Draft Framework Adjustment 53

To the

Northeast Multispecies FMP

Appendix II: Analytics Techniques

Identifying location and times of spawning for Gulf of Maine cod

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By

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Introduction:

At its September/October meeting, the Council tasked the Groundfish Plan Development Team (PDT) with evaluating the biological impacts of spawning closure options for GOM cod in draft Framework Adjustment 53 (FW 53) to the Multispecies (Groundfish) fishery management plan. Two options were identified at the Council meeting, and the PDT requested that it work with the Committee after the September/October Council meeting to further evaluate the efficacy of those time/areas for protecting spawning GOM cod. The options in FW 53 include 30 minute blocks that would be closed for specific months to protect spawning cod. Several independent data sources and methods were used to examine the time-area blocks with high concentrations of spawning cod.

Cod spawning biology:

The GOM stock of Atlantic cod is comprised of two genetically distinct groups whose spawning activity overlaps in space, but not in time (i.e., "winter" and "spring" spawners) (Kovach et al., 2010; Zemeckis et al., 2014). Within these broad groups are several smaller sub-components that form spawning aggregations at predictable times and locations. At one time, numerous aggregations of spawning cod could be found all along the GOM coast (Ames 2004). Unfortunately, most of these spawning grounds are now vacant, and current cod spawning activity appears restricted to a narrow range of coastline from NH to MA. Cod exhibit high fidelity to their spawning sites, and recent studies on spring spawning GOM cod have shown that tagged females are capable of returning to the same precise spawning location (within <10m) over multiple years (Dean et al., 2014; Zemeckis et al., 2014). This spatial and temporal predictability makes individual spawning groups particularly vulnerable to depletion, and there is little indication that once a site-specific spawning component is lost that the area can be recolonized.

Some of the remaining GOM cod spawning aggregations are well documented and small seasonal fishery closures have been implemented in an attempt to protect them from disruption and depletion (Armstrong et al., 2013). However, these examples as well as similar experiences in other cod stocks have pointed to a need for broader-scale measures (i.e., at the scale of 30-min blocks) to prevent further loss of population structure and enhance the potential for recruitment success in the future (Zemeckis et al., 2014).

Trawl surveys:

We examined the spatial distribution of spawning cod from 5 trawl surveys in the Gulf of Maine: NEFSC spring, NEFSC fall, MADMF spring, MADMF fall, and the Industry-based cod survey (IBS). The NEFSC and MADMF surveys have narrow seasonal coverage, limiting their applicability to spawning cod (
Figure 1). Additionally, because these surveys were designed to provide information on a wide variety of species, they have relatively low catches of cod and even smaller sample sizes of sex and maturity data.

The IBS cod survey was specifically designed to study stock distribution and demographics of cod in inshore Gulf of Maine waters (< 75 fathoms) from Cape Cod to the Bay of Fundy. The IBS survey gathered detailed information on the spawning condition of captured animals (see section *Spawner CPUE*). The IBS was a cooperative research effort that employed 4 industry vessels to simultaneously survey the entire study area with high intensity over five back-to-back cruises starting in mid-November and continuing through May:

Cruise	Dates	Season
1	Nov 14 - Dec 31	Winter
2	Jan 1 - Feb 12	Winter
3	Feb13 - Mar 17	Winter
4	Mar 18 - Apr 19	Spring
5	Apr 20 - May 31	Spring

Each vessel used an identical net equipped with a mensuration system to ensure equivalent net geometry and fishing power among vessels. The survey used a systematic fixed station design (standardized grid) as well as a random stratified sampling design for areas that fishermen designated as "hot spots" with traditionally high catch rates. Due to its singular focus on Atlantic cod, the IBS provided an order of magnitude more biological samples (i.e., sex, maturity) from this species than the other surveys (NEFSC, MADMF). The broad seasonal overlap with cod spawning, high spatial resolution and large sample sizes make the IBS an invaluable source for describing the spawning activity of cod in the GOM.

The August 2008 peer-review of the Cod IBS acknowledged its utility for this purpose:

> *"The Cod IBS provides valuable information on cod in the Gulf of Maine when no other sources of data are available. The Cod IBS is a good example of a cooperative project."*
>
> *"The survey provides high resolution information on the spatial and temporal distribution, size composition, maturity and potentially age of cod and augments existing surveys."*
>
> *"Survey data are useful in determining the location and timing of cod in spawning condition as well as the coincidence of spawning cod with rolling closures."*
>
> *"The utility of the Cod IBS data relative to the fishery closure areas (rolling closures) lies mostly in the identification of the areas containing spawning fish during specific times of the year. Generally, the monthly closed areas matched well with the areas where the highest catches of spawning fish could be found. In that respect, the survey data are useful to determine the location and timing of cod in spawning condition."*

Trawl survey data were used in two separate ways to identify areas of cod spawning activity:

1) CPUE of cod in spawning conditions, and;
2) Presence of significantly skewed sex ratios

Spawner CPUE:

Cod were considered "spawning" if they were classified as ripe, running, or spent using standard macroscopic maturity criteria. While it is possible to find cod in spawning condition some distance from the specific spawning sites, a high abundance of spawning cod is typically seen as a reliable indicator of spawning location. In particular, females in spawning condition are likely to be near the spawning area as hydrated eggs (i.e., "ripe") are typically released within 36 hours and ovulated eggs (i.e., "running") within 5 hours (Kjesbu et al., 1990).The CPUE (kg/tow) of cod in spawning condition was calculated for each survey tow (Figure 2) and summarized by 30-min square ("block") and season, using the arithmetic mean (Figure 3). For the purpose of identifying blocks with spawning activity, the mean's sensitivity to outliers is a useful property that can help indicate the presence of cod spawning aggregations. Each 30-min block was classified into low (<1 kg/tow), medium (1-8 kg/tow) or high (>8 kg per tow) categories.

For the winter cruises, only Massachusetts Bay (Block 125) was assigned to the "high" category, with the neighboring blocks of 124, 132, 133, as well as 123 and 139 falling into the "medium" category. A very low level of spawning fish was detected in nearly all other sampled blocks, but these areas were dominated by zero catches.

In the spring, blocks covering Massachusetts Bay (Block 125), Ipswich Bay (Block 133) and Jefferies Ledge (Block 132) were identified as having "high" CPUE of spawning cod. Stellwagen Bank (Block 124), Bigelow Bight (Block 139), and the offshore ledges of Platts (Block 138), Fippennies (Block 130) and Cashes (Block 129) all fell into the "medium" category. Notably, the backside of Cape Cod was identified as having either "high" (Block 123) or "medium" (Block 114) CPUE of spawning cod; however, these areas are technically part of the Georges Bank stock area.

