Strengths and Weaknesses of the Northeast Fisheries Science Center’s Bottom Trawl Survey

White Paper

Moulton Groundfish Trawl Task Force

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I. Introduction:

New England's traditional groundfish fishery is in crisis. The fishery, known as the Northeast multispecies fishery, is operating under a disaster declaration that was issued by the Secretary of Commerce on September 13, 2012. This declaration stems from recent groundfish stock assessments that concluded several stocks, such as Gulf of Maine cod that once served as the economic backbone of the fleet, are at extremely low levels of abundance. The reduced quotas deemed necessary to rebuild these stocks not only have direct economic impacts on the industry, but they also have a compounding effect by constraining the ability of fishermen to harvest more abundant stocks.

Socio-economic indicators are increasingly conveying the rapid decline that is occurring in the groundfish fishery in response to low quotas. Between 2007 and 2015, the Northeast multispecies fishery's revenue declined by 43.9% (Murphy et al. 2018). This downward trend stems from both decreases in landings and lower aggregate prices. Murphy et al. (2018) also reported that the total number of active vessels in 2015 with allocated groundfish landings dropped to a low of 269 vessels in 2015, which amounted to a 54.9% decline over this 9-year time-period. Furthermore, they reported a 69.1% decrease in the number of trips between 2007 and 2015 and the overall fishing effort (# of groundfish days) has decreased by 46.8% between 2007 and 2015 (Murphy et al. 2018).

Contrary to scientific reports, fishermen in New England are experiencing a very different reality on the water than should be expected of stocks at extremely low levels of abundance. Many fishermen in New England have been reporting unsuccessful efforts to actively avoid species such as cod in the Gulf of Maine. For instance, in a fishery-wide survey in 2018, 63.6% of fishermen responded that incidental catches of choke species are impeding their ability to fish, and that they either have to lease additional quota, avoid fishing in certain areas, or stop fishing altogether (Grabowski et al. 2018). This active disruption of fishing activity potentially contributes to the high levels of stress and mistrust that the northeast groundfish fishery is currently experiencing (Grabowski et al. 2018), compounding the challenges of managing these stocks.

The shift towards quota-managed fisheries, annual catch limits (ACLs) and accountability measures (AM) as required by the Magnuson-Stevens Reauthorization Act of 2006, places a premium on accurate abundance estimates for determining allowable catch. For example, if the abundance of a choke stock is underestimated, then fishermen will have more difficulty avoiding them and rapidly reach their limit, leading to unnecessary economic constraints on the industry and management challenges. Conversely, if the abundance of the stock is overestimated, fishermen may inadvertently overfish the stock, resulting in further declines in abundance.

The Northeast Fisheries Science Center's Multispecies Bottom Trawl Survey is one of the key sources of fishery independent data used in groundfish stock assessments. Other fisheries surveys, including the Massachusetts inshore survey, the Maine – New Hampshire inshore survey, and the Department of Fisheries and Oceans, Canada bottom trawl survey on Georges

Bank, provide important information including relative abundance indices of pre-recruit fish. There is a widespread concern among fishermen that the abundance estimates significantly influenced by these surveys paint a different picture than their collective experience on the water.

The groundfish task force formed in 2015 at the request of U.S. Congressman Seth Moulton. The goal of the groundfish task force is to: (1) review the statistical strengths and weaknesses of bottom trawl surveys to determine which types of species it is best suited for vs. those that would benefit most from additional data sources, (2) Identify alternative data sources and sampling methods that would bolster efforts to assess groundfish stocks, and (3) build collaborations between industry and research scientists. The intended audience for this document includes but is not limited to fisheries scientists and managers, the Northeast Fishery Science Center, Northeast Regional Coordinating Council, New England Fishery Management Council and supporting committees, like the Groundfish Plan Development Team, Scientific and Statistical Committee, and Groundfish Advisory Panel.

II. Background on the Federal and State Bottom Trawl Surveys:

The Northeast Fisheries Science Center's Bottom Trawl Survey samples both inshore and offshore areas from the Scotian Shelf to Cape Hatteras including the Gulf of Maine, Georges bank and Southern New England. Sampling of the inshore areas have been inconsistent over time due to funding limitations and the increasing prevalence of fixed fishing gear such as lobster traps. Inshore areas are surveyed by the Massachusetts Division of Marine Fisheries Trawl Survey and the Maine-New Hampshire Inshore Trawl Survey, and these survey indices are regularly reviewed as part of the stock assessment process. In addition to enumerating the numbers and weight of the groundfish catches, sampling efforts during the survey is also conducted to obtain length, age, maturity, and stomach contents. These data provide critical information on the size and age composition and reproductive capacity of the groundfish resources. Additionally, other data such as genetic sampling is conducted opportunistically to support stock structure, and ecosystem studies, among others. Oceanographic data are also collected, including temperature, salinity, water chemistry, zooplankton and ichthyoplankton.

