Atlantic States Marine Fisheries Commission

ADDENDUM II TO AMENDMENT 3 TO THE ATLANTIC HERRING INTERSTATE FISHERY MANAGEMENT PLAN

Gulf of Maine Spawning Protections

Sustainable and Cooperative Management of Atlantic Coastal Fisheries

Approved April 2019

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1.0 INTRODUCTION

The Atlantic States Marine Fisheries Commission (ASMFC) is responsible for managing Atlantic Herring (*Clupea harengus*), under the authority of the Atlantic Coastal Fisheries Cooperative Management Act (ACFMA). The U.S. Atlantic herring fishery is currently managed as a single stock through complementary fishery management plans (FMPs) by ASMFC and the New England Fishery Management Council (NEFMC). ASMFC has coordinated interstate management of Atlantic herring in state waters (0-3 miles) since 1993. Management authority in the exclusive economic zone (EEZ, 3-200 miles from shore) lies with the NEFMC and National Marine Fisheries Service (NMFS).

Atlantic herring reproduce by spawning (releasing) eggs each year in the fall and early winter months. To protect aggregations of spawning fish and support the sustainability of the resource, spawning closures are annually implemented in the Gulf of Maine (GOM). The start of these closures is determined by the collection of biological samples which are used to project inter-annual changes in the timing of spawning. The closures are initially implemented for four weeks, but can be extended for two additional weeks if sampling indicates the continued presence of spawning fish.

Results of the 2018 Benchmark Stock Assessment indicate that the health of the Atlantic herring resource has declined in recent years. Specifically, the Assessment found that recruitment has been well below the time-series average since 2013, with 2016 representing the lowest level of recruitment on record (NEFSC 2018). In addition, spawning stock biomass, a measure of the reproductively mature portion of the population, has decreased.

This Addendum strengthens the protections provided to spawning herring in Area 1A by: 1) lowering the threshold that triggers initial spawning closure; 2) increasing the length of the initial spawning closure; and 3) lowering the threshold that triggers a re-closure due to spawning activity, in order to provide greater protection to the stock.

2.0 OVERVIEW

2.1 Statement of the Problem

The 2018 Benchmark Stock Assessment indicated significant declines in recruitment in the Atlantic herring stock, particularly over the last five years. This suggests a reduction in herring biomass in the coming years. Given successful spawning and recruitment are essential to the future health of the resource and fishery, the Board initiated Addendum II to consider strengthening the protections provided to spawning herring in the Gulf of Maine.

2.2 BACKGROUND

2.2.1 Atlantic Herring Spawning

Atlantic herring primarily spawn in the northern extent of the species range (Cape Cod to Newfoundland). Within the Gulf of Maine-Georges Bank stock complex, three primary spawning regions have been identified: 1) the coast of Gulf of Maine; 2) Georges Bank; and 3) Nantucket Shoals. Each of these primary spawning areas are comprised of smaller, discrete spawning sites (e.g. Jeffreys Ledge in the Gulf of Maine). Figure 2 provides an overview of known herring spawning locations in New England waters.

Atlantic herring generally reproduce in the late summer and fall; however, the onset and duration of spawning may vary by several weeks from year to year (Winters and Wheeler, 1996). In addition, spawning typically occurs earlier in the eastern Gulf of Maine as opposed to the western Gulf of Maine and waters off of Massachusetts and New Hampshire (Reid et al., 1999).

When spawning, herring deposit adhesive eggs that stick to coarse sand, pebbles, cobbles, and boulders on the ocean floor (NEFMC 2018). Essential fish habitat identified for herring eggs include benthic habitats of inshore and offshore Gulf of Maine, Georges Bank, and Nantucket shoals in depths of 5-90 meters (NEFMC 2018). Eggs are often laid in layers, creating mats along the ocean floor. A single female herring can produce between 55,000 and 210,000 eggs (Kelly and Stevenson, 1983). Once hatched, herring larvae can be found in the inshore and offshore pelagic habitats of the Gulf of Maine, Georges Bank, and in the upper Mid-Atlantic Bight (NEFMC 2018).

2.2.2 Benchmark Stock Assessment

Results of the 2018 Stock Assessment presented concerning trends for the Atlantic herring resource. The assessment showed that age-1 recruitment has been below the time-series average for the last five years (Figure 3) (NEFSC 2018). In addition, four of the six lowest estimates of recruitment have occurred in recent years (2013, 2015, 2016, and 2017) (NEFSC 2018). While the assessment did note that recruitment estimates at the end of the model time series may have greater uncertainty, the document highlighted that 2016 represented the lowest level of annual recruitment on record (NEFSC 2018).

Overall, the assessment concluded that, in the terminal year of the model (2017), the stock is not overfished and overfishing is not occurring; however, the assessment did state that, given declines in recruitment, spawning stock biomass is likely to remain low, putting the stock at risk of being overfished (NEFSC 2018). In addition, the assessment noted that without improved recruitment, the probability of overfishing in the future is high (NEFSC 2018).

2.2.3 Existing Gulf of Maine Spawning Closure Protocol

Under Amendment 3, spawning aggregations in the Gulf of Maine are protected through the use of 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 (Figure 1). Based on the goals of the Atlantic Herring Fishery Management Plan (which include providing adequate protection for spawning herring, preventing overfishing of discrete spawning units, achieving full utilization of herring catch, and maximizing social and economic benefits of the fishery), these spawning closures look to reduce interaction between fishing and spawning while also providing access to quota (ASMFC 2016).

The implementation of the spawning closures is determined by the GSI_{30} 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 GSI_{30} 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 the majority 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 determine by a trigger value established in Amendment 3. 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. Implementation dates of spawning closures from 2015-2018 can be found in Table 1.

2.2.4 Evaluation of Current Protections

In a January 2018 memo to the Board (Dean *et al.,* 2018; included as Appendix 1), the Atlantic Herring Technical Committee (TC) evaluated the performance of the GSI_{30} spawning closure protocol. The aim of this review was to assess whether the program was meeting its objectives, given it had been implemented two years prior. Data used in this evaluation included spawning samples collected through 2017. The memo evaluated several components of the GSI_{30} protocol, including the trigger value and the length of the closure, and updated the calculation of default closure dates. The TC also looked at the overall success of the GSI_{30} protocol and concluded that it represents a significant improvement over the previously used system as it is better able to respond to inter-annual changes in the timing of spawning (Dean *et al.,* 2018).

One of the questions evaluated in the TC memo was whether spawning commences near the current trigger value. This is an important question to ask since initiating a closure too early or too late may diminish the effectiveness of the spawning closures. To answer this question, the TC compared the start of spawning closures in Massachusetts/New Hampshire to the estimated percentage of spawning herring in the population (Dean *et al.,* 2018). Only closures in the Massachusetts/New Hampshire spawning area were evaluated given significantly fewer samples have been collected in Eastern Maine and Western Maine. Overall, the TC found that, from 2015 to 2017, the current GSI_{30} trigger value (25) resulted in a spawning closure that started within a few days of when the population reached 25% spawning (Figures 4 and 5) (Dean *et al.,* 2018). For example, in 2017, the spawning closure started 2 days prior to there being approximately 25% spawning herring in the population.

An important question to ask following the TC's analysis is whether initiating a closure when approximately 25% of the population is spawning is appropriate given the condition of the stock. The TC's memo does note that reducing the GSI_{30} trigger value would initiate a spawning closure earlier and would reduce the probability of exceeding 25% spawning fish in the catch (Figure 5). However, it is important to note that a lower trigger value corresponds with an earlier default date which may precipitate the need for a longer closure to provide protection throughout the spawning season (Dean *et al*., 2018). In addition, lowering the trigger value may shorten the time available to collect spawning samples and project a closure given the earlier default date.

The TC memo also evaluated whether the existing four week closure period is sufficient to cover the typical spawning season. To conduct this analysis, the TC defined a spawning season as starting when 25% of the herring population has begun spawning and ending when 75% of the herring population has ended spawning (Dean *et al.,* 2018). The TC then compared the lengths of the spawning seasons under this definition. The analysis showed that, between 2015 and 2017, spawning seasons in the Massachusetts/New Hampshire area were 4 weeks, 2.3 weeks, and 4.9 weeks, respectively (Figure 4). The TC expressed greater confidence in the longer spawning season estimates given a significantly higher number of samples in 2015 and 2017. Based on these results, the TC concluded that use of the 4 week initial spawning closure would likely result in frequent use of the re-closure protocol (Dean *et al.,* 2018). The TC also noted that if the Section was interested in simplifying the closure protocol and increasing protection during spawning, the Section could consider a longer initial closure period of five to six weeks (Dean *et al.,* 2018). Notably, longer closure periods may result in a greater overlap between the three spawning closures, resulting in multiple areas being closed at the same time.

It is important to highlight that the trigger value and the closure length are interconnected components of the spawning closure protocol. Earlier trigger values which decrease the percentage of spawning herring in the catch result in longer spawning seasons (Figure 6). As a result, under a lower trigger value, a longer closure may be needed to provide protection throughout the spawning season. Table 2 outlines the relationship between the trigger value and the approximate length of the spawning closure season. Specifically, it shows that as the trigger values decrease, the percentage of spawning herring in the population at the start of the closure also decreases but the average length of the spawning season increases. For example, under a trigger value of 23, a spawning closure is initiated when approximately 20% of the herring population is spawning and the average spawning season length is 4.3 weeks (but can range up to 5.7 weeks). Under a trigger value of 22, a spawning closure is initiated when approximately 15% of the herring population is spawning and the average spawning season length is 5.1 weeks (but can range up to 6.6 weeks).