Despite the intensive sampling and broad seasonal footprint of the IBS, this survey did not completely encompass the entire spawning periods of GOM cod. In particular, the beginning of the winter spawning season (before November 15) and the end of the spring spawning season (after May 31) were not sampled. Furthermore, the short time series (2004-2007) provides a recent "snapshot" of spawning activity, and some areas that formerly may have been quite important to the reproductive capacity of the stock may have been depleted when these data were collected. As such, the areas identified by the IBS should be seen as a subset of where cod spawning occurs.

For the draft FW 53 GOM cod spawning area closure alternatives (in section 4.2.1), Sub-Option A appears to have good overlap with the areas identified as having high CPUE of spawning cod from the IBS for the months of November - May. However, as there are no IBS data for June and July, and adequacy of proposed closures for these months should be evaluated using other data sets (see sections *ichthyoplankton surveys* and *acoustic telemetry*). Also, several blocks with "medium" abundance of spawning cod would be vulnerable under this option. Sub-Option B appears to provide only partial protection of spawning cod, particularly in the spring.

Skewed sex ratios:

During spawning, males and females segregate themselves on the spawning ground, with males exhibiting higher activity over a larger area. This causes males to become more vulnerable to capture, leading to predominantly male-skewed sex ratios in survey or fishery catches (Dean et al., 2014). This phenomenon can be utilized to identify specific locations where spawning behavior occurs. When not spawning, the ratio of females to males is expected to be 1:1. Therefore, identifying survey tows with a sex ratio (SR) that is significantly different from 1:1 indicates spawning activity. All bottom trawl survey tows with a sufficient sample size (n>=5 sex observations) were evaluated for the presence of a significant SR skew using a two-tailed exact binomial test (α=0.05). The resulting probabilities were further adjusted for multiple comparisons by controlling the false discovery rate.

The IBS was the most relevant dataset for this approach, given the broad temporal overlap with spawning and generally high sample sizes. Of the IBS tows conducted in winter, significantly skewed sex ratios were detected in blocks 124, 125 and 139 (
Figure 5). For the spring cruises, blocks 124,125,132,133 were found to contain significantly skewed SRs. Only a handful of tows from the NEFSC surveys were found to have a significant SR skew (Blocks 124 and 125 in both spring and fall), but this survey is not well suited for this method given the low number of sex observations and limited coverage of inshore areas (**Error! Reference source not found.**). Because the MADMF fall survey does not occur at a time of year when cod are typically spawning, it is not surprising that none of the 3,200+ tows were found to have a significant SR skew. However, within the limited survey area of the MADMF spring survey, the same precise locations of spawning activity were identified as in the IBS dataset (Figure 6 - near Cape Ann, in blocks 124 and 133).

Ichthyoplankton surveys:

The MARMAP ichthyoplankton survey (1977-1987) provides a unique picture of GOM cod spawning, because it is the only data source that offers a measure of spawning activity in every month of the year.

Once released, cod eggs are generally pelagic and their distribution is largely influenced by oceanographic currents. The duration of this incubation period is strongly temperature dependent (Marteinsdottir et al., 2000) and given the average water temperature in the GOM over the course of a spawning season, the expected time to hatch is 15 days in winter and 9 days in spring. A study of the dispersal of cod eggs and larvae in the GOM using a highly-resolved hydrodynamic model found that the maximum dispersal over 15 days was approximately 100 km (Churchill et al., 2011). Assuming an egg mortality rate of 10% per day estimated from MARMAP data (Mountain et al., 2003), the median age of eggs at peak spawning would be approximately 6 days in winter and 4 days in spring. Therefore, we conclude that the maximum dispersal (distance from the spawning location) of the typical egg would be ~40 km in winter and ~25 km in spring. Therefore, it is reasonable to assume that quarter-degree blocks (~40 km x 55 km) with elevated egg densities correspond to spawning locations.

Maps of cod egg density from MARMAP surveys (1977-1987) were examined from Berrien and Sibunka (1999) and used to assign a maximum observed egg density to each 30-min block for each month (Figure 8). These data both corroborate and complete the seasonal profile of spawning activity provided by the IBS (Figure 12). Specifically, the winter spawning season spans the months of November-February, whereas the spring season encompasses the months of April-July. It appears that very limited spawning occurs in the months of August, October and March, with a complete absence of spawning in September.

The MARMAP data represent spawning areas during the 1970's and 1980s and may capture spawning aggregations that have since been depleted or extirpated. Regardless, the areas of spawning activity indicated by this method are similar to those described by sex ratio and spawner CPUE data from trawl surveys. For the winter months, elevated egg densities were found most consistently in blocks 124, 125, 132, 133 and 139, with the highest levels observed in Massachusetts Bay (block 125). As with the IBS dataset, the backside of Cape Cod (blocks 123, 114) was also identified as a spawning area; however, it should be noted that these blocks are technically part of the Georges Bank cod stock. For the spring spawning season, blocks 124, 125, 132, 133, 139, and 140 all achieved the highest level of observed egg density. These data provide some indication of a latitudinal progression of spawning activity, with peak egg density occurring earlier in Massachusetts Bay than in Ipswich Bay. However, it should be noted that the timing of the shift in closure areas under the FW53 Sub-options do not align well with the available data.

Acoustic telemetry:

Several acoustic telemetry experiments have been conducted recently on groups of spring spawning cod in the GOM (Dean et al., 2012, 2014; Zemeckis et al., 2014; Siceloff and Howell, 2013 – all occurring in blocks 125 and 133). While narrow in scope, each study provides direct empirical evidence from individual spawning aggregations. Given the high resolution and the multi-year observational capabilities of this technology, tagged fish were documented returning to the same precise spawning location year after year. A spring spawning aggregation was observed to be intact for over 100 days, corroborating other sources of data on the temporal span of the spawning season. Significant spawning activity was observed from acoustically tagged cod in June and July, which is in agreement with the MARMAP surveys of cod egg density.

Of note, a similar acoustic telemetry study is currently underway to describe the activity of winter spawning cod in Massachusetts Bay (blocks 125 and 124). The finding of this project will be subject to a peer review upon completion and in the interim early information is being provided for informational purposes only. Preliminary data from this project are only relevant for the end of the winter spawning season (surviving tagged fish will return to the spawning ground this winter), but the departure of spawning fish from the study area by mid-February corroborates the IBS and MARMAP datasets.

