of each of the mid-water pair trawl vessels were interviewed to gain a perspective from industry on where spawning takes place for herring and their overall thoughts on the topic. This component of the herring fishing industry was the focus since they are the only vessels that target herring offshore. In general, industry felt that there was not one specific area that you would catch spawning herring and that it varies year to year. One group could not envision how a closure would work on Georges Bank due to the variability from year to year in spawning and cautioned that a closure on Georges Bank would cripple the midwater fleet. Another group did not believe that the midwater fleet is interacting with spawning herring on Georges Bank; in their experience, it is a rare event to catch spawning herring. This coincides with the fact that of the 17,529 herring sampled over the 50 year period by DMR, only 237 were in maturity stage 6 or U (ripe and running; Figure 2.2.9).

The fishing industry that was interviewed believe that the bottom type on Georges Bank where they fish (sandy bottom with no structure and a tide of 2 knots) is not conducive to spawning. They believe that fish are spawning more along the shoal waters along the Northern Edge of Georges Bank where the habitat is better suited for spawning (as is supported by the data; e.g., Figure 3.3). They do not fish in that area of Georges Bank due to the possibility of tearing up their nets. There was one fisherman who indicated the general areas where herring can be caught that have roe and where they spawn. Fish with roe can occur along the whole edge of Georges Bank from Canada to Cape Cod between August and November. There were a couple areas where he has caught spawning fish including the Northern Edge east of the 1300 line in 50 fathoms, near the “BB” buoy south of Chatham, and when there are small fish (non-spawning) to the east you can find the large spawning fish near Cultivator Shoal. He used to find spawning fish in the Great South Channel but has not seen any in four or five years. It was noted that most of the spawning fish were large and of very good quality.

Each representative had their own explanations on the decrease of herring and offered ways to remedy the issue. Many would like to see more sampling including tagging programs, otolith work, surveys that include multiple gear types and have industry data included in assessments. They believe that the small fish are more abundant than the latest assessment indicates and that it can be shown with more sampling. One captain was worried about herring shifting where they spawn. Until about ten years ago, he would catch herring from Virginia up to Long Island while targeting mackerel. He has heard reports that there have been eight trips to Georges Bank this fishing year, with no herring and fears that they have shifted to Canadian waters where there have been reports of herring landed in large quantities.

One of the captains highlighted that when he catches spawning herring, he also catches a larger amount of haddock than he has ever previously caught. He used to find only a couple haddock mixed in with spawning herring, but with the rebound of haddock, he is finding more and more haddock mixed in with the spawning herring. He believes that the haddock are consuming the herring as well as the eggs and either lowering the recruitment or possibly forcing the herring to spawn in new areas that may not be as suitable. It was also raised by a group of captains (who are also able to purse seine) that if they were allowed to target mackerel using a 3 inch brailer instead of the normal 1 inch brailer, it would reduce the amount of small mackerel as well as limit the herring bycatch in the mackerel fishery. This would reduce the pressure on herring while allowing them to fish on a healthy stock. The abundance of river herring is another concern, one captain has seen more than ever before and believes that the river herring are taking over prime areas. Historically, the large balls of sea herring were able to push the river herring away from the prime feeding areas but with the smaller amounts of sea herring he does not believe they can compete with the river herring for the prime areas. All of the groups we interviewed were appreciative that we reached out to industry and welcome more science and research into the issue.

2.7. Observer Data

Herring spawning condition is not identified in Northeast Fisheries Observer Data, but we explored the written comments made by observers from all gear types and fisheries for accounts

of spawning Atlantic herring (1989-2019) and herring eggs (2008-2019) (G. Chamberlain, pers. comm). There were very few entries of hauls where captains classified catch as spawning herring. A large amount (> 5,000) of comments recorded by observers contained unclassified fish eggs or unclassified eggs, but observations could not be classified as Atlantic herring eggs with confidence. These comments were too limited to make inferences about location and timing of spawning herring or herring eggs.

3. Building a Consensus

Similar to DeCelles et al (2017), a consensus approach was applied to identifying spawning areas on Georges Bank and Nantucket Shoals. Polygons from multiple sources were layered to examine areas of overlap which were inferred as more consistent areas of spawning. Data layers for this exercise included larval data (Figure 2.1.1), DMR portside monitoring data (specifically, maturity stage 6; Figure 2.2.9), and trawl survey data (maturity stage U; Figure 2.4.3) and eggs in diet of groundfish (i.e., Food Habits database: Figure 2.5.1). Additionally, maps from previous publications were layered in including a historical representation of herring spawning on Georges Bank (Olsen et al 1977; Figure 3.1) and egg EFH¹ (NEFMC 2013; Figure 3.2). Maps were georeferenced in Google Earth where polygons were created and saved as KML files which were layered on top of each other in R. Resultant maps are shown in Figures 3.3 (colored by data source) and 3.4 (monochrome).

In general, all spawning associated activity, from ripe and running adults to evidence of eggs, occurred along the Northern Edge of Georges Bank from Cape Cod to the Northern Flank. However, there were also areas of high overlap of multiple data sources that may indicate more consistent spawning. These include an area to the west of the Great South Channel (northern Nantucket Shoals) and an area on the Northern Flank. Note how adults tend to aggregate to the north of putative spawning areas (in deeper water or near the edge of the bank), egg areas tend to be up on the bank and larval areas tend to be downstream of these areas. Figure 3.5 shows the areas of highest overlap (i.e., where 3 or more sources agreed). In this case, two distinct areas emerged; one to the west of the Great South Channel and the other on the Northern Flank.

Figure 3.6. shows overlap of data sources by decade. Here, only larval, DMR and trawl survey data were used since these had records that spanned multiple decades. While harder to infer consensus areas due to smaller data sets, spawning appeared to move from the west in the 1980s, to across the northern edge of the shelf in the 1990s and 2000s to distinctly west and east areas in the 2010s.

Overlap of areas of high density of maturity stage R + U herring from both DMR data and the trawl survey over each decade was also considered (Figure 3.7). Similar to other depictions, this showed areas of high overlap, among decades and data sets, at the Great South Channel and the

¹ The prior egg EFH designation was used because it focused on known locations of herring egg beds. The current, April 2018 designation from Omnibus Habitat Amendment 2 includes these egg bed locations plus locations where very small larvae were captured in plankton surveys. Since these same plankton data were used in separate analyses elsewhere in this report, the prior egg designation was found to be a more appropriate layer for the consensus exercise presented here.

Northern Flank. Consensus areas from this figure are shown in Figure 3.8 (where 4 or more polygons overlapped). Figure 3.9 shows how this compares to the consensus areas shown in Figure 3.5. Again, it appears that the adult spawning condition herring tend to aggregate slightly to the north and off the bank compared to consensus areas that include eggs and larval herring (more on the bank).

Figure 3.1. Known specific spawning grounds for various fishery species including Atlantic (sea) herring (dark red polygons; from Olsen et al. 1977).

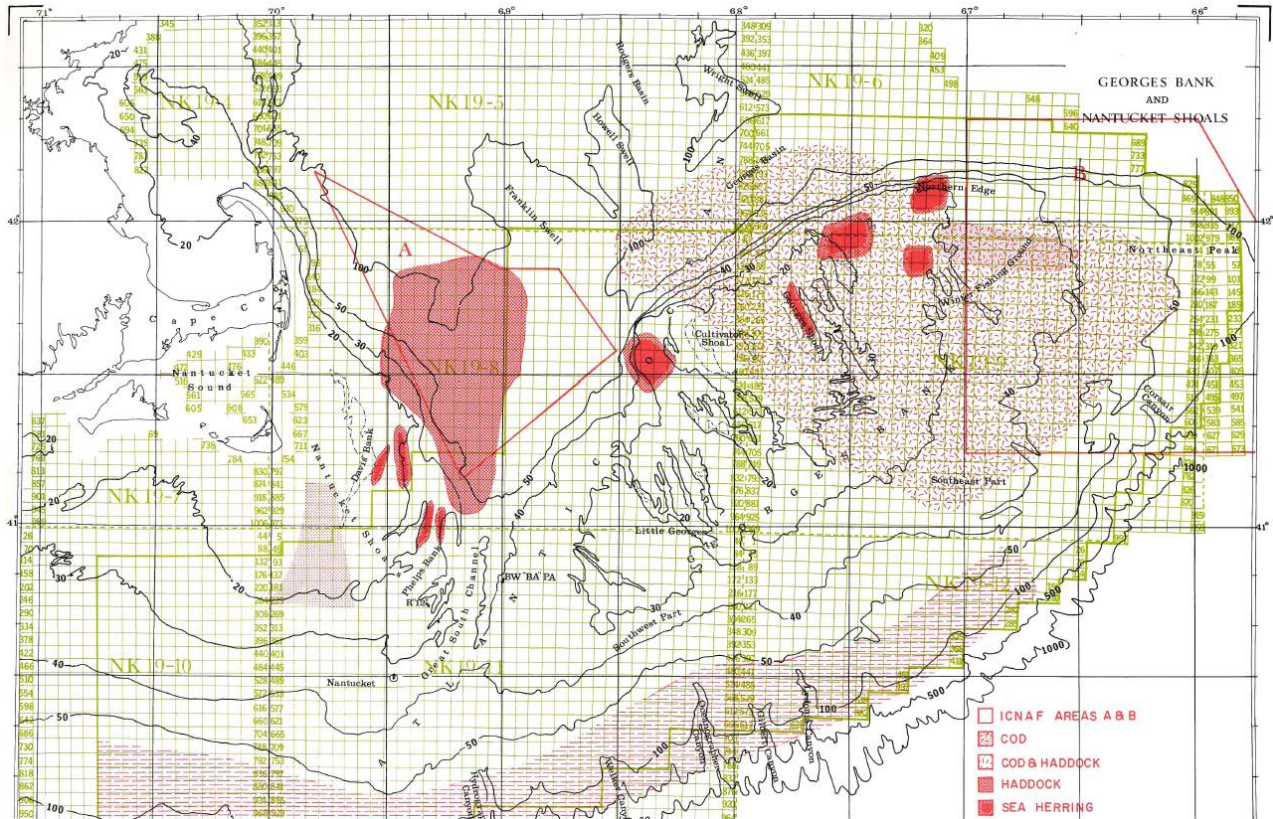


Figure 3.2. EFH for herring eggs from Amendment 5 to the Fishery Management Plan (FMP) for Atlantic Herring (NEFMC 2013).

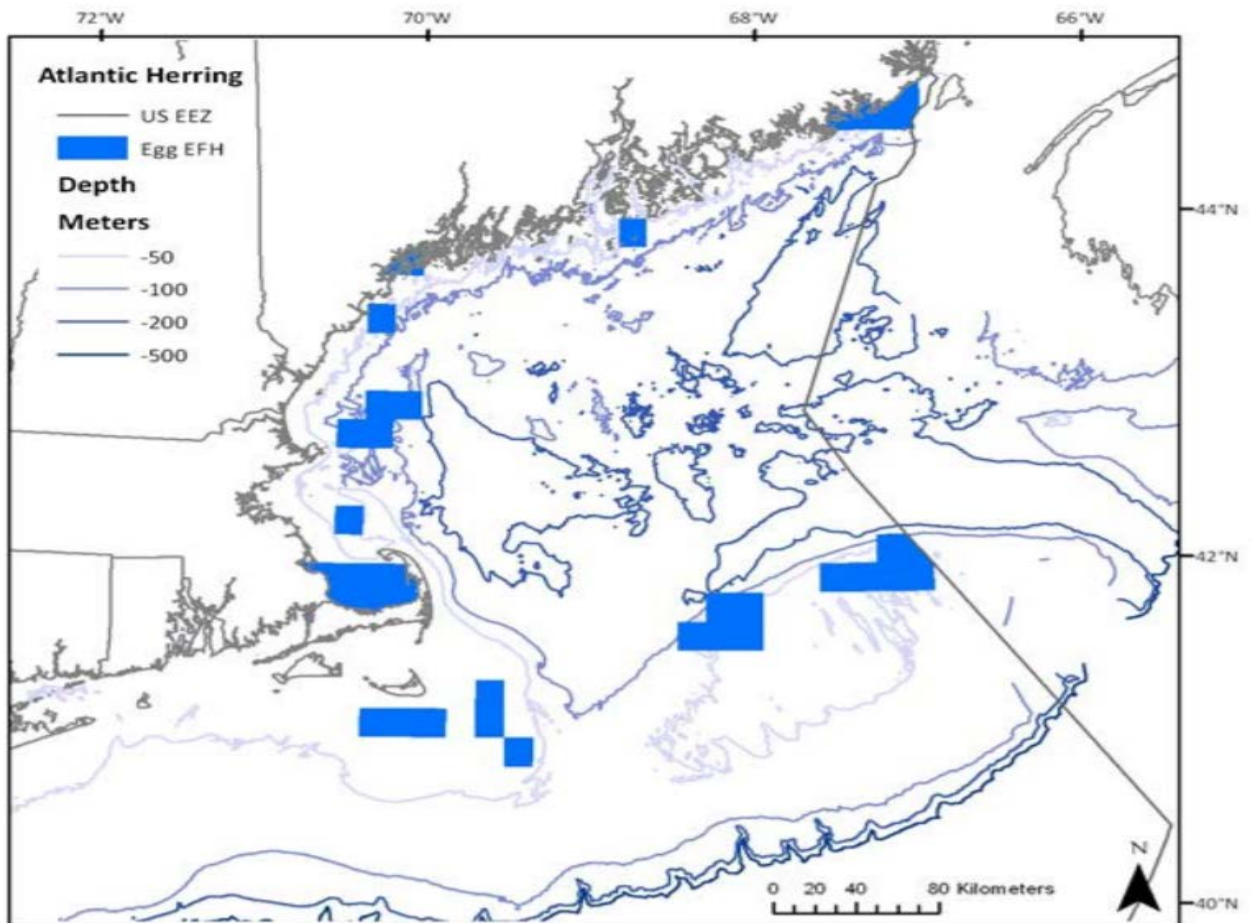


Figure 3.3. Areas of overlap between multiple data sources including data from food habits database (diet data; Figure 2.5.1), larval monitoring (Figure 2.1.1), egg EFH (Figure 3.2), historical spawning grounds (Figure 3.1), DMR portside monitoring (mat stage U; figure 2.2.9), and fall trawl survey (mat stage U; Figure 2.4.3). 100 m isobath is shown.

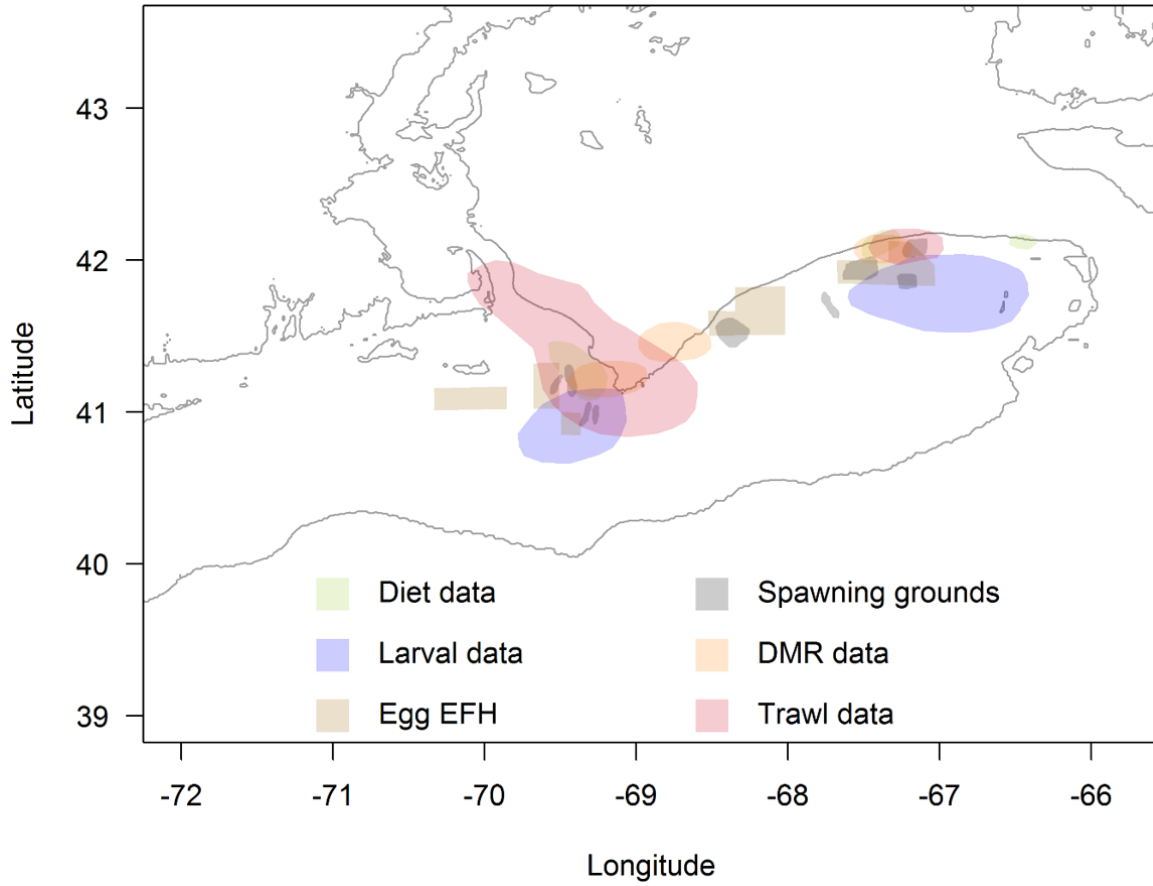


Figure 3.4. Same as Figure 3.3 but all in same color to highlight areas of overlap through darker shading. 100 m isobath is shown.

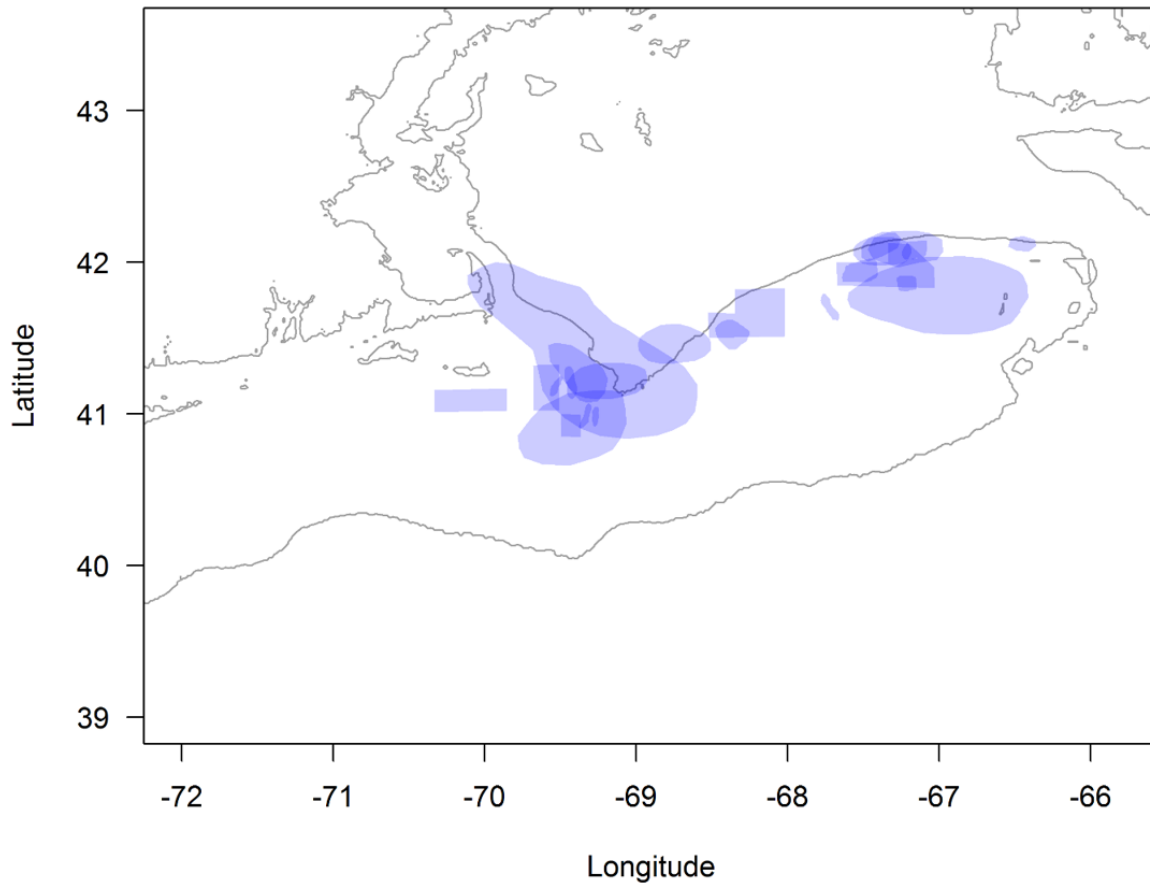


Figure 3.5. Consensus areas from Figure 3.4 where 3 or more overlaps occurred between different data sources. 100 m isobath is shown.

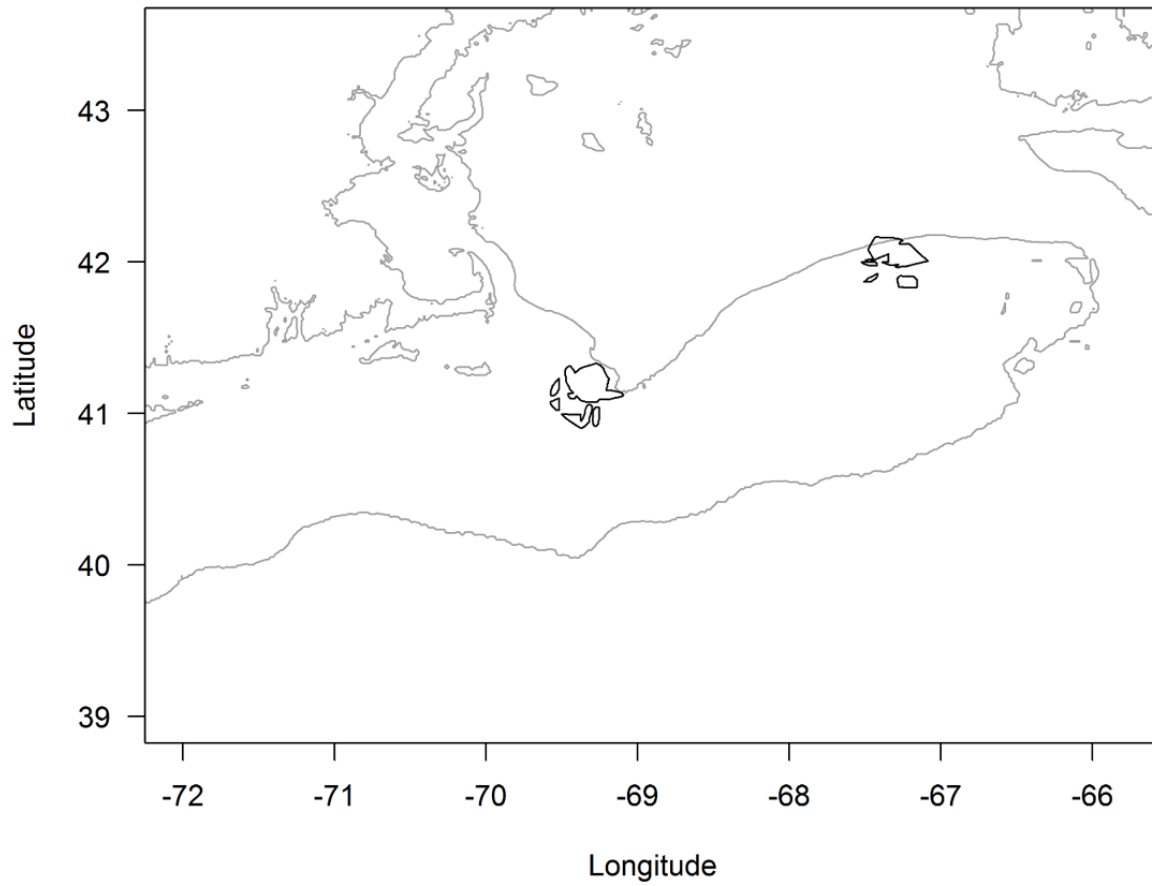


Figure 3.6. Overlap areas of spawning between different data sources by decade. 100 m isobath is shown.