2.2.5 Overview of Herring Fishery

The domestic Atlantic herring fishery is predominately commercial. Landings in the Atlantic herring fishery increased in the 1960's, peaking in 1968 at 477,767 mt (1.05 billion pounds; NEFSC 2018), largely due to a foreign fishery which developed on Georges Bank. Catch declined in the early 1980's to 44,613 mt (98.4 million pounds) in 1983 but subsequently increased through the late 1980's and early 1990's (NEFSC 2018). Landings in the 2000's were fairly stable around 113,358 mt (250 million pounds) but have decreased over the last four years to 50,250 mt (111 million pounds) in 2017 (NEFSC 2018).

Several gear types participate in the Atlantic herring fishery, including mid-water trawls, purse seines, small mesh bottom trawls, and fixed gear. In recent years, the majority of Area 1A landings have come from purse seiners (80% of landings between 2012 and 2015). Historically, 0% of the Area 1A sub-ACL has been allocated to the months of January – May. In addition, vessels using single and paired midwater trawls are prohibited from fishing for Atlantic herring in Area 1A between June 1 and September 30.

In recent years, the greatest amount of herring from Area 1A has been landed in July and August (Table 3). Specifically, between 2015 and 2017, average herring landings in July and August were 6,067 mt and 7,564 mt, respectively. Average Area 1A landings were lower in September (2015-2017 average is 2,688 mt) and then increased again in October (2015-2017 average is 5,768 mt). This increase in October coincides with mid-water trawl vessels being permitted to fish for herring in Area 1A. Monthly landings trends are likely impacted by the existing spawning closures, which occur in the fall and prohibit directed fishing for herring in portions of Area 1A.

The 2018 annual catch limit (ACL) for the Atlantic herring fishery was originally set at 111,000 mt. However, in response to results from the 2018 Benchmark Stock Assessment (see *Section 2.2.2*), NOAA Fisheries took an in-season action to reduce the 2018 ACL to 49,900 mt in order to decrease the risk of overfishing in 2018 and increase the estimated herring biomass in future years. It is expected that ACLs in 2019 through 2021 will continue to be low given the condition of the stock; a proposed ACL for 2019 is 24,488 mt. Given these low quotas, it is possible that the directed herring fishery will catch the majority of Area 1A sub-ACL prior to the implementation of spawning closures in the fall. As a result, the full benefits and/or costs of changes to the spawning protocol may not be evident for several years.

3.0 MANAGEMENT PROGRAM

This Addendum establishes a new management program that modifies the provisions of *Section 4.2.6: Spawning Restrictions* in Amendment 3 to the Interstate Fishery Management Plan for Atlantic Herring. Table 2 outlines the relationship between the GSI_{30} trigger value and the closure length.

Issue 1: GSI_{30} Trigger Value= 23

The new GSI_{30} trigger value is 23. This trigger value closes the fishery at an earlier date to provide more protection to pre-spawning fish and reduces the probability of catching spawning fish at the beginning of the spawning season. The default closure dates associated with this trigger value are below. Please note: the default dates are based on analysis from spawning samples collected from 2005-2017.

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

Issue 2: Spawning Closure Length

Six Week Initial Closure

The spawning closures established in Area 1A will be for six (6) weeks. As shown in Table 2, for a GSI_{30} trigger value of 23, a six week closure is longer than the maximum observed spawning season of 5.7 weeks.

Issue 3: Re-closure Protocol

Significant number of spawn herring= 20% or more

A spawning closure can be extended for two (2) additional weeks if one (1) sample taken from within a spawning closure area, by Maine, New Hampshire or Massachusetts, indicates a significant number of spawn herring. Sampling will resume in the final week of the initial closure period or at the end of the initial closure period. Mature or 'spawn' herring are defined as Atlantic herring in ICNAF gonadal stages V and VI. A sample is defined as a minimum of 80 randomly selected adult sized fish, with a target of 100 fish, from a fishery dependent or independent source.

Moving forward, for the re-closure protocol, a 'significant number' of spawn herring is defined as 20% or more mature herring, by number in a sample, that have yet to spawn. This corresponds to the percentage of spawning herring in the population when an initial closure is implemented under a trigger value of 23.

4.0 COMPLIANCE SCHEDULE

Addendum II is effective as April 30, 2019. States must implement the required changes as outlined in section 3. Management Program by August 1, 2019.

5.0 LITERATURE CITED

Atlantic States Marine Fisheries Commission (ASMFC). 2016. Amendment 3 to the Interstate Fishery Management Plan for Atlantic Herring. 105p.

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

Dean, M., Cieri, M., and R. Zobel. 2018. A Review of the modified Gonadal-Somatic Index (GSI) Monitoring System for Atlantic Herring Spawning Closures in US Waters. http://www.asmfc.org/uploads/file/5a95d99eHerringSpawningClosureReport_Jan2018.pdf

New England Fishery Management Council (NEFMC). 2018. Amendment 8 to the Atlantic Herring Fishery Management Plan Draft Environmental Impact Statement. Volume 1. https://s3.amazonaws.com/nefmc.org/Herring-A8-DEIS.Submission.April-12.pdf

6.0 TABLES

Table 1: Area 1A spawning closure implementation dates from 2015 – 2018. Bolded text represents spawning closures which were enacted via the default date. It is important to note that the 2015 closures were implemented under the previously used length-based spawning closure protocol given Amendment 3 was not finalized until 2016.

	Eastern Maine	**Western Maine**	**Massachusetts/New Hampshire**
2015	**Aug. 15 – Sept. 11**	**Sept. 1 – Sept. 28**	**Sept. 21 – Oct. 18;** Re-closure Oct. 21 – Nov. 3
2016	**Aug. 28 – Sept. 24**	Sept. 18 – Oct. 15	Oct. 2 – Oct. 29
2017	**Aug. 28 – Sept. 24** Re-closure Oct. 16 – Oct. 30	Sept. 26 – Oct. 24	Oct. 1 – Oct. 28 Re-closure Oct. 29 – Nov. 11
2018	**Aug. 28 – Sept. 24**	**Oct. 4 – Oct. 31**	Oct. 26 – Nov. 22

Table 2: Relationship between GSI_{30} trigger value, approximate percentage of spawning herring in population when the closure begins, and spawning season length. Average spawning season lengths are based on data from 2015-2017. The range of spawning season lengths represents the shortest and longest spawning season length between 2015 and 2017 for each trigger value.

GSI_{30} Trigger Value	**Approx. % of Spawners in Population When Closure Begins**	**Avg. Spawning Season Length (2015-2017)**	**Range of Spawning Season Length**
25 (status quo)*	25%	3.7 weeks	2.3 – 4.9 weeks
23	20%	4.3 weeks	2.7 – 5.7 weeks
22	15%	5.1 weeks	3.4 – 6.6 weeks

*Value previously established under Amendment 3. The new trigger value established under Addendum II is 23

Table 3: Average Atlantic herring Area 1A landings (in metric tons) by month for 2015-2017. During these years, the directed herring fishery in Area 1A began in June and, as a result, the months of January – May are not shown in the table.

Month	**Average 2015-2017 Landings (mt)**
June	3,098
July	6,067
August	7,564
September	2,688
October	5,768
November	2,040
December	837

7.0 FIGURES

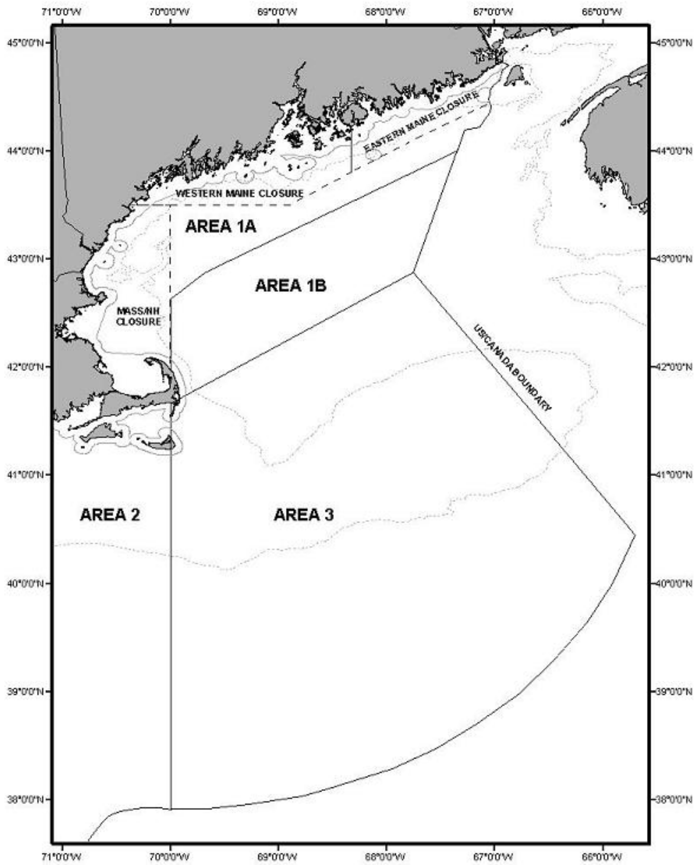

Figure 1: Atlantic herring management areas and spawning closure areas in the Gulf of Maine.

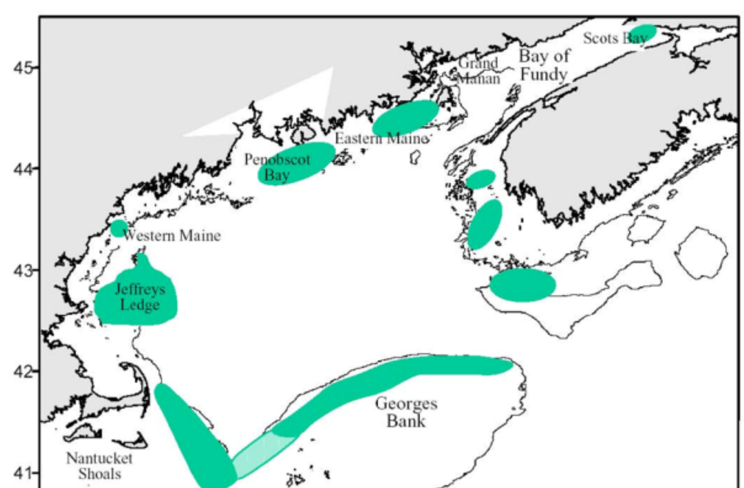

Figure 2: Overview of major Atlantic herring spawning areas, identified in green, in the Gulf of Maine and on Georges Bank. Source: Overholtz et al. 2004.