Passive acoustic monitoring

The mating system of cod involves vocalizations (i.e., "grunts"), primarily arising from agonistic interactions between males competing over mating territories. Cod spawning grunts are sufficiently distinct that they can be discerned from other fish and marine mammal sounds, and

the frequency of their occurrence has been used as a proxy for the intensity of spawning activity (Hernandez et al., 2013). Arrays of moored underwater hydrophones have successfully recorded cod spawning grunts from both the winter (blocks 124, 125, 133) and spring (blocks 125, 133) spawning groups. While use of this technology is limited by a relatively narrow detection range and a labor intensive analytical process, the peaks in vocal activity correspond well with the other measures of the seasonal distribution of cod spawning activity: Winter = late November to early December; Spring = late May to early June. It should be noted that while the passive acoustic observations of spring pawning GOM cod have been published in a peer-reviewed journal (Hernandez et al., 2013), the data from winter spawning cod are preliminary observations from an ongoing project and should be considered accordingly.

Conclusions:

Multiple independent data sources and analytical approaches were used to identify the areas important to spawning cod in the GOM, at the scale of the 30-min month-block. Notable discrepancies exist between these analyses and the FW53 closure sub-options (Section 4.2.1.2 - Sub-Option A and Sub-Option B), including:

1) Significant spawning occurs in February and July, both of which are absent from sub-options A and B
2) March appears to be a time with limited spawning, yet is included in both sub-option A and B
3) The northward shift in closure areas (from May to June) under both sub-option A and B does not match existing data on the latitudinal progression of spawning. Blocks 124 and 125 continue to be important in June.
4) Sub-option B would protect a small fraction of the area that is import to spring spawning cod

An alternative Sub-option C should be considered that will more fully protect spawning cod, while at the same time allow access to areas that do not support aggregations of spawning cod. Based on these analyses, we recommend the closure of blocks 124, 125, 132, 133 for the months of November through February, and blocks 124, 125, 132, 133, 139, 140 for the months of April through July.

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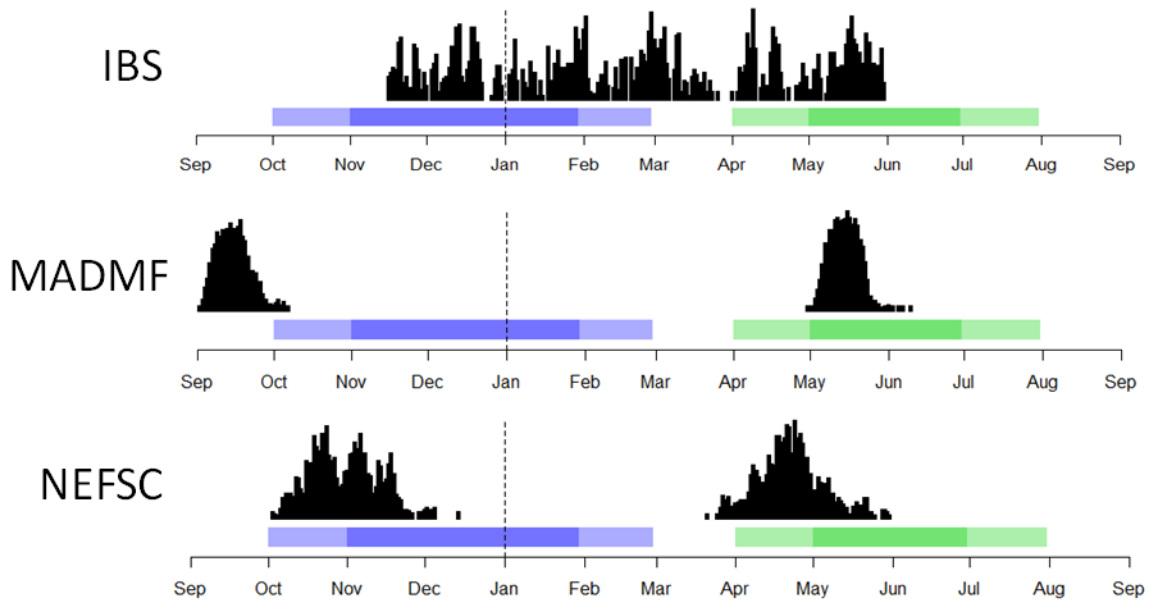

Figure 1. Histogram of tow dates for the IBS, MADMF and NEFSC bottom trawl surveys, in relation to cod spawning seasons in the GOM (blue = "winter"; green = "spring").

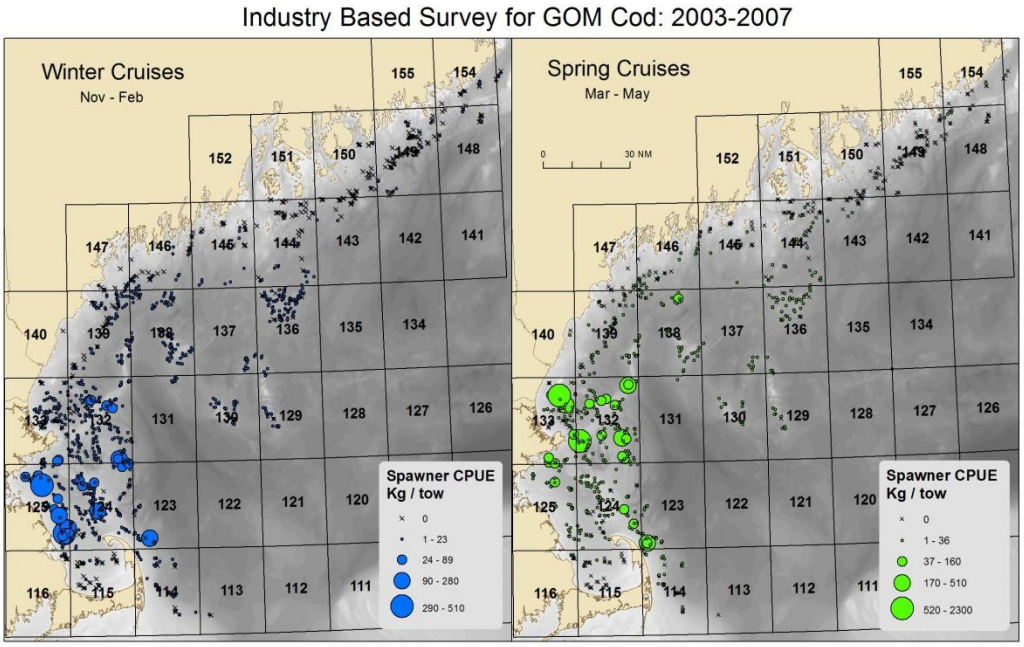

Figure 2. Distribution of weights of ripe, ripe and running and spent cod (kg) for winter and spring period in the IBS survey (2003-2007).