The spring survey typically samples Multispecies groundfish habitats from late March through mid-May. The fall survey generally samples groundfish habitat from mid-September through mid-November. However, the seasonal timing of both surveys has varied. For example, the median sample date was mid-April for the spring survey and mid-October for the fall survey in the 1990's, but the surveys have been delayed in recent years to mid-May and mid-November. The NEFSC survey operates 24 hours/day with approximate equal number of day/night stations, though there are seasonal differences (slightly more daytime stations in the spring and nighttime tows in the fall). Evaluations of day/night catch rates have shown no appreciable differences, and the use of either day or night stations would decrease survey precision due to the loss of sampling density.

III. Trawl Survey Focal Areas of Concern

In the process of reviewing the overarching strengths and weaknesses of the bottom trawl survey and determining which species it is best suited for, the taskforce identified the following four areas: (1) *Trawl calibration and catch efficiency* - efforts to calibrate the NOAA ship Henry B. Bigelow relative to the Albatross and accurately calculate how efficiently each species is captured by the different vessels is exceptionally critical for accurately assessing regional groundfish stocks and connecting the past 10 years to the previous 45. (2) *The relationship between sampling effort and error measurement* – species that are not distributed and captured uniformly and consistently (i.e., those that have higher coefficients of variation) would benefit most from additional sampling and/or additional data sources. (3) *The effects of fish use of habitat and density dependence on catch efficiency* – the trawl survey is less likely to catch species that prefer more complex habitat, and consequently they likely have lower catch efficiencies. And (4) *the effects of environmental forces on catchability* – the distributions of many marine fish species are changing (e.g., shifting to higher latitudes and/or deeper, colder water) in response to environmental forcing, thereby potentially affecting their catchability and consequently the performance of the survey.

1. <u>Calibration/efficiency</u>

Problem:

The NOAA Fisheries Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl surveys began in 1968 and 1963, respectively, providing the longest regional time series of fishery independent information for Gulf of Maine fish and invertebrates. The NEFSC bottom trawl survey has utilized three vessels and three door configurations throughout the time series of the survey. The largest change in the survey time series occurred in 2009 when the FSV Albatross IV was decommissioned and replaced by the FSV Henry B. Bigelow. In an effort to maintain a consistent survey time series for use in stock assessments, an extensive field experiment was conducting employing paired towing operations between the FSV Albatross IV and the FSV Henry B. Bigelow during 2007 and 2008 (Brown et al, 2007). Analysis of the data resulting from 636 usable paired tows was used to estimate a series of calibration factors to convert survey indices to 'Albatross IV/Polyvalent door' equivalents (Miller et al. 2010). Subsequently, some stock assessments have calculated length-specific calibration factors for species with sufficient data. It is possible that as the Bigelow time series becomes longer, it will be used as a standalone survey index without calibration, and thereby reducing any uncertainty associated with the calibration factors.

Recent field research on comparative efficiency of the NEFSC bottom trawl survey suggests that implied estimates of survey efficiency (i.e., the proportion of fish in the path of the trawl that is captured) are overestimated by several stock assessments. NEFSC worked with a commercial fisherman to compare catches from the NEFSC trawl and a trawl modified with a chain sweep that was assumed to have greater efficiency for capturing flatfish. If the chain sweep trawl was assumed to have 100% efficiency, the maximum relative efficiency of the NEFSC trawl survey was significantly greater than the efficiencies implied by stock assessment model estimates of catchability for yellowtail flounder (Legault et al. 2016), witch flounder (NEFSC 2017), and several other flatfish. Validating estimates of survey catchability and implied efficiency with additional research would potentially provide model-independent estimates of scale or within model diagnostics that would identify if there are scaling issues.

The new survey trawl designed for and used on the Bigelow possesses characteristics that should result in high catch efficiency of species that are often found close to, but not physically at the ocean floor and possess the tendency to move upward when threatened by approaching trawl gear. For New England multi-species, these species include haddock, redfish and pollock. Concerns have been raised by industry that these three species seem to be the only species that have shown positive relative indices during the Bigelow series. Although the Bigelow time series appears to be producing informative survey indices for monkfish and the skate complex, many other highly demersal species (e.g., flounder species and those that dive downward and attempt to get underneath the trawl sweep such as Atlantic cod, Engas et al. 1998) have steep and negative trending indices or are not exhibiting the increases in abundance as perceived within the commercial or recreational fisheries. The issue is raised here in the context of the Albatross/Bigelow calibration and catch efficiencies, and is not toward the gear configuration itself. This task force recognizes that the Northeast Trawl Advisory Panel is making progress toward understanding the performance of the survey gear ~~as being outside of our scope of interests~~.

Research Recommendations:

Several approaches to evaluating catchability and its components (area swept and efficiency) are promising for improved understanding of the NEFSC trawl survey and its application as an index of abundance for use in stock assessments:

- The calibration experiment designed to estimate the relative catchability of the Albatross and Bigelow survey protocols had fewer stations than planned because of logistical problems (e.g., 130 paired stations in the experiment caught cod in both surveys), and the estimates of relative catchability are uncertain. However, the Bigelow survey started in 2009 and now has a time series that can be considered as a separate index than the Albatross series, as demonstrated in the 2018 benchmark stock assessment of summer flounder. We recommend that the Bigelow survey series should be considered as a separate index for all stock assessments to remove the uncertainty in survey calibrations.
- Several field experiments offer approaches to estimate relative efficiency. Chain sweep experiments have been successful for estimating maximum efficiency, and relative

efficiency estimates have been used to derive a maximum limit for estimates of survey catchability, as demonstrated in the 2018 benchmark stock assessment of summer flounder. Similarly, comparison of catches from different bridle lengths can be used to estimate herding efficiency and to justify the most appropriate calculation of area swept (e.g., wing spread vs. door spread). Under-bag studies can also measure escapement of fish under the footrope to derive footrope efficiency estimates. We recommend that such efficiency studies should be used to derive the maximum limit for catchability estimates in stock assessment models.