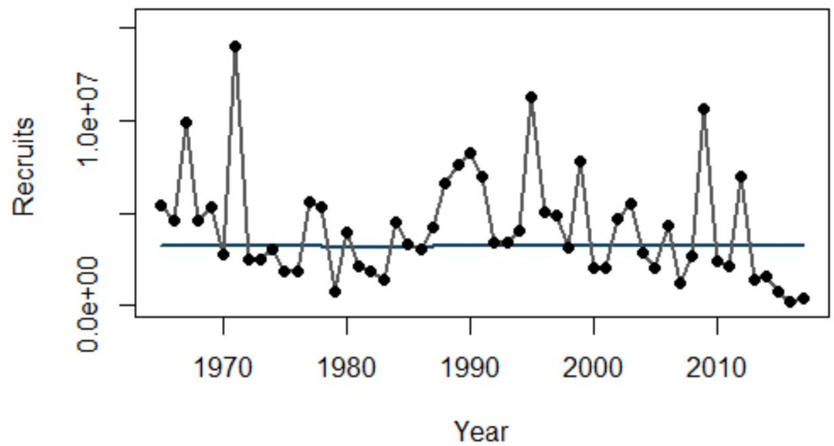

Figure 3: Atlantic herring annual recruitment, in 1000's, from 1965-2017. The horizontal line is the time-series average. Source: NEFSC 2018.

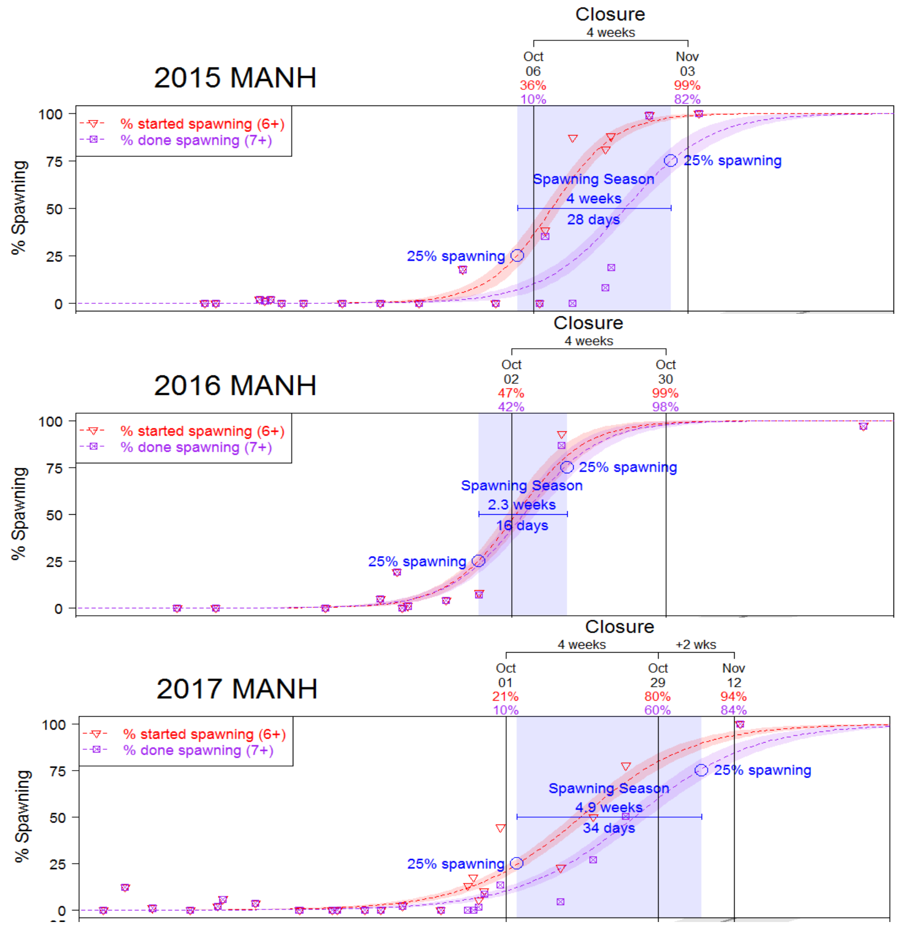

Figure 4: Estimated spawning seasons under the current GSI_{30} spawning closure protocol for the Massachusetts/New Hampshire spawning area in 2015 through 2017. The spawning season is identified by the blue shaded regions while the black vertical lines represent the spawning closures enacted by management. The length of the spawning season is calculated as starting when 25% of the herring population has begun spawning and ending when 75% of the herring population has ended spawning. The trigger value used to initiate the spawning closures was 25. In 2017, there was the use of the two week re-closure protocol given the continued presence of spawning herring. It is important to note that in 2015, the previously-used spawning closure protocol was used to determine the spawning season, as opposed to the GSI_{30} protocol shown above. As a result, the 2015 closure dates shown above do not match those in Table 1. Source: Dean et al. 2018.

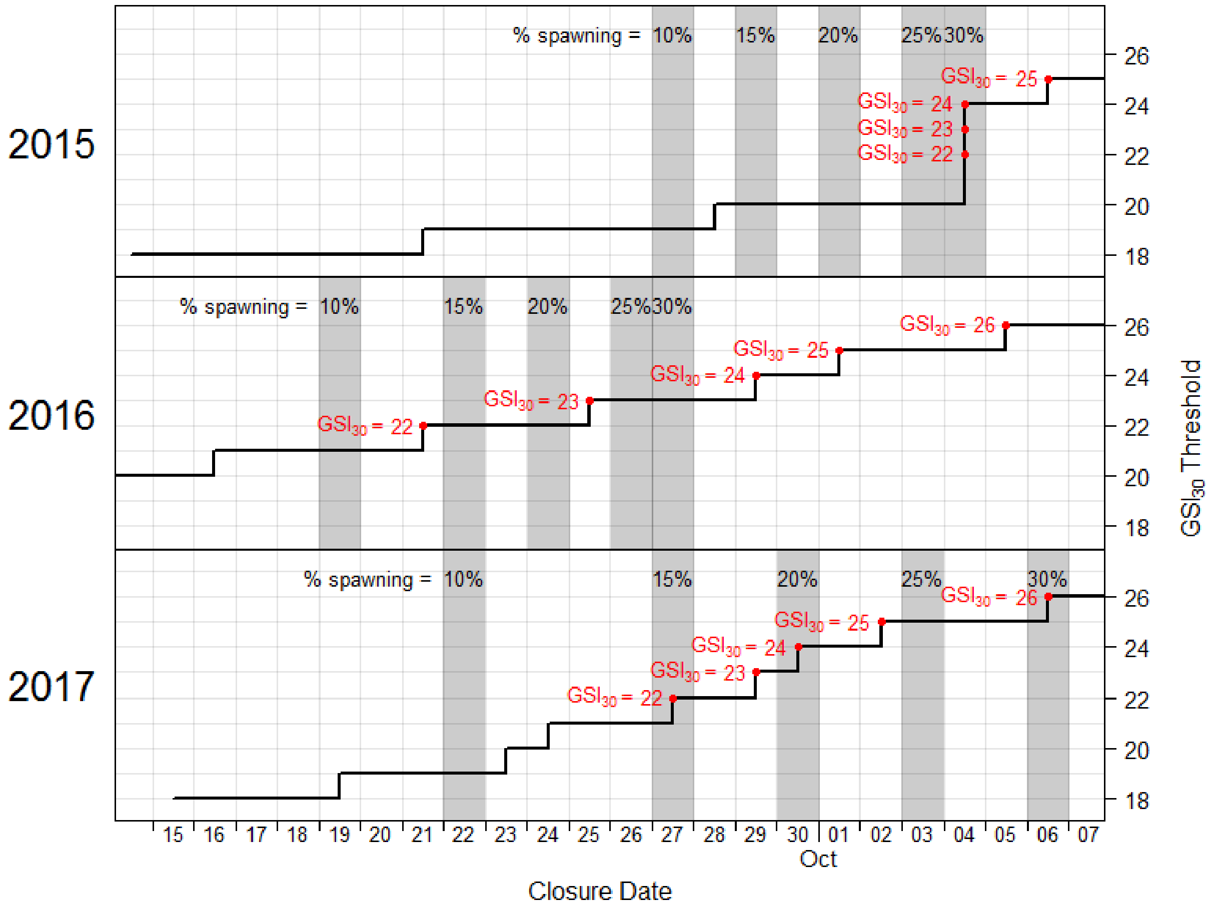

Figure 5. Date when the Massachusetts/New Hampshire spawning closure would have started, under different GSI_{30} trigger values. The vertical gray bands indicate the percent of the population expected to be spawning for that trigger value in a given year. Note: in 2015, spawning closures under GSI_{30} trigger values 24, 23, and 22 all would have started on the same date due to a lack of resolution in the samples; several samples were collected at the beginning of spawning but few were taken when approximately 15%-25% of the population was estimated to be spawning. Source: Dean et al. 2018.