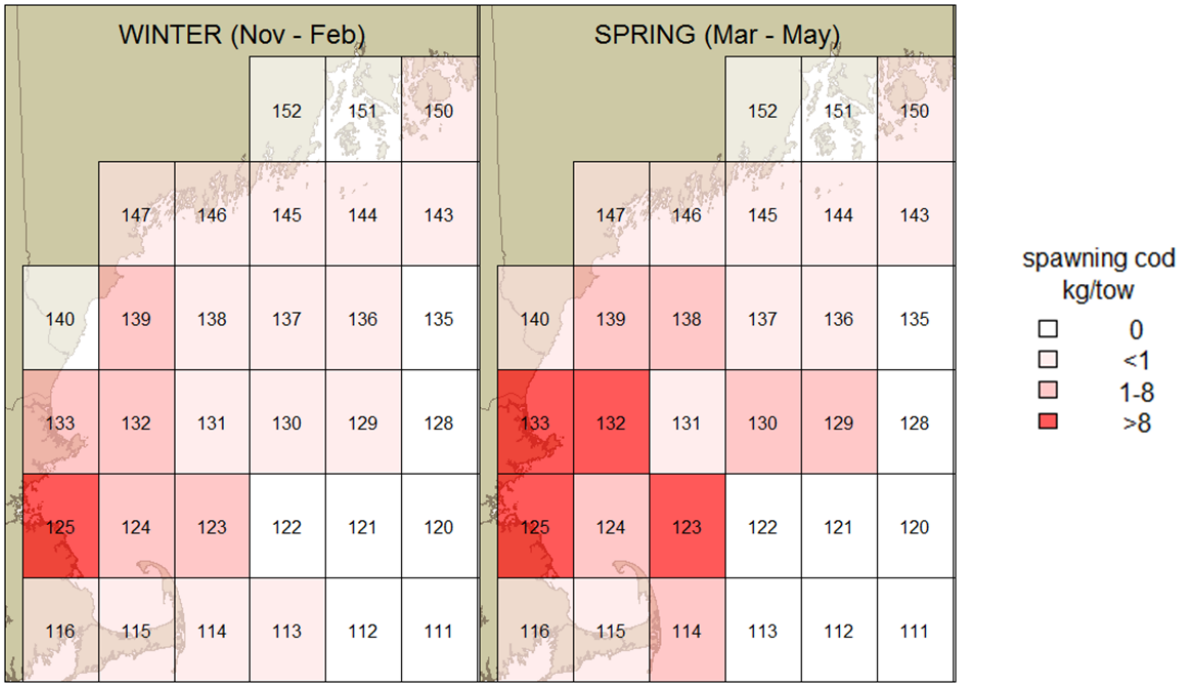

Figure 3. Mean CPUE of spawning cod from the IBS by block and season.

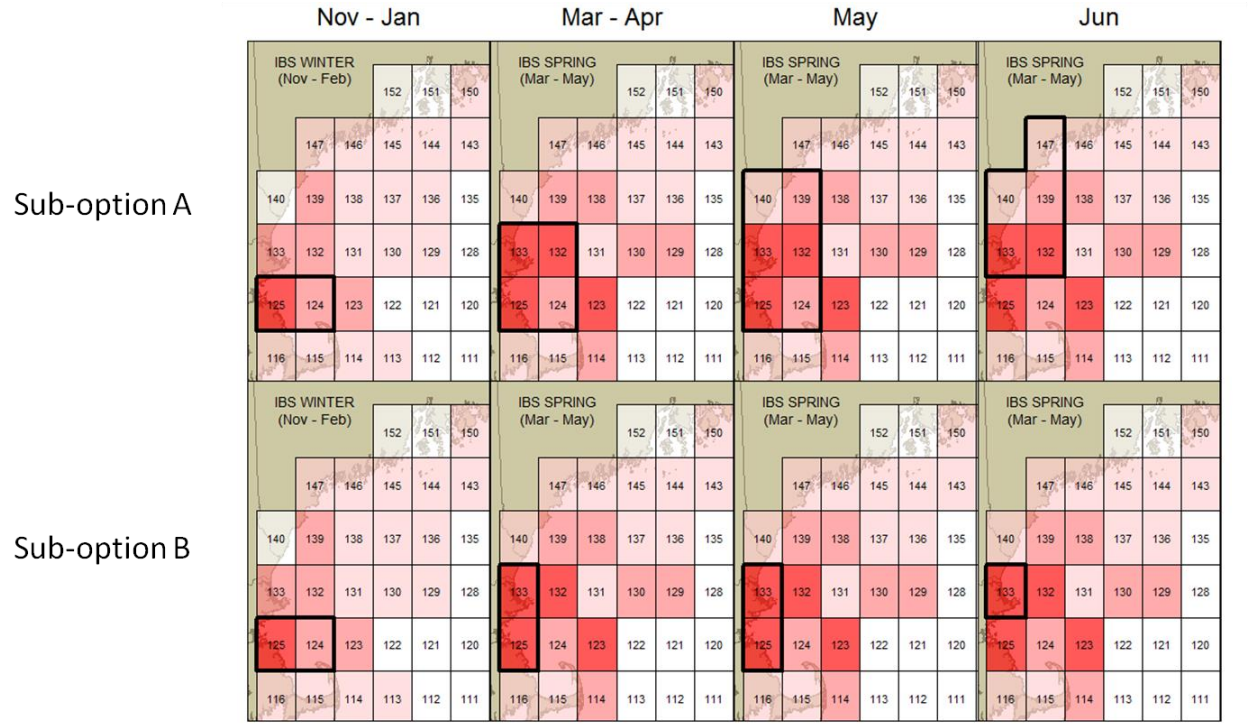

Figure 4. Mean CPUE of spawning cod by season from the IBS, as compared to the two sub-options identified in FW 53. Blocks under consideration for closure are outlined in bold. It should be noted that IBS did not operate in June, and data from all spring cruises (March-May) are shown for comparison.