- The NEFSC survey protocol does not consider several factors of trawl efficiency that are considered by fishermen, such as the direction of the tow relative to currents. Therefore, we support the recommendation to have side-by-side comparisons of the Bigelow and commercial fishing vessels to better understand relative catchability and efficiency of the NEFSC trawl survey protocol.
- The NEFSC survey protocol includes excluding or moving stations on hard bottom or in areas with fixed fishing gear. These protocols produce nonrandom samples and potentially biased indices (e.g., if fish are more densely distributed in areas with hard bottom or fixed gear). We recommend that the frequency of excluded or moved stations should be explicitly documented and routinely evaluated to consider the potential bias. We also recommend that relative density should be evaluated in areas of fixed gear or hard bottom relative to adjacent areas that are sampled by the NEFSC survey to evaluate the potential bias.

2. <u>Sampling effort/error measurement</u>

Problem:

Stock assessments are sensitive to the variability of catches among survey stations, as measured by the coefficient of variation (CV). In general, species with higher CV's are more challenging to assess, resulting in less accurate stock assessments. When species are highly aggregated, high CVs would be expected relative to more evenly distributed species, thereby challenging efforts to accurately assess abundances of these aggregated species. Many of the species in the Gulf of Maine exhibit schooling behavior, and thus present this challenge. With the current amount of sampling effort that is conducted for the Northeast Fisheries Science Center's Bottom Trawl Survey and the Massachusetts Inshore Trawl Survey, confidence intervals are highly variable and tend to be large for many species such as cod (see Figure 14 below from the 2017 Groundfish Operational Assessment for Gulf of Maine Atlantic cod). For example, in the Gulf of Maine, the catch is usually dominated by large catches at one or two stations and many stations with few or no cod; a sample of 300 fish is the difference between the 1980's index and the current low level of the index (Figure 14).

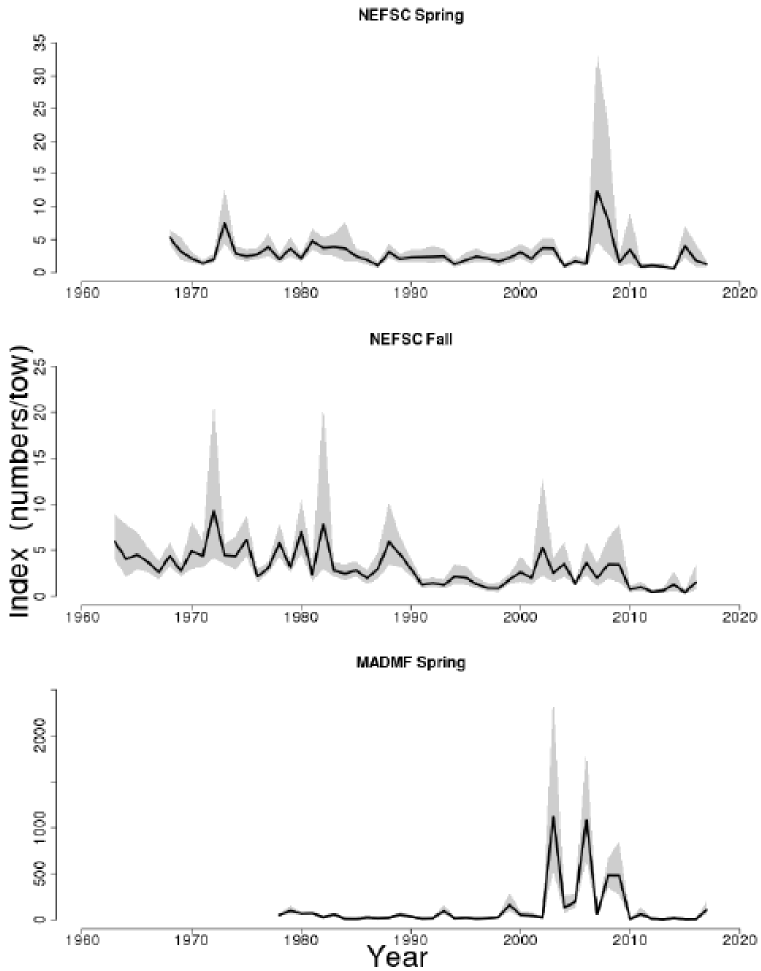

Figure 14: Indices of biomass for the Gulf of Maine Atlantic cod between 1963 and 2017 for the Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl surveys and Massachusetts Division of Marine Fisheries (MADMF) spring bottom trawl survey. The 90% lognormal confidence intervals are shown.