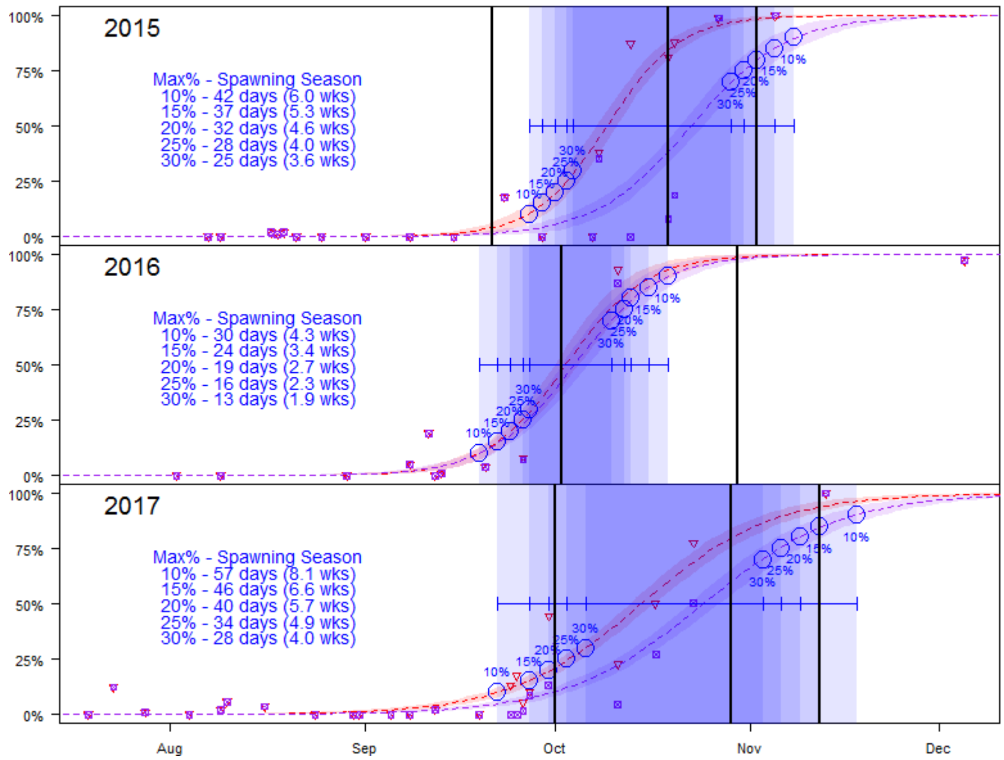

Figure 6. Effect of choice of maximum allowable percentage spawning in the catch on duration of the spawning season. This figure shows that as a lower percentage of spawning fish in the catch is required, the length of the season closure extends. Source: Dean et al. 2018.

8.0 APPENDIX

Atlantic States Marine Fisheries Commission

A Review of the modified Gonadal-Somatic Index (GSI) Monitoring System for Atlantic Herring Spawning Closures in US Waters

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January 2018

Introduction

In 2015, the ASMFC adopted Amendment 3 to the Atlantic Herring FMP, which established a new model-based GSI monitoring program for herring spawning closures. This closure system, first implemented in 2016, replaced an earlier program that had operated for more than 15 years. The earlier system relied on monitoring the development of female herring (stages 3-5) within 2 size classes and compared the average observed GSI of each size class to its own threshold. Once three consecutive samples within a week showed that either size class exceeded their threshold, the fishery would close. If three consecutive samples were not available in the week prior, area-specific default closure dates would apply. Amendment 3 sought to critically evaluate the parameters and assumptions of this earlier system (size classes, GSI thresholds, default dates, closure duration) and implement modifications to improve performance.

Since the adoption of Amendment 3, there has been a concerted effort to collect GSI and maturity data from all sampled herring (not just stage 3-5 females) throughout the entire spawning season, including during the closure period. These new data provide an invaluable perspective from which to evaluate the performance of the current spawning closure program. The aim of this paper is to review the current spawning closure system in light of these new data, and evaluate the validity of the model's assumptions and whether the program in general is meeting its objectives.

Program Objectives

There are four main objectives of the ASMFC herring spawning closure program:

1) *Reduce interaction between fishing and spawning:*

   From a management perspective, it is impractical to eliminate *all* fishery-spawning interaction and still allow full utilization of the annual quota. Consequently, there must be some acceptable low level of spawning fish present in the catch both before and after the spawning closure. A long-established rule allows the fishery to operate if a sample contains less than 25% spawning fish after the closure has been lifted (i.e., re-closure protocol). For the purpose of this review, we will mirror this logic and consider <25% spawning to be acceptable at the beginning of the season as well.

2) *Maximize coverage of the spawning season AND access to quota*:

To provide the greatest benefit with the least cost, the spawning closure should ideally cover the spawning season and no more. This requires understanding the timing and duration of spawning and aligning the closure system to the reproductive cycle. Closing the fishery too early or too late may unnecessarily restrict the fishery and provide inadequate protection for spawning herring.

3) *Account for interannual variation in spawning time*:

The onset of spawning in Atlantic herring can vary by several weeks from one year to the next. Measuring gonadal development via sequential GSI samples allows for predicting when spawning is likely to commence each year. Over-reliance on fixed closure dates (i.e., "default" dates) increases the possibility of a mismatch between the closure and spawning.

4) *Allow flexibility to extend closures, if necessary*:

Given the observation error inherent in small samples from a high-volume fishery, combined with the natural variability in reproductive biology, there may be instances when the timing and duration of the spawning closure is insufficiently matched to the actual spawning season. In these cases, a backup measure is needed to prevent the fishery from opening prematurely to significant spawning activity.

Current Closure Protocol

Samples are routinely collected from the directed herring fishery as it operates within the three defined spawning areas (EM = Eastern Maine; WM = Western Maine; MANH = Massachusetts/New Hampshire). Samples of 100+ fish are collected and the GSI of female herring in maturity stages 3-5 are recorded. To account for the effect of length on GSI, all values are standardized to that of a 30 cm fish (i.e., GSI_{30}), using a previously established formula. Once three samples from a given spawning area have been collected and processed, a linear model is fit to the mean GSI_{30} of stage 3-5 females, using sample date as the sole predictor variable. If a significant increase in GSI_{30} can be detected ($\alpha = 0.05$), the model is used to predict the closure date (i.e., when the threshold value of $GSI_{30} = 25$ will be reached). The model and predicted closure date are updated as additional samples are collected. Once the predicted closure date is five days away, the closure date is announced to the fishery (and thus 'fixed', regardless of subsequent samples). If an update to the model predicts that the threshold value will be reached in less than five days, the closure date will be set at five days from the model update date (i.e., a five day notice to the fishery will always be provided). If there are insufficient samples to predict a closure date, a default closure date, which represents the average date that the threshold value would have been reached in past sampling seasons, will apply.

Validity of Assumptions

Several assumptions underlie the current spawning closure program. The validity of each is evaluated here using recent full-season maturity and GSI data for the Massachusetts-New

Hampshire (MANH) spawning area. Unfortunately, a lack of samples from the other spawning areas (Western Maine, Eastern Maine) prevents an equivalent analysis.

Assumption 1: Larger herring arrive and spawn earlier than smaller herring

It has long been noted that within a sample of fish, the GSI of smaller herring is less than that of larger herring. However, during the re-design of the spawning closure program, existing data suggested that this was due to larger herring maturing earlier, and that all sizes approached a similar maximum GSI prior to spawning. Consequently, the length effect on GSI was estimated from sample data and used to adjust all GSI values to that of a standard length (i.e., GSI_{30} = expected GSI of a 30 cm female herring).

Recent data confirm this assumption in that larger herring comprise a greater portion of fishery samples early in the season, and are replace by smaller fish as the spawning season progresses (Figure 1). In addition, the average size of fish decreases sequentially as the population moves through the maturity stages (Figure 2). This suggests that not only are larger fish present earlier; they are also maturing and likely spawning before smaller fish. The 30 cm standardization also appears to be having the desired effect of combining information from all sizes to achieve a more consistent measure of the maturation for the spawning population as a whole (Figure 3).

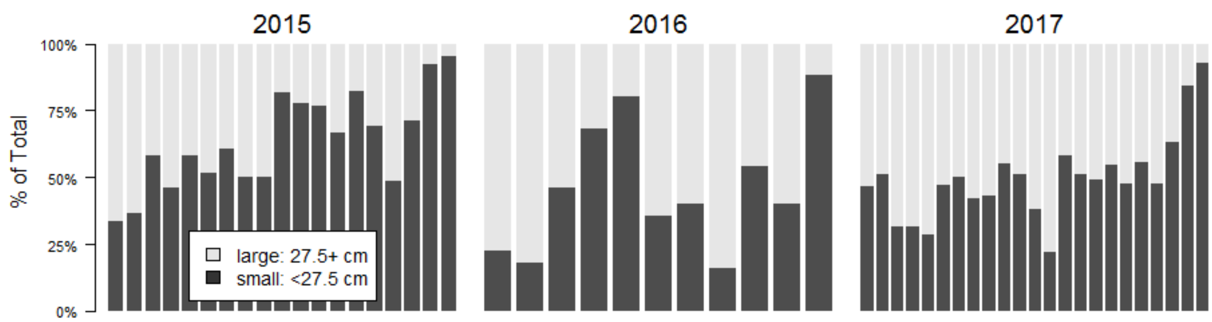

Figure 1. Fraction of herring in “large” or “small” size classes over the sequence of samples from the Massachusetts-New Hampshire spawning area, 2015-2017.