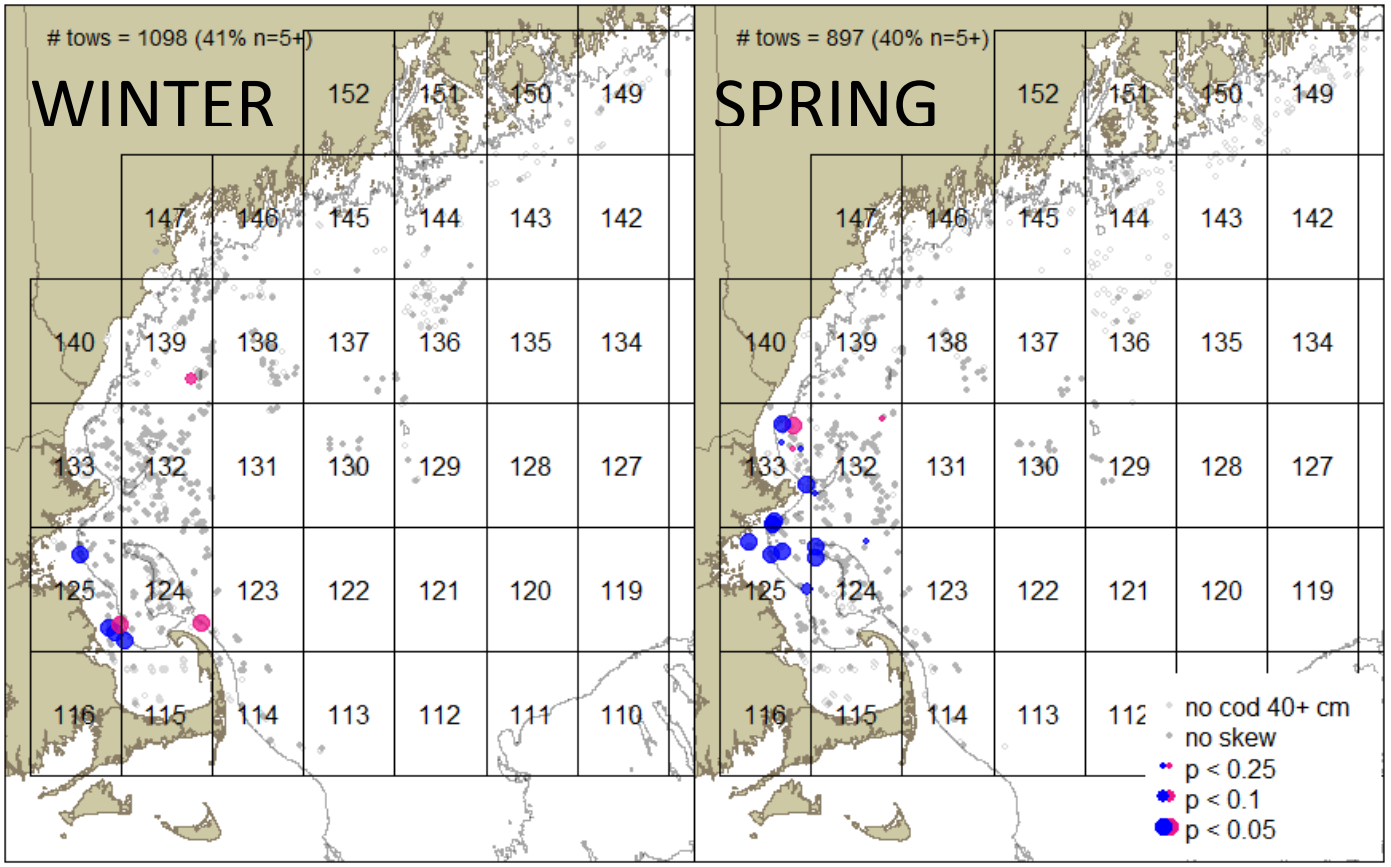

Figure 5. Location of tows with significantly skewed cod sex ratios in the IBS survey, indicating the presence of spawning behavior. Blue dots represent a significant male skew, whereas pink dots represent a significant female skew. The size of the dot is proportional to the *p*-value of the significance test (i.e., larger dots indicate a stronger sex ratio skew).

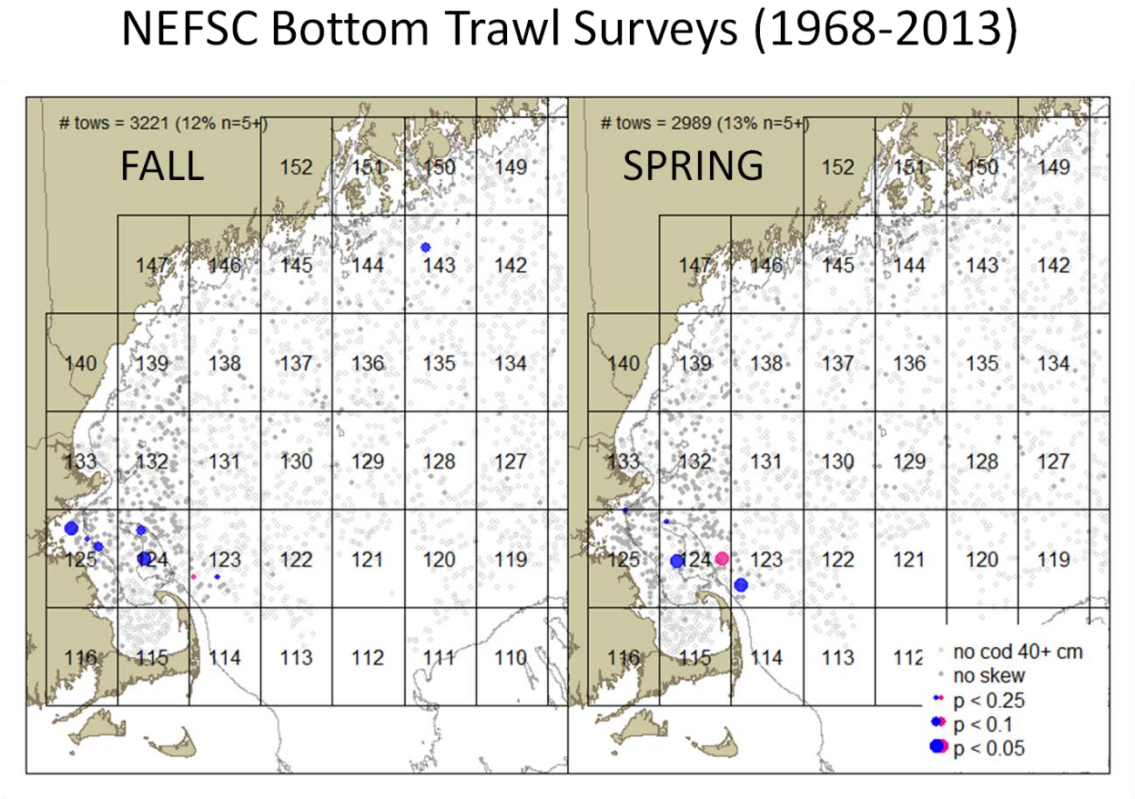

Figure 6. Location of tows with significantly skewed cod sex ratios in the NEFSC bottom trawl surveys, indicating the presence of spawning behavior. Blue dots represent a significant male skew, whereas pink dots represent a significant female skew. The size of the dot is proportional to the *p*-value of the significance test (i.e., larger dots indicate a stronger sex ratio skew).