Research Recommendations:

Efforts to enhance our understanding of variability (e.g., CV) associated with fish species captured in the trawl surveys will benefit from considering the following concerns and subsequent lines of research:

- (1) Increasing the number of samples collected during the survey, (2) redefining the strata to reflect new distributions of fish from closed area management and environmental change are the two classic ways of dealing with this problem, and (3) considering alternative survey designs.
- Alternative sampling, including acoustics, open-codend video, and tagging studies should all be considered. A combination of these with traditional sampling to examine

population size, gear catchability (selectivity, efficiency, and vulnerability) would all enhance and improve assessments.

- Improving field collection on environmental data, studies examining how these effect fish behavior (distribution and vulnerability) and incorporating these into the assessment models would also improve their estimates as many species appear to be shifting their distributions and aggregation behavior based on environmental variability.
- The confidence limits currently used assume a lognormal distribution, which do not account for the patchy distributions of cod (e.g., 2007 and 2008 almost all catch came from 2-3 stations; see GARM III report) and many other fishery species in the region. One approach would be to calculated CIs using a nonparametric bootstrap to avoid distributional assumptions.
- For species where large increases in sampling efforts would likely be needed to reduce the uncertainty in these biomass indices, targeted sampling could instead be used to reduce the CV in important stocks, potentially making the assessments more accurate. Studies examining how alternative sampling designs that more closely target the known footprint of a fish's distribution would help elucidate how best to sample them.

3. Fish use of habitat, density-dependence, and their joint influences on catch efficiency

Problem:

Although trawl surveys are preferred by many fisheries scientists because they allow relative fish densities to be calculated, a major limitation of this approach is its ability to sample across habitats of varying complexity. In particular, trawl efficiency is inversely related with habitat complexity, with the most complex bottom (cobble, boulder, and rock ledge) presenting a challenge due to the risk of gear hang-ups.

Several harvested groundfish species use complex substrates at specific life history phases. For instance, age-0 and age-1+ juvenile cod have been found to associate with cobble, boulder, seagrass and kelp habitats, presumably to avoid predation (Gotceitas and Brown 1993, Gotceitas et al. 1995, Tupper and Boutilier 1995, Gregory and Anderson 1997, Grant and Brown 1998, Laurel et al. 2003, Grabowski et al. 2018). Other species, such as wolffish and cusk, associate with hard substrates throughout most of their life-history (Bigelow and Schroeder 1953, Collette and Klein-MacPhee 2002, Hare et al. 2012). Thus, efforts to quantify abundances of these species will benefit from inclusion of alternative data sources (see Section IV below).

For many species, habitat use can be density-dependent. For instance, Robichaud and Rose (2006) found that YOY cod were captured predominately at sites with seagrass in poor recruitment years, whereas they were common at most sites when recruitment was high. If older age classes that are caught by state and federal groundfish trawl surveys are also displaying density-dependent use of hard substrate, then this could affect catch rates. In particular, species with ideal free distributions (Fretwell and Lucas 1970) will occupy the best habitat patches first.

At low densities, there is little incentive to leave high quality patches. An alternative hypothesis is that fish schooling behavior affords them some protection, resulting in greater ability to survive outside of more complex habitat patches. Thus, schooling behavior might explain why Robichaud and Rose (2006) caught higher densities of cod at poor habitat sites when recruitment was high. Additional research aimed at determining the degree to which structured habitat use by groundfish is density dependent for older age classes targeted by trawl surveys would help determine if species catch rates by trawl surveys are skewed by these processes.

Density also can have an effect on catchability during trawling operations. Aglen et al. (1997) and Godo et al. (1999) discuss results of video and trawl experiments on catchability of groundfish under different densities. Prior to this work, catchability during trawl surveys was assumed to be proportional to CPUE and stock abundance and constant between surveys (i.e., the trawl will catch the same proportion of fish available to it regardless of density). Godo et al. (1999) demonstrated that catchability of cod, haddock and American plaice (*Hippoglossoides platessoides*) decreases at low densities due to behavioral differences between schools and individuals. Essentially, dense schools are more susceptible to being caught, whereas individuals will more frequently employ behaviors to avoid capture (e.g., diving below footrope). This potential source of bias is a bigger concern for index-based stock assessments that rely on catch data.

Research Recommendations:

Several lines of research are needed to help elucidate how habitat complexity and density-dependence interact to affect fish use of habitat:

- Long-line and gillnet surveys are commonly used to survey more structured habitats. These surveys may be ongoing in the Gulf of Maine (See Section 3. *Using additional data sources and approaches* below), but it is unclear the degree to which they are currently being used in stock assessment or fisheries management to ground-truth estimates derived from the trawl surveys.
- Habitat complexity likely interacts with catchability, and consequently potentially confounds the ability of gear to determine if differences in catch among habitats reflect actual differences in relative abundance (Peterson and Black 1994). Thus, we recommend studies be conducted that examine how catchability varies by habitat. This recommendation includes both trawl surveys (e.g., it is unclear if catchability on gravel is equivalent to sand and mud) and gear that can be used to extend sampling into highly structured habitats (e.g., gillnets, longlines).
- Research investigating the habitat preferences of critical (i.e., early, spawning) life-history phases of fishery species would help identify where and when particular habitats are critical. In addition to identifying habitat preferences, research focusing on how density influences habitat use would be beneficial.