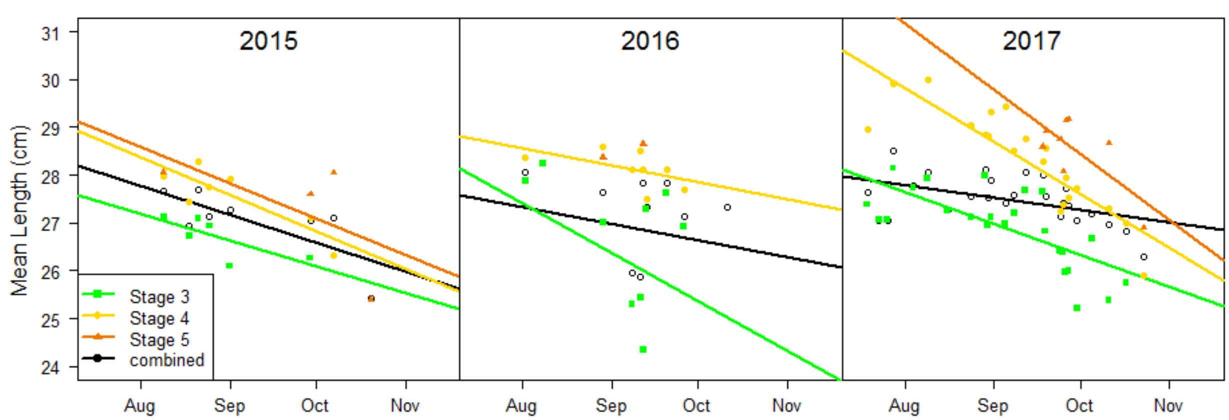

Figure 2. Mean length (cm) of female herring sampled for GSI, by maturity stage and sample date.

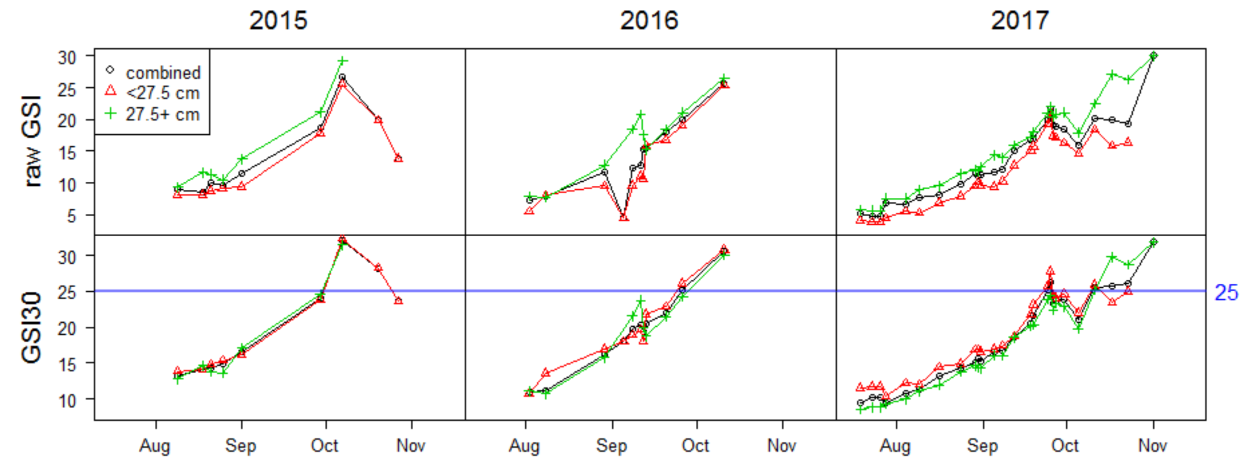

Figure 3. Mean GSI (top) and mean GSI_{30} (bottom) by sample year, date, and size class.

Assumption 2: Spawning commences near the closure threshold of GSI_{30} = 25

To adequately address this assumption, we need an objective measure of when spawning actually occurs. Prior to the collection of full-season maturity data, the only information available to us were pre-spawning GSI measurements from prior seasons. As such, the closure threshold was selected from a range of observed values at the high end of maturity stage 5, which is the last stage prior to spawning. While this approach is relevant for the maturation of an individual herring, the mean GSI of a sample (and the population) represents a mix of individuals with different developmental trajectories, even after accounting for the length effect. In other words, the peak GSI for the population may be less than that of individual fish due to this heterogeneity in spawning time.

Fortunately, by collecting maturity samples both during and after the spawning season, we can now quantitatively describe the timing and duration of the spawning season. Although more “noisy” than GSI data, we can clearly see a sequential progression of maturity stages in each of the last three years (Figure 4). The earliest samples are dominated by stage 3 (early maturing) fish, followed in sequence by later maturity stages and ending in post-season samples comprised primarily of spent (stage 7) and resting (stage 8) fish. Interestingly, the last sample in each year included some fish just entering the maturation cycle (stage 2), suggesting a portion of the population may spawn in the spring.

To describe the start of the spawning season, we fit a logistic regression to the proportion of fish in each sample that had begun to spawn (stages 6+). Likewise, to describe the end of the spawning season, we fit a logistic regression to the proportion of fish that had completed spawning (stages 7+). In both cases, stages 1 (juveniles) and 2 (initial maturation) were omitted from this analysis because it is not likely they would have spawned in the current season. A threshold percentage value can then be selected, above which we consider the “spawning season” to be underway (Figure 5). As mentioned previously, there is a long-standing rule that accepts 25% spawning herring in a fishery sample; however, lower values could be selected if there is a desire to further minimize the potential for fishery-spawning interaction. Please keep in mind that a 25% threshold for defining for the spawning season refers to the expected value for the population, meaning that individual samples may contain greater than, or less than, 25% spawning herring.

The previous closure system was still in effect in 2015, yet for the first time we were able to collect maturity samples throughout the entire spawning season. The closure began on the default date of 9/21 in this year due to a lack of 3 consecutive GSI samples from either large or small herring above their respective thresholds. In retrospect, maturity data indicate that this resulted in closing the fishery nearly two weeks early (Figure 6). Consequently, when the initial four-week closure ended, additional samples contained more than 25% spawning fish, leading to an additional two-week closure. In total, the fishery was closed for six weeks, even though the spawning season (under the 25% definition) was only four weeks long. However, if the new model-based system had been in place in 2015, the closure would have achieved a better match to the spawning season, beginning 3 days after the 25% spawning point and likely without the need for a re-closure (Figure 7).

The progression of spawning appears to have occurred earlier and more rapidly in 2016 (Figure 8). However, with only one sample during the closure and one post-season sample, the description of the spawning season has the greatest uncertainty in this year. The newer model-based closure protocol was first implemented in this year, resulting in a closure 5 days after 25%[1]. A sample collected 10 days into the closure period contained 87% spent or resting herring, indicating the bulk of the population had already spawned. No additional samples were available until early December, when it was further confirmed that the spawning season had concluded. The logistic model fit to these data suggested the entire 2016 spawning season was only 2.3 weeks long; However, it should be emphasized that the scarcity of samples toward the end of the season adds significant uncertainty to this estimate. It's possible that the season was several weeks longer and we simply lacked the temporal resolution to measure it.

The 2017 season resulted in the most detailed and complete description of spawning to date, with 29 samples collected between July 19th and November 1st (Figure 9). In this year, the model-based system resulted in a closure that was slightly before 25% spawning (2 days). The accumulation of fish entering and passing through the spawning stage can clearly be seen in the sequence of maturity samples. These data suggest that the 2017 spawning season was 4.9 weeks long (34 days), making the initial 4-week closure period insufficient. Samples collected during the fourth closure week indicated that 50% had yet to finish spawning, resulting in an additional 2-week re-closure.

The current GSI_{30} threshold of 25 appears to result in a closure that starts within a few days of the point when 25% of the population is expected to be spawning, considered here to be the start of the spawning season. However, in years with few GSI samples (2015) or accelerated maturation (2016), the current threshold may result in greater than 25% spawners in the catch. Selecting a lower GSI_{30} threshold (i.e. 23 or 24) would reduce this possibility. Regardless, the current model-based system achieves a far better match to the spawning season than the prior

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[1] The model actually recommended closing on 10/1/16, four days after 25% spawning, but managers opted to wait an additional day.

version, which tended to close the fishery several weeks early and rely more heavily on default dates.

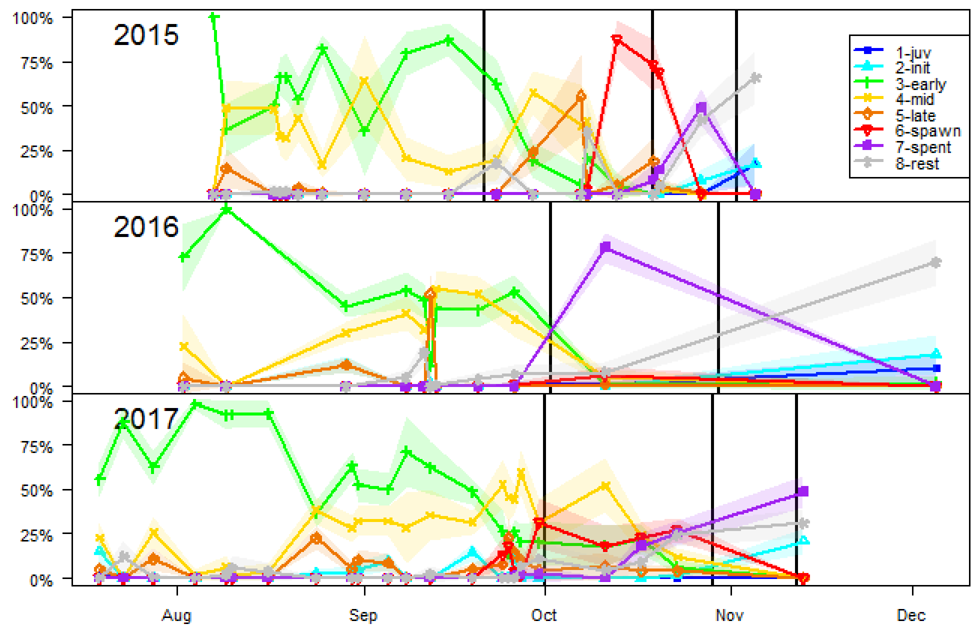

Figure 4. Fraction of MANH herring in each maturity stage by sample year and date. Black vertical lines indicate closures.