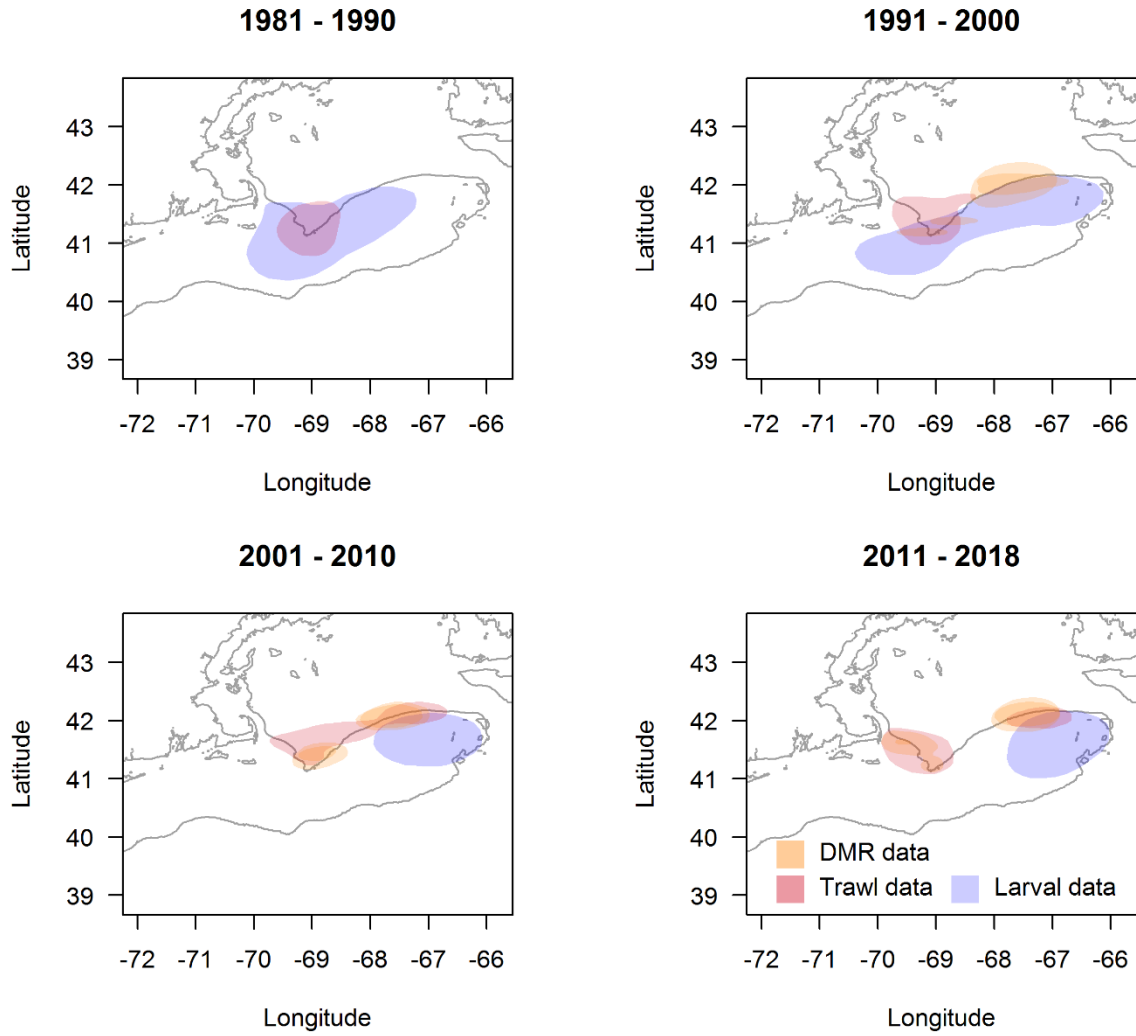


Figure 3.7. Overlap areas for maturity stage R+U herring from both DMR and trawl survey data sets for multiple decades (see Figure 3.6). 100 m isobath is shown.

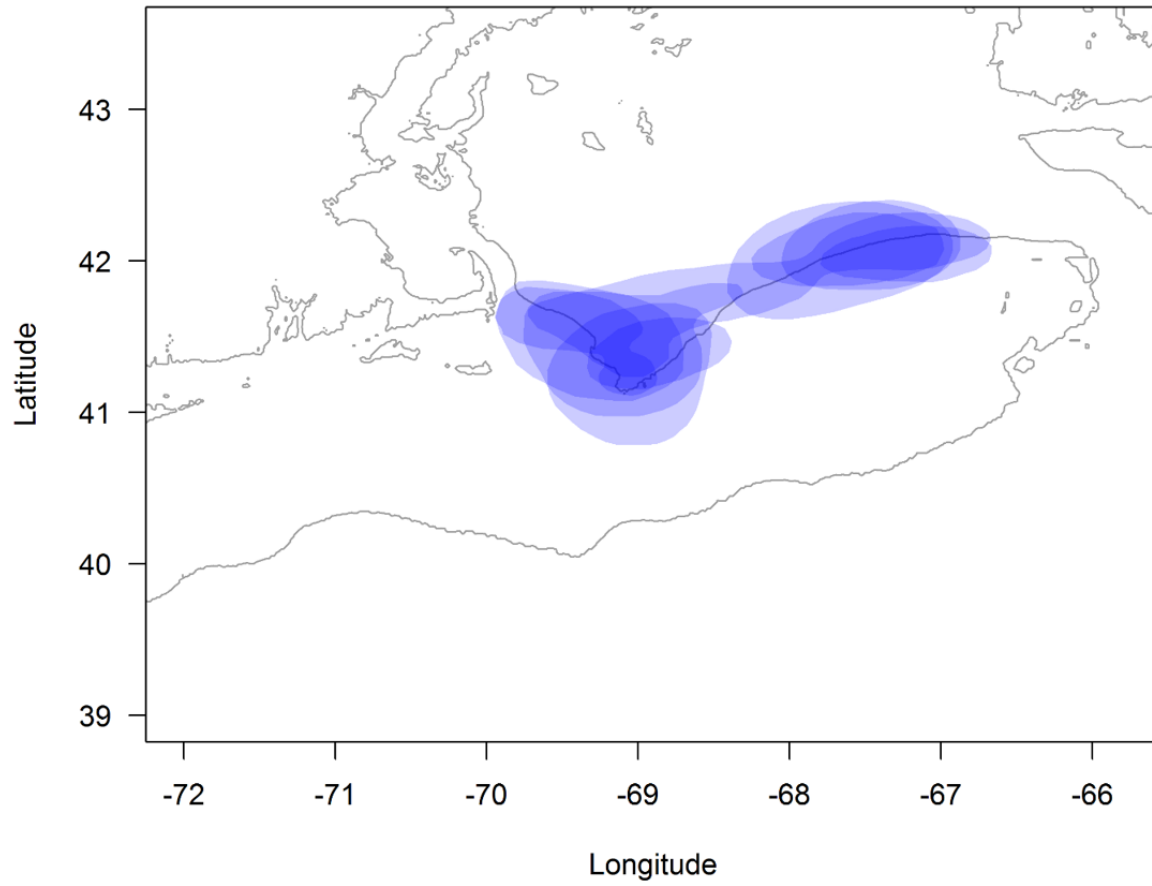


Figure 3.8. Consensus areas from Figure 3.7 where 4 or more overlaps occurred between different decades and data sources (DMR and trawl survey data). 100 m isobath is shown.

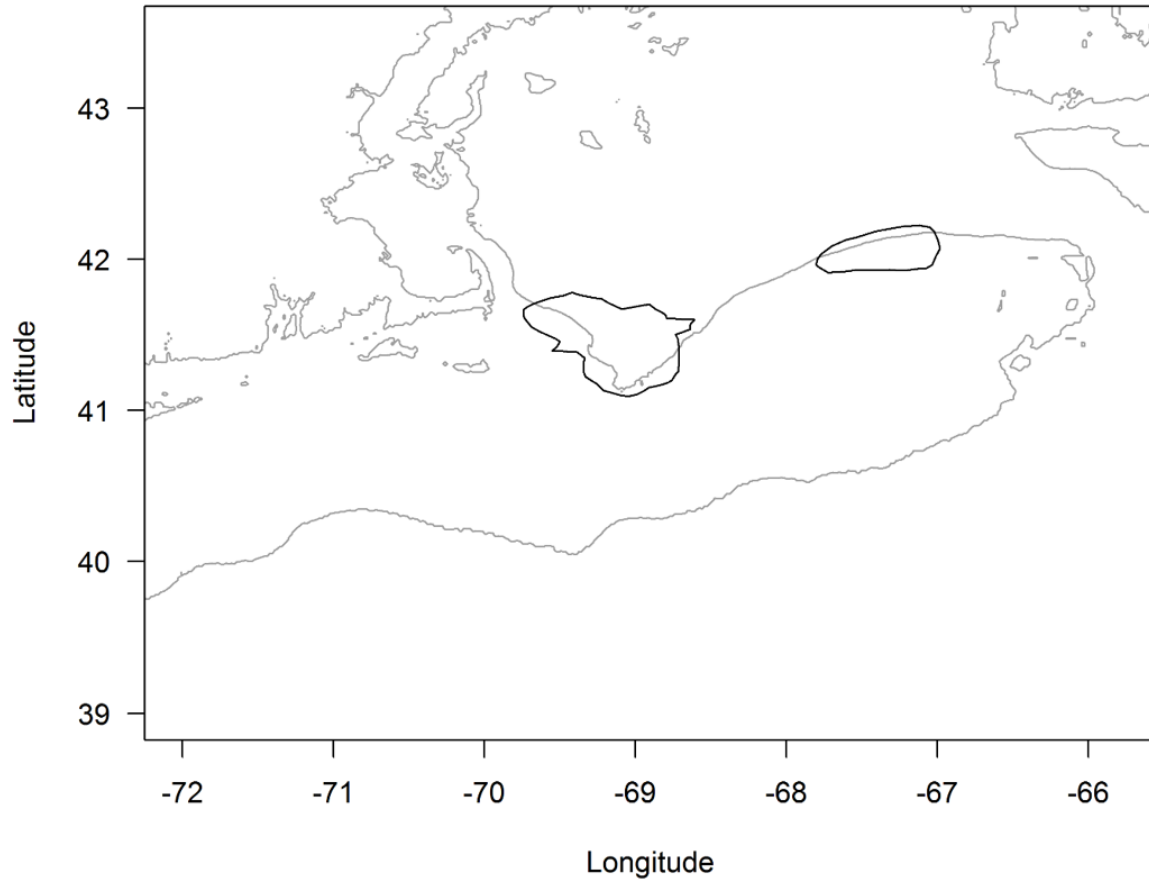
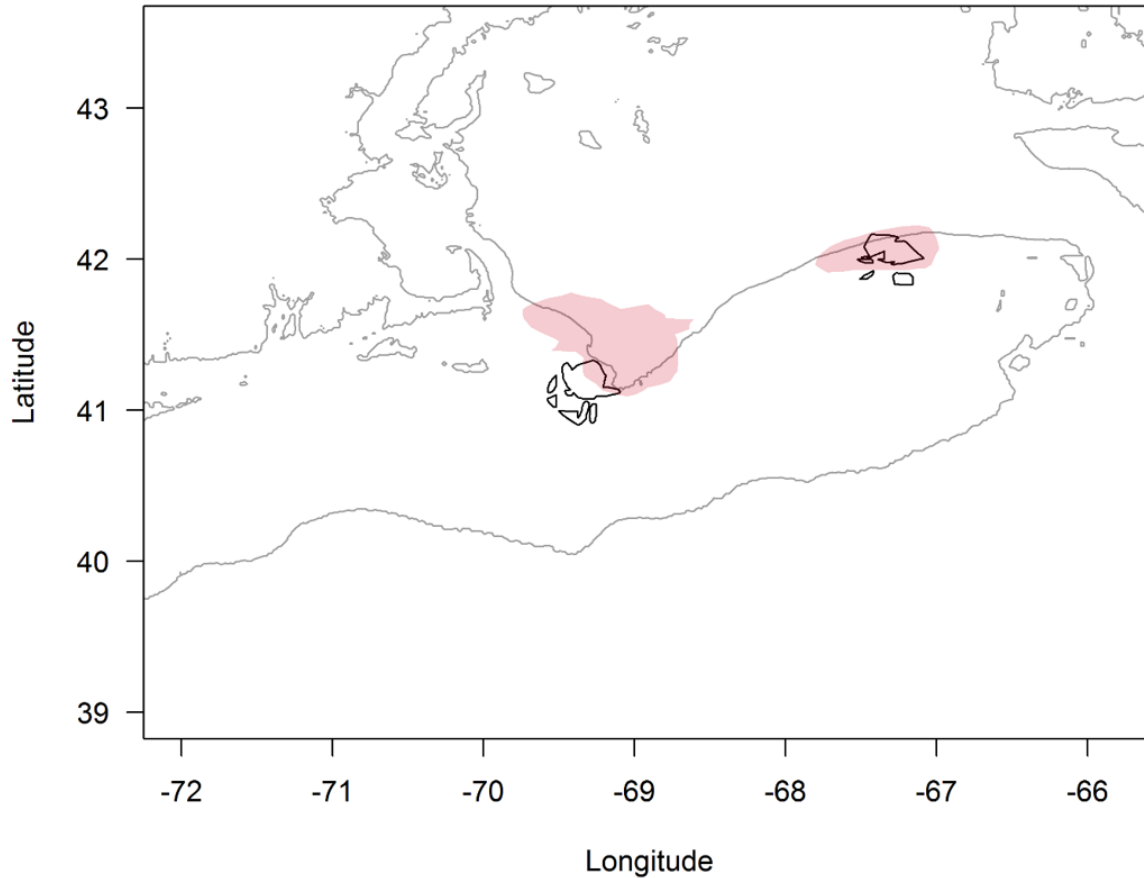


Figure 3.9. Comparison between consensus areas using all data sources (areas with black borders; from Figure 3.5) and those from multiple decades using mature fish (mat stage R+U) only (red shaded areas; from Figure 3.8). 100 m isobath is shown.



4. Herring Fishing Effort

Consensus spawning areas were compared to maps of fishing effort using two different approaches. First, the DMR portside monitoring database was used as a first layer since this approximates fishing effort in space. Figure 4.1 shows the 2-D kernel density estimates of sample locations from the whole DMR dataset. Fishing effort was concentrated along the northern edge of Georges Bank with high densities seen near the Northern Flank which overlapped partially with an area of high spawning activity. Another area of high sample density was seen to the east of the Great South Channel and did not overlap with the area of high spawning activity in that region. Figure 4.2. shows effort variation among decades from the DMR data. In every decade, there was some overlap with the spawning area at the Northern Flank and little to no overlap with the spawning area near the Great South Channel.

Second, effort data was examined in the form of raster layers of herring fishing revenue for the years 2007-2017 (Benjamin et al 2018). A similar picture emerged using this data.

Particularly, fishing effort was concentrated along the northern edge of Georges Bank and overlapped somewhat with the spawning area on the Northern Flank (Figure 4.3). Figure 4.4 shows how effort varies among sets of years. In the most recent years (2016/2017), herring revenue was concentrated near the Northern Flank spawning area and less spread out along the edge as in previous years.

Finally, consensus spawning areas were compared to different management areas and boundaries (Figure 4.5). The eastern Georges Bank spawning area overlaps to a high degree with Closed Area II and the Closed Area II Habitat Closure Area. The western spawning area did not overlap with previous groundfish closed areas. However, it overlaps to varying degrees with a new habitat management area (Great South Channel HMA) and the inshore mid-water trawl gear prohibition area proposed in Herring Amendment 8 to address potential localized depletion.

Figure 4.1. 2-dimensional kernel density estimates of fishing effort during spawning season (September and October; see Figure 2.3.1) for all years from DMR portside monitoring (i.e., location of industry samples). Total sample size is shown. Boxes enclose consensus spawning areas from Figure 3.5. 100 m isobath is shown. Points are sample locations.

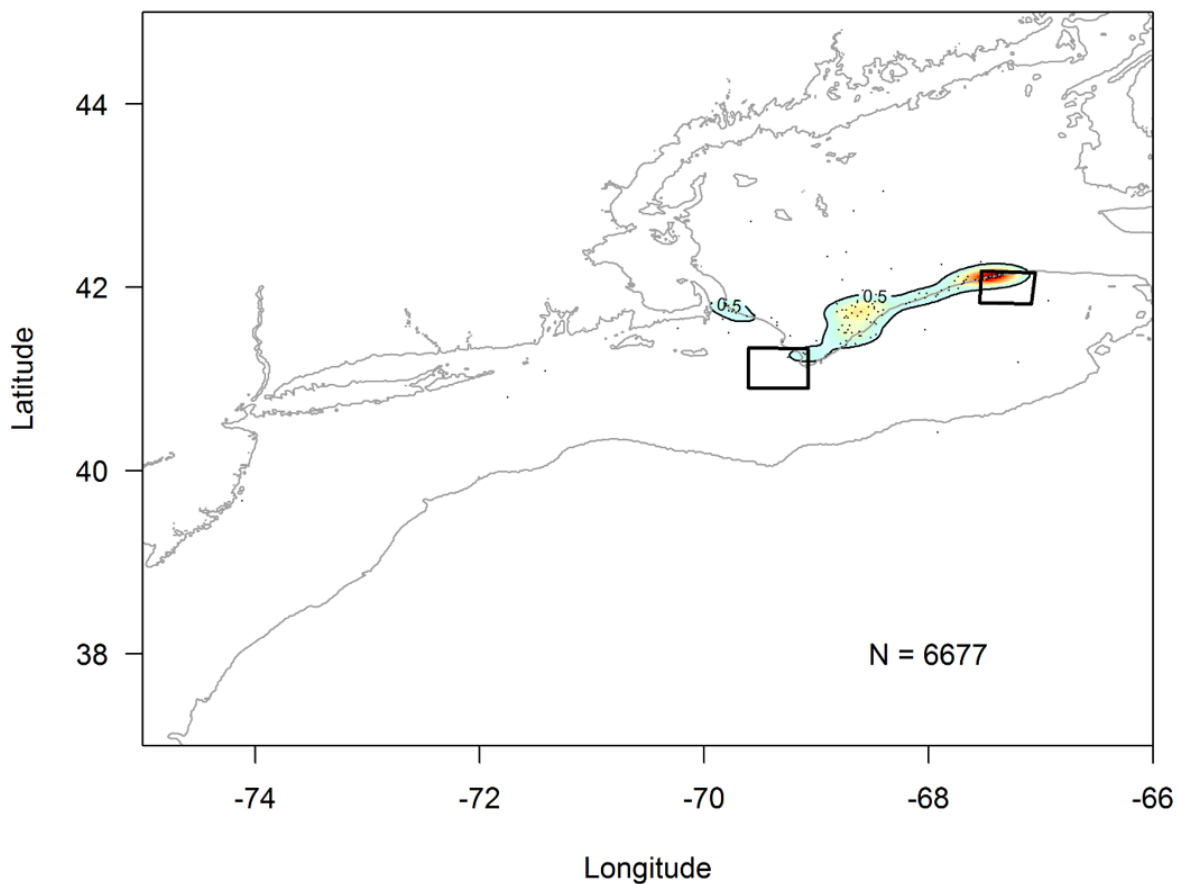


Figure 4.2. 2-dimensional kernel density estimates of fishing effort during spawning season (September and October; see Figure 2.3.1) by decade from DMR portside monitoring (i.e., location of industry samples). Sample sizes are shown. Boxes enclose consensus spawning areas from Figure 3.5. 100 m isobath is shown. Points are sample locations.

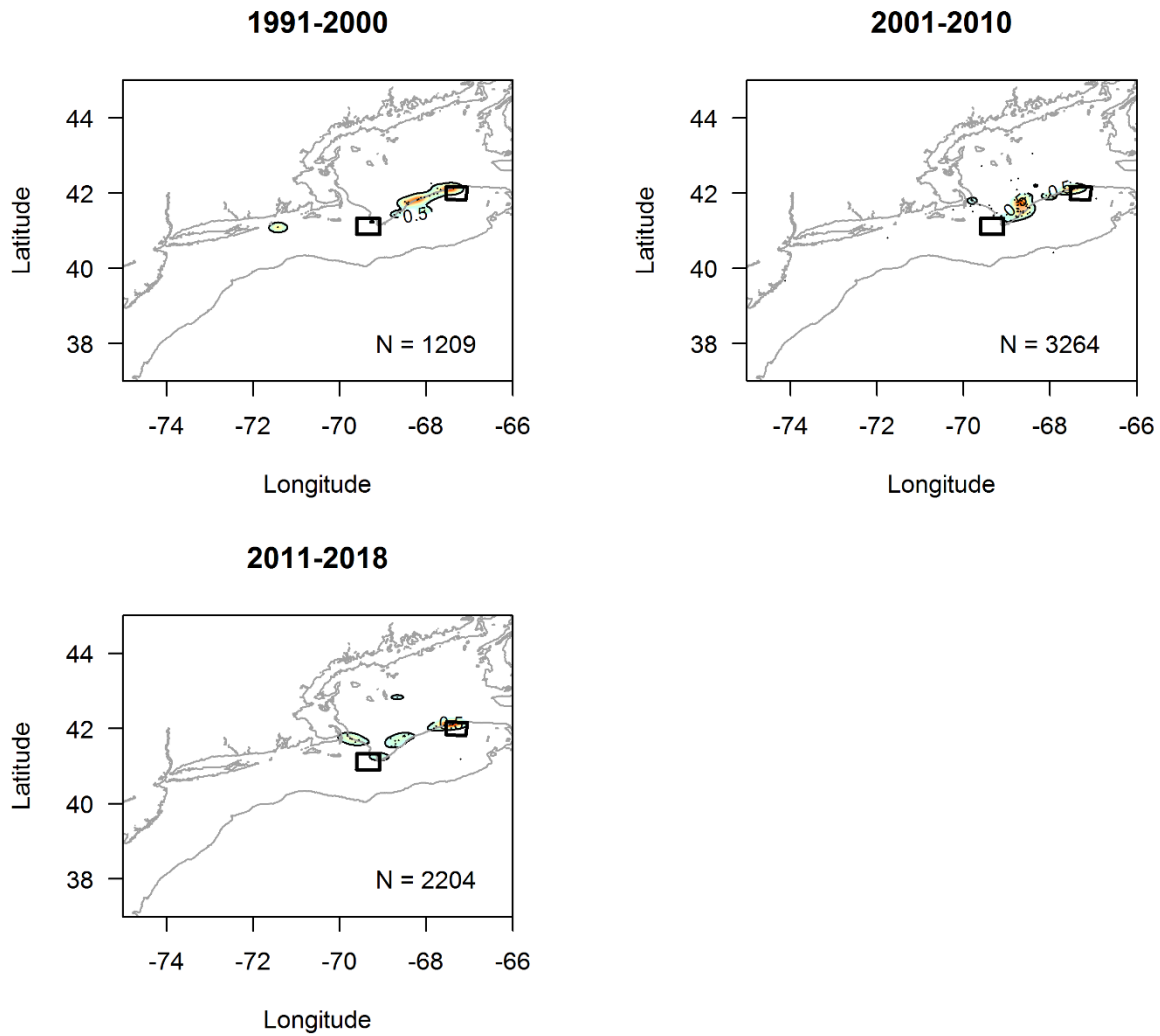


Figure 4.3. Fishing effort as herring revenue (\$/0.25km²) for the period 2007-2017. Data from Benjamin et al (2018). Boxes enclose consensus spawning areas from Figure 3.5. 100 m isobath is shown.