- Efforts to examine how habitat affects fish growth and survival (i.e., Level 3 EFH) is critical to furthering efforts to determine how habitat complexity affects fish productivity (Level 4 EFH).

4. Environmental shifts and its influence on behavior/catchability

Problem:

A key assumption in the application of bottom trawl data to index species abundance is that catch-per-unit effort (CPUE) is proportional to population abundance and that catchability, the proportionality constant between the index and true population size, is stationary over time (Zimmerman et al. 2003, Wilberg et al. 2010). A standardized methodology is typically applied in surveys to maintain stationary catchability over time and when changes in methods are necessary (e.g., vessels, nets, ect.) it is typical to calibrate the new catch per unit effort (CPUE) against the old.

Decadal climate variability, rapid "regime shifts" in the ecosystem, or slower persistent directional changes (e.g., climate change) can affect fish behavior and impact the catchability of fishery independent surveys (Wilberg et al. 2010). Factors, such as temperature, can influence the behaviour of fish (e.g., feeding habits, swimming speed of fish) or the density and spatial distribution of fish within the survey area (Swain et al 2000, King et al. 2015). Shifts in distribution can alter the availability and subsequently catchability of fish to the survey upon which many stock assessments are dependent, especially for seasonally migrating stocks whose distributions may fall outside of the survey area (Walters 2003, Wilberg et al. 2009). Furthermore, periodic changes in the distribution of fish due to storms can also dramatically alter the availability of fish to the survey (Bailey and Secor 2016). Failure to acknowledge the influence of climate on the performance of surveys can lead to possible misinterpretation of trends indicated by survey data. Changes in environmental conditions can result in time-varying catchability in research surveys.

The influence of changes in environmental conditions on survey catchability should be critically evaluated, particularly when alternative sources of information (e.g., fishery dependent data) indicate that survey trends may not be accurately indexing stock-wide trends. Time-varying catchability can be explicitly accounted for in stock assessment, however, this approach has only been applied in few instances to date (Wilberg et al. 2010, Punt et al. 2014). The effects of bottom temperature on survey catchability was documented for flathead sole (*Hippoglossoides elassodon*) and explicit inclusion of temperature was found to improve the fit of the stock assessment model (Stockhausen and Fogarty 2007). Availability of Atlantic cod (*Gadus morhua*) to the bottom trawl survey in the Gulf of St. Lawrence was found to be significantly correlated with bottom temperature, however, explicit inclusion of time-varying catchability did not improve fit of the stock assessment (Swain et al. 2000). In addition, there are ongoing efforts to account for the influence of temperature-dependent changes in geographic distribution and seasonal migration on survey observations through development of annual estimates of the proportion of thermal habitat surveyed for American butterfish and scup in the NEFSC and NEAMAP surveys (Manderson et al. 2015, 2017). This approach can measure the effects of changing habitat dynamics on the availability of a fish population to fishery independent surveys. Furthermore, fishery-independent survey designs that focus on timing sampling in relation to environmental state rather than calendar date, may be an option to address the impacts of shifts in distribution and phenology on system observations. To develop a full understanding of the performance of survey gear (i.e. catchability, availability, and selectivity) in relation to ambient environmental and habitat conditions we need to simultaneously collect environmental information (e.g., habitat and oceanographic characteristics; Karp et al. 2018).

Research Recommendations:

We recommend exploring the impact of environmental factors on catchability of the trawl survey, this can be explored through various approaches outlined below:

- The influence of changing environmental conditions, such as bottom temperature, on survey CPUE should be assessed using modeling approaches, such as generalized additive models (GAMs). If an impact is detected, CPUE standardization can potentially be used to account for the influence of environmental change on catchability over time. Alternatively, the impacts of time varying catchability on fishery independent indices due to changing environmental conditions can be explicitly accounted for within the framework of a stock assessment.
- The influence of temperature-dependent changes in geographic distribution and seasonal migration on survey observations can be accounted for through development of annual estimates of the proportion of thermal habitat surveyed. This approach involves development of species-specific habitat suitability models and can be used to improve estimates of stock abundance.
- Furthermore, lower effort survey techniques, such as acoustic or video surveys, can be considered to pair with existing trawl surveys or to sample at higher spatial or temporal resolution and provide secondary estimates of abundance.

IV. Alternative Data Sources and Options

In addition to discussing the above factors that affect the efficacy of the trawl survey, the taskforce identified the following potential solutions: (1) *Improve the interpretation of the existing data* – enhancing the efficiency and application of existing data would increase the accuracy of stock assessments. (2) *Developing/improving the prioritization process for additional sampling efforts* – here we discuss how to prioritize which species deserve greater sampling effort. And (3) *Using additional data sources and approaches* – here we contemplate a variety of additional surveys currently ongoing in the region.

1. <u>Improving the interpretation of the existing data</u>

Improving the efficiency of existing data

A major point of contention in the region is the accuracy of the information from NOAA's biannual multispecies bottom trawl survey. Fishermen believe that the strata that underlie the survey's stratified random design do not reflect the spatial distribution for many groundfish stocks, notably cod and flatfish. This could lead to higher variability and the potential for false signals of abundance due to mismatch between sample design and the true stock footprint. Another problem is that the total area swept by the trawl survey amounts to a very small percentage of the total bottom area. For instance, the survey covers ~0.001% of the 54,000 km^2 of management area in the Gulf of Maine each spring and fall.