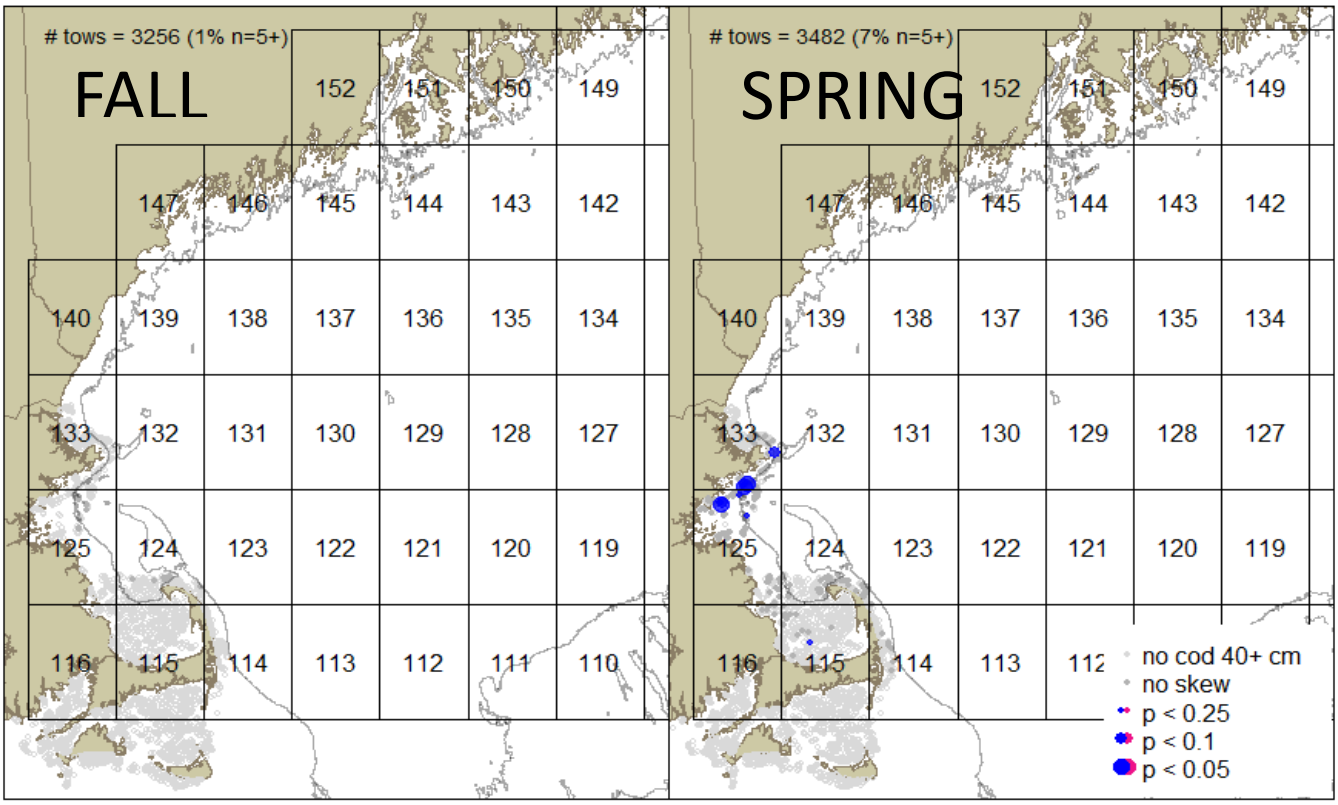

Figure 6. Location of tows with significantly skewed cod sex ratios in the MADMF bottom trawl surveys, indicating the presence of spawning behavior. Blue dots represent a significant male skew, whereas pink dots represent a significant female skew. The size of the dot is proportional to the *p*-value of the significance test (i.e., larger dots indicate a stronger sex ratio skew).

Sub-option A

Sub-option B

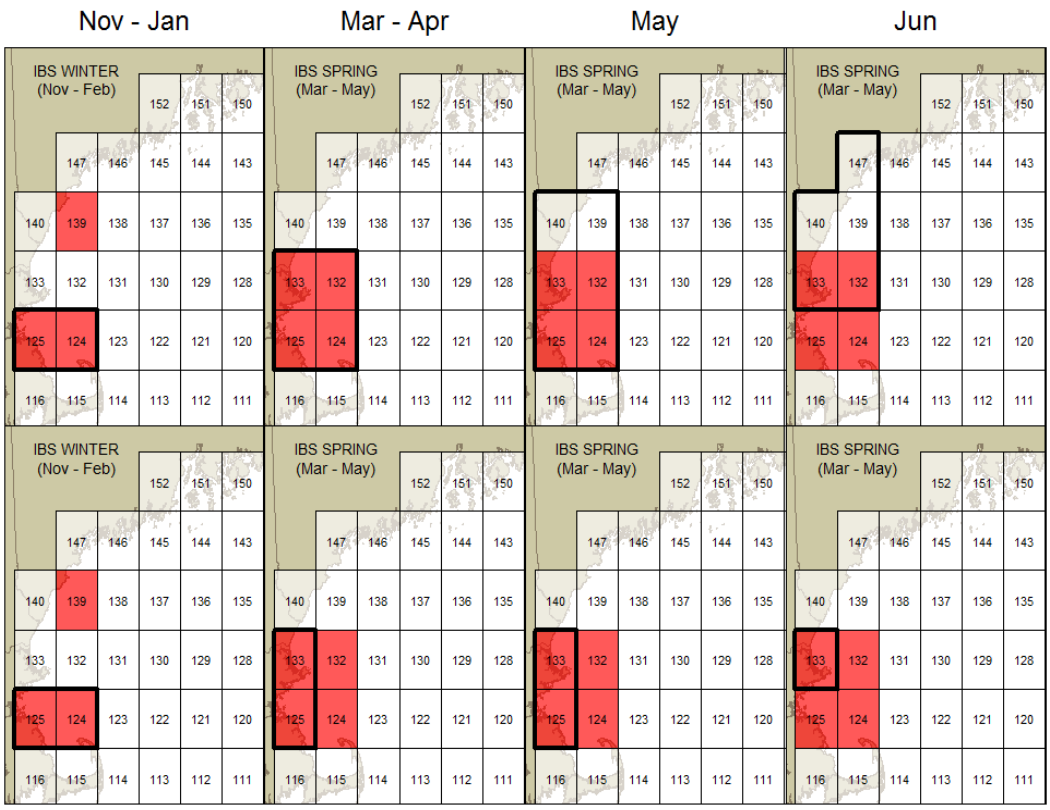

Figure 7. Blocks containing tows from the IBS with significantly skewed cod sex ratios, indicating spawning behavior. Blocks under consideration for closure under the FW 53 sub-options outlined in bold. It should be noted that IBS did not operate in June, and data from all spring cruises (March-May) are shown for comparison.