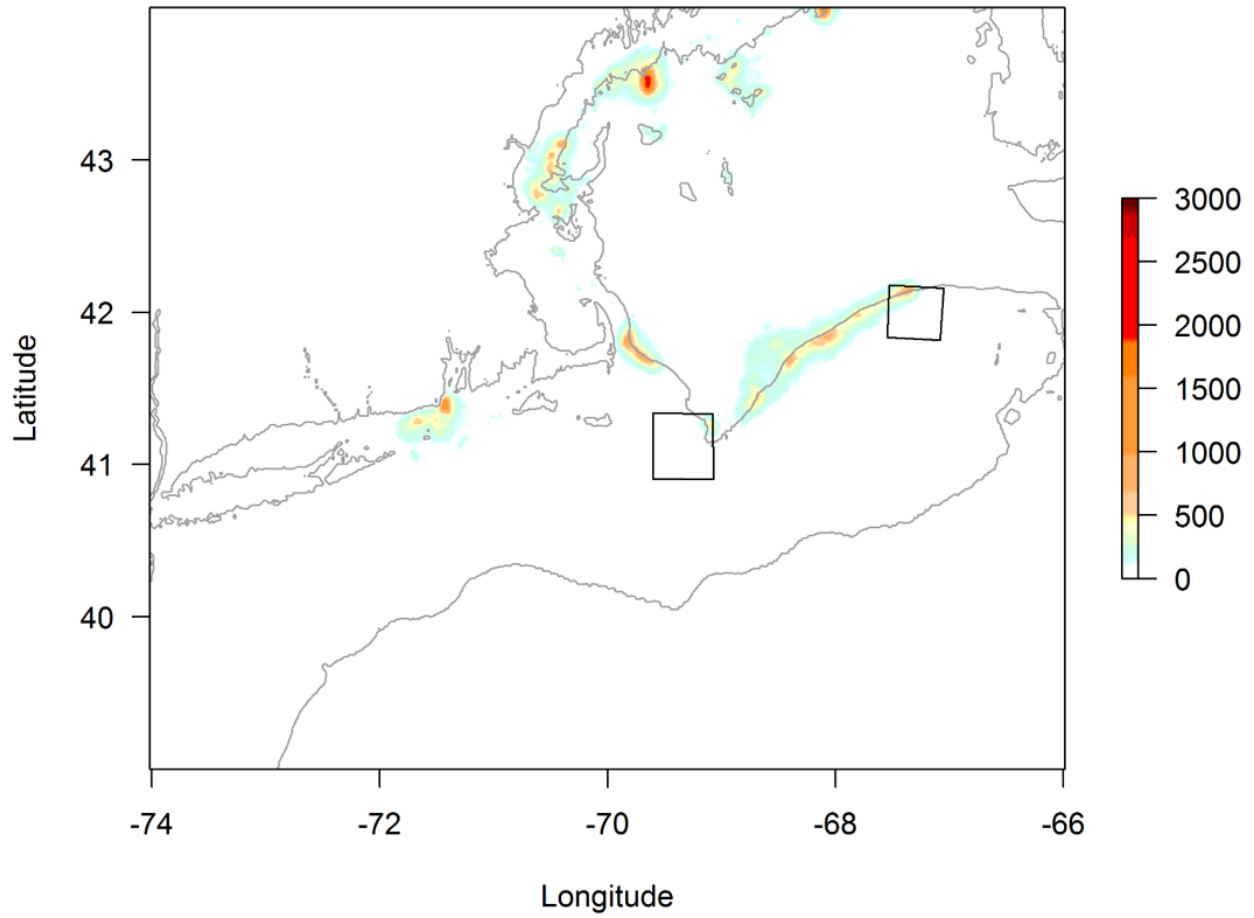


Figure 4.4. Fishing effort as herring revenue (\$/0.25km²) for 4 3-year periods from 2007-2017. Data from Benjamin et al (2018). Boxes enclose consensus spawning areas from Figure 3.5. 100 m isobath is shown.

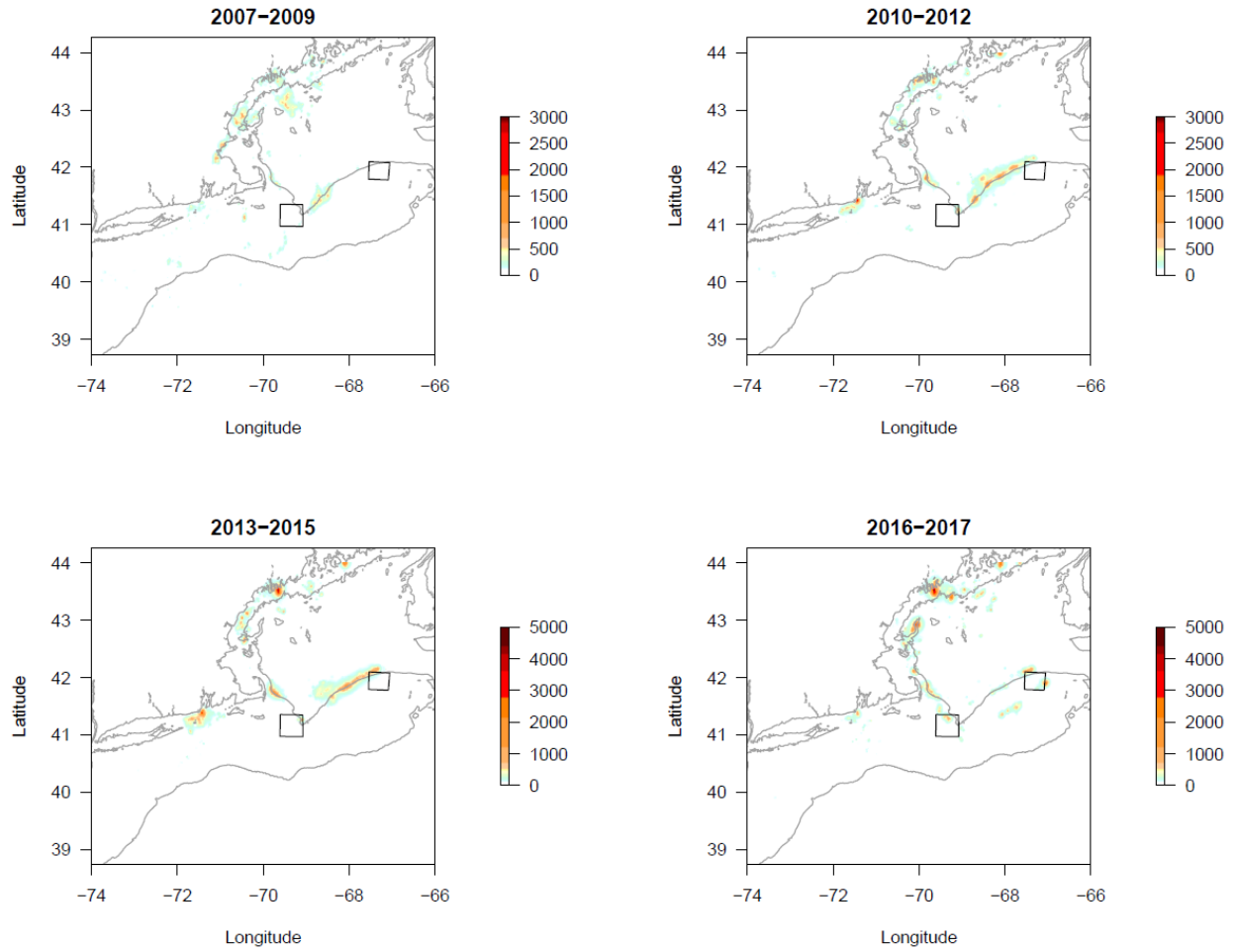
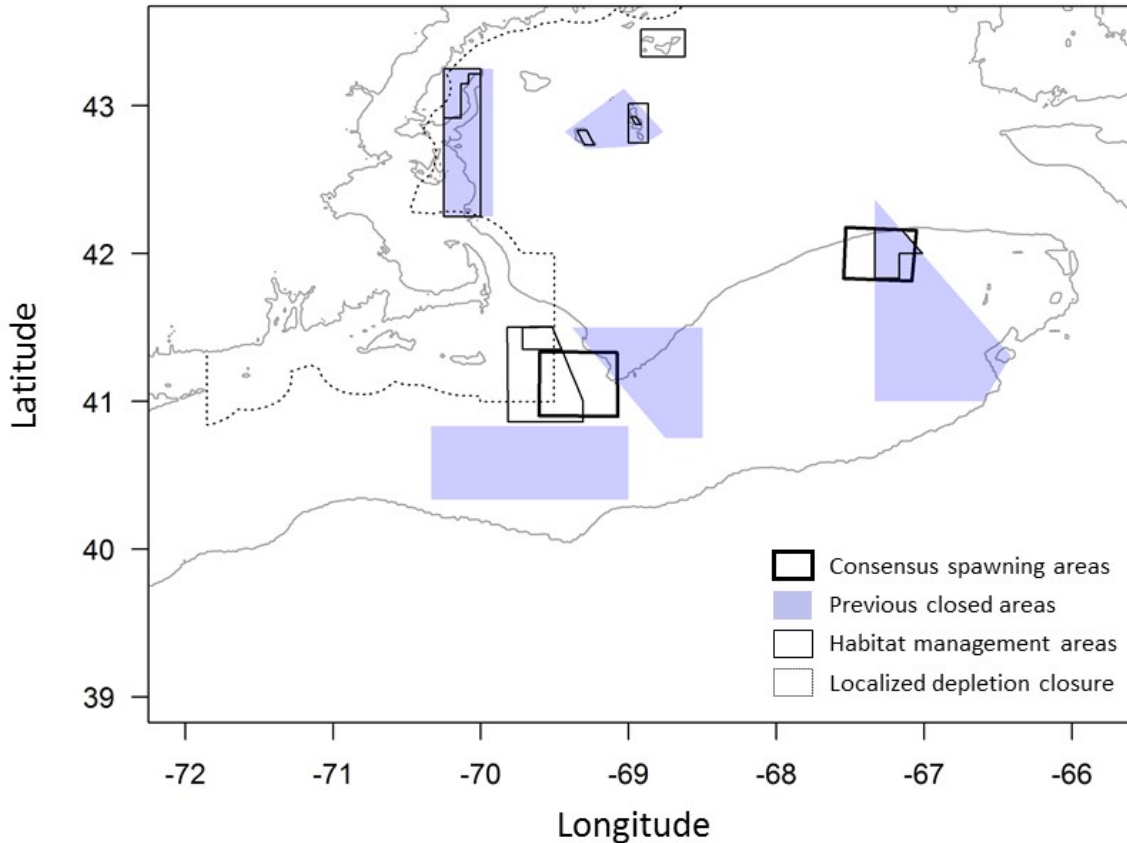


Figure 4.5. Consensus spawning areas in relation to groundfish closed areas, habitat management areas and the proposed localized depletion closure. The southernmost purple area, the Nantucket Lightship Closed Area, was removed in April 2018 via OHA2, and Closed Area I, to the east of the western herring spawning area, was made seasonal as described in the text. The remaining purple areas are still in effect as year-round closures (note that the boundary of the closure in the western Gulf of Maine was adjusted slightly via OHA2). 100 m isobath is shown.



5. Potential Impacts to Offshore Spawning from Other Sources

5.1. Potential Fishery Impacts

This document outlines existing information to infer most likely locations of herring spawning activity on Georges Bank. This takes into account information from multiple life stages of herring including areas of highest density of spawning adults, eggs and larvae. Directed fishing on spawning adults could affect spawner biomass, as well as potentially disrupt spawning activity (e.g., school formation; this has not been definitively shown although see Stockwell et al [2013] for possible effect of midwater trawling on non-spawning herring schools). However, directed herring fishing is less likely to impact eggs and subsequent larvae since eggs adhere to

the bottom and herring fishing activity is primarily in the water column and not on the ocean floor. In this sense, fishing activities that directly interact with bottom habitat during the period of highest spawning activity (i.e., September and October; note that herring eggs hatch within 10-15 days of spawning; Bigelow and Schroeder 1953) may be expected to cause the highest risk to this stage of reproduction.

There are three main fisheries that interact with the bottom around the locations that have been identified as areas of likely spawning and egg deposition. These include groundfishing (bottom trawls), and the sea scallop and surf clam/ocean quahog fisheries (scallop and hydraulic dredges), all of which employ bottom-tending gear. Note that an exact spatial/temporal analysis of fishing activity in relation to herring spawning areas is beyond the scope of this review. The following is meant only to identify potential areas of overlap.

The multispecies groundfish fishery operates year-round on Georges Bank and appears to overlap with consensus herring spawning areas. Figure 5.1.1 shows groundfish vessel locations that are inferred to be fishing (i.e., speed less than 4 knots from vessel monitoring system or VMS for the years 2015-2016). Fishing activity is relatively high inside the western consensus herring spawning area, particularly throughout the central portion of the box which may contain the highest herring spawning activity. Only a small portion on the northeast corner of the western spawning box has been protected by a year round groundfish closure (i.e. Closed Area I; see Figure 4.5). Roughly half of the eastern consensus herring spawning area lies within Closed Area II (Figure 4.5) and is therefore protected from groundfish gear. However, the western half of the eastern box is not protected and has also seen a relatively high level of groundfishing activity which could potentially impact herring eggs. It should be noted that groundfish closed area boundaries have been modified in more recent years, and some of these boundaries are no longer relevant. For example, as of April 2018 Closed Area I is no longer closed year-round, a new area farther to the west is now closed to all bottom tending fishing year-round (Great South Channel Habitat Management Area), and only the northern portion of Closed Area I is closed February 1 - April 15 as a groundfish spawning protection measure (NEFMC, 2016). Furthermore, the fishing effort maps that have been included here are annual maps because that is what was available. Seasonal effort maps (i.e. September – November) would be more relevant to assess the potential overlap and risk to herring spawning areas.

The sea scallop fishery operates year-round on Georges Bank and also appears to overlap to a substantial degree with consensus herring spawning areas (Figure 5.1.2). The location of highest scallop fishing intensity, as inferred from VMS (again for vessels moving less than 4 knots for the years 2015-2016), overlaps with consensus herring spawning areas primarily on western Georges Bank, but also in the northwest corner of the eastern spawning area (Figure 5.1.2). Habitat descriptions for scallops and where herring are likely to spawn are also similar. Specifically, sea scallop adults live on coarse substrate, usually gravel, shells and rock at depths ranging from 18-110m (Hart and Chute 2004). Atlantic herring also spawn on rocky, pebbly, or gravelly bottoms, shell substrates, and on clay to some extent, but probably never on soft mud (Bigelow and Schroeder 1953). Figure 5.1.3 shows how herring spawning areas coincide mostly with pebble and cobble dominated habitats. Again, seasonal effort maps would be more relevant

to assess the potential overlap and risk to herring spawning areas from scallop fishing. In general the herring spawning areas do not overlap with rotational scallop closures, but rather with ‘open’ scallop bottom.

Figure 5.1.4 shows surfclam/ocean quahog fishing activity for 2015-2016 (VMS locations filtered for vessels moving at speeds less than 4 knots). Areas of highest fishing intensity do not appear to overlap appreciably with consensus herring spawning areas. In the eastern Georges Bank spawning area, there is no overlap, while in the western area there is some overlap on the western portion of the spawning box. It should be noted that the surf clam/ocean quahog fishery uses hydraulic dredges that mainly operate on soft bottom comprised of sandy sediment with the preference to be large grain sand (DeAlteris and Allen 2016) (Figure 5.1.3). It should also be noted that the areas where surfclam/ocean quahog fishing takes place has been changing in more recent years, with more effort shifting to areas farther offshore including Georges Bank (MAFMC, 2018). Vessels targeted surf clams on GB in the 1980s, and not again until 2009. The herring spawning areas are fished for surfclams, and not for ocean quahogs (NEFMC, 2019). As of April 2019, the Great South Channel HMA is closed to clam dredges; an action to reopen discrete exemption areas for clam and mussel dredging is currently under review by NMFS.

Figure 5.1.1. Spatial extent of multispecies groundfish fishery as inferred from VMS data where vessels are moving at a speed of less than 4 knots (2015-2016). Data from Northeast Ocean Data Portal; <https://www.northeastoceandata.org/>). Thick black boxes enclose consensus herring spawning areas (from Figure 3.5). 100 m isobath is shown.

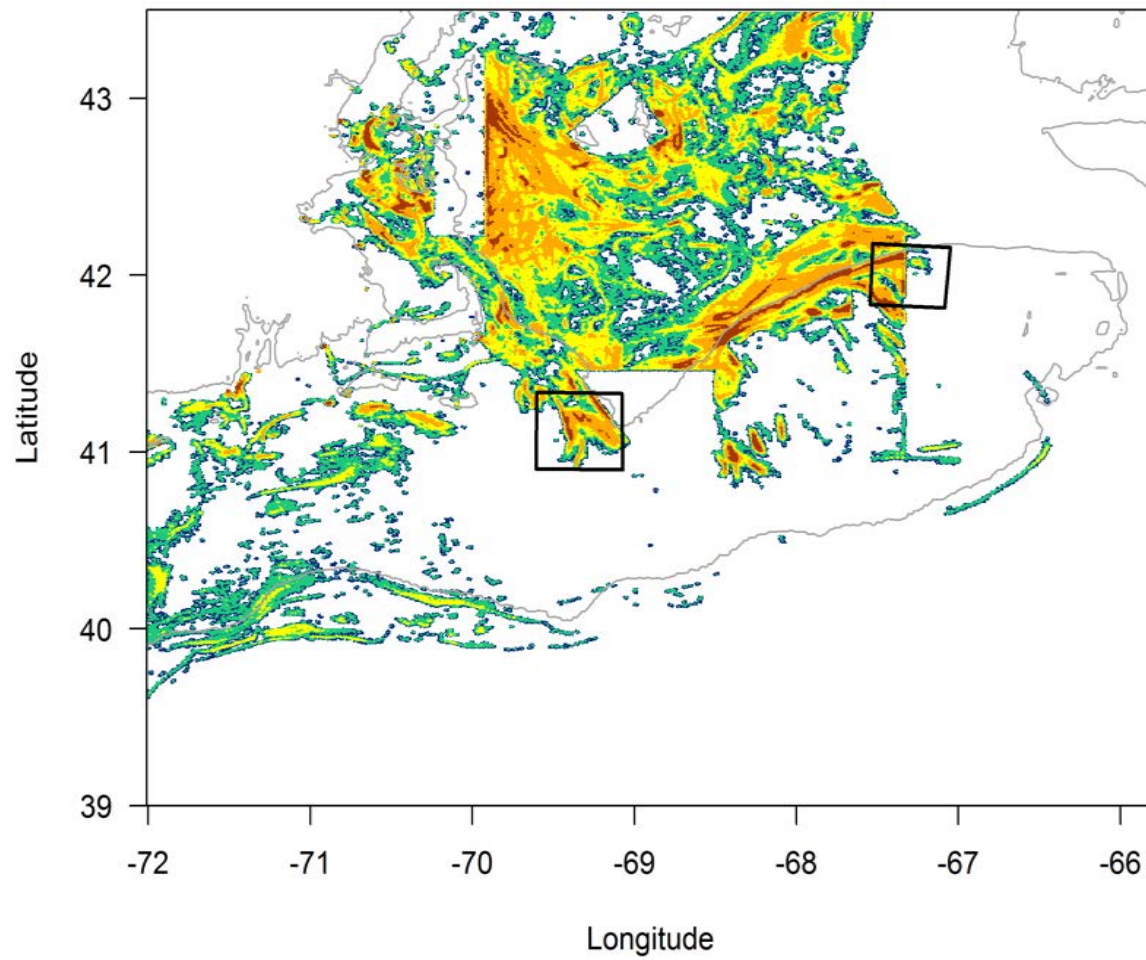


Figure 5.1.2. Spatial extent of scallop fishery as inferred from VMS data where vessels are moving at a speed of less than 5 knots (2015-2016). Data from Northeast Ocean Data Portal; <https://www.northeastoceandata.org/>). Thick black boxes enclose consensus herring spawning areas (from Figure 3.5). 100 m isobath is shown.

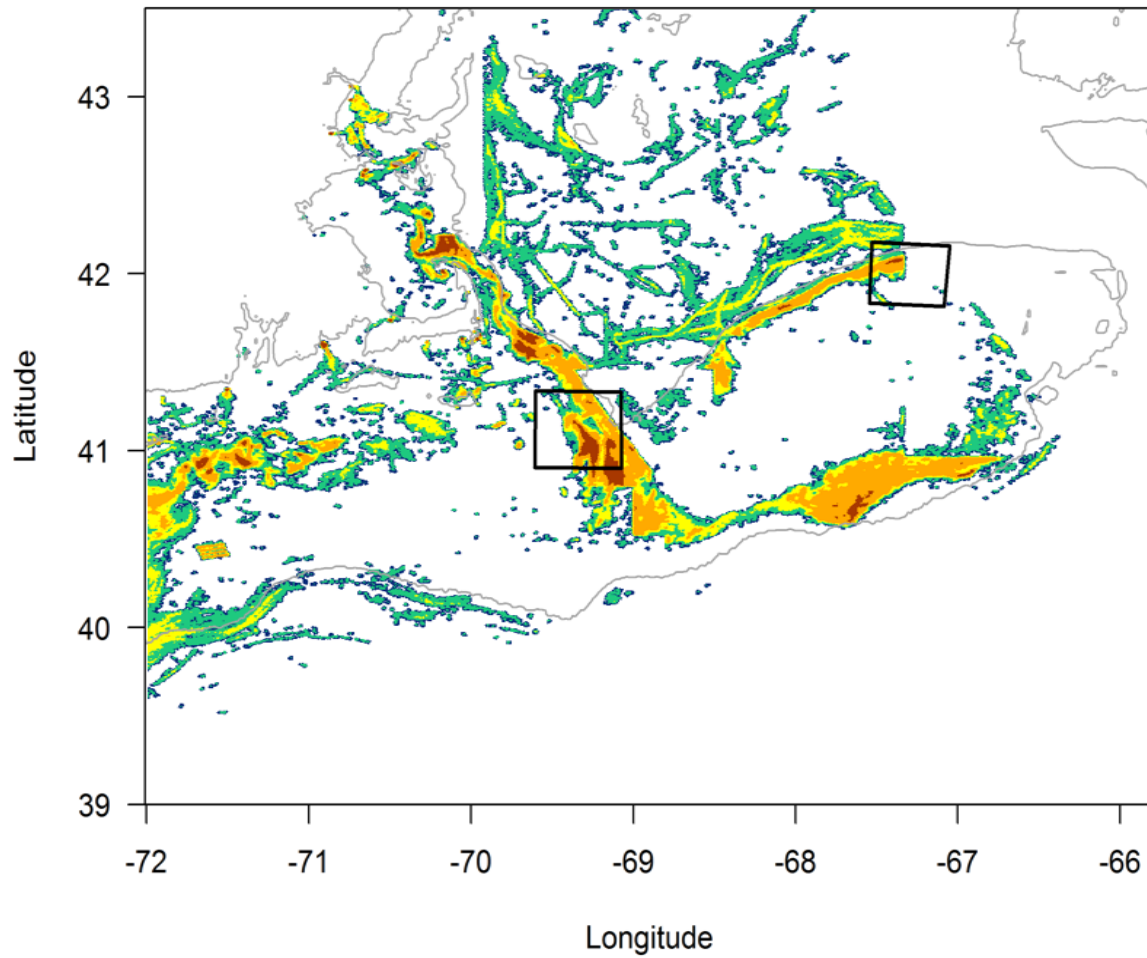


Figure 5.1.3. Predominant habitat type for Georges Bank and consensus spawning areas. Data from Harris and Stokesbury (2010). Prepared with aid from NEFMC staff. 100 m isobath is shown.