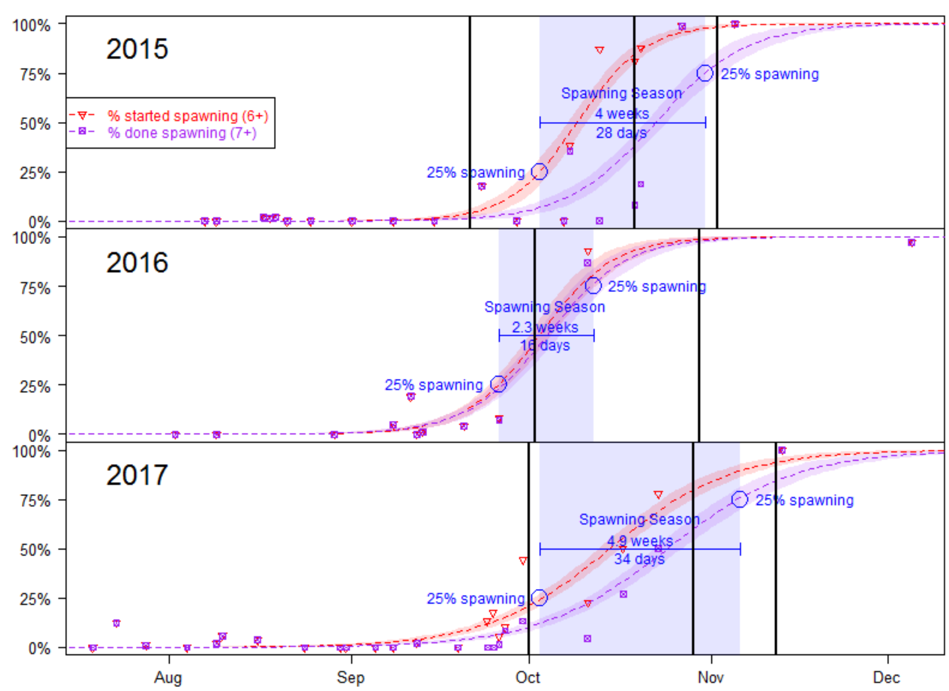

Figure 5. Observed fraction of sampled herring that had started spawning (red: stage 6+) and completed spawning (purple: stage 7+), with fitted logistic regression lines. The shaded blue region represents the spawning season, as defined by the period between when 25% of fish had begun to spawn and when 25% of fish had yet to complete spawning. Vertical black lines represent spawning closures.

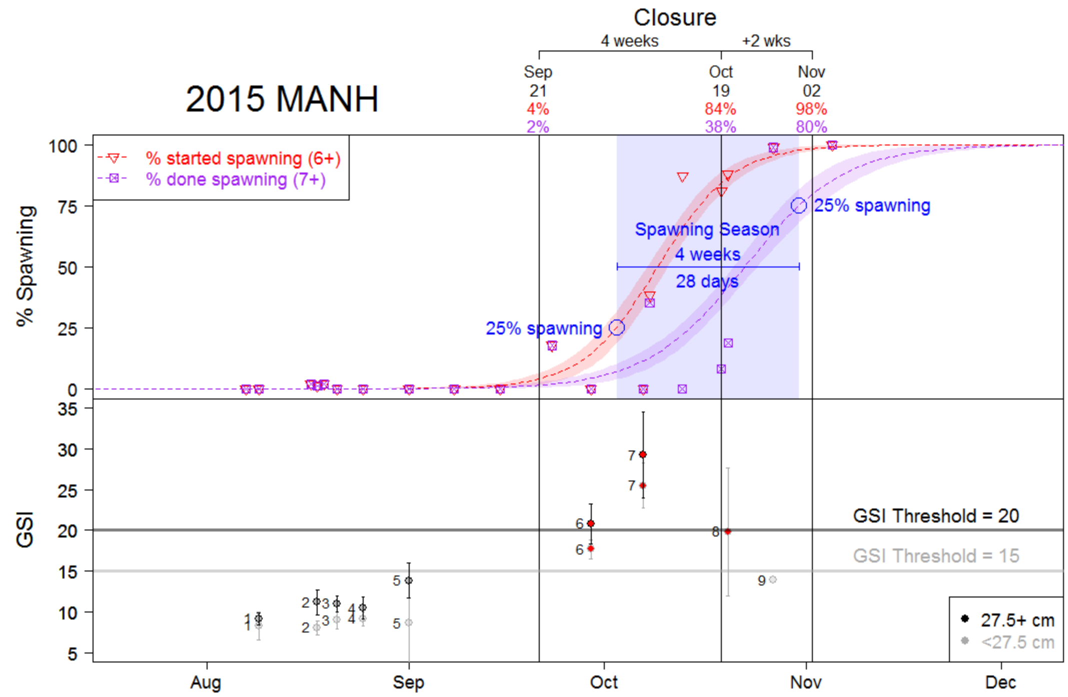

Figure 6. Estimated spawning season (top) and mean GSI (bottom) by sample date, for 2015 in the MANH spawning area. Closure dates refer to the actual closure dates under the old closure system.

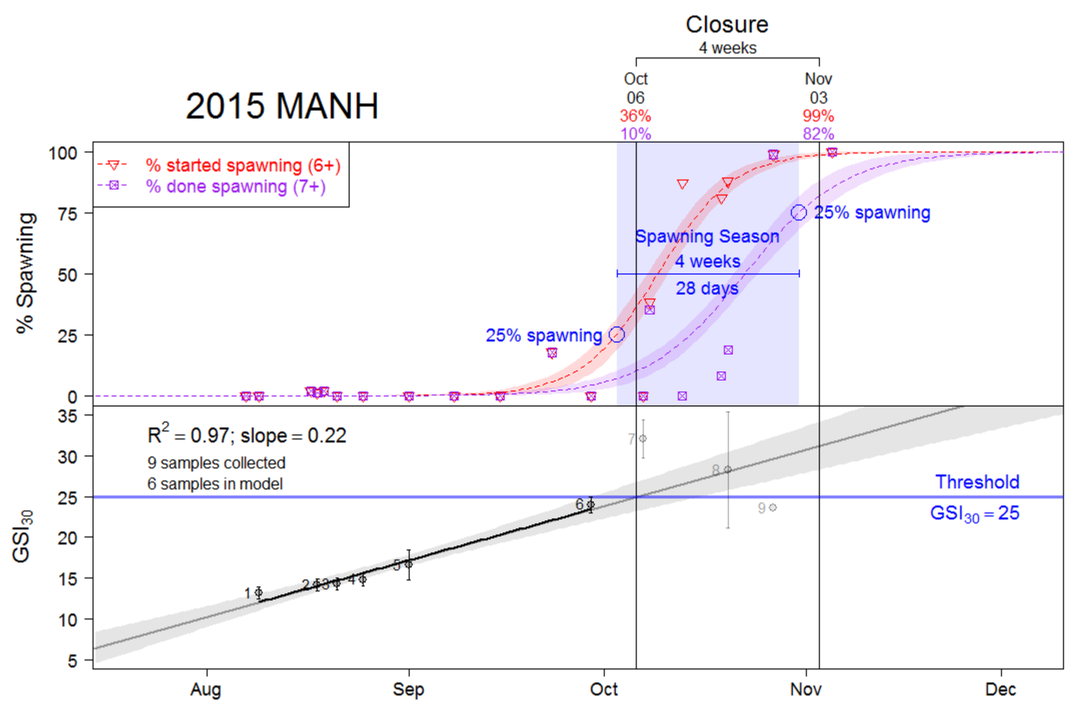

Figure 7. Estimated spawning season (top) and mean GSI_{30} (bottom) for 2015 in the MANH spawning area. Closure dates refer to what would have occurred under the current model-based system.

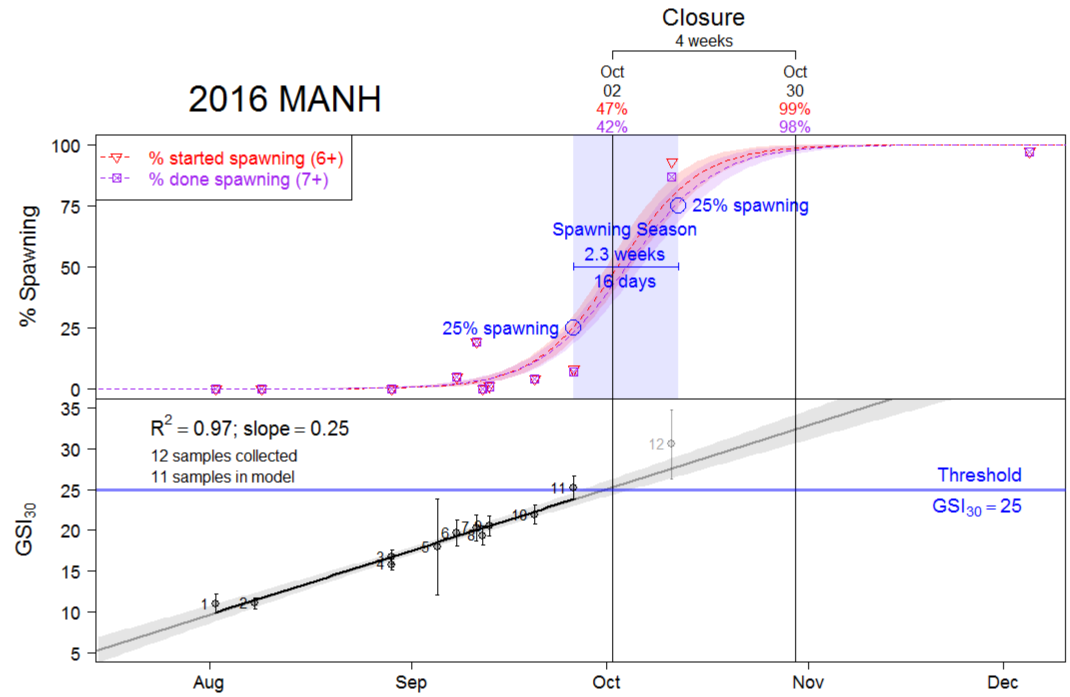

Figure 8. Estimated spawning season (top) and mean GSI (bottom) for 2016 in the MANH spawning area. Closure dates refer to the actual closure dates under the current closure system.