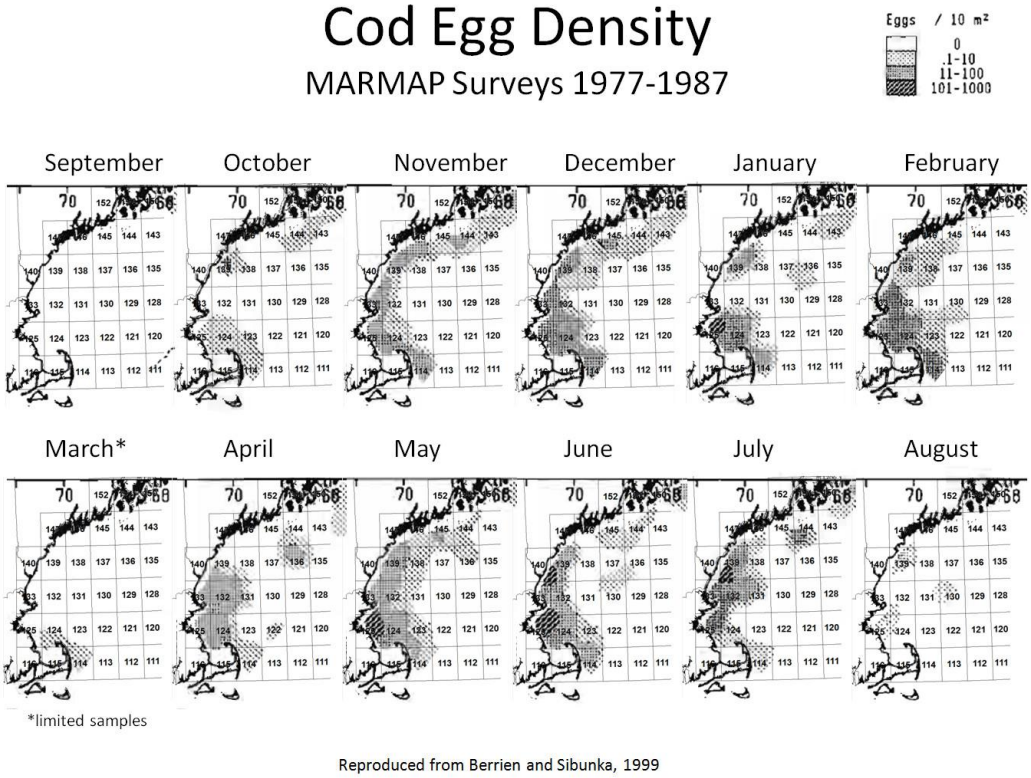

Figure 8. MARMAP cod egg densities by Month in relation to 30-min blocks. Figures were reproduced from from Berrien and Sibunka (1999). Note that the scale of egg density bins represent increasing orders of magnitude.

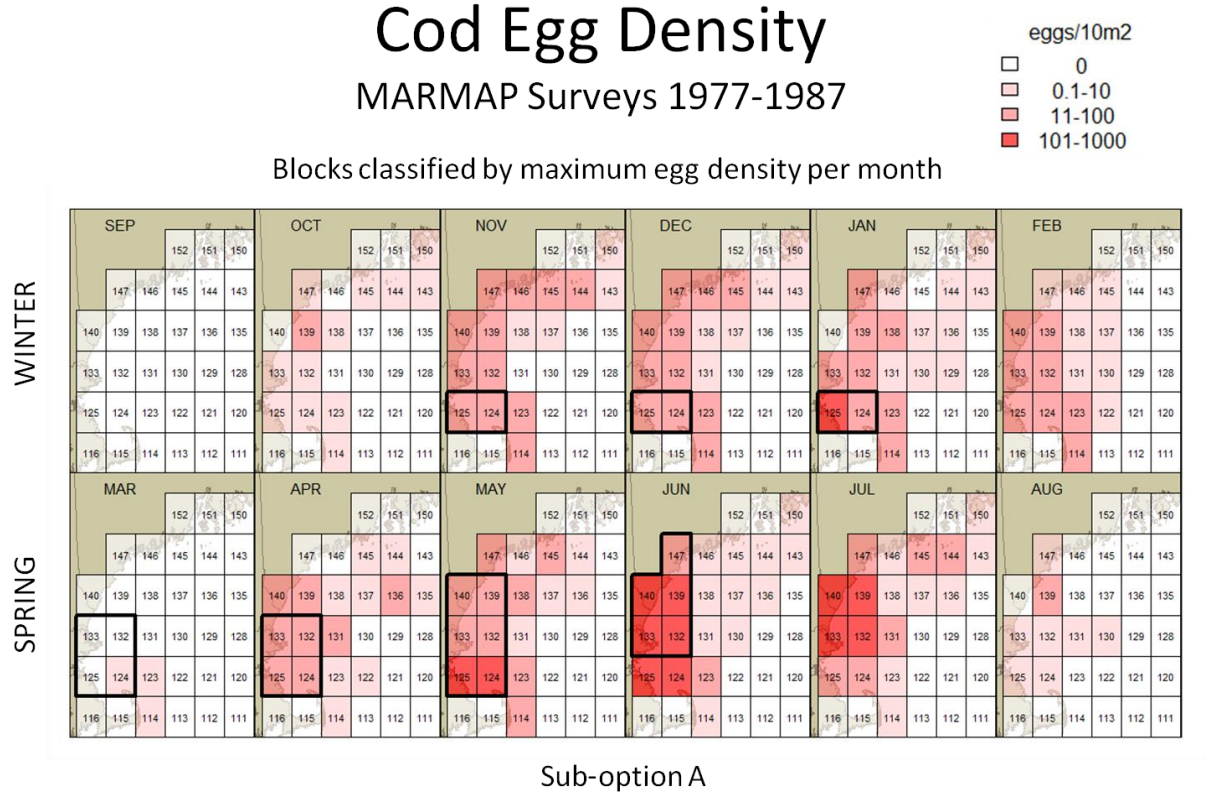

Figure 9. Maximum observed cod egg density per block from the MARMAP ichthyoplankton survey. Blocks under consideration for closure under the FW 53 sub-option A are outlined in bold. Note the presence of significant spawning activity in February and July.