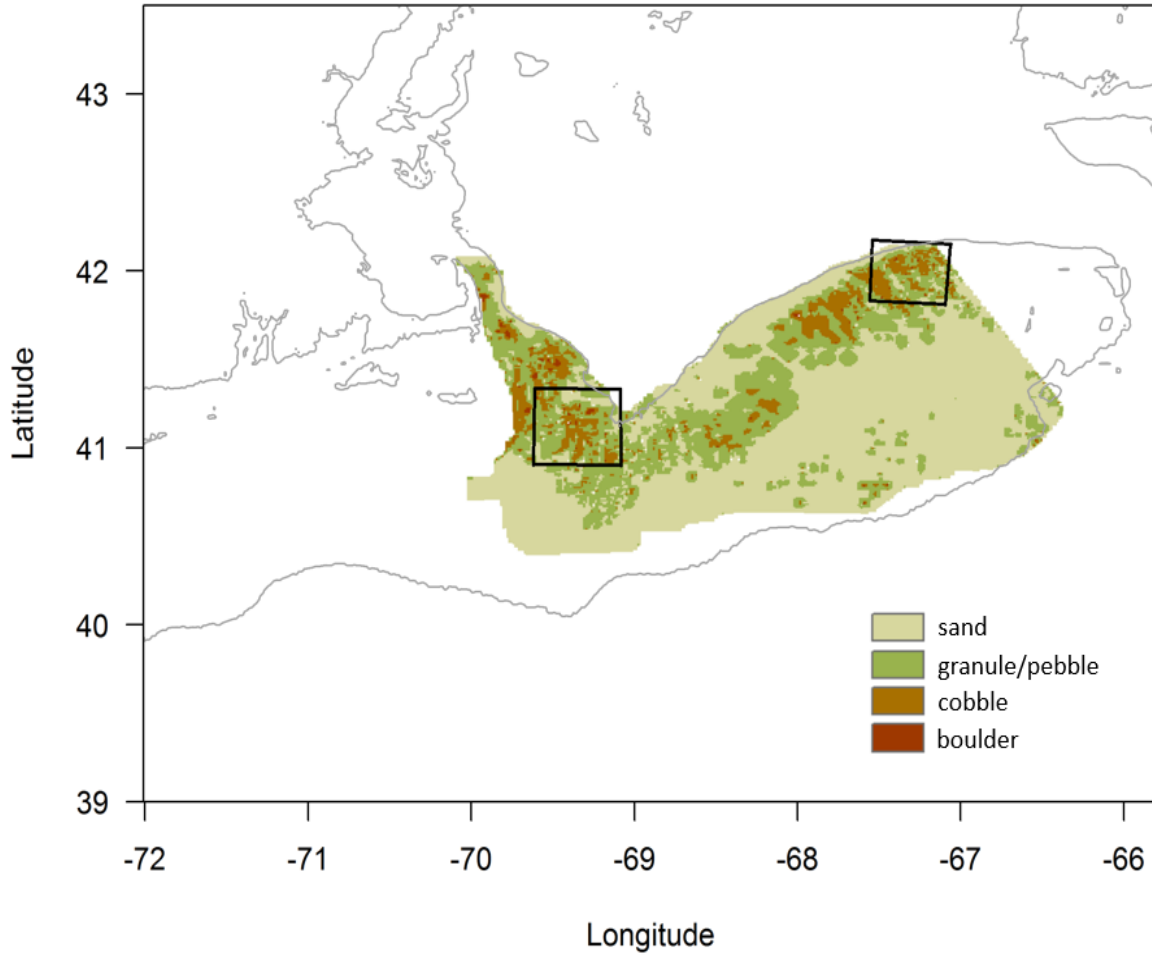


Figure 5.1.4. Spatial extent of surf clam/ocean quahog fishery as inferred from VMS data where vessels are moving at a speed of less than 4 knots (2015-2016). Data from Northeast Ocean Data Portal; <https://www.northeastoceandata.org/>). Thick black boxes enclose consensus herring spawning areas (from Figure 3.5). 100 m isobath is shown.

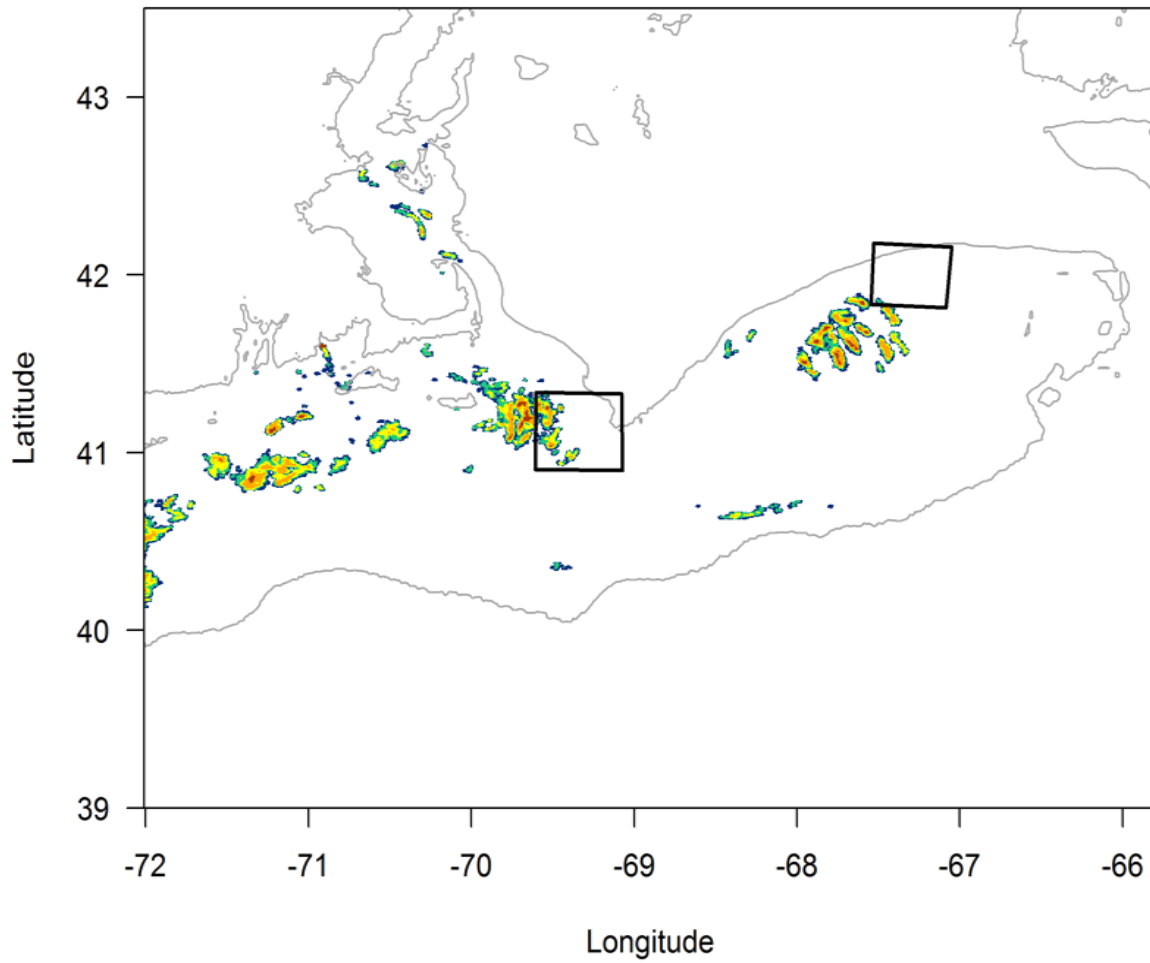
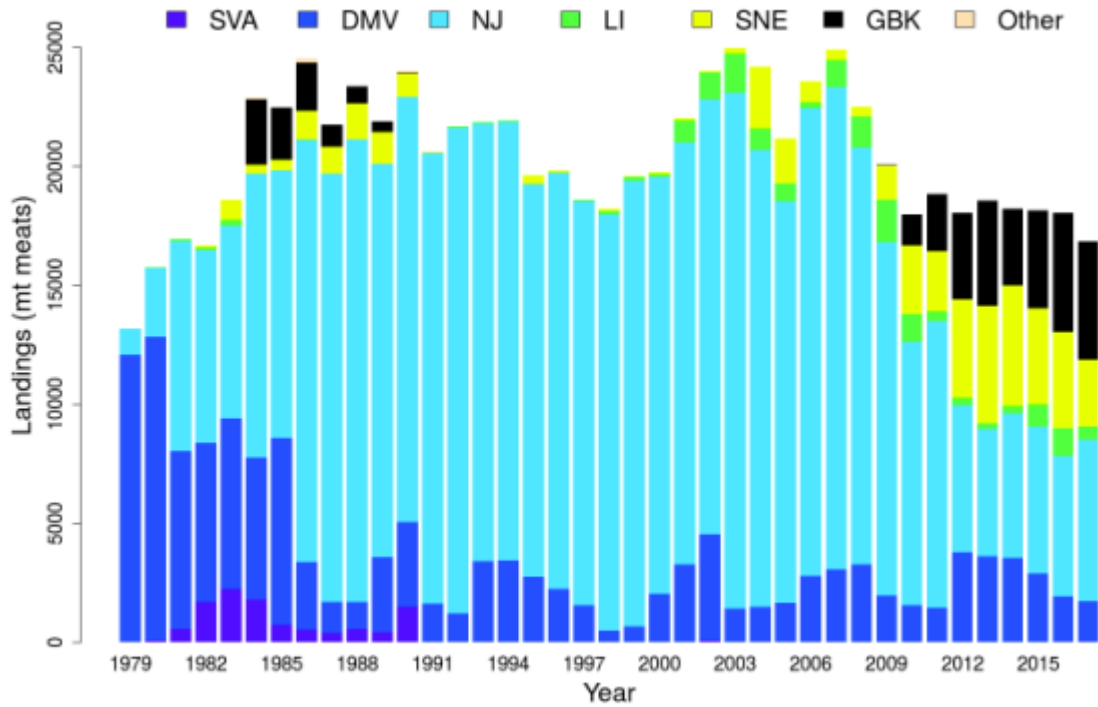


Figure 5.1.5. Average Surf clam landings from the US EEZ during 1979-2016, and preliminary 2017.



Source: Dan Hennen Pers. Comm., NEFSC 2018, as cited in MAFMC (2018a).

5.2. Potential Climate Threats

The Gulf of Maine is warming at a rate faster than 99% of the world's oceans (Pershing et al. 2015). This has had myriad effects on species distributions (Pinsky et al. 2013) and predator-prey interactions (Record et al. 2019) in the northeast. While many species may be acutely affected by warming water (e.g., Atlantic cod, which appear to show temperature-dependent increases in mortality; Pershing et al. 2015), other species may be less affected owing mostly to their increased mobility. Herring may be one species that may be somewhat buffered by its ability to shift distributions away from warming water. In their climate vulnerability assessment for northeast fish stocks, Hare et al. (2016) scored herring as being highly exposed to climate change but low in terms of their overall biological sensitivity to this change because of their ability to move. Predating this, Murowski (1993) found that with ocean warming, Atlantic herring will likely occur northward of their current distribution.

While herring show potential for distributional shifts which could shield them from the effects of warming, they do demonstrate strong natal homing for spawning (McQuinn 1997). This could be problematic for recruitment success and larval growth with warming waters and increasing ocean acidification (Leo et al. 2018, Nash and Dickey-Collas 2005). Hufnagl and Peck (2011) showed that using more northern spawning ground or delaying timing of fall spawning may not be as favorable for larval growth and survival due to the limitations of daylength and possible mis-match with prey abundances. Spawning site fidelity may also mean that certain spawning sites are abandoned altogether if conditions become too inhospitable. Sherwood et al. (2017) conducted an acoustic survey of Atlantic herring throughout the Maine coast from 2012 to 2016. They found that in warm (heatwave; Pershing et al. 2019) years, herring appeared to be overabundant in inshore Maine waters (Figure 5.2.1). That is, the entire spawning stock for the northeast stock complex appeared to use Maine coastal waters as a thermal refuge during the spawning season (August – October). While adults may have avoided the worst of warming effects, spawning may have been strongly affected in areas too warm to occupy.

Sherwood et al. (2017) also found that spawning appears to be less active in the easternmost region of Maine compared to historical records (see Figure 5.2.2). This agrees with a recent study by Record et al. (2019) who showed that *Calanus finmarchicus*, a preferred copepod prey for herring, has decreased in this region and also resulted in the westward shift of right whales which also prey on *C. finmarchicus*. Thus, climate change may also affect herring through changes to the food web and their prey. This is a particularly salient point since *C. finmarchicus* are predicted to be absent from the Gulf of Maine by 2050 as they are predominantly a north-temperate, sub-arctic species (Reygondeau and Beaugrand 2011). There are no substitutes for this lipid-rich prey in the Gulf of Maine.

Figure 5.2.1. Relationship between Gulf of Maine sea surface temperature (SST) anomaly and fraction of total spawning stock biomass that was observed (acoustically) in Area 1A inshore (< 90m) between 2012 and 2016. Proportions based on acoustic biomass from Sherwood et al. (2017) in relation to SSB from latest herring stock assessment (NEFSC 2018).

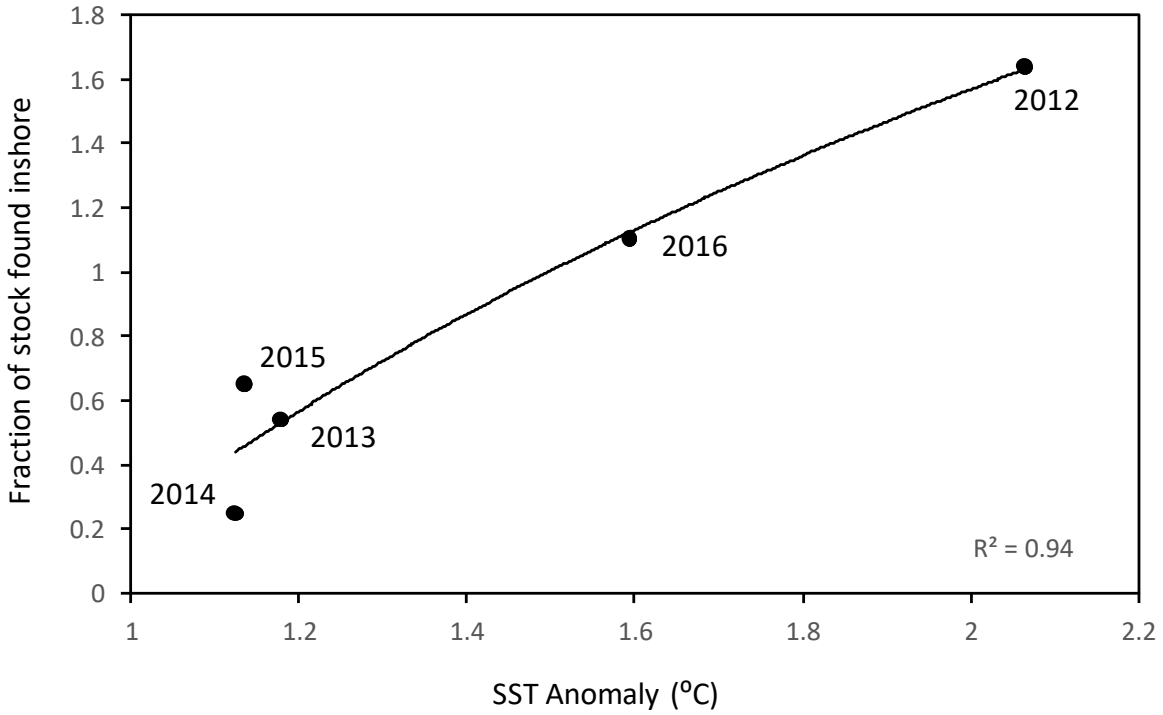
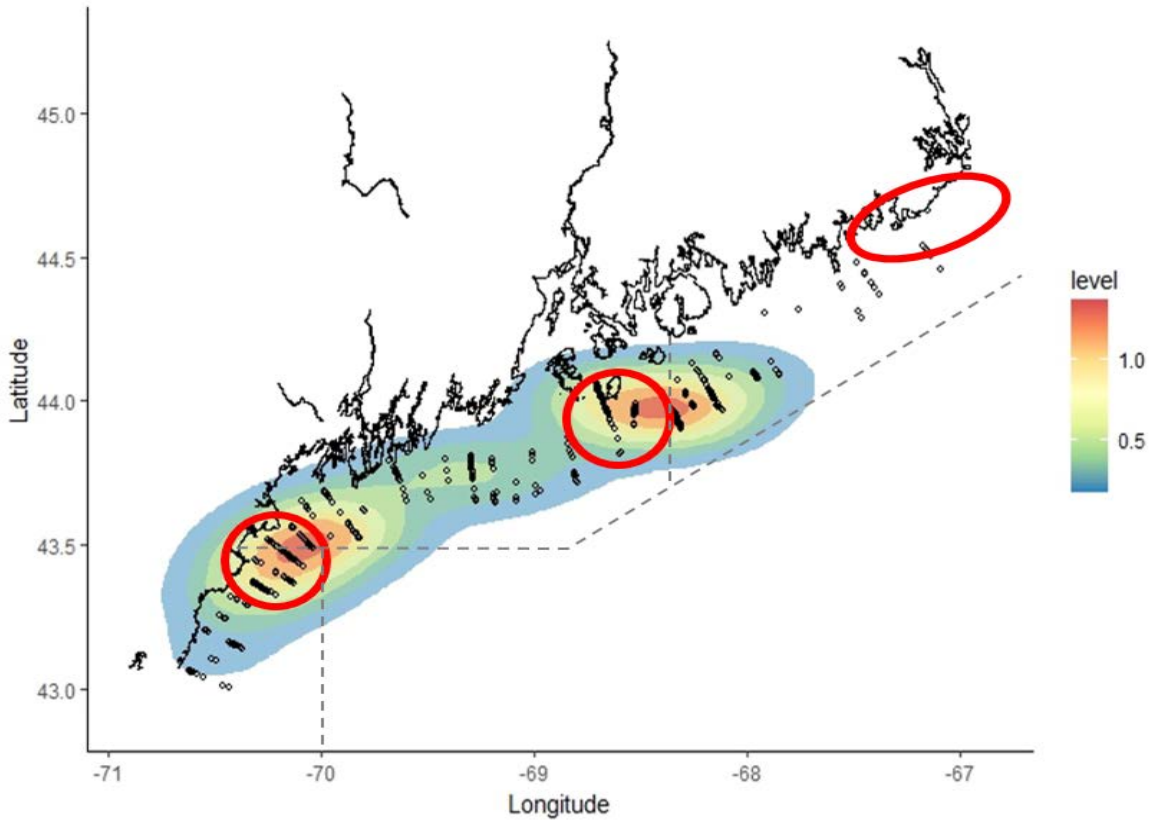


Figure 5.2.2. Kernel densities of spawning school distribution determined from acoustic survey conducted between 2012 and 2016 (Sherwood et al. 2017). Red ellipses are historical egg deposition areas (see Figure 3.2). Note that very little spawning activity was observed in eastern area.



5.3. Potential Threats from Predators

Herring are the preferred prey for a large number of predators including numerous groundfish, sharks, tuna, seabirds and whales (see NEFMC 2003 for a comprehensive review of “The role of Atlantic herring in the northwest Atlantic ecosystem”). The Northeast Fisheries Science Center’s food habits database is one of the most complete sources of information for quantifying the impact of predators on herring (Link and Almeida 2000). A list of predators from the database known to feed on herring in the northeast is shown in Table 5.3.1. Within these species, there exists some region- and sex-specific differences in herring predation as indicated. What is most relevant for this review is that the trend in predation pressure index (PPI; measures total predation by the listed species on herring) has varied mostly without trend near the time series mean (Deroba 2018). Thus, while individual predator species, and their impact on herring, may have fluctuated in abundance over time, the overall predation pressure appears to remain constant and therefore may not be a variable threat to spawning herring. It should be noted that this index only tracks predation by species captured in the food habits database (i.e., from the bottom trawl surveys).

What the food habits database does not capture accurately is the impact that certain predators may have on egg and larval stages of herring. Larvae may be subject to a range of different predators including other herring (e.g., Fuiman 1989), mackerel (Pepin et al. 1987) and even gelatinous zooplankton (Möller 1984); competition with these may also cause a decline in recruitment (Lynam et al. 2005). A number of different predators feed on herring eggs including haddock (*Melanogrammus aeglefinus*), Atlantic cod (*Gadus morhua*), pollock (*Pollachius virens*), winter flounder (*Pseudopleuronectes americanus*), yellowtail flounder (*Pleuronectes ferruginea*) and longhorn sculpin (*Myoxocephalus octodecimspinosus*). Of these, one species in particular may be strongly related to large changes in herring reproductive success in the northeast – haddock, which within the food habits database were the species most commonly observed to contain eggs in their stomachs (Figure 5.3.1).

Haddock have undergone major changes in abundance since the 1960's and herring recruitment seems to be highest when haddock are at low abundance (Figure 5.3.2). Indeed, Richardson et al. (2011) linked declines in the herring population with egg predation by haddock in the northeast. Bax (1998) also noted that haddock and cod predation on eggs can account for 40-60% egg mortality in Norway. More recently, haddock are at record high levels on Georges Bank (278% of target biomass; NEFSC 2017) and herring recruitment is at all-time lows (Figure 5.3.2). Spatially, haddock occupy the same areas as spawning herring (and eggs) and this has been particularly evident in the most recent decade (Figure 5.3.3). Interestingly, haddock seem to overlap with herring spawning at fine scales mostly in the eastern area and less so in the western spawning area. This is somewhat at odds with the larval data that show that larval herring are most abundant in the eastern area most recently (Figure 2.1.2) suggesting that egg predation is lower here. A potential reason for this is that the trawl survey may not necessarily capture haddock distribution at the exact time when herring eggs are on the bottom. It is also of note that very few herring eggs were observed in the diet of fish in the food habits database (Section 2.5). This could be because of a mismatch between sampling for fish and spawning, but also because eggs are likely to be highly digested and unidentifiable by the time stomachs are dissected. A more directed study of haddock predation on herring eggs would be warranted.

Figure 5.3.1. Number of stomachs by species observed to contain Clupeid or *Clupea harengus* (herring) eggs. Data from NEFSC food habits database.

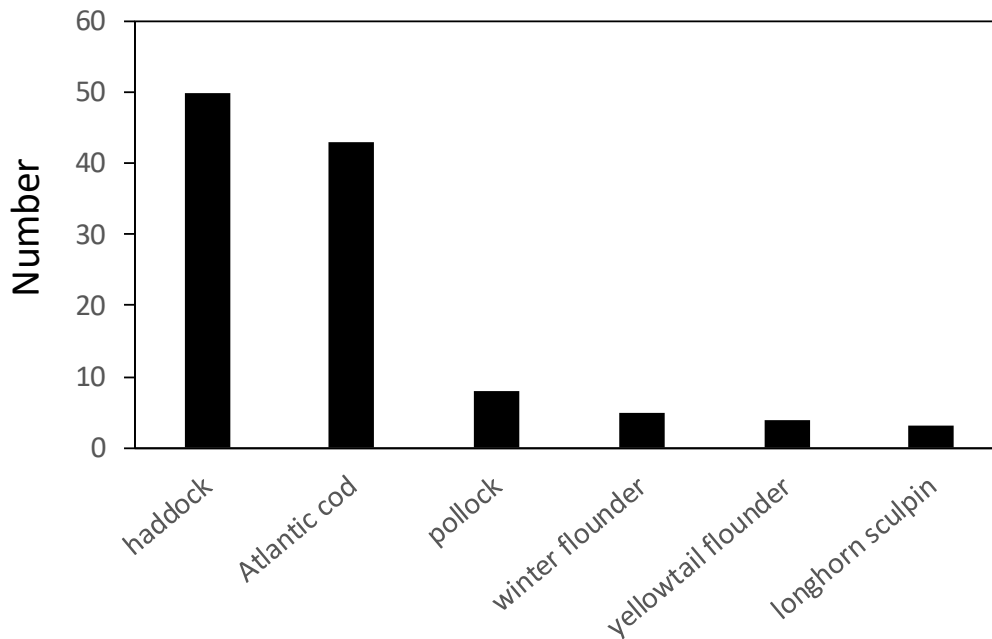


Table 5.3.1. List of predators on Atlantic herring that had at least 10 stomachs containing herring and positive occurrences of herring in at least 0.1% of stomachs, combined among all years and seasons from the food habits database (from Deroba 2018).