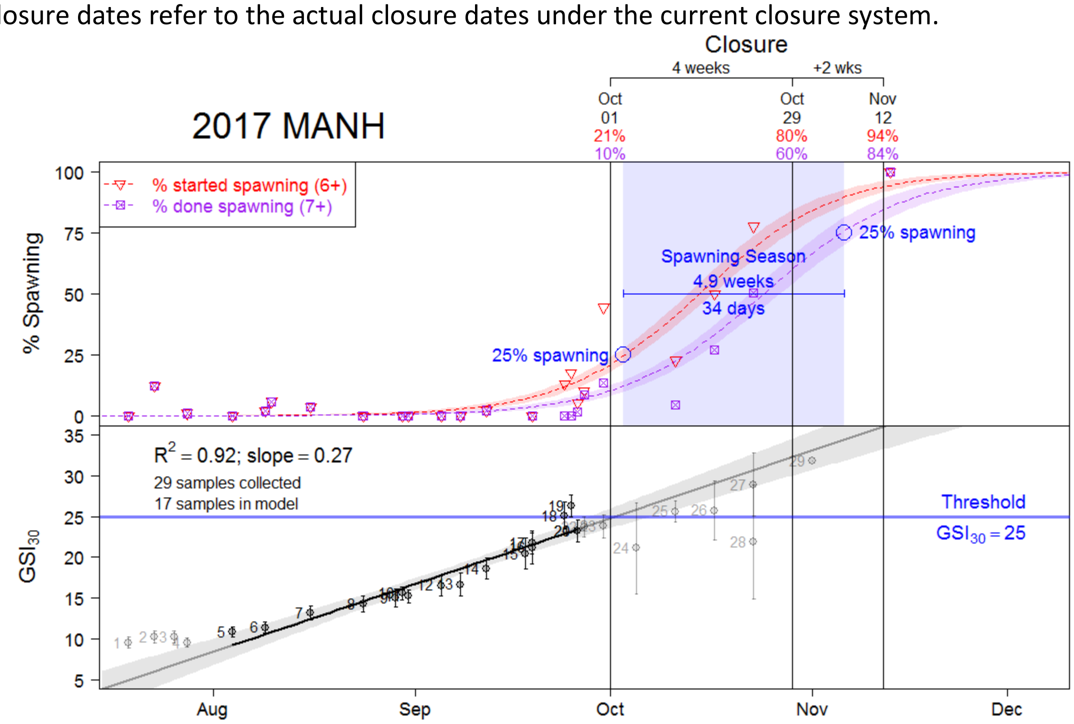

Figure 9. Estimated spawning season (top) and mean GSI (bottom) for 2015 in the MANH spawning area. Closure dates refer to the actual closure dates under the current closure system.

Assumption 3: Four weeks is a sufficient to cover the typical spawning season

The appropriate closure duration largely depends upon the percent of spawning fish deemed to be acceptable in fishery catches. Under the assumption that 25% spawning is acceptable, the spawning seasons of 2015-2017 were estimated to be between 2.3 to 4.9 weeks long; although, there is far greater confidence in the longer season estimates (2015 and 2017) than with the shorter (2016) due to a low number of samples from during/after the closure in that year. Consequently, an initial closure period of 4 weeks is likely to result in frequent use of the re-closure protocol to extend the closure. If the uncertainty inherent in frequent use of the re-closure protocol is deemed undesirable, the initial closure period could be lengthened (e.g., to 5 or 6 weeks). Furthermore, if 25% is considered an unacceptable level of spawners in the fishery, alternative values could be selected. However, it should be noted that lowering the management target for maximum acceptable % spawning will increase the defined spawning season (Figure 10) and therefore require a longer initial closure period, a lower GSI_{30} threshold (Figure 11) and an earlier default date (Table 1).

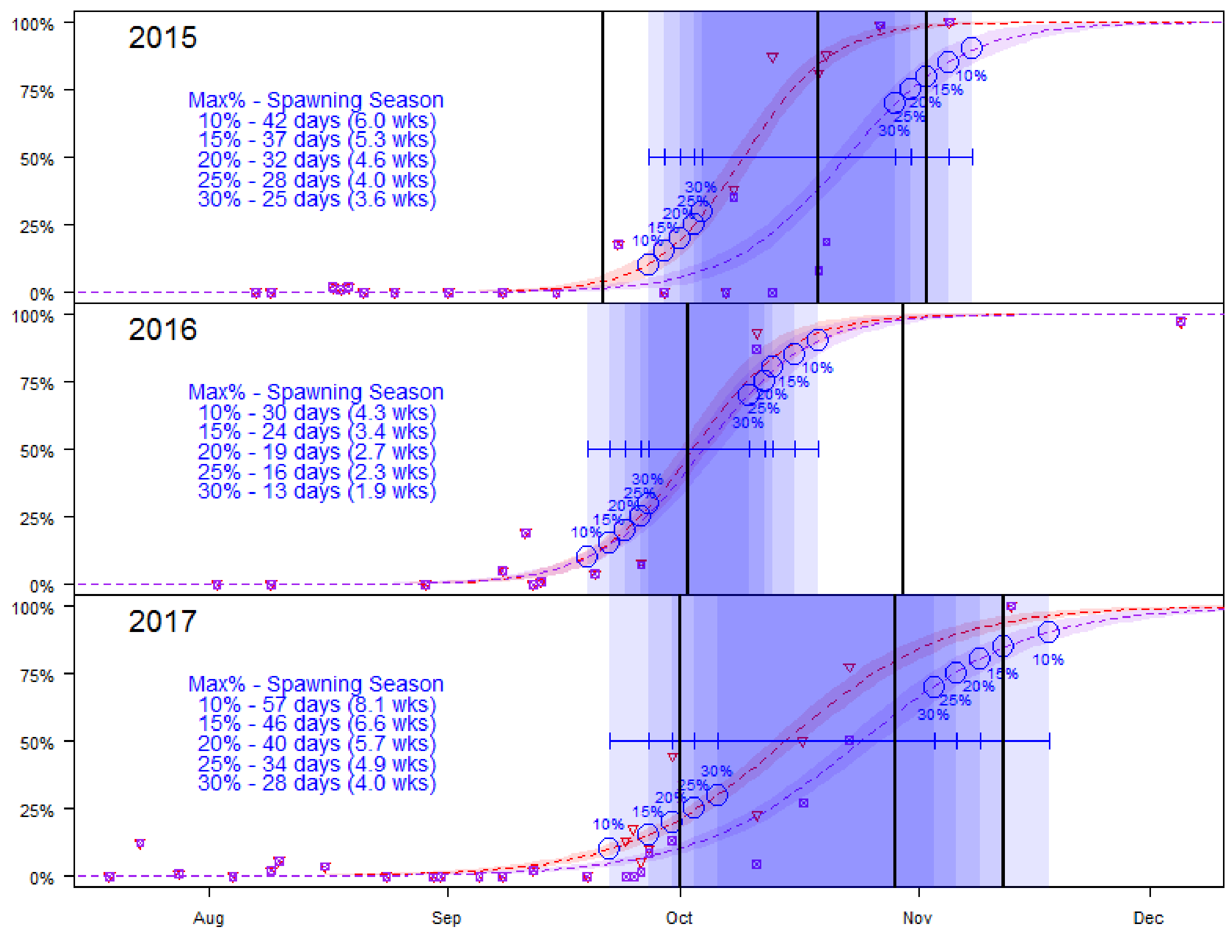

Figure 10. Effect of choice of maximum allowable % spawning in the catch on duration of the spawning season.