Understanding the "footprint" of particular species such as cod, and how the footprint changes with season and environmental conditions, could provide a powerful way to gain enhanced insight from existing data. For example, trawl survey and fishery observations could be used to build seasonal habitat models that integrate species observations with environmental variables, including depth, bottom type, temperature, and other parameters, to estimate the relative likelihood of species occurrence at a given location. The output of these models would be maps for a particular point in time. Comparing these maps to maps developed by fishermen based on their experience could highlight gaps in sampling or knowledge, and perceptions. The maps could then inform the design of future surveys or highlight areas where industry perceptions are not reflected in the data.

The maps could also be used in a more quantitative manner by dynamically defining the strata used to compute swept area abundance. Each stratum will define a region with similar habitat characteristics and likelihood of encountering the target species (i.e., maximizing the between strata variance and minimizing the within strata variance). Such an analysis would produce new trawl-survey indices for each stock based on the species-specific strata.

Improving the application of existing data

A major challenge in the region is the pace of change, both in the environment and in the management system. For example, unusually warm conditions in 2012 led to a redistribution of many fish in both space and time and likely impacted biological processes such as growth, reproduction, and mortality. On the human side, major shifts in management such as changes in days at sea or quota impact the behavior of fishermen, altering the relationship between fishery dependent data (i.e., catch statistics) and the abundance of fish in the water. While many of the changes are known, it is challenging to anticipate if and how they might be interacting to influence fish stocks.

Fishery scientists have developed a number of techniques that increase the flexibility of the models that underlie the stock assessments. For example, including environmental indicators in an existing stock assessment model can account for one kind of change, potentially improving the performance of the model. Other modeling approaches have been developed that can handle non-stationarity, even if the source of the changes is not understood. Neither approach is currently used for any of the groundfish in New England. Using a range of models and testing model performance over time could enhance this process.

2. Developing/improving the prioritization process for additional sampling efforts

The taskforce discussed several factors that should be considered when developing a prioritization process for additional sampling efforts, whether they be additional bottom trawl survey or other types of sampling efforts. First, species with high coefficients of variation would potentially benefit from additional sampling efforts. Careful consideration should be given to determining the amounts and types of additional sampling that would most efficiently reduce these CVs. Second, species that occupy structured habitats that are not sampled well would benefit from additional effort using gear types (e.g., gillnets, longlines) capable of sampling within them. The NEFSC GOM longline survey is already attempting to address this issue. Third, species that have disproportionately high socioeconomic impacts when quotas are reduced should be prioritized. These impacts could stem directly from reductions in quotas of previously valuable species or indirectly when these reductions limit access to other key stocks (i.e., bottlenecks).

The Mid-Atlantic and New England Fishery Management Councils formed a Northeast Trawl Advisory Panel (NTAP) to review, discuss and make recommendations related to a host of survey trawl related issues. Some of the items raised by the Panel have been focused on making improvements to the existing independent data collection efforts of the federal trawl survey while others have focused on research efforts that would augment the current process to fill necessary data gaps. For instance, NOAA Fisheries is evaluating alternative approaches to integrate fishing industry vessels with NEFSC Spring and Fall Bottom Trawl Surveys by the NOAA Ship *Henry B. Bigelow* in ways that maintain survey data collection quality and time series integrity. An internal NEFSC working group is being established to appraise a wide range of options for scientific and logistic feasibility. The group will work closely with the Northeast Trawl Advisory Panel (NTAP), and seek broader industry input via the Council process. *These ongoing efforts are outside of the scope of this task force.*

3. Using additional data sources and approaches

There are several data sources currently being collected that could benefit ongoing efforts to assess commercial stocks, including both in parameterizing models and as context for comparison with model outputs/trajectories. These efforts include but are not limited to the

Industry Based Survey (IBS) conducted by MA DMF, the video bottom surveys conducted by University of Massachusetts Dartmouth, and studies/analyses using fisheries dependent data (e.g., LPUE and CPUE series and swept area biomass estimates).

The Swept Area Biomass Video Survey conducted by UMass Dartmouth

Although a wealth of information can be collected during trawl surveys, there are several challenges associated with this approach. Resources to conduct surveys are limited, both in terms of available time and funding, which limits the number of tows that can be completed in a given year. Trawl surveys are inherently time consuming; the time required to set and haul the trawl, sample the catch, and transit between sampling locations is substantial. Therefore, during a typical survey, the cumulative area swept by the survey net is very small relative to the size of the survey area. Limited survey coverage contributes to negative stakeholder perceptions and reduced confidence in the survey methods. Another disadvantage of a traditional trawl survey is that the catch is aggregated from the entire tow, and data about how each species was distributed along each tow path is lost. Increasing trawl survey effort, to provide greater accuracy, is usually not a cost-effective approach; the use of innovative technology such as video, and or acoustics to complement trawl surveys has been recommended in recent reviews of the NEFSC's data collection processes (Johnston, 2013).