PREDATOR	Region (R) or Sex (S) distinctions
ATLANTIC_COD	R – Georges Bank, Gulf of Maine
ATLANTIC_HALIBUT	NA
BLUEFISH	NA
GOOSEFISH	R – North, South
HADDOCK	R – Georges Bank, Gulf of Maine
POLLOCK	NA
RED_HAKE	R – North, South
SEA_RAVEN	NA
SILVER_HAKE	R – North, South
SPINY_DOGFISH	S – Male, Female, Unidentified
STRIPED_BASS	NA
SUMMER_FLOUNDER	NA
THORNY_SKATE	NA
WHITE_HAKE	NA
WINTER_SKATE	NA

Figure 5.3.2. Time series of haddock spawning stock biomass (NEFSC 2017) and herring recruitment (NEFSC 2018) from the 1960s to the present.

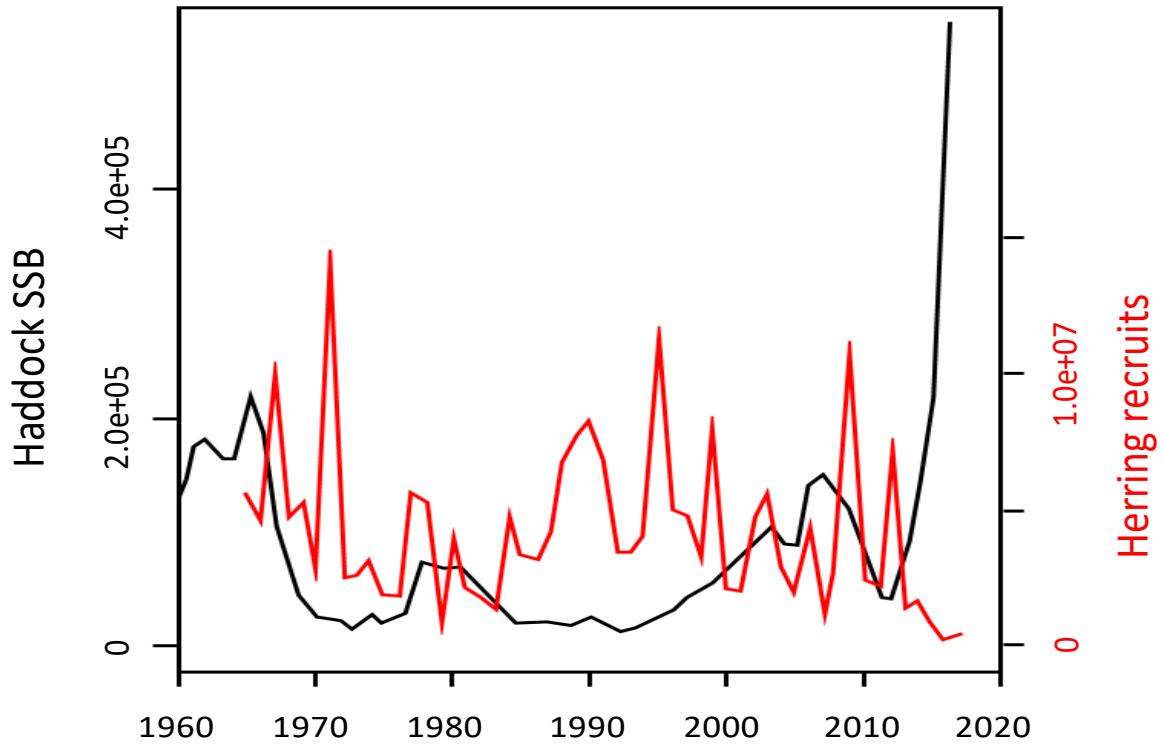
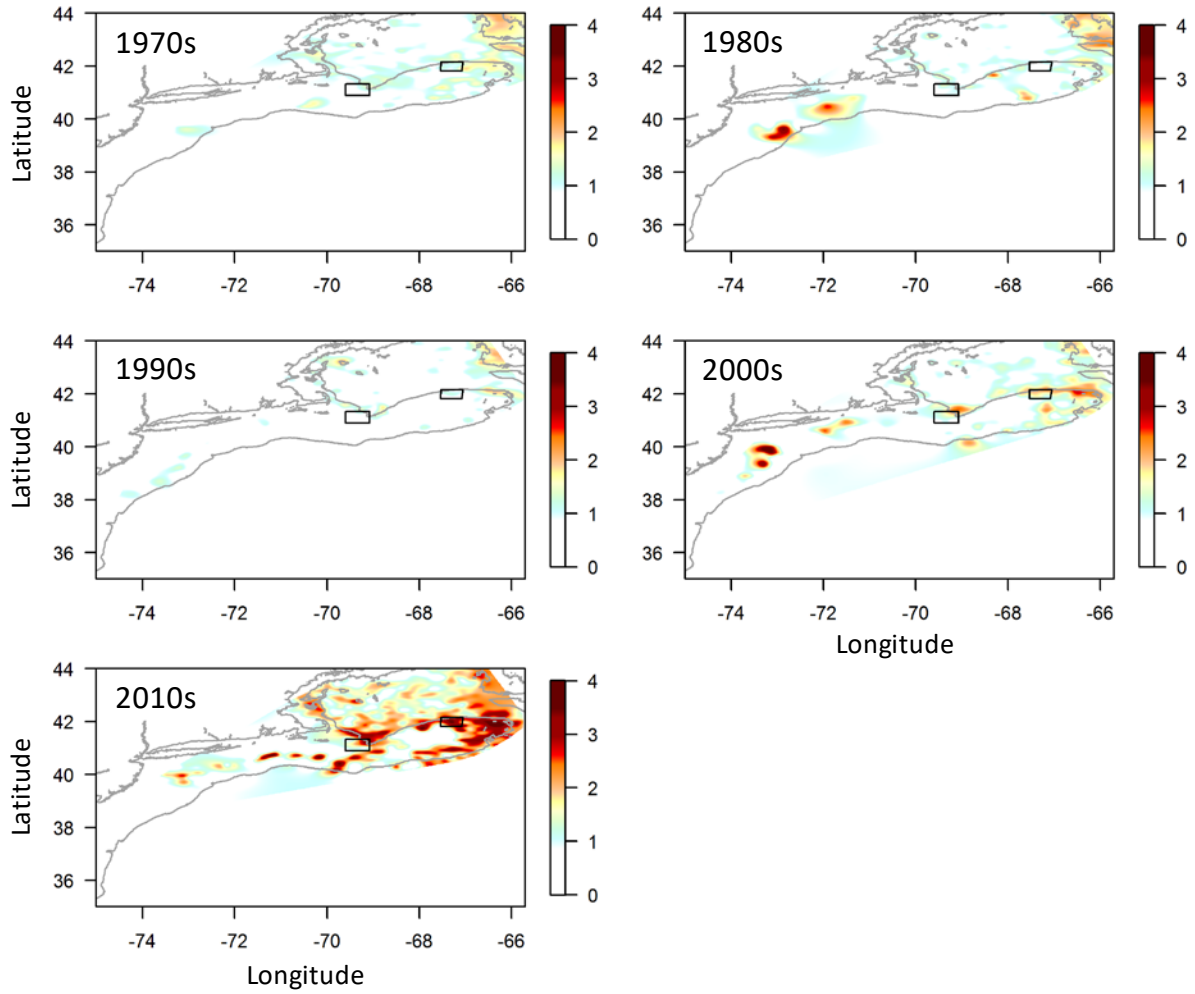


Figure 5.3.3. Spatial distribution of haddock as log abundance per tow by decade. Data from NEFSC fall bottom trawl survey. Consensus herring spawning areas (boxes) are shown. 100 m isobath is shown.



6. Research Recommendations

The following research recommendations were developed by the Herring PDT during review of this draft report. The Herring PDT includes all the members of the ASMFC Atlantic Herring Technical Committee. These recommendations are provided as input on future research in the region on this topic.

Overall PDT input: Overall, the easiest and most cost-effective approach is likely enhancing portside sampling efforts, followed by potentially enhancing collection of spawning data by at-sea observers and ASM. A fishery independent survey would be costly, and would take five or so years to complete; however, it would provide data from the entire area and season, not just where and when the fishery operates. Before a new survey is designed and implemented to support this subject, the goal of the survey should be defined so it is clear what benefits that survey would have over existing data collection methods. Finally, it is important to note that the herring stock is currently at low abundance; therefore, research conducted now may not be representative of spawning behavior when herring biomass is larger.

1. Enhance portside sampling efforts:

There is currently portside sampling occurring throughout the fishery, including herring trips from Georges Bank. However, the total number of trips from that region is much lower than the GOM for a variety of reasons, e.g. seasonality of the fishery, increased costs to fish offshore, sampling efforts are more concentrated in Maine and Massachusetts, etc. Therefore, while the current system is capable of sampling trips from GB, the current level is insufficient to track spawning activity on GB. The current portside sampling provides some information on seasonality of spawning on Georges Bank, but given how much this can change annually (approx. 5-6 weeks), there is a need for dedicated processing of portside samples over multiple years. An enhanced program could be designed to specifically target trips from GB during the spawning season. More resources could be used to increase the number of future samples, targeting trips from GB as described above, but it should be noted that the current level of sampling of GB trips would not be adequate to monitor a real-time spawning measure similar to the one that is in place for the GOM. If there are any samples that have not been processed those should be prioritized first, and then efforts to increase the number of samples from trips on GB.

2. Develop a new spawning survey of Atlantic herring on GB:

Fishery independent sampling of herring and spawning condition on GB would be useful, but may be cost prohibitive, i.e. \$200,000 a year or more. Specific stations and seasons would need to be identified in advance, and could be sampled using fishing gear, survey gear, and/or acoustics. The overall design could be similar to the acoustic survey previously conducted by NEFSC on GB. The survey should probably span about five years to capture annual variability, with multiple stations targeting herring during spawning season across the area including places the fishery does not operate. While somewhat dated and limited, there is previous research and published literature on this topic that will hopefully be part of the NEFMC discussion document. Due to the relatively large expense of this approach, it may be prudent to fully evaluate past

literature and research first, and then identify any knowledge gaps specific to management needs before a large spawning survey is funded.

3. Examine the feasibility of collecting spawning data at-sea by observers and ASMs, and on land by portside samplers:

The Fisheries Sampling Branch (FSB) could examine the possibility of collecting spawning data at sea on observed trips (NEFOP and ASM) if conditions allow. If it is feasible to collect these data at sea then new data fields could potentially be added or even a separate data collection sheet (e.g. total weight of fish, gonad weight, and spawning condition). Information like this could provide complementary spawning data, at a superior spatial scale (tow by tow vs averaging location in stat area), to what is being collected through portside sampling efforts. It is understood that adding fields would likely slow down the work of observers, and may require some post processing of fish samples taken at sea. It could cost more to have portside samplers do this work dockside, so it may even be possible for portside samplers to send NEFOP samples that could be worked up by NMFS at a later time instead.

The federal Atlantic herring fishery (midwater trawl) portside sampling program is scheduled to begin in April 2020. The collection of spawning data is not currently part of that sample design and was not included in draft regulations. Therefore, there would be additional costs and details that would need to be considered. The federal portside program may be a potential source of spawning data from landed catch in the future, but many details would need to be considered first.

7. References

- Bax, N.J. 1998. The significance and prediction of predation in marine fisheries. *ICES Journal of Marine Science* 55: 997-1030.
- Benjamin, S., Lee, M.-Y., and DePiper, G. 2018. Visualizing fishing data as rasters. Northeast Fisheries Science Center Reference Document 18-12. 24 p.
- Bigelow, H. B., and Schroeder, W. C. 1953. Fishes of the Gulf of Maine. *Fishery Bulletin US*, 53: 1–577.
- Boyar, H.C., Cooper, R.A. and Clifford, R.A. 1973. A study of the spawning and early life history of herring (*Clupea harengus* harengus L.) on Jeffreys Ledge in 1972. ICNAF Research Document 73/96, Series No. 3054. 27 p.
- Clarke, M., and Egan, A. 2017. Good luck or good governance? The recovery of Celtic Sea herring. *Marine Policy* 78: 163-170.
- DeAlteras, J., Allen, R. 2016. U.S. Atlantic Surfclam and Ocean Quahog MSC Fishery Assessment Report.
- DeCelles, G.R., Martins, D., Zemeckis, D.R., and Cadrin, S.X. 2017. Using fishermen’s ecological knowledge to map Atlantic cod spawning grounds on Georges Bank. *ICES Journal of Marine Science* 74: 1578-1601.
- Deroba, J.J. 2018. Working paper: predation pressure index to inform natural mortality. Appendix B5 of 65th Northeast Regional Stock Assessment Workshop (65th SAW) Assessment Report. Northeast Fisheries Science Center Reference Document 18-11.
- DFO. 2014. Canadian Atlantic Herring (*Clupea harengus*) – SWNS Rebuilding Plan – Atlantic Canada. Canadian Department of Fisheries and Oceans. <http://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/herring-hareng/herring-hareng-2013-eng.html>
- Finley, A., Banerjee, S., Hjelle, O. and Bivand, R. 2017. ‘MBA’: Multilevel B-Spline Approximation. R package version 0.0-9.
- Fuiman, L.A. 1989. Vulnerability of Atlantic herring larvae to predation by yearling herring. *Marine Ecology Progress Series* 51: 291-299.
- Goode, G.B. 1884. The fisheries and fishing industry of the United States. United States Commission of Fish and Fisheries.
- Hare, J.A., Morrison, W.E., Nelson, M.W., Stachura, M.M., Teeters, E.J., Griffis, R.B., Alexander, M.A., Scott, J.D., Alade, L., Bell, R.J., Chute, A.S., Curti, K.L., Curtis, T.H., Kircheis, D., Kocik, J.F., Lucey, S.M., McCandless, C.T., Milke, L.M., Richardson, D.E., Robillard, E., Walsh, H.J., McManus, M.C., Marancik, K.E., Griswold, C.A. 2016. A vulnerability assessment of fish and invertebrates to climate change on the Northeast U.S. Continental Shelf. *PLoS ONE* 11(2): e0146756.

- Hart, D.R., Chute, A.S. 2004. Essential fish habitat source document. Sea scallop, *Placopecten magellanicus*, life history and habitat characteristics. DIANE Publishing.
- Harris, B.P., Stokesbury, K.D.E. 2010. The spatial structure of local surficial sediment characteristics on Georges Bank, USA. *Continental Shelf Research* 30: 1840-1853.
- Hufnagl, M., and Peck., M.A. 2011. Physiological individual-based modelling of larval Atlantic herring (*Clupea harengus*) foraging and growth: insights on climate-driven life-history scheduling. *ICES Journal of Marine Science* 68: 1170-1188.
- ICES. 2017. Icelandic summer spawning herring. ICES NWWG Report 2017. <http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2017/NWWG/13-NWWG%20Report%202017%20Sec%2011%20Icelandic%20summer%20spawning%20herring.pdf>
- ICES. 2017b. Stock Annex: Herring (*Clupea harengus*) in Subarea 4 and divisions 3.a and 7.d, autumn spawners (North Sea, Skagerrak and Kattegat, eastern English Channel). ICES Stock Annex 2017. http://www.ices.dk/sites/pub/Publication%20Reports/Stock%20Annexes/2018/her.27.3a47d_SA.pdf
- Kelly, K.H. and Stevenson, D.K. 1983. Comparison of reproductive characteristics and age composition of Atlantic herring (*Clupea harengus*) spawning groups in the Gulf of Maine. Maine Department of Marine Resources. Research Reference Document 83/29. 46 p.
- Leo, E., Dahlke, F.T., Storch, D., Portner, H.-O., Mark, F.C. 2018. Impact of ocean acidification and warming on the bioenergetics of developing eggs of Atlantic herring *Clupea harengus*. *Conservation Physiology* 6: coy050.
- Link, J.S., Almeida, F.P. 2000. An overview and history of the Food Web Dynamics Program of the Northeast Fisheries Science Center, Woods Hole, Massachusetts. NOAA Technical Memorandum NMFS-NE-159.
- Lough, R.G., Hannah, C.G., Berrien, P., and Brickman, D. 2006. Spawning pattern variability and its effect on retention, larval growth and recruitment in Georges Bank cod and haddock. *Marine Ecology Progress Series* 310: 193-212.
- Lynam, C.P., Heath, M.R., Hay, S.J., Brierley, A.S. 2005. Evidence for impacts by jellyfish on North Sea herring recruitment. *Marine Ecology Progress Series* 298: 157-167.
- MAFMC (2018). Mid-Atlantic Fishery Management Council Atlantic Surfclam Information Document. Dover, DE: Mid-Atlantic Fishery Management Council. 15 p.
- McQuinn, I.H. 1997. Metapopulations and the Atlantic herring. *Reviews in Fish Biology and Fisheries* 7: 297-329.
- Möller, H. 1984. Reduction of a larval herring population by jellyfish predator. *Science* 224: 621-622.
- Munroe, T.A. 2002. Herrings. Family Clupeidae. In: Bigelow and Schroeder's fishes of the Gulf of Maine. 3rd ed. Washington, DC: Smithsonian Institution Press. p. 111-160.

- Murowski, S.A. 1993. Climate change and marine fish distributions: forecasting from historical analogy. *Transactions of the American Fisheries Society* 122: 647-658.
- Nash, R.D.M., Dickey-Collas, M. 2005. The influence of life history dynamics and environment on the determination of year class strength in North Sea herring (*Clupea harengus* L.). *Fisheries Oceanography* 14: 279-291.
- NEFMC. 2003. The role of Atlantic herring, *Clupea harengus*, in the northwest Atlantic ecosystem. Newburyport MA: New England Fisheries Management Council Draft Working Document. 61 p. http://archive.nefmc.org/herring/planamen/final_a1/appendix5.pdf
- NEFMC. 2006. Final Amendment 1 to the Atlantic Herring Fishery Management Plan incorporating the Environmental Impact Statement. Vol. I and II. Newburyport, MA: New England Fishery Management Council in consultation with the ASMFC, MAFMC and NMFS, 1660 p.
- NEFMC. 2013. Amendment 5 to the Fishery Management Plan (FMP) for Atlantic Herring: Appendices. Newburyport, MA: New England Fisheries Management Council in consultation with the NMFS, ASMFC and MAFMC, 1102 p.
- NEFMC. 2016. Omnibus Habitat Amendment II Volumes I-VI and Appendices. Newburyport, MA: New England Fisheries Management Council in consultation with the NMFS and MAFMC.
- NEFMC. 2019. Amendment 8 to the Atlantic Herring Fishery Management Plan Including a Final Environmental Impact Statement and Initial Regulatory Flexibility Analysis. Newburyport, MA: New England Fishery Management Council in consultation with the NMFS and MAFMC, 563 p. (under review)
- NEFMC. 2019b. Clam Dredge Framework Adjustment. Newburyport, MA: New England Fisheries Management Council in consultation with the NMFS and MAFMC, 209 p. (under review)
- NEFSC. 2017. 2017 assessment update of Georges Bank haddock. https://www.nefsc.noaa.gov/groundfish/operational-assessments-2017/docs/wps/2017_HAD_GB_RPT.pdf
- NEFSC. 2018. 65th Northeast regional stock assessment workshop (65th SAW) assessment summary report. Northeast Fisheries Science Center Reference Document 18-08.
- Noskov, A.S. and Zinkevich, V.N. 1967. Abundance and mortality of herring, *Clupea harengus* Linnaeus, on Georges Bank according to the results of egg calculation in spawning areas in 1964-66. ICNAF Res. Doc. 67/98, Ser. No. 1897. 16 p.
- Nychka, D., Furrer, R., Paige, J. and Sain, S. 2019. 'Fields': Tools for Spatial Data. R package version 9.8-3.
- Olsen, S., Brown, D., Charles, G., Grigalunas, T., Kowalski, T., Norton, V., Parker, H., Saila, S., Sedgwick, S. and Sutinen, J. 1977. Fishing and petroleum interactions on Georges Bank, volume II: The characteristics of the two industries, potential future trends, and an assessment of

foreseeable conflicts. Prepared for the New England Regional Commission by the Coastal Resources Center Graduate School of Oceanography, University of Rhode Island. 74 p.

Óskarsson, G.J., and Taggart, C.T. 2009. Spawning time variation in Icelandic summer-spawning herring (*Clupea harengus*). Canadian Journal of Fisheries and Aquatic Sciences 66: 1666-1681.

Overholtz, W.J., Jacobson, L.D., Melvin, G.D., Cieri, M., Power, M., Libby, D.A. and Clark, K. 2004. Stock assessment of the Gulf of Maine – Georges Bank Atlantic herring complex, 2003. U.S. Department of Commerce. NEFSC Reference Document 04-06.

Pepin, P., Pearre, S. jr., Koslow, J.A. 1987. Predation on larval fish by Atlantic mackerel *Scomber scombrus*, with a comparison of predation by zooplankton. Canadian Journal of Fisheries and Aquatic Sciences 44: 2012-2018.

Pershing, A.J., Alexander, M.A., Hernandez, C.M., Kerr, L.A., Le Bris, A., Mills, K.E., Nye, J.A., Record, N.R., Scannell, H.A., Scott, J.D., Sherwood, G.D., Thomas, A.C. 2015. Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery. Science 350: 809-812.

Pershing, A.J., Record, N.R., Franklin, B.S., Kennedy, B.T., McClenachan, L., Mills, K.E., Scott, J.D., Thomas, A.C., Wolff, N.H. 2019. Challenges to natural and human communities from surprising ocean temperatures. Proceedings of the National Academy of Sciences 116: 18378-18383.

Pinsky, M.L., Worm, B., Fogarty, M.J., Sarmiento, J.L., Levin, S.A. 2013. Marine taxa track local climate velocities. Science 341: 1239-1242.

Record, N.R., Runge, J.A., Pendleton, D.E., Balch, W.M., Davies, K.T.A., Pershing, A.J., Johnson, C.L., Stamieszkin, K., Ji, R., Feng, Z., Kraus, S.D., Kenney, R.D., Hudak, C.A., Mayo, C.A., Chen, C., Salisbury, J.E., Thompson, C.R.S. 2019. Rapid climate-driven circulation changes threaten conservation of endangered north Atlantic right whales. Oceanography 32: 162-169.

Reid, R.N., Cargnelli, L.M., Griesbach, S.J., Packer, D.B., Johnson, D.L., Zetlin, C.A., Morse, W.W. and Berrien, P.L. 1999. Essential Fish Habitat Source Document: Atlantic Herring, *Clupea harengus* L., Life History and Habitat Characteristics. Highlands, NJ: U.S. Department of Commerce.

Reygondeau, G., Beaugrand, G. 2011. Future climate-driven shifts in distribution of *Calanus finmarchicus*. Global Change Biology 17: 756-766.

Rich, W.H. 1929. Fishing Grounds of the Gulf of Maine. U.S. Commissioner of Fisheries, Washington, D.C.