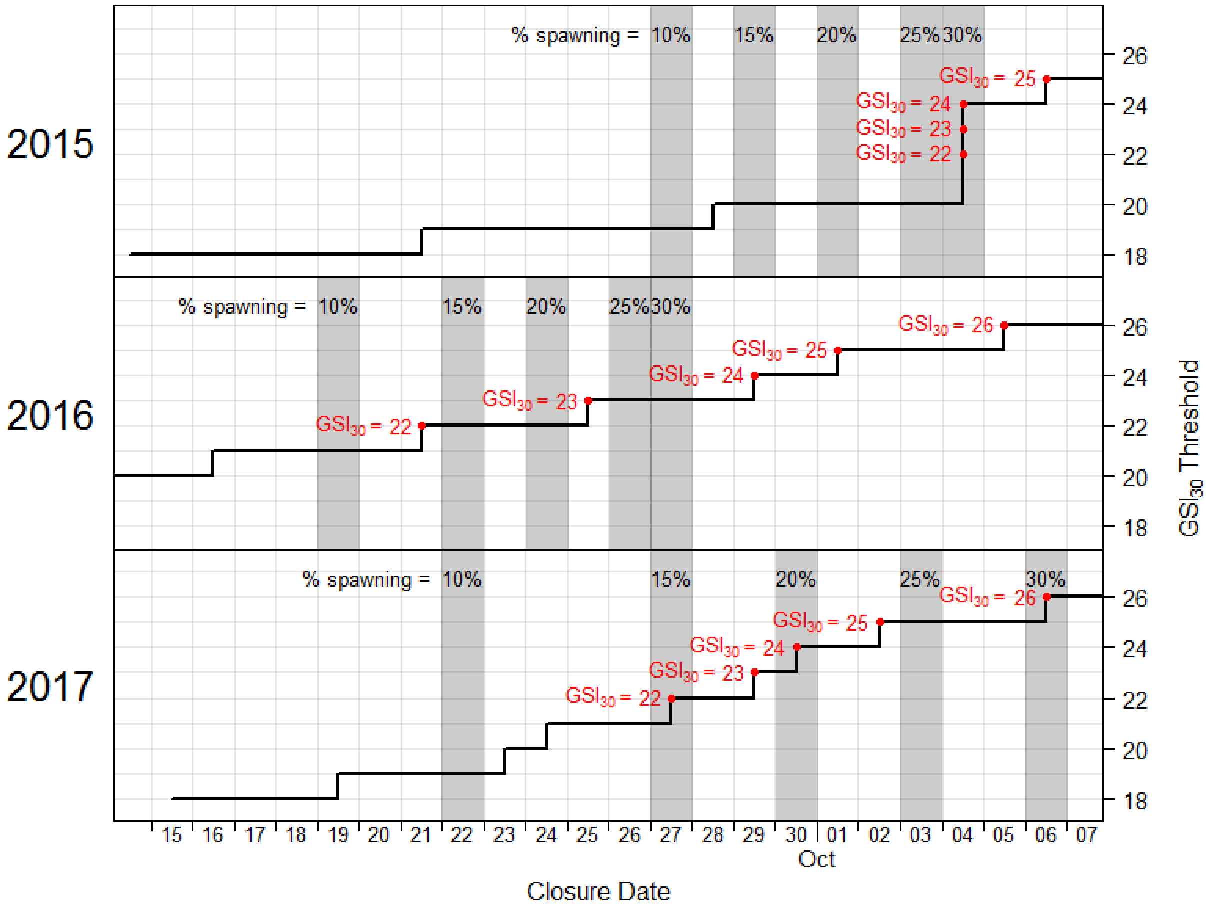

Figure 11. Date when the MANH spawning closure would have started, under different GSI_{30} thresholds. The vertical gray bands indicate the percent of the population expected to be spawning.

Table 1. Updated default dates for different GSI_{30} thresholds and spawning areas, using GSI observations from 2005-2017. As with the original analysis conducted under Amendment 3, sample data from the WM and MANH spawning areas were combined due to a lack of detectable difference in spawning time. There are insufficient samples from which to estimate a default date for the EM area. As such, the previous default date would remain (based on historical observations of herring eggs on lobster traps).

	Default Date		
GSI_{30} Threshold	MANH	WM	EM
26	Oct-6	Oct-6	Aug-28
25	Oct-1	Oct-1	Aug-28
24	Sep-27	Sep-27	Aug-28
23	Sep-23	Sep-23	Aug-28
22	Sep-19	Sep-19	Aug-28

Assumption 4: GSI increases linearly during the last 2 months prior to spawning

During the development of Amendment 3, a review of 15 years of sample data suggested that a linear model could adequately represent the increase in GSI during the pre-spawning period (i.e., ~2 months preceding spawning), despite an expected exponential relationship over the full course of gonadal development. The recent effort to sample the population over the full season now provides us with a longer time series of GSI observations to evaluate the conditions under which this assumption remains valid.

Data from the most recent 3 sampling seasons indicate that the rate of change in mean GSI_{30} (i.e., slope of the linear model) does increase slightly as the population approaches spawning (Figure 12). This results in a trend toward earlier forecasted closure dates with the addition of subsequent samples. However, the linear model continued to explain more than 90% of the variation in mean GSI_{30} (i.e., R^2) prior to the spawning closure in all years. In 2017 (the year with the best sampling coverage), it appears that GSI_{30} increased linearly over most of the pre-spawning period, and only departed from linearity in the days immediately preceding spawning (at the GSI_{30} threshold of 25). Subsequent samples during the closure period showed that mean GSI became more variable as fish moved out of the spawning stage, leaving behind a smaller pool of pre-spawning (stage 3-5) females to sample from. Although four GSI samples were collected from the MANH spawning area in July of 2017, the Herring PDT decided to omit these samples from the model due to concerns that further extending the period of observation could increase non-linearity, and because July samples were never included in the original analysis from which the system was developed.

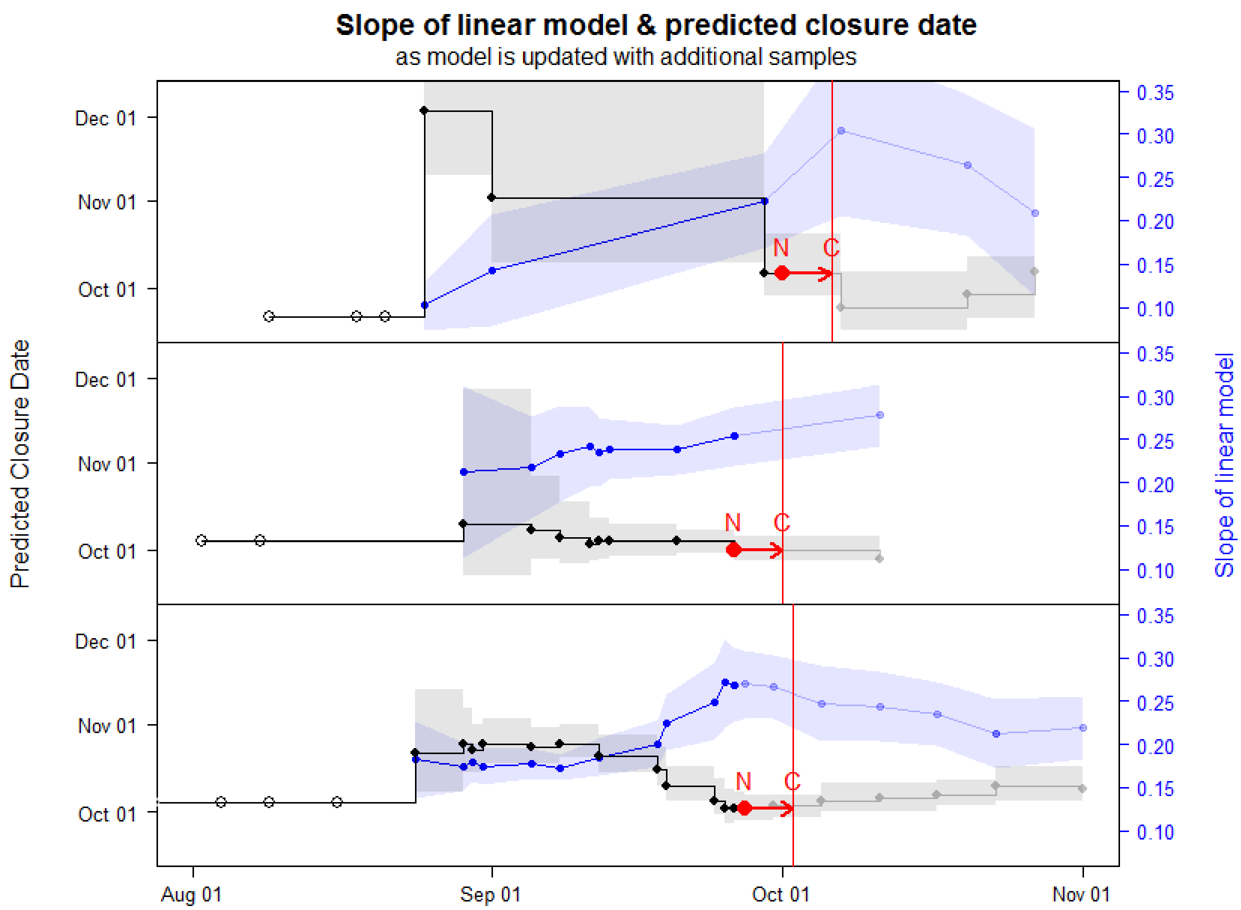

Figure 12. Slope of linear model GSI$_{30}$~DATE (blue, right y-axis) and predicted closure date (black, left y-axis) as the model is updated with additional samples. Open black circles show where the default closure date would apply: when <3 samples have been collected and/or the model fails to detect a significant increase in GSI$_{30}$. The red point labeled "N" indicates when the closure date is finally selected and the fishery notified. The red vertical line labeled "C" indicates the final selected closure date (5 days after the notify date). Darker points and lines indicate samples used in the model, whereas lighter points and lines indicate samples collected after the final closure date was selected.

Conclusions and Considerations for the Section

The current model-based spawning closure system appears to be meeting all of the Section's main objectives. The assumptions regarding length effects and spawning time appear sound, which allows the new system to be far better aligned with the reproductive biology of the population. Overall, this represents a clear improvement over the previous system.

If managers want to further minimize the risk of spawning herring in the catch, the TC notes two changes for consideration by the Section.

1) The TC found that in the two years with the most comprehensive maturity data (2015, 2017), the spawning season lasted 28 days and 34 days, respectively. This suggests that 2 week re-closures may occur frequently in the herring fishery, given that the initial closure period is currently set at 4 weeks. To simplify the herring closure protocol, provide greater predictability to industry, and provide greater protection during the spawning season, the Section could consider a longer closure of 5 or 6 weeks, reducing the need for a 2-week re-closure.

2) To further minimize the risk of spawning herring at the beginning of the season, a lower GSI_{30} threshold could be selected. As a reminder, the current threshold is 25; however, analysis suggests that a GSI_{30} threshold of 23 or 24 would reduce the probability of greater than 25% spawners in the catch. In addition, this change would have the added benefit of shortening the monitoring period by restricting it to the portion of the season when GSI increases most linearly. This may result in more consistent closure forecast dates from one sample to the next. However, please note that lowering the GSI_{30} threshold will require an earlier default date (Table 1) and will further increase the likelihood for re-closures, if the initial closure period remains at 4 weeks.

Finally, the TC highlights the need for fishery independent sampling during the spawning closures, especially in eastern and western Maine where there has are fewer fishery-dependent samples available. The information that these samples provide will be critical for our ability to further evaluate and improve the performance of this system.