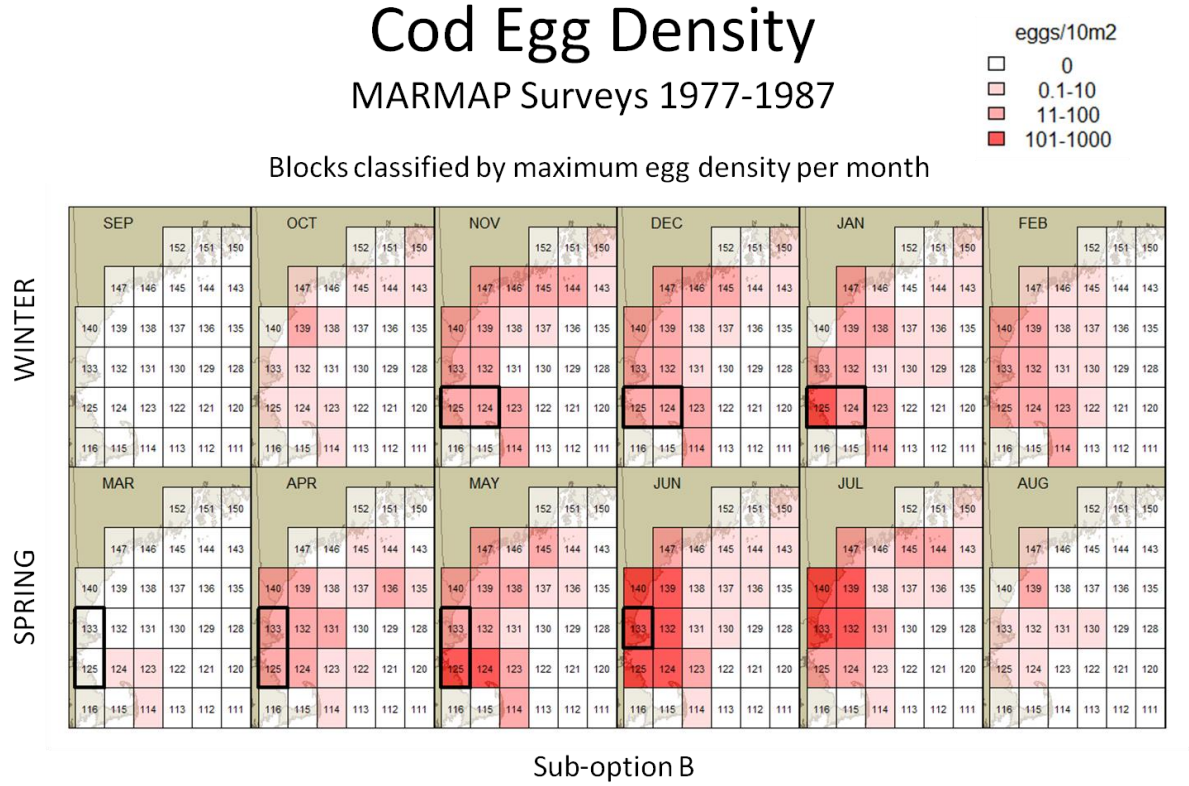

Figure 10. Maximum observed cod egg density per block from the MARMAP ichthyoplankton survey. Blocks under consideration for closure under the FW 53 sub-option B are outlined in bold. Note the presence of significant spawning activity in February and July.

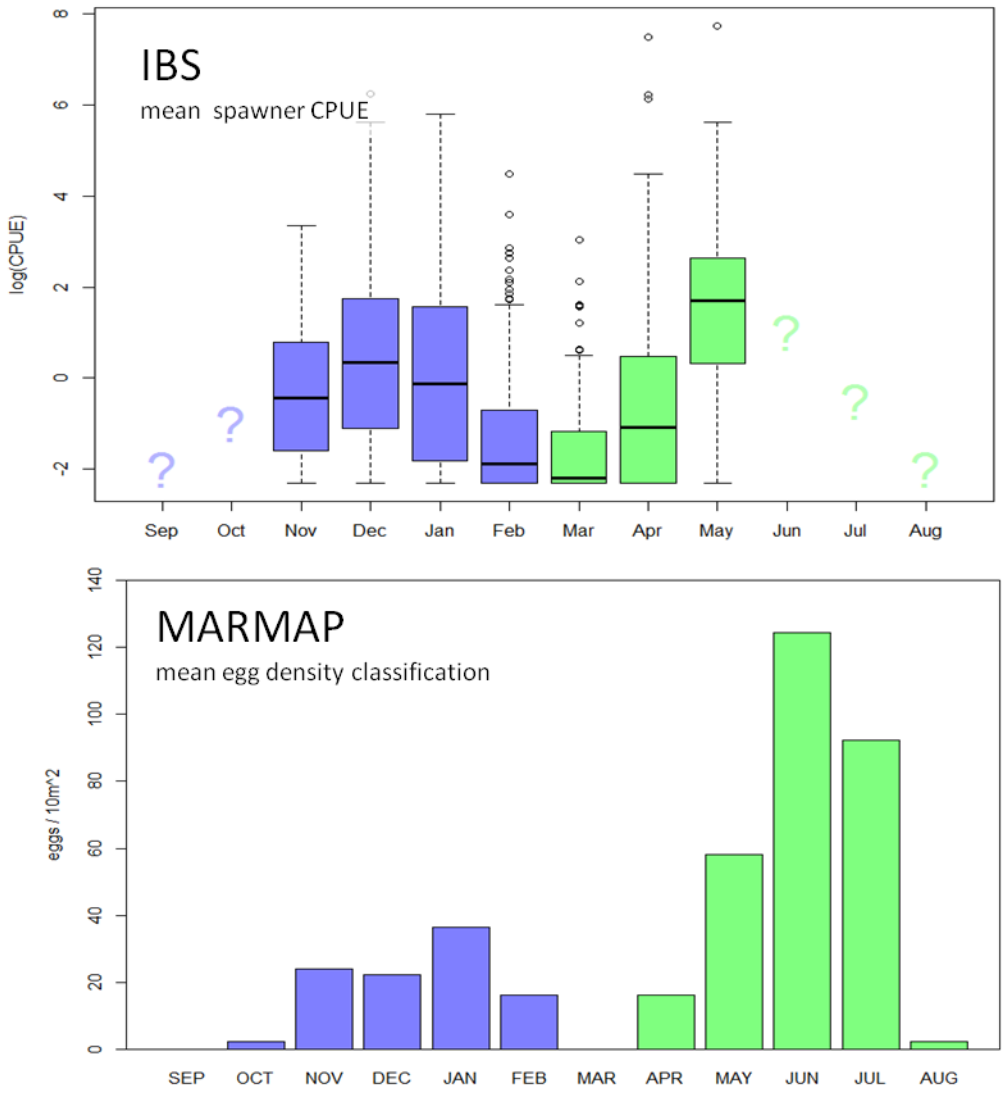

Figure 11. Seasonal distribution of cod spawning activity in the GOM, as evidenced by the IBS trawl survey (above), and the MARMAP ichthyoplankton survey (below). The IBS did not operate between the months of June and October, while MARMAP had very few samples from the GOM in March. "Winter" spawning months are shown in blue and "spring" spawning months are shown in green.