Richardson, D.E., Hare, J.A., Overholtz, W.J., Johnson, D.L. 2010. Development of long-term larval indices for Atlantic herring (*Clupea harengus*) on the northeast US continental shelf. ICES Journal of Marine Science 67: 617-27.

- Richardson, D.E., Hare, J.A., Fogarty, M.J., Link, J.S. 2011. Role of egg predation by haddock in the decline of an Atlantic herring population. *Proceedings of the National Academy of Sciences* 108: 13606-13611.
- Ridgeway, G.J. 1975. A conceptual model of stocks of herring (*Clupea harengus*) in the Gulf of Maine. ICNAF Research Document 75/100. 17 p.
- Ripley, B., Venables, B., Bates, D.M., Hornik, K., Gebhardt, A., and Firth, D. 2019. 'MASS': Support Functions and Datasets for Venables and Ripley's MASS. R Package version 7.3-51.4.
- Sherwood, G.D., Baukus, A., Chawarski, J. 2017. Continuation of the Maine inshore acoustic herring survey: Collaborative research to support the Maine lobster industry. Final Report to the 2014 Saltonstall-Kennedy Grant Program. 68 pp.
- Sinderman, M.A., and Iles, T.D. 1985. Atlantic herring (*Clupea harengus*) distribution in the Gulf of Maine-Scotian Shelf area in relation to oceanographic features. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 880-887.
- Smith W.G., and Morse, W.W. 1993. Larval distribution patterns: early signals for the collapse/recovery of Atlantic herring in the Georges Bank area. *Fishery Bulletin US* 91: 338-347.
- STECF. 2007. Evaluation of Closed Area Schemes. Commission Staff Working Document, Subgroup on management of stocks (SGOMS), of the Scientific, Technical, and Economic Committee for Fisheries (STECF). Commission of the European Communities.
https://stecf.jrc.ec.europa.eu/documents/43805/44876/07-09_SG-MOS+07-03+-+Evaluation+of+closed+areas+II.pdf
- Stevenson, D.K. 1989. Spawning locations and times for Atlantic herring on the Maine coast. Maine Department of Marine Resources. 89/5. 16 p.
- Stockwell, J.D., Weber, T.C., Baukus, A.J., Jech, J.M. 2013. On the use of omnidirectional sonars and downwards-looking echosounders to assess pelagic fish distributions during and after midwater trawling. *ICES Journal of Marine Science* 70: 196-203.
- Van Overzee, H.M.J., and Rijnsdorp, A.D. 2015. Effects of fishing during the spawning period: implications for sustainable management. *Reviews in Fish Biology and Fisheries* 25: 65-83.
- Venables, W.N. and Ripley, B.D. 2002. *Modern Applied Statistics with S*. Fourth edition. Springer.
- Wickam, H., Chang, W., Lionel, H., Pederson, T.L., Takahashi, K., Wilke, C., Woo, K., and Yutani, H. 2016. 'GGplot2': Create Elegant Data Visualizations Using the Grammar of Graphics. R Package version 3.2.0.
- Winters, G.H., and Wheeler, J.P. 1996. Environmental and phenotypic factors affecting the reproductive cycle of Atlantic herring. *ICES Journal of Marine Science* 53: 73-88.



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DRAFT MEMORANDUM

DATE: June 1, 2020
TO: Herring Committee
FROM: Herring Plan Development Team (PDT)
SUBJECT: **Initial input on Framework 7 (GB spawning action)**

The Herring Committee met on March 3, 2020 to begin development of Framework 7, an action to protect spawning of Atlantic herring on Georges Bank. During the meeting, the Committee recommended what the objectives of the action should be and identified a handful of tasking items for the PDT to work on to support Framework 7. The PDT met on April 4 and May 14 to develop Framework 7 and review initial analyses. This memo summarizes initial input from the PDT for Committee consideration.

First, the PDT reviewed the draft goal and objective developed by the Herring Committee, to “*develop measures to protect spawning adults of Atlantic herring and/or Atlantic herring egg mats to increase overall herring biomass. The objective of this action is to consider similar measures as in Area 1A for other spawning components of this resource (i.e. Georges Bank and Nantucket Shoals).*”

The motion was perfected by the Committee to include “and/or” before herring egg mats to clarify that if there is not enough information to support measures for adult herring or herring egg mats, the action could focus on just one life history stage. The maker of the motion clarified that the intent of the motion is to leave the door open in terms of which fisheries this action could include. As this action proceeds, it may consider measures that would restrict other fisheries in the region, not just the herring fishery. The Council approved the goal and objective for this action at the April 2020 Council meeting.

The PDT has two questions/comments about the goal and objectives developed for Framework 7:

1. The alternatives developed will have different levels of protection depending on their size, location, starting date, duration, and fisheries restricted. How much protection is desired? Does the Committee have more direction about the level of protection these alternatives should meet? For example, is the goal to protect some spawning activity/egg development on GB, most spawning activity/egg development, etc.?
2. When the Commission developed the GOM spawning areas it was considered whether the primary objective was to: A) protect spawning fish from being harvested; or B) protect the act of spawning from fishing activity by reducing or eliminating fishing disturbance/interaction. The PDT members that are involved in both plans explained that

ultimately, the primary objective of the GOM spawning closures is the former - protection of spawning fish from harvest, as that objective is more feasible. However, the PDT noted that more conservative alternatives, i.e. larger and longer closures, could address the second objective as well – reduce disturbance of spawning activity. Does the Herring Committee have any additional input specific to these two objectives previously considered by the Commission?

Next, the PDT reviewed the tasking items from the Herring Committee related to Framework 7. The Committee did not identify a specific range of alternatives, but rather, provided some direction for PDT analysis. First, the Committee requested that the PDT look at herring egg mats in more detail, specifically which fisheries may have impacts (mobile and/or fixed gear) and what do we know about herring egg mats (e.g. suitable habitat conditions, location, size). In addition, as the range of alternatives is developed the Committee recommended the PDT focus on protections for adult herring first, and then on spatial closures that would protect herring egg mats, if that is possible and practical. Second, related to potential closure dates the Committee recommended that the PDT look at default dates at this time because it would be more practical than implementing real time monitoring of spawning condition and specific trigger thresholds is very time and resource intensive, and thus impractical. The Committee did not want to specify the level of spawning maturity the default closure dates should be based on (i.e. % of gonadal somatic index (GSI)). It was pointed out by a PDT member present at the meeting that it may be useful to set default dates using the same GSI triggers that are in place for the ASMFC measures to be consistent.

1.0 Herring Egg Mats

The PDT consulted with the Habitat PDT to summarize what is known about herring eggs in this region as well as potential impacts of fishing on herring egg mats. The EFH source document for Atlantic herring includes a detailed summary of the existing information available (Stevenson and Scott, 2005). There is limited information on herring egg mat locations and little direct research on the potential impacts of fishing on herring egg mats. Attachment 1 to this memo summarizes the primary information available and provides a list of references.

2.0 Default closure dates

Several years ago, ASMFC considered modifications to the Gulf of Maine spawning closures, including adjusting how and when the spawning areas close. Those spawning closures, implemented as Addendum II to Amendment 3 to the ASMFC Atlantic Herring Management Plan, are driven by real-time GSI data of adult fish collected from port samplers. However, each area also has a default date that is in place if real time data are not available. The PDT replicated the GSI timing analyses developed for Addendum II, using data from herring fishing trips from Georges Bank only. Attachment 2 includes more detail about these analyses.

Based on these analyses, the estimated mean date when the closure threshold was reached over the 22-year period from 1998-2019 was September 14th, which is 10 days earlier than the Massachusetts/New Hampshire and Western Maine spawning areas of the GOM (Figure 7 of Attachment 2). Under a 6-week closure period, a Georges Bank spawning closure would re-open on October 26th. If an 8-week period were to be adopted, the closure would begin on September 7th and re-open on November 2nd. The extension of one week in either direction would encompass spawning activity occurring both early and later in the season.

3.0 Initial PDT input on range of alternatives

The PDT primarily used the results from the GB Spawning Discussion Document (NEFMC, 2019)¹ to inform potential alternatives. At this stage, the PDT is not recommending specific spatial management areas; instead, this section presents several approaches the Committee could use to define alternatives. The GB Spawning Discussion Document included an overlap analyses of several data sets. The PDT recommends that these areas of overlap could be used to define potential alternatives. The PDT has developed three examples for discussion purposes. The Committee could endorse these examples or provide more feedback about priority data sources to consider.

For Option 1, the GB Spawning Discussion Document identified areas where three or more of the six data layers overlapped (See Figures 3.3-3.5 in that document and Figure 1 below). This exercise highlighted two distinct areas, one on eastern Georges Bank, and one in western Georges Bank.

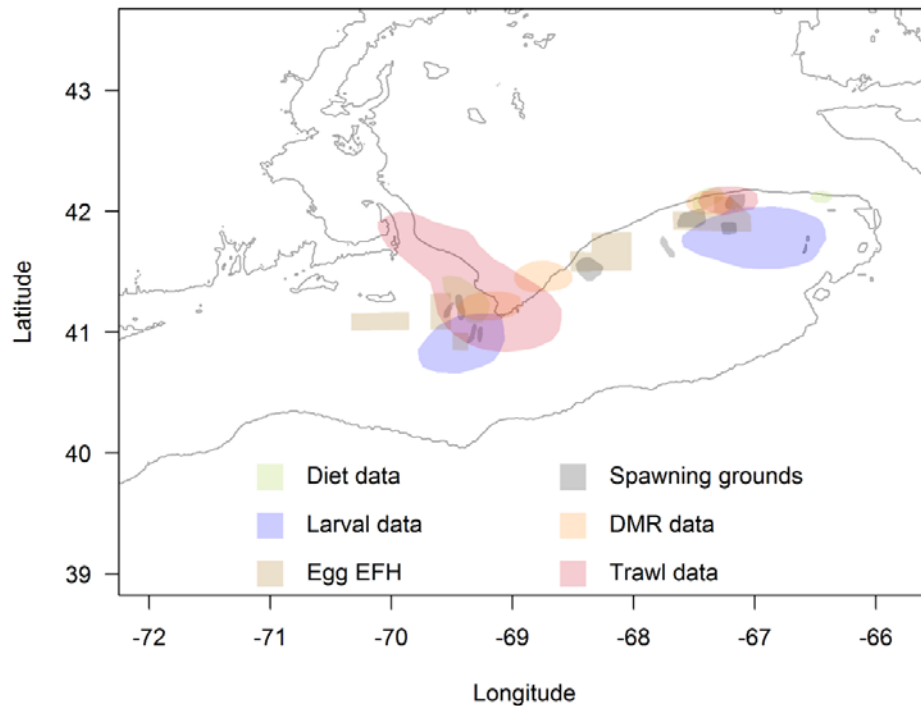


Figure 1 – Areas of overlap between multiple data sources including data from food habits database, larval monitoring, egg EFH, historical spawning grounds, DMR portside monitoring (mat stage U), and fall trawl survey (mat stage U). 100 m isobath is shown. This is Figure 3.3 of GB Spawning Discussion Document.

Figure 2 shows Option 1, which includes an area on eastern GB (top) and western GB (bottom). This option is about 3,500 km² for both areas combined. The PDT discussed that a possible modification to this option could be to expand the area by 25% for example, to recognize that areas of spawning vary annually, and a larger area would improve the likelihood of overlap with future spawning activity.

¹ GB Spawning Discussion Document (NEFMC, 2019) https://s3.amazonaws.com/nefmc.org/2_Herring-Spawning-Review-191122.final.pdf

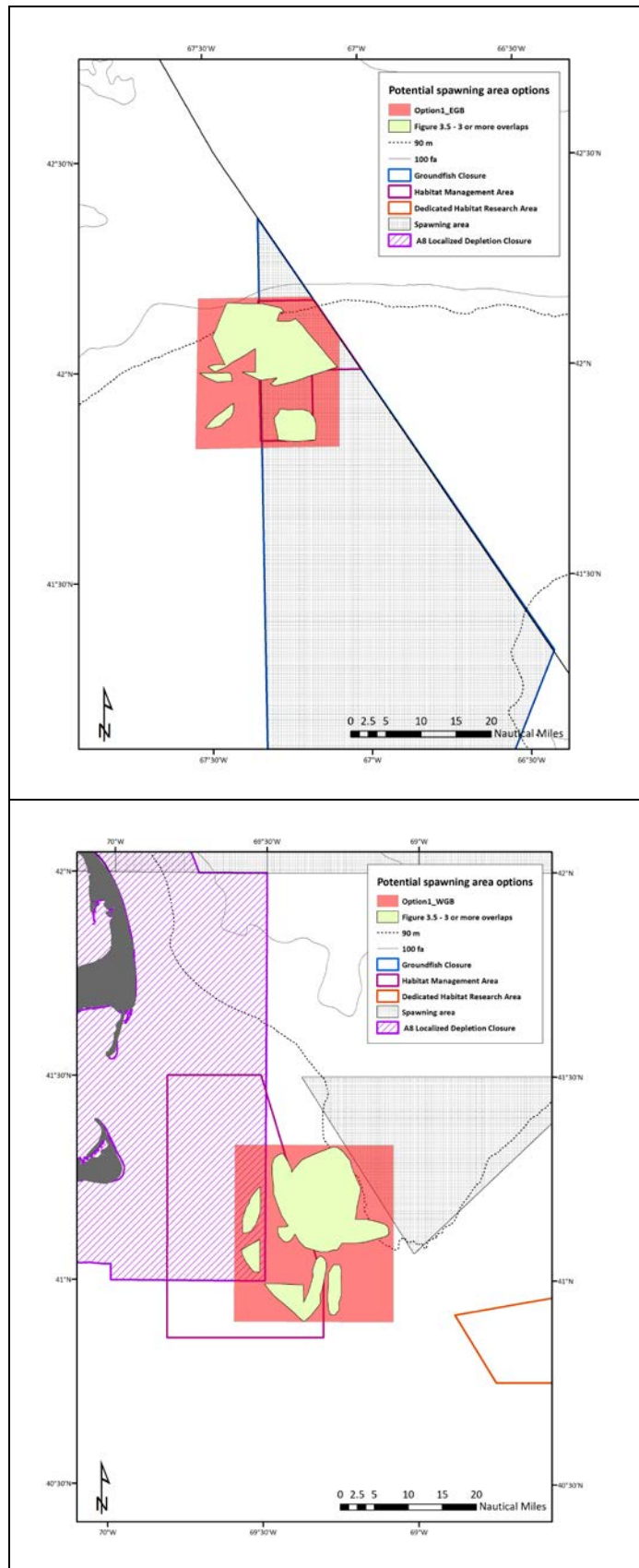


Figure 2 – Potential approach to identify GB spawning areas (Option 1), eastern GB area on top and western GB area on bottom. Option 1 based on areas where three or more datasets overlap.

For Option 2, the PDT instead focused on the spawning adult datasets only. This option also uses analyses from the GB Spawning Discussion Document that displayed the location of spawning adults from both the NEFSC bottom trawl fall survey as well as Maine DMR portside samples of spawning adults by decade (1981 – 2018) (See Figures 3.6 and 3.7 in that document and Figure 3 below). The candidate areas for Option 2 are shown in Figure 4, two separate areas again on eastern and western GB where three or more coverages overlap. The eastern GB area is very similar to the eastern GB area highlighted in Option 1; however, the western GB areas are quite different. This potential approach focuses on locations of adult spawning herring and recognizes spatial variation by decade, compared to the previous approach which includes additional datasets including location of herring larvae, herring egg EFH, etc.

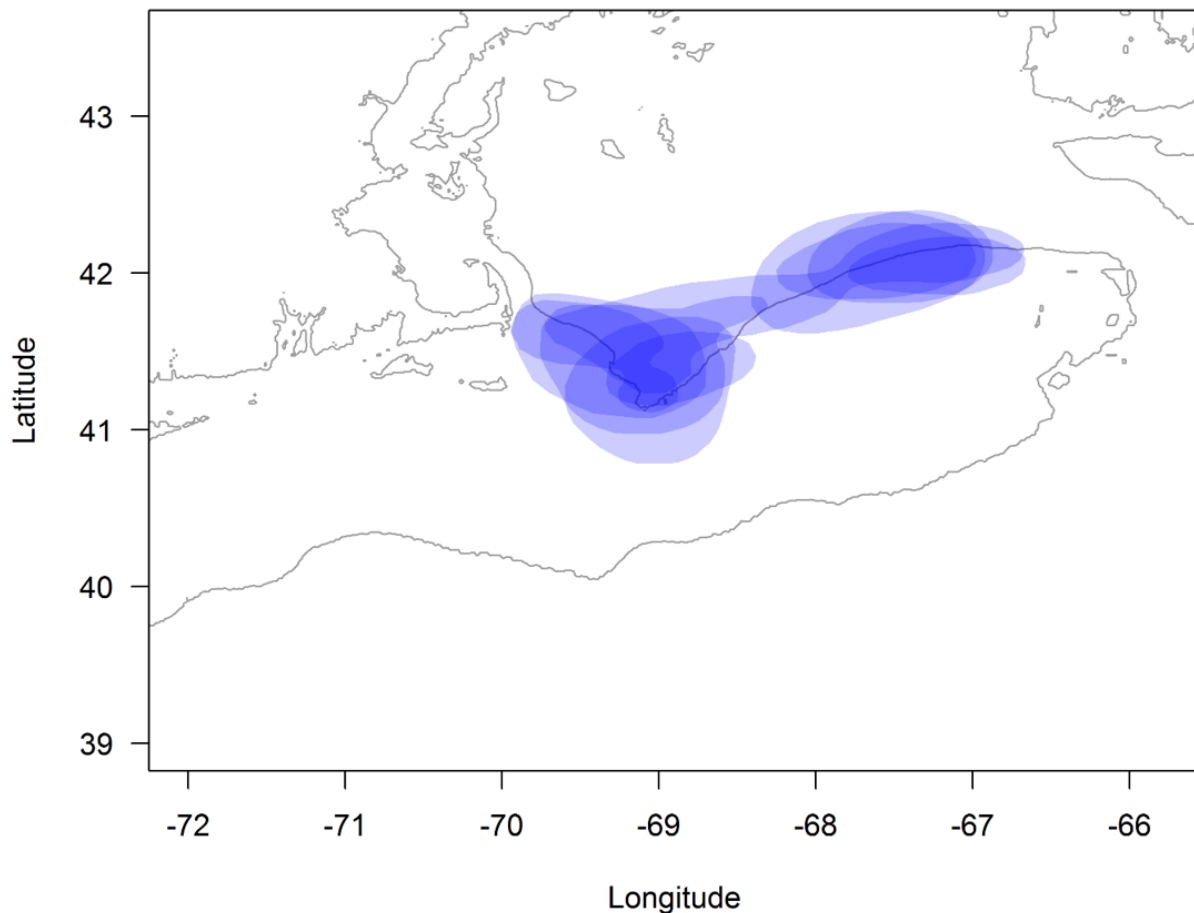


Figure 3 - Overlap areas for maturity stage R+U herring from both DMR and trawl survey data sets for multiple decades. 100 m isobath is shown. This is Figure 3.7 of GB Spawning Discussion Document.

Figure 4 shows Option 2, which also includes an area on eastern GB (top) and western GB (bottom). The areas have a high degree of overlap with Option 1 for eastern GB, but not western GB. Option 2 is about 5,500 km², with most of the increase in area related to the area on western GB, since the areas in eastern GB for both Option 1 and 2 are about 1,500 km².

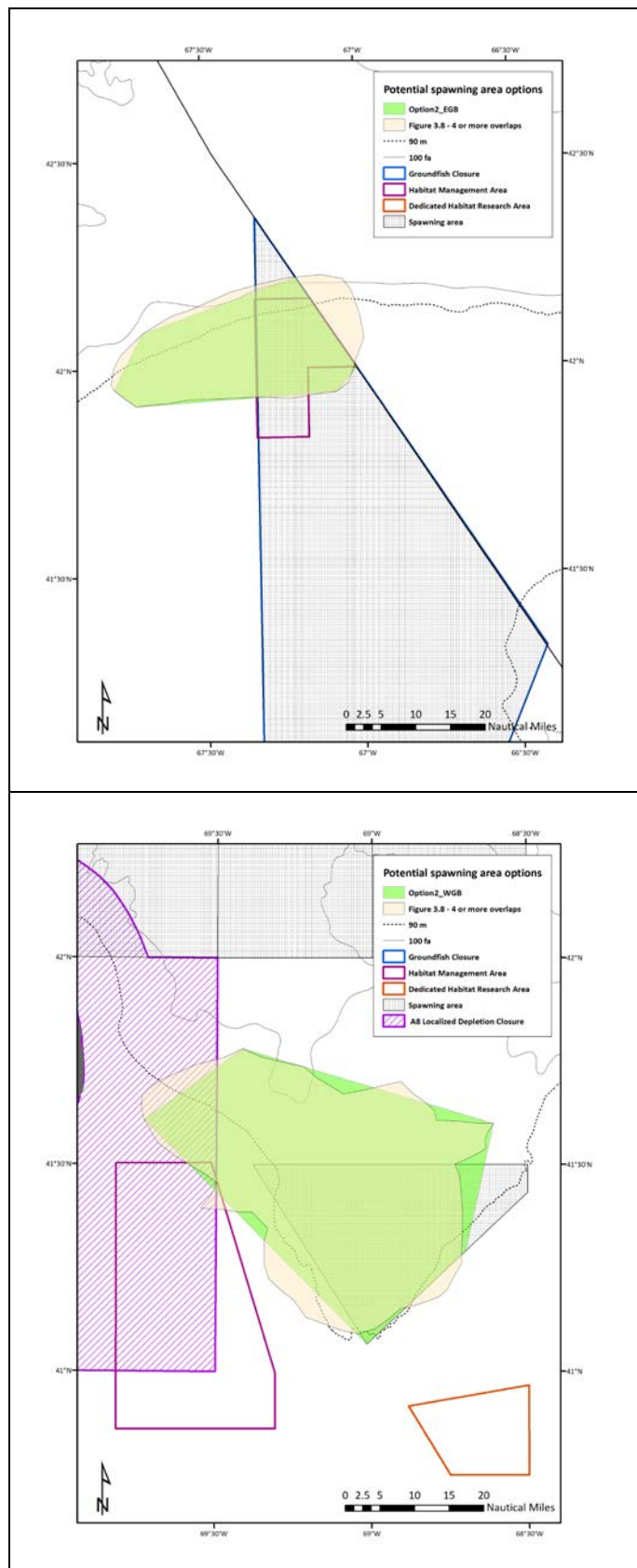


Figure 4 – Potential approach to identify GB spawning areas (Option 2), eastern GB area on top and western GB area on bottom. Option 2 based on overlap of spawning adult datasets by decade.

Finally, the PDT explored another option that would incorporate most of the core areas identified in Option 1 as well as Option 2, recognizing that spawning locations vary over time. This option would be the most conservative and would essentially close the entire northern edge of Georges Bank (Figure 5). The estimated size of this option in blue is just under 10,000 km² (about 9,900 km²).