Underwater video techniques have been developed over the last 60 years to investigate the abundance, distribution, behavior, and biodiversity of marine species (Mallet and Pelletier, 2014). Recent research suggest that cameras can be used to identify, measure and quantify fish passing through a trawl net. Since 2013, scientists at the University of Massachusetts Dartmouth, School for Marine Science and Technology (SMAST) have worked to develop a video system that could be installed in the cod end of a demersal trawl and used to survey groundfish in the northwest Atlantic (DeCelles et al. 2017, Stokesbury et al. 2017). This approach has several potential advantages enhancing a traditional trawl survey. First, by using the camera to record the fish as they pass through the net, we can tow the net with the cod end open, so that the net does not fill with fish, allowing us to make long duration (e.g., two to four hour) survey tows. With this approach, samples are collected over much longer distances, increasing the proportion of time spent actively trawling versus setting and hauling the net (Rosen et al., 2013, Rosen and Holst 2013, Stokesbury et al. 2017). Secondly, during these open cod end tows the fish are not retained in the net, which substantially reduces the mortality associated with the survey. Finally, the video can be used to gain information about the distribution of fish species along the path of the trawl, which increases the spatial resolution of the survey. For example, approximately 92 hours of video have been recorded during the two field trials completed in the Gulf of Maine in 2018.

This video survey provides a mechanism to address the discrepancy between fishermen's observations and recent stock assessments by providing improved information on specific fish aggregations. It is a physically robust system and has successfully operated on a commercial vessel under fall, winter and spring sampling conditions. It produces high resolution video images of groundfish that are simultaneously collected with location, depth, time and net configuration. It is possible to identify groundfish to species and obtain a count of Atlantic Cod as they pass through the net; flatfish can also be identified as a group and we are working towards species identification. The counts can be grouped by time interval and these can be randomly sampled to produce an estimate of abundance that has tighter confidence limits than traditional swept area abundance estimates. The amount of sea floor sampled per day is greatly increased without killing greater numbers of fish. The ability to work on commercial fishing vessels, and for fishermen to see what is being collected in the net in real-time, is very powerful.

The Industry Based Survey (IBS) conducted by MA DMF

The Northeast Fisheries Science Center funded an Industry Based Trawl Survey (IBS) targeting Atlantic cod in the Gulf of Maine that was executed by the Massachusetts Department of Marine Fisheries (MADMF) from 2003 through 2007. This industry survey covered the entire US portion of the Gulf of Maine out to 140 meters in depth. This broad study area was sampled five times each year, working continuously from November through May. Between 2003 and 2007 a total of 2,504 successful tows were completed on five industry vessels. The MADMF reinitiated a second IBS effort in 2016 utilizing funding from the groundfish disaster aid and completed 325 successful survey tows last year.

NEFSC bottom longline survey

In an effort to more effectively sample hard bottom areas that cannot be effectively sampled using bottom trawls, the NEFSC established a pilot bottom longline survey conducted in the Gulf of Maine in commercial vessels. The objective of the survey is to increase sampling of several data-poor and depleted stocks specifically associated with rocky habitat, while also enhancing data collection for some data-rich stocks already well-sampled on the NEFSC research bottom trawl survey. The longline survey, conducted in the western and central Gulf of Maine (GM) during spring and autumn, was funded by the National Cooperative Research Program (NCRP) during 2014-2015, and additional non-competitive funds were procured for the 2016-2017 survey seasons. The Gulf of Maine longline survey overlaps temporally and spatially with the NEFSC bottom trawl survey coverage of the area and was designed to sample complex, rocky habitat not easily accessible to the bottom trawl survey. However, to have comparability to the bottom trawl survey catches, the longline survey stratified random design was based on the NEFSC BTS stratification of depth and area and then further stratified by ‘rough’ and ‘smooth’ bottom type within the strata area to account for habitat.

Fishery Dependent Data

The New England groundfish fishery constitutes one of the largest sources of fishery data. These fishery-dependent data include data catch, discards, observer data, port samples, study fleet, electronic monitoring, and they can be used as a direct measure or an index of catch. Currently, windowpane flounder and ocean pout are assessed using an index-based model (AIM), and Atlantic halibut is assessed using a replacement yield model (RYM). One of the challenges of using catch data as an index of population abundance involves correcting for the many shifts in fisheries management that have occurred over the past 30 years. For instance, the implementation of several large closed areas in the Gulf of Maine and on Georges Bank has drastically shifted the spatial footprint of fishing effort over this time-period. Another major shift involved the transition from days-at-sea to catch shares, which again likely changed the spatial allocation of fishing effort in New England waters. In addition, implementation of gear size and type restrictions as well as changes in quota allocations also make using fisheries dependent data as an index of catch challenging. Finally, there have been many other changes in fisheries management laws over the past 3 decades that have affected how the industry allocates effort, and hence likely influences the reliability of catch data as an index of population abundance of targeted species.