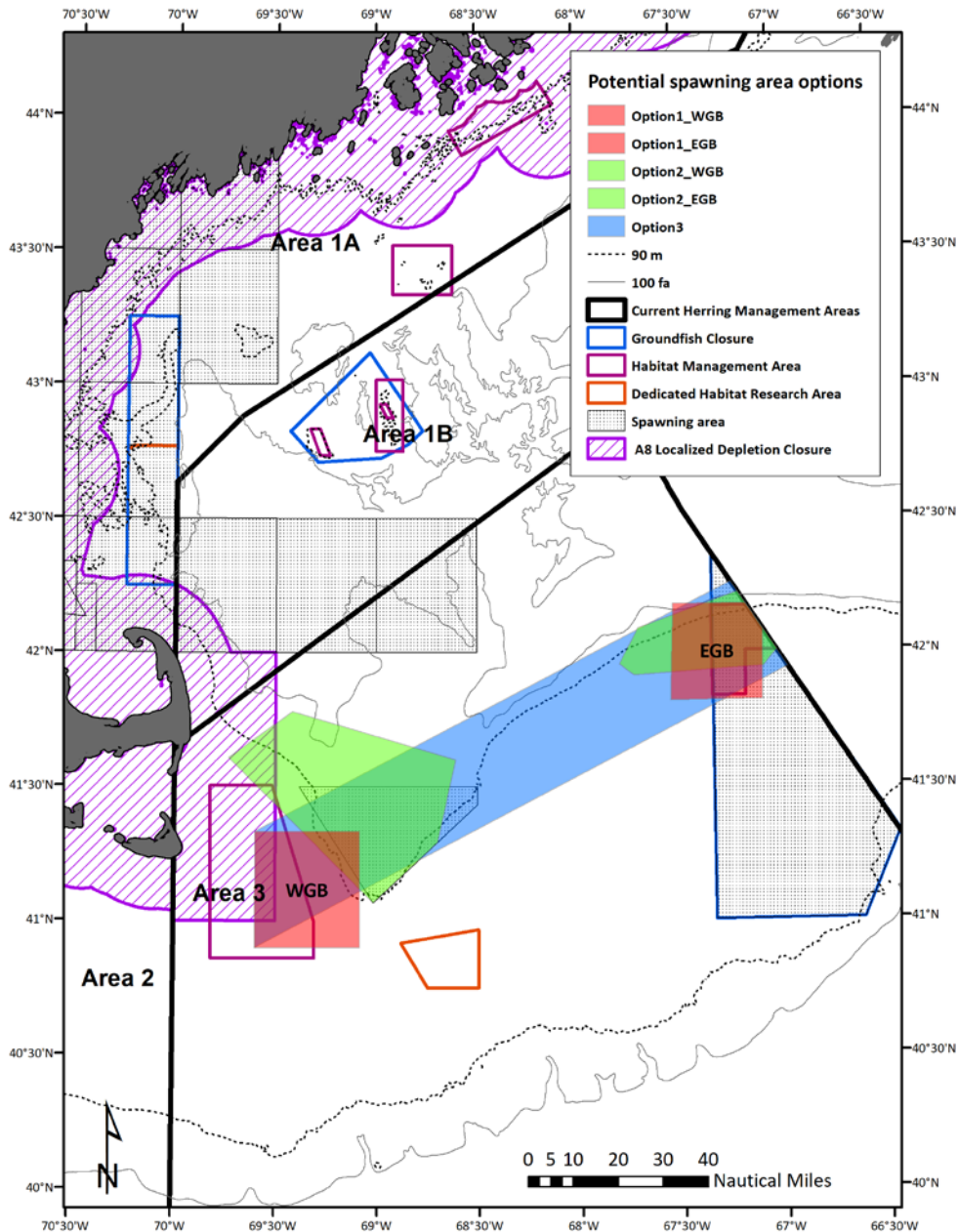


Figure 5 – Potential approach to identify GB spawning areas (Option 3 in blue). Option 3 based on identifying an area that would encompass most of Option 1 and 2 and include areas in between to recognize interannual variability.

Egg protections alternatives

In terms of location, in the absence of direct data on the recent location of egg mats, the initial recommendation is to use the same spatial areas developed for protection of adult spawning herring since eggs are released close to the bottom. Therefore, the locations of egg mats are expected to be relatively close to the locations that adult herring spawn. In addition, data inputs to Option 1 include locations of egg beds and newly hatched larvae, and thus are partly based on egg mat distribution.

In terms of timing, herring egg incubation is influenced by temperature but generally varies between 10 and 15 days after eggs are released in the Gulf of Maine/Georges Bank region (Stevenson and Scott, 2005). As recommended above, the potential spawning closure season may be six or eight weeks to include the season when most observations of adult herring were in spawning condition. Therefore, an additional two weeks could be added at the end of the window to specifically protect egg mats from impacts of fishing activity. However, it should be noted that there is variation on when and where spawning takes place; therefore, without real time GSI data to monitor spawning condition during the season, it will be difficult to protect spawning with relatively short seasonal restrictions.

To date, the Council has not limited the scope of this action to herring fishing only. It may also include alternatives to protect herring egg mats from other fishing gears such as bottom trawls, dredges, pots, etc. The PDT has not yet spent extensive time exploring the various potential effects of fishing on herring egg mats from different gear types. There is limited research on that topic and what is available has been summarized in Attachment 1. The PDT briefly discussed that it could be possible to allow pelagic gears in these areas during the egg incubation period if pelagic gears are fished in the water column with minimal impacts on benthic egg mats.

Finally, Figure 6 shows the PDT strawman ideas overlaid with seabed forms and sediment grain size. Seabed form is based on bathymetry data and combines depth and slope of the seafloor to show depressions, ridges, flat areas, and steep areas. The grain size data shown here indicates the percentage of the seabed in each grid cell that is covered by granule or pebble. Herring spawn on rocky, pebbly, or gravelly bottoms shell substrates, and on clay to some extent, but probably never on soft mud (Bigelow and Schroeder, 1953). These figures have been included to show that seabed form or sediment grain size could also be used to inform potential alternatives.

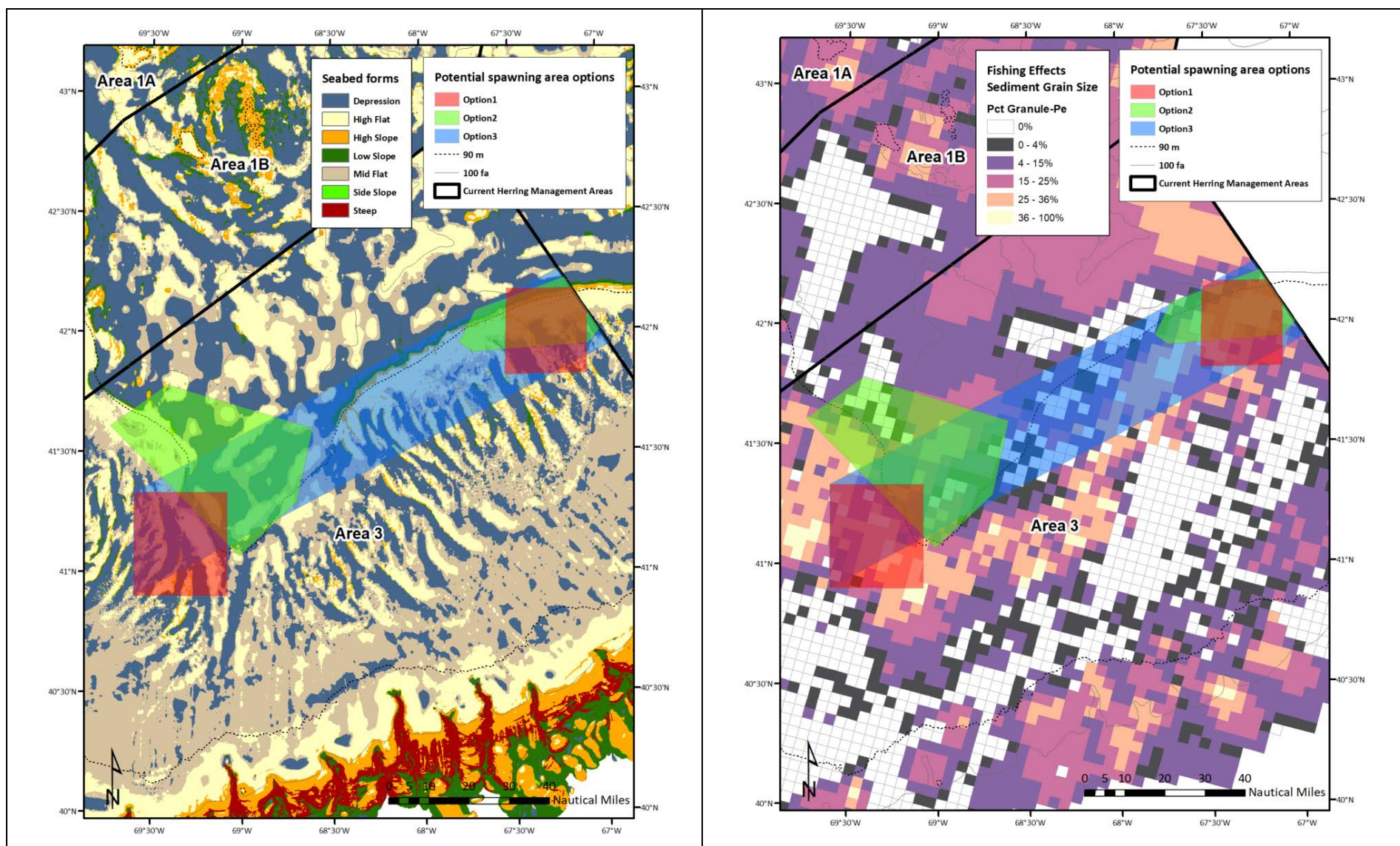


Figure 6 – Potential herring spawning areas compared to seabed forms and sediment grain size.

General PDT input – Issues to consider

1. The areas and seasons adopted may not capture all the among and within year variability. The PDT expects spawning fish will still be caught outside of closure areas, just as they are relative to the spawning closures in the GOM. A more flexible, real-time system is desirable since spawning areas and seasons vary annually. If a more dynamic system is not feasible in this action, it would be useful to review this information after several years and potentially adjust boundaries and/or seasons. The PDT notes that the spawning closures that are in place in the GOM have taken over a decade to refine, so there should be an expectation that any measure adopted would need to be reviewed and adjusted as more information is available.
2. After IFM implementation there may be improved data on spawning of Atlantic herring on GB (i.e. more GSI samples from dockside monitors, additional sampling from at-sea monitors at higher observer coverage rates (50%), etc.). However, this would require specific training and collection of spawning specific data are not currently planned. In order to use these data to inform adjustments in the future, more resources would need to be invested to expand the current protocols.
3. The action could include alternatives that are not complete closures to herring fishing, instead a “tolerance” of spawning fish would be allowed. For example, during a certain season trips from Area 3 could not have more than 20% stage 5 and 6 fish. The GOM spawning closures previously had a 20% tolerance for spawning fish, but that measure was problematic to enforce and was removed.
4. The PDT discussed whether it was possible to develop alternatives that protect adult spawning fish from harvest but allow fishing on juvenile herring. While it may be possible to target juvenile fish in the water column above spawning adult fish closer to the bottom, at this time the PDT does not plan to develop those alternatives in this action due to concerns about enforceability.
5. Finally, given the stock status of herring data collected now and previously at lower stock sizes may not be representative of the stocks spawning behavior when it is rebuilt.

References:

Bigelow HB Schroeder WC.1953. Fishes of the Gulf of Maine. Rev. ed. Washington (DC): US Government Printing Office. Fishery Bulletin no. 74 of the Fish and Wildlife Service, US Department of the Interior.

NEFMC, 2019. GB Spawning Decision Document.

https://s3.amazonaws.com/nefmc.org/2_Herring-Spawning-Review-191122.final.pdf

Attachment 1

Atlantic herring spawning and egg mats

On Georges Bank, Atlantic herring spawn in aggregations on the northern edge of Nantucket Shoals and along the northern flank (Stevenson and Scott, 2005). These spawning areas contracted to a few isolated locations when the stock was at low abundance levels and were observed to expand as abundance levels increased in the 1980s and 1990s (Melvin and Stephenson, 2007; Stevenson and Scott, 2005).

Female herring deposit their eggs in discrete mats on the seafloor in areas with strong tidal currents at water depths ranging from 5 to 90 m (Stevenson and Scott, 2005). The habitat characteristics and requirements for Atlantic herring eggs are summarized in the Essential Fish Habitat source document (Table 1, reproduced from Stevenson and Scott, 2005). Eggs may be deposited on a variety of sediment types, but gravel has been identified as the predominant egg mat substrate on the northern edge of Georges Bank (Drapeau 1973; Valentine and Lough 1991). Surveys conducted on Georges Bank from 1964 to 1970 found egg beds to be restricted to elongated areas of gravel substrate at depths of 40 to 50 m, situated between gravelly sand regions and sand ridges about 10 to 20 m in height (Valentine and Lough 1991). Due to the strong bottom currents present in spawning areas on Georges Bank, finer sediments (i.e., sand and mud) are not sufficiently stable for secure adhesion of egg mats, and transitions from gravel to finer sediment have been observed to delineate the edges of egg beds (Stevenson and Scott, 2005). Egg mats, which can measure up to 5 cm in thickness, may consist of many layers (Stevenson and Scott, 2005). It is inferred that strong currents provide oxygen to eggs, prevent siltation, and remove metabolites (Drapeau 1973). Studies of Atlantic herring in the Northeast Atlantic demonstrate that habitat structure (emergent flora and fauna) are important for hatching success by increasing surface area and egg aeration (P. Auster, personal communication).

Egg mats can cover large regions of the seafloor (Stevenson and Scott, 2005); in 1964, an egg mat observed on Georges Bank measured about 65 km² (Noskov and Zinkevich, 1967). The locations of egg mats have been documented by Anthony et al. (1970), Caddy and Isles (1973), and Pankratov and Sigaev (1973), and are reflected in the EFH map. The herring egg EFH map also reflects locations where larvae <=10mm were found in various ichthyoplankton surveys conducted between 1971 and 2013. Herring larvae hatch at between 4 and 10 mm total length (Fahay 2007), so larvae that are 10 mm or smaller in size are expected to be close to the location where their eggs were incubated. Herring larvae have exhibited a similar distribution pattern to spawning adults, occupying increasingly large areas of Georges Bank as the herring population grew in the late 1980s and 1990s (Figure 7).

Exact timing of Atlantic herring spawning events may vary year-to-year by several weeks due to interannual variability in oceanographic conditions (Winters and Wheeler, 1996). Spawning occurs from late August to December in the Georges Bank/Nantucket Shoals region, with a peak in September and October (Stevenson and Scott, 2005). Larval surveys in 1971-1975 indicated that spawning occurred on a temporal-spatial gradient, starting with northeast Georges Bank in September and extending southwest over a period of weeks to Nantucket Shoals, where spawning occurred in October (Grimm 1983). Herring egg incubation period is influenced by temperature but generally varies between 10 and 15 days in the Gulf of Maine/Georges Bank region (Stevenson and Scott, 2005).

Table 1 - Summary of habitat characteristics and requirements for Atlantic herring in the northwest Atlantic continental shelf ecosystem

Eggs

Habitat	Discrete, demersal, egg “beds” in coastal waters and on offshore banks and ledges in the Gulf of Maine and on Georges Bank with strong bottom currents and coarse substrate.
Depth	5-90 m.
Substrate	Boulders, rocks, gravel, coarse sand, shell fragments, macrophytes, and on a variety of benthic organisms and man-made structures (e.g., lobster traps); not on mud or fine sand.
Temperature	Bottom temperatures over egg beds ranged from 7-15°C; egg development normal 1-22°C; development rates/incubation times inversely related to temperature (10-15 days at 8-13°C).
Salinity	32-33 ppt in situ, maximum hatching success 20-35 ppt (lab studies).
Other	Low hatching success at dissolved oxygen concentrations < 20% saturation; 100% mortality of eggs under 1 cm of sediment, 85% mortality under thin film of sediment.
Predators	Cod, haddock, cunner, red hake, sand lance, probably moon snails, hermit crabs and starfish.
Prey	Not applicable.

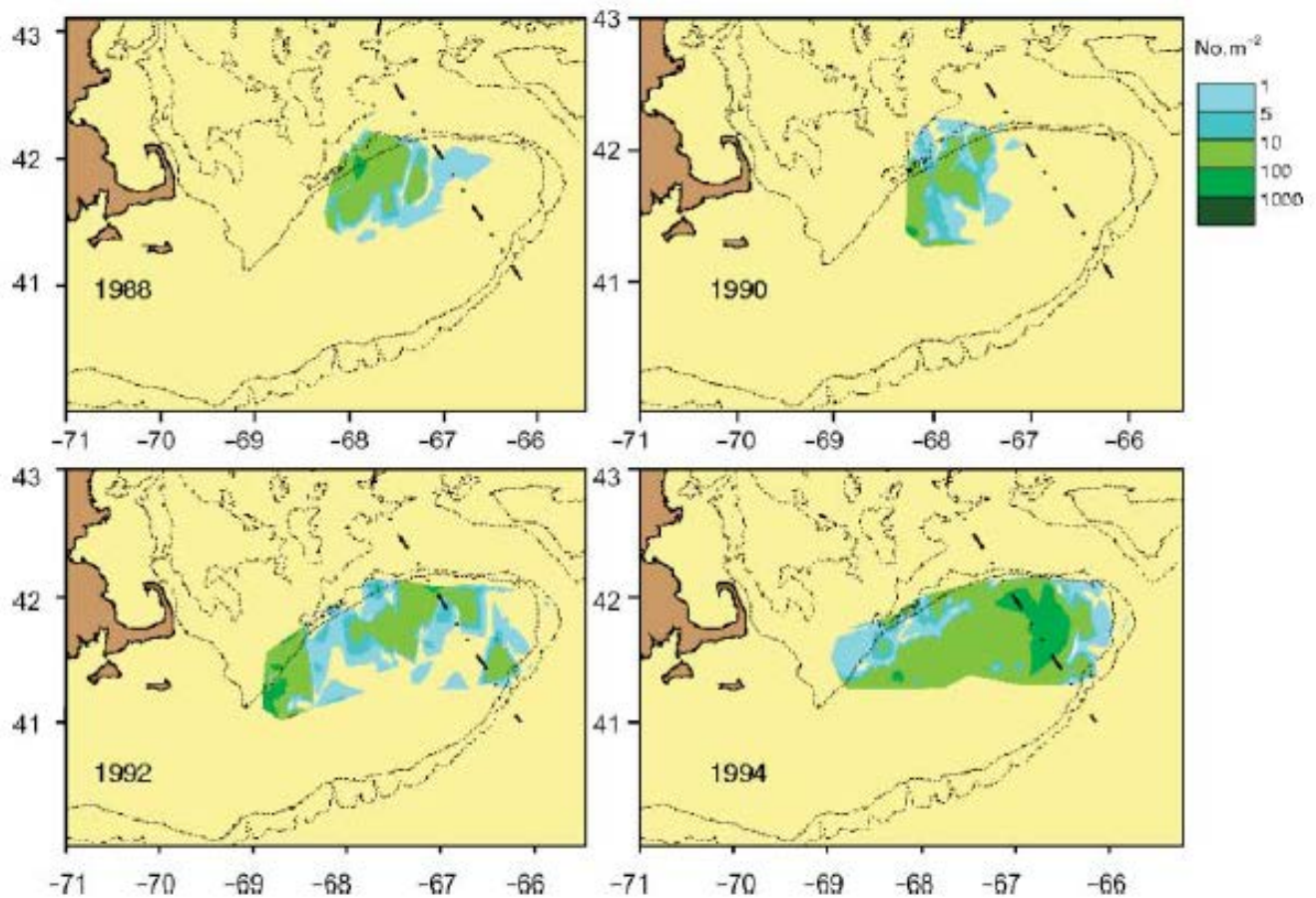


Figure 7 - From Melvin and Stephenson, 2007. Distribution of recently hatched larvae (<10 mm total length) on Georges Bank in four representative years, 1988, 1990, 1992, and 1994.

Fishing effects on egg mats

There are numerous studies examining the physical effects of fishing gears on seabed structures and fauna. Gear impacts vary by gear type, gear design, and benthic habitat characteristics in the region being fished (Grabowski et al. 2014). Fishing gear that contacts the seafloor can disturb the substratum in fished areas, with the magnitude of the effect being determined by towing speed, gear configuration, substratum characteristics, and water current strength (Jennings and

Kaiser, 1998). Benthic trawl gear has been shown to penetrate substrata to depths of a few centimeters. Surface impressions (i.e., ripples) in the sediment can be smoothed over by trawls, while trawl doors can leave depressions in the substrate (Jennings and Kaiser, 1998). Trawl and dredge gear can churn sediment due to both direct contact with the sediment and turbulence behind fishing gear. Suspended sediments which result from fishing disturbance have been reported to settle out within hours, although horizontal displacement may occur, particularly in areas with strong currents (Mayer et al., 1991; O'Neill et al., 2013).

Inferring from this research, the potential effects that bottom-tending gear types may be anticipated to have on herring egg mats include direct disturbance/detachment of eggs and settlement of resuspended sediment on egg mats. In a laboratory study, covering Atlantic herring eggs with a thin layer of sediment caused 85% mortality, although suspended sediments at concentrations of up to 7,000 ml/l were not shown to influence hatching success (Messieh et al. 1981). The potential for resettled sediments to cover herring egg mats due to fishing gear disturbance has not been directly studied; while there could be risk of increased sediment loads on egg beds, the strong currents in spawning areas could mitigate this effect by sweeping suspended sediments away from spawning sites.

Fewer studies have estimated secondary effects of gear effects on fishery resources, i.e. how fishing gear alteration of the seabed affects stock production (Collie et al., 2017). For example, fishing gears may smooth the sediment rendering it less suitable for attachment of egg mats, which could lead to lower hatch rates and thereby lower recruitment.

References Cited

- Anthony, V., V.I. Sauskan, and J.K. Sigaev. 1970. Cooperative herring egg survey - Georges Bank, 1969: International Commission for the Northwest Atlantic Fisheries, Redbook 1970, Part III, p. 123-133.
- Caddy, J. F., and T.D. Isles. 1973. Underwater observations on herring spawning grounds on Georges Bank: International Commission for the Northwest Atlantic Fisheries, ICNAF Research Bulletin No. 10, p. 131-139.
- Collie, J., J.G Hiddink, T. van Kooten, A.D. Rihnsdorp, M.J. Kaiser, S. Jennings, and R. Hilborn. 2017. Indirect effects of bottom fishing on the productivity of marine fish. *Fish and Fisheries* 18:619-637.
- Drapeau, G. 1973. Sedimentology of herring spawning grounds on Georges Bank. *Int. Comm. Northwest Atl. Fish (ICNAF) Res. Bull.* 10: 151-162.
- Grabowski, J.H., M. Bachman, C. Demarest, S. Eayrs, B.P. Harris, V. Malkoski, D. Packer, and D. Stevenson. 2014. Assessing the vulnerability of marine benthos to fishing gear impacts. *Reviews in Fisheries Science and Aquaculture* 22(2):142-155.
- Grimm, S.K. 1983. Changes in time and location of herring (*Clupea harengus* L.) spawning relative to bottom temperatures in Georges Bank and Nantucket Shoals areas, 1971-1977. *Northwest Atl. Fish. Organ (NAFO) Sci. Counc. Stud.* 6:15-34.

Jennings, S., Kaiser, M.J., 1998. The Effects of Fishing on Marine Ecosystems, in: Blaxter, J.H.S., Southward, A.J., Tyler, P.A. (Eds.), *Advances in Marine Biology*. Academic Press, pp. 201–352. [https://doi.org/10.1016/S0065-2881\(08\)60212-6](https://doi.org/10.1016/S0065-2881(08)60212-6)

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S., Poiner, I.R., 2002. Modification of marine habitats by trawling activities: prognosis and solutions. *Fish Fish.* 3, 114–136. <https://doi.org/10.1046/j.1467-2979.2002.00079.x>

Mayer, L.M., D.F. Schick, R.H. Findlay, and D.L. Rice. 1991. Effects of commercial dragging on sedimentary organic matter. *Marine Environmental Research* 31:249-261.

Messieh, S.N., Wildish, D., Peterson, R.H. & Canada. Department of Fisheries and Oceans. Biological Station (St. Andrews, N.B.) 1981, Possible impact from dredging and spoil disposal on the Miramichi Bay herring fishery, Fisheries and Oceans, St. Andrews, New Brunswick.

Melvin, G.D. and R.L. Stephenson. 2007. The dynamics of a recovering fish stock: Georges Bank herring. *ICES Journal of Marine Science* 64(1):69-82.

Noskov, A.S., and V.N. Zinkevich. 1967. Abundance and mortality of herring, *Clupea harengus* Linnaeus, on Georges Bank according to the results of egg calculation in spawning areas in 1964-66. *ICNAF Res. Doc.* 67/98, Ser. No. 1897, 16 pp.

O'Neill, F.G., Robertson, M., Summerbell, K., Breen, M., Robinson, L.A., 2013. The mobilisation of sediment and benthic infauna by scallop dredges. *Mar. Environ. Res.* 90, 104–112. <https://doi.org/10.1016/j.marenvres.2013.06.003>

Pankratov, A. M., and I.K. Sigaev. 1973. Studies on Georges Bank herring spawning in 1970, International Commission for the Northwest Atlantic Fisheries, *ICNAF Research Bulletin* No. 10. p. 125-129.

Stevenson, D.K., and M. L. Scott. 2005. Essential Fish Habitat Source Document: Atlantic herring, *Clupea harengus*, life history and habitat characteristics. NOAA Technical Memorandum. NMFS-NE-192. 84 pp.

Valentine, P.C., and R.G. Lough. 1991. The sea floor environment and the fishery of eastern Georges Bank. U.S. Dep. Inter. Geol. Surv. Open-File Rep. 91-439. 25 pp.

Winters, G.H. and J.P. Wheeler. 1996. Environmental and phenotypic factors effecting the reproductive cycle of Atlantic herring. *ICES Journal of Marine Science* 53:73-88.

Attachment 2

Using a Gonadal Somatic Index (GSI) to inform a spawning closure for Atlantic herring on Georges Bank

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May 2020

Introduction

The spawning season of Atlantic herring can vary by several weeks from year to year (Sinclair & Tremblay, 1984; Winters & Wheeler, 1996) and GSI has effectively been used for in-season monitoring to inform adaptive fishery closures in the Gulf of Maine, under the direction of the Atlantic States Marine Fisheries Commission (ASMFC 2016; ASMFC 2019). This system requires consistent and regular observations of the reproductive state of herring prior to spawning, typically from fishery catches. When such samples are unavailable, either due to sampling limitations or a lack of fishing, a “default closure date” applies that represents the historical average date that herring GSI has been observed to cross the closure threshold. Georges Bank does not receive the same level of consistent pre-spawning fishing activity as in the Gulf of Maine (Figure 1), making in-season monitoring and adaptive closures infeasible. Regardless, sufficient historical GSI samples from Georges Bank exist to inform the calculation of a default closure date.

Methods

The GSI of female herring increases in an approximately linear fashion during the later stages of development (Figure 2). This offers the opportunity to use a simple linear model, fit to pre-spawning GSI data, to forecast the date when development is near complete. However, observed GSI is also positively related to fish length (Figure 3), and this effect needs to be accounted for due to the heterogeneity in fish size across samples. The ASMFC method of GSI monitoring estimated this length effect in the GOM and this coefficient is used to standardize all GSI observations to a common fish size of 30 cm (i.e., GSI_{30}). Once a sufficient number of samples has been collected ($n = 3$) and an informative linear model can be fit ($p < 0.05$), this model is used to forecast the date when GSI_{30} surpasses a value of 23, representing day 1 of the spawning closure. This somewhat arbitrary closure threshold was selected by ASMFC fishery managers and represents a tradeoff between spawning protection and maintaining fishery access. Recent full-season sampling of herring maturity stages in the GOM suggests that approximately 25% of fish have begun to spawn when mean GSI_{30} reaches 23 (Figure 4). It was also estimated that the time between when 25% have begun to spawn and when 25% have yet to spawn ranged between 2.5 and 5 weeks over the period 2015-2017 (Figure 5). For this reason, ASMFC managers selected a closure length of 6 weeks to ensure a low probability of fishery interaction with spawning.

To estimate a default closure date for Georges Bank, the mean date when $GSI_{30} = 23$ was calculated using all sample data collected from Herring Management Area 3, treating YEAR as a random effect in the linear model (i.e., $GSI_{30} \sim DATE + (1|YEAR)$). This is equivalent to how default dates were calculated by ASMFC for GOM spawning areas. Given the interannual variability in herring spawning time and the inability to conduct in-season adaptive closures, an 8-week closure period was also considered in addition to the ASMFC default of 6-weeks. In order to maintain alignment with the reproductive phenology of Georges Bank herring, the 8-week closure alternative would start 1 week prior to the 6-week alternative and end 1 week later.

Application of these methods to Georges Bank sample data implies several assumptions: 1) the relationship between herring length and GSI is the same as in the GOM; 2) GSI₃₀ of developing female herring increases linearly prior to spawning on Georges Bank; 3) Herring on Georges Bank achieve a similar maximum GSI₃₀ as in the GOM (i.e., a closure threshold of GSI₃₀ = 23 is relevant to Georges Bank). The Georges Bank sample data were further explored in order to examine the validity of these assumptions.

Results

Although numerous GSI samples have been collected from Georges Bank herring trips, relatively few have been collected in recent years (Figure 1), and most of these have occurred in September, too late to act as an “early-warning” system to inform in-season adaptive closures. Regardless, the apparent linear increase in developing female GSI (Figure 2) makes these data useful for estimating the date when the closure threshold was reached. A strong relationship between GSI and fish length necessitated standardizing GSI to a common length (Figure 3). The length coefficient estimated from the Georges Bank sample data ($\beta_l = 1.85$ increase in GSI per cm; S.E. = 0.03) was indistinguishable from the value used by ASMFC in the GOM ($\beta_l = 1.84$ increase in GSI per cm; S.E. = 0.04). As such, the parameters of the ASMFC length standardization were adopted ($\beta_l = 1.84$; standard length = 30 cm), for the sake of simplicity.

The distribution of observed female GSI₃₀ values was somewhat higher on Georges Bank than in the GOM, particularly for later developmental stages (Figure 6). However, this is to be expected for two reasons: 1) A concerted effort to collect early pre-spawning samples in the GOM to inform in-season adaptive closures resulted in more low GSI observations; and 2) The fishery on Georges Bank has been unconstrained by spawning closures, resulting in more high GSI observations. Given this explanation for the observed differences, the ASMFC closure threshold of GSI₃₀ = 23 was considered relevant for Georges Bank.

The estimated mean date when the closure threshold was reached over the 22-year period from 1998-2019 was September 14th, which is 10 days earlier than the MANH and WM spawning areas of the GOM (Figure 7). Under a 6-week closure period, a Georges Bank spawning closure would re-open on October 26th. If an 8-week period were to be adopted, the closure would begin on September 7th and re-open on November 2nd.

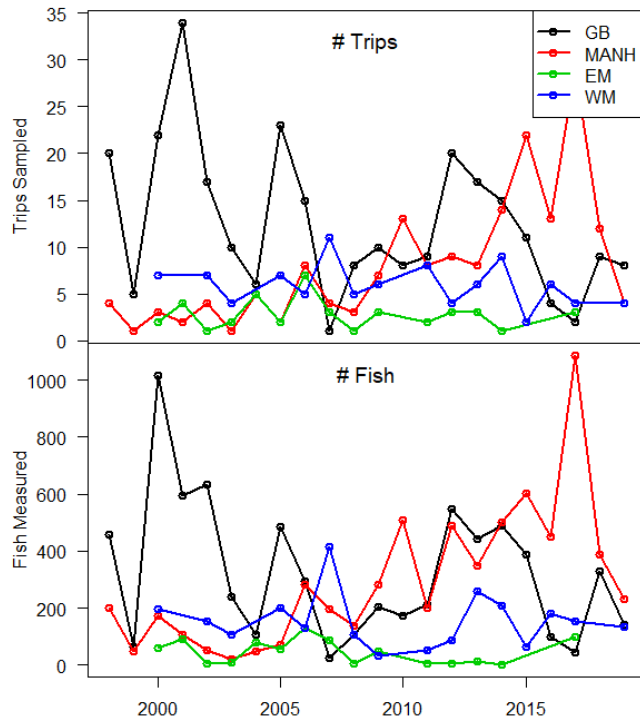


Figure 1. [top] Annual number of Management Area 3 (Georges Bank) herring trips sampled by either MEDMR or MADMF, 1998-2019; [bottom] Total number of individual fish measured from these samples.

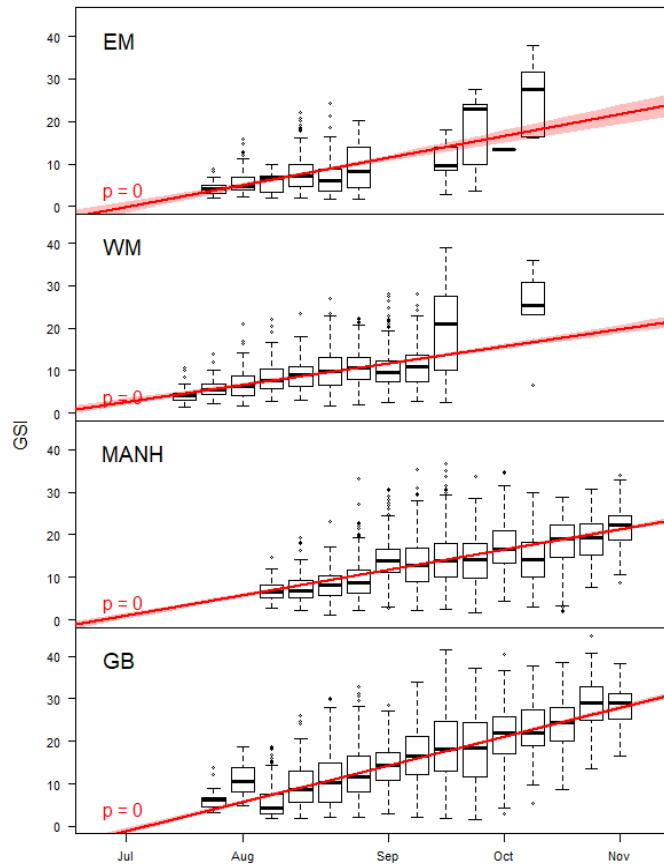


Figure 2. Relationship between developing female GSI (stages 3-5) and sample week for Georges Bank (GB) and the Gulf of Maine (EM, WM, MANH).

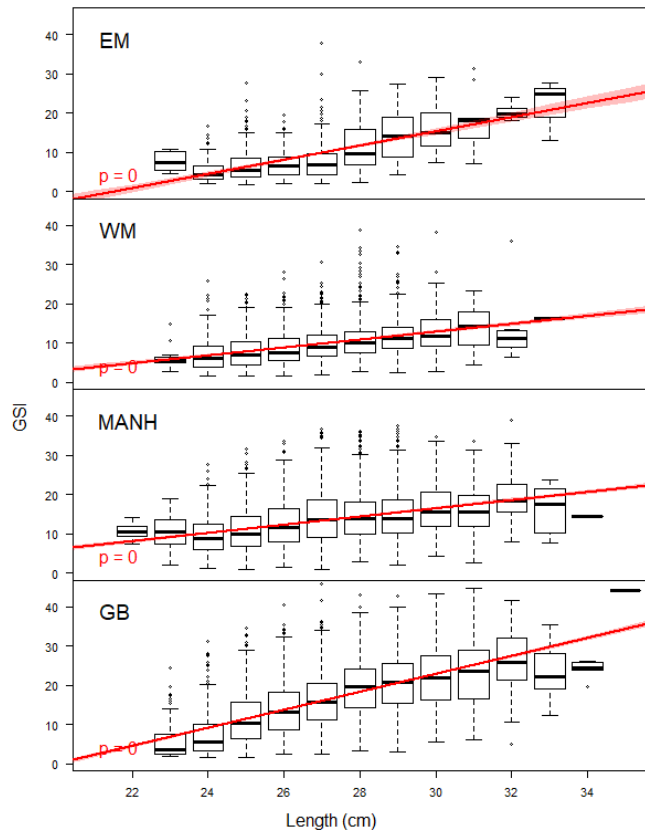


Figure 3. Relationship between developing female GSI (stages 3-5) and fish length for Georges Bank (GB) and the Gulf of Maine (EM, WM, MANH).

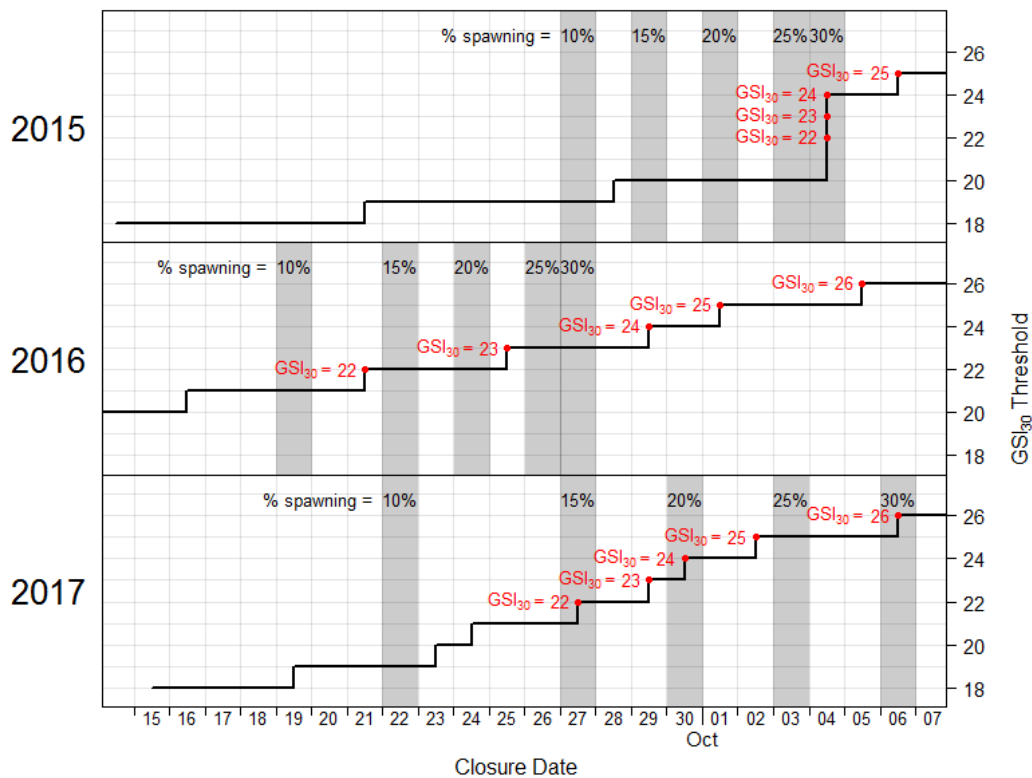


Figure 4. GSI₃₀ by date for the MANH spawning area of the GOM, 2015-2017. The vertical gray bands indicate the estimated percent of the population that had begun to spawn (from ASMFC, 2019).

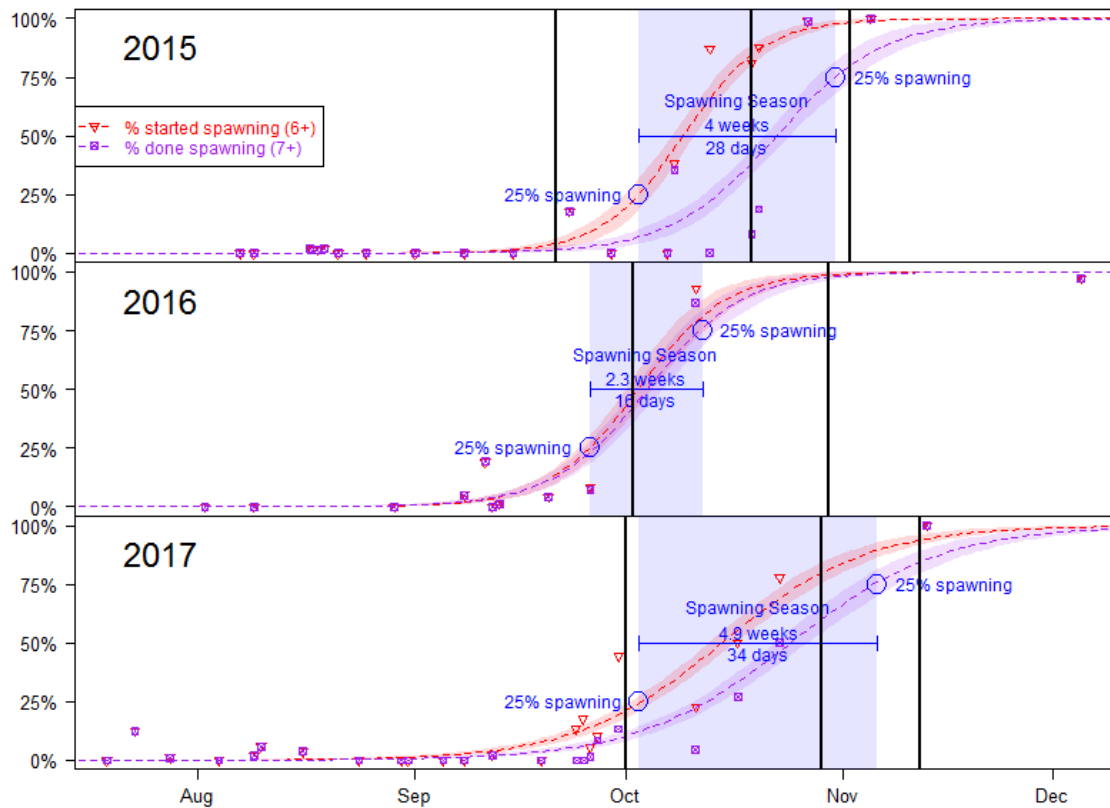


Figure 5. Observed fraction of sampled herring that had started spawning (red: stage 6+) and completed spawning (purple: stage 7+) for the MANH area of the GOM. The shaded blue region represents the spawning season, as defined by the period between when 25% of fish had begun to spawn and when 25% of fish had yet to complete spawning. Vertical black lines represent spawning closures and re-closures (from ASMFC, 2019)

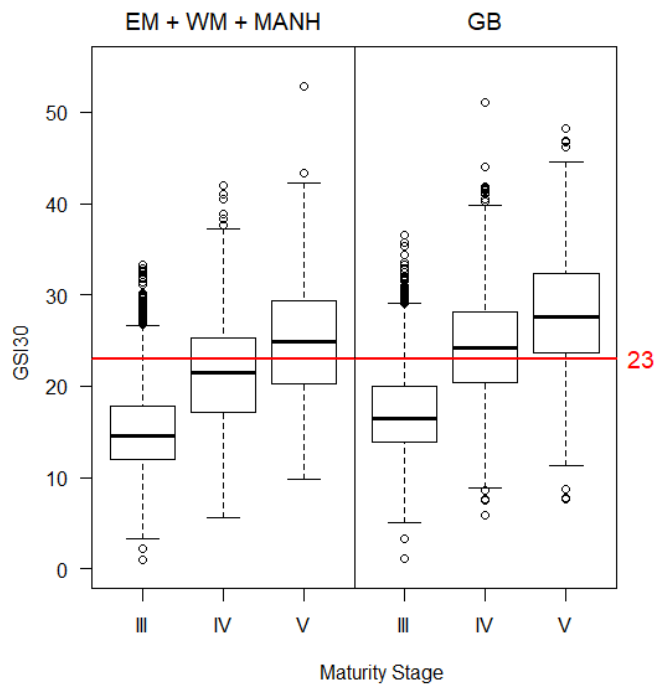


Figure 6. Distribution of observed female GSI30 by developmental stage for the GOM (left) and on Georges Bank (right). The red horizontal line indicates the closure threshold.

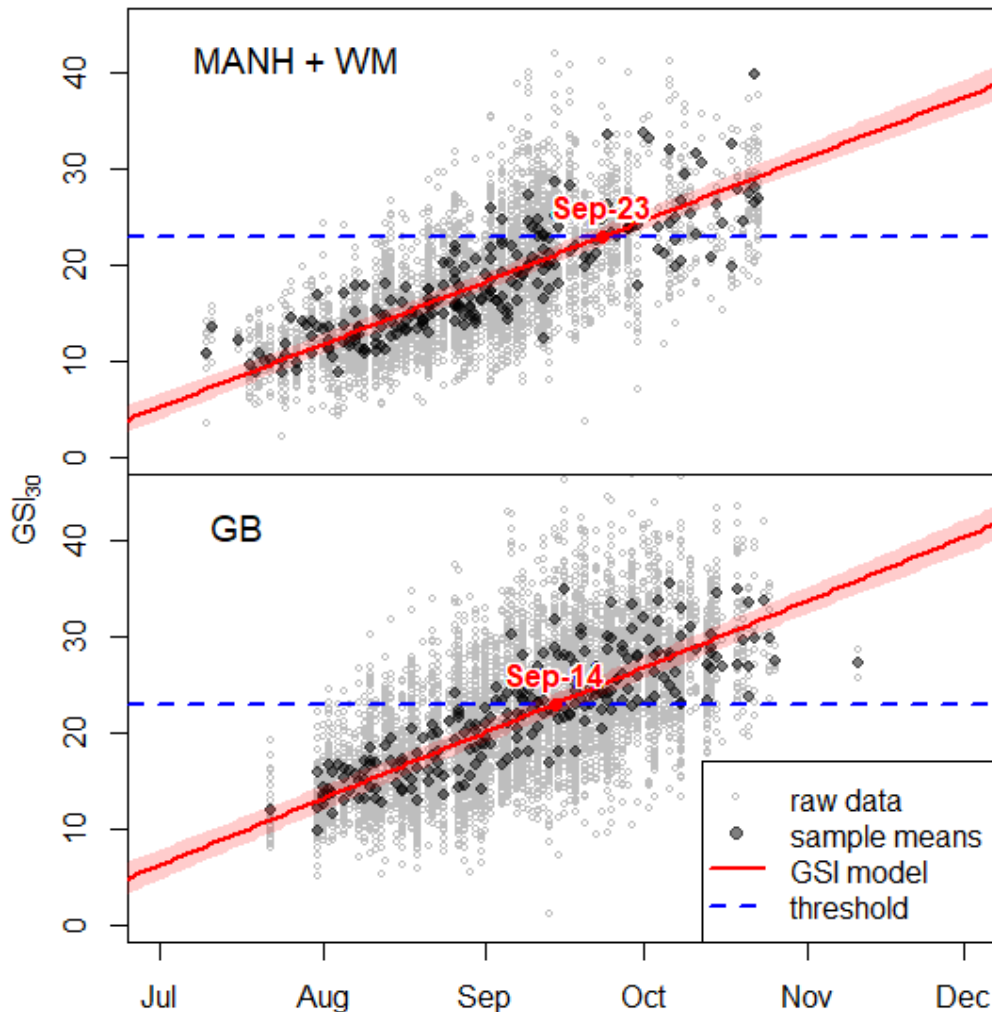


Figure 7. Predicted mean date the closure threshold (blue dashed line) was reached from over 20 years of GSI sampling, in the GOM (top) and on Georges Bank (bottom).

References

- [ASMFC, 2016. Technical Report on Gonadal-Somatic Index-Based Monitoring System for Atlantic Herring Spawning Closures in US Waters. Amendment 3 to the Interstate Fishery Management Plan for Atlantic Herring, Appendix 1, 92-105.](#)
- [ASMFC, 2019. Gulf of Maine Spawning Protections. Addendum II to Amendment 3 to the Interstate Fishery Management Plan for Atlantic Herring, 1-29.](#)
- Sinclair, M., & Tremblay, M. I. (1984). Timing of Spawning of Atlantic Herring (*Clupea harengus harengus*) Populations and the Match-Mismatch Theory. *Canadian Journal of Fisheries and Aquatic Sciences*, 41: 1055–1065.
- Winters, G. H., & Wheeler, J. P. (1996). Environmental and phenotypic factors affecting the reproductive cycle of Atlantic herring. *ICES Journal of Marine Science*, 53: 73–88.