Catch data can also help inform more complex models (e.g., statistical catch at age or ASAP) by providing information about the size range (excluding smaller fish that are not able to be landed) and proportion at length. Again, changes in fisheries management could influence these data. For instance, the implementation of closed areas has created refugia for cod, with cod inside the major closed areas (e.g., Western Gulf of Maine Closed Area, Cashes Ledge Closure Area, and Closed Areas I and II) on average older than those caught adjacent to and outside of these closures (Sherwood and Grabowski 2016). In this instance, models should consider using a dome-shaped selectivity curve if harvesting pressure is lower on these larger cod that remain primarily within the closed areas. However, these and other existing or new data should first be examined to evaluate whether there is evidence of differential selectivity at age, and a plausible mechanistic basis for a specific selectivity function. In the example above, the mechanistic explanation, that there is less mortality within the large closed area on larger, more sedentary cod, is plausible. Whether additional data exist to support this finding deserves further attention.

Another topic worth exploring is whether commercial species caught as bycatch in other fisheries (e.g., cod bycatch in the lobster fishery or yellowtail flounder in the sea scallop fishery) provide a useful additional index of these species' abundances. This information could be particularly valuable when bycatch is caught in areas that are not well sampled by existing surveys (e.g., inshore coastal Maine).

As mentioned above, understanding the "footprint" of species such as Atlantic cod that are currently considered overfished could help guide targeted fisheries independent sampling efforts aimed at better describing the abundance, size-frequency distribution, spawning stock biomass, etc. of these species. The fisheries dependent data would be extremely useful in helping identify the temporal and spatial footprints of each harvested species, especially for those that are infrequently caught by NOAA's groundfish trawl survey. Given the wide range of gear currently used, these efforts could also help identify specific gear types that might be more effective at sampling fish that are using habitats that cannot effectively be sampled by trawls or those that are more capable at evading the trawl survey.

The New England Fishery Management Council formed the Fishery-Dependent Data Working Group to focusing on many of the issues and opportunities outlined above (NEFMC 2018).

V. Conclusions

After reviewing the overarching strengths and weaknesses of the bottom trawl survey, the taskforce identified the following four areas and potential solutions:

(1) *Trawl calibration and catch efficiency*: We recommend that the Bigelow survey series should be considered as a separate index for all stock assessments to remove the uncertainty in survey calibrations. In addition, we suggest that efficiency studies should be used to derive maximum limit for catchability estimates in stock assessment models. Efforts to quantify potential sources of bias such as excluded tows due to gear conflicts are needed, as are side-by-side tows of the Bigelow and commercial fishing vessels to better understand relative catchability and efficiency of the NEFSC trawl survey protocol.

(2) *The relationship between sampling effort and error measurement*: We recommend that Confidence Intervals associated with abundance estimates be calculated using a nonparametric bootstrap to avoid distributional assumptions.

(3) *Increasing the use of additional data sources*: combining the current stratified-random tow survey with more targeted efforts aimed at sampling key species that are under sampled by a low frequency survey aimed at sampling throughout a much larger management area would be helpful. For instance, understanding the "footprint" of species such as Atlantic cod that are currently considered overfished could help guide targeted fisheries independent sampling efforts aimed at better describing the abundance, size-frequency distribution, spawning stock biomass, etc. of these species. Thus, the fisheries dependent data and other data sources mentioned above in Section IV. would be extremely useful in helping identify the temporal and spatial footprints of each harvested species.

(4) *The effects of fish use of habitat and density dependence on catch efficiency*: We recommend greater clarity on how relative abundance measures that are capable of sampling in structured habitats such as the ongoing Gulf of Maine long-line survey are currently being used. In addition, we suggest studies that examine how catchability and fish density interact with the catchability of these gears to remove potential sources of

bias. Finally, research investigating the habitat preferences of critical (i.e., early, spawning) life-history phases of fishery species and whether habitat use is density-dependent would benefit efforts to build towards Level 4 EFH (i.e., how habitat affects fish productivity).

(5) *The effects of environmental forces on catchability*: The influence of changing environmental conditions, such as bottom temperature, on survey CPUE should be assessed using modeling approaches, such as generalized additive models (GAMs). The influence of temperature-dependent changes in geographic distribution and seasonal migration on survey observations can be accounted for through development of annual estimates of the proportion of thermal habitat surveyed. Finally, lower effort survey techniques, such as acoustic or video surveys, could be evaluated and considered in tandem with existing trawl surveys.

In reviewing many of the other data sources currently being collected that could benefit ongoing efforts to assess commercial stocks, the taskforce sees ample opportunity to include these both in parameterizing models and as context for comparison with model outputs/trajectories. We reviewed the Industry Based Survey (IBS) conducted by MA DMF, the video bottom surveys conducted by University of Massachusetts Dartmouth, NEFSC bottom longline survey, and studies/analyses using fisheries dependent data (e.g., LPUE and CPUE series and swept area biomass estimates). There are significant challenges (i.e., cost) to increasing the number of tows and downsides (i.e., loss of continuity) to altering the design of the NOAA trawl survey. Furthermore, in many cases, expanding the number of tows will not address the primary problem, such as sampling a species that prefers structured habitat that is unable to be towed efficiently or at all. Therefore, there is great value in exploring whether relative abundance trends in these alternative data sources are similar to or different from species that the trawl survey struggles to sample effectively for the various reasons raised in Section 3 above (Trawl Survey Focal Areas of Concern).

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