Bottom Trawl Survey Mitigation Plan

I. Purpose of the survey

The Northeast Fisheries Science Center (NEFSC) Bottom Trawl Survey (BTS) is the primary source of synoptic, shelf-wide, multiseason, annually repeated fish and oceanographic data on the Northeast U.S. Shelf. Furthermore, it is the primary data source of relative abundance data for 48 stock assessments (and an important component of an additional 6 assessments), as well as the source of population demography, maturity, and stomach contents data for the region (Tables 1 and 2). It is also a reliable source of other biological samples, as requested, from internal and external partners (Table 3). The loss or partial loss of this dataset would interrupt a nearly continuous time series dating to 1963 (with sporadic sampling as early as 1948) and have significant impacts on fisheries science and management in the Northeast U.S.

The objectives of the NEFSC BTS are twofold: (1) to monitor trends in biological parameters (e.g., recruitment, biomass, growth, maturity, mortality) and geographic distribution of fish and invertebrates of the Northwest Atlantic Continental Shelf; and (2) collect and monitor ecosystem-level data for broad-scale oceanographic and environmental changes.

The BTS is fully standardized, including sampling gear construction and performance, vessel(s), standard operating procedures, and spatiotemporal sampling consistency. For more information on the standard protocols and gear requirements, see Politis et al. (2014). Survey catch is identified to species level for all fish and a subset of invertebrates (i.e., decapods, cephalopods, some bivalves), and aggregate catch weights are recorded for each species. Biological samples and individual weights are collected for subsampled fish, subsampled invertebrates, and all protected species.The gear captures smaller size classes than commercial gears, and therefore provides estimates of cohorts before they enter the fishery, as well as critical samples of immature fish to inform maturity curves. Oceanographic sampling (addressed by the EcoMon Survey Mitigation Plan) includes a vertical conductivity, temperature, and depth (CTD) cast at all trawl stations, oblique bongo plankton tows at a subset of stations, and continuous measurement of additional variables via a surface water flow-through system.

BTS data are a critical component of many stock assessments in the Northeast and Mid-Atlantic (Table 1). Notably, the Terms of Reference for Research Track Assessments require the consideration of survey data: “Present the survey data used in the assessment… and provide a rationale for which data are used. Describe the spatial and temporal distribution of the data. Characterize the uncertainty in these sources of data" (NEFSC 2022). Additionally, all finfish stock assessments (with the exception of Atlantic herring) use maturity data from the BTS for determining maturity and therefore spawning stock biomass. Survey data are also required for the production of other NEFSC and external products including:

- Seasonal Bottom Trawl Resource Survey Reports
- Annual NEFSC Regional State of the Ecosystem Reports
- Numerous stock assessments, reports, and associated working papers (including those listed in Table 1)
- A variety of projects external to the NEFSC, including numerous regional fishery management plans and the Mid-Atlantic and Northeast regional ocean data portals
- NOAA Fisheries Distribution Mapping and Analysis Portal (DisMAP)

The use of oceanographic (CTD and bongo) data is addressed in the EcoMon Survey Mitigation Plan.

Table 1. Stock assessments led by the Northeast Fisheries Science Center (NEFSC) Population Dynamics Branch requiring NEFSC Bottom Trawl Survey (BTS) data. Stock abbreviations: Cape Cod/Gulf of Maine (CCGOM), Eastern Georges Bank (EGB), Eastern Gulf of Maine (EGOM), Georges Bank/Gulf of Maine (GBGOM), Georges Bank (GBK), Gulf of Maine (GOM), Southern New England (SNE), Southern New England/Mid-Atlantic (SNEMA), Western Gulf of Maine (WGOM). Transboundary Resource Assessment Committee = TRAC. Reliance on BTS (i.e., how much the current assessment approach depends on BTS data): Low = BTS data have minor impact on the assessment; Major = BTS data affect 1 or more indices and have a major impact on the assessment; Complete = The BTS represents the only or primary index used in the assessment.

Species	Stock	Assessment Type	Reliance on BTS	BTS Season
Bass, Black sea	Unit	Model-Based	Major	Fall & Spring
Bluefish	Unit	Model-Based	Low	Fall
Butterfish	Unit	Model-Based	Major	Fall & Spring
Cod, Atlantic	SNE	Model-Based	Major	Spring only
Cod, Atlantic	EGB (TRAC)	Index based	Major	Fall & Spring
Cod, Atlantic	GBK	Model-Based	Major	Fall & Spring
Cod, Atlantic	EGOM	Model-Based	Major	Fall & Spring
Cod, Atlantic	WGOM	Model-Based	Major	Fall & Spring
Crab, Jonah	Unit	Index based	Major	Fall & Spring
Cusk	Unit	Index based	Complete	Fall & Spring
Dogfish, Atlantic Spiny	Unit	Model-Based	Major	Spring only
Flounder, Summer	Unit	Model-Based	Major	Fall & Spring
Flounder, Windowpane	GBGOM	Index based	Complete	Fall & Spring
Flounder, Windowpane	SNEMA	Index based	Complete	Fall
Flounder, Winter	GBK	Model-Based	Complete	Fall & Spring
Flounder, Winter	GOM	Index based	Complete	Fall & Spring
Flounder, Winter	SNEMA	Model-Based	Low	Fall & Spring
Flounder, Witch	Unit	Index based	Complete	Fall & Spring
Flounder, Yellowtail	GBK (TRAC)	Index based	Complete	Fall & Spring
Flounder, Yellowtail	SNEMA	Model-Based	Complete	Fall & Spring
Flounder, Yellowtail	CCGOM	Model-Based	Complete	Fall & Spring
Haddock	GOM	Model-Based	Complete	Fall & Spring
Haddock	EGB (TRAC)	Index based	Complete	Fall & Spring
Haddock	GBK	Model-Based	Complete	Fall & Spring
Hake, Red	North	Index based	Complete	Fall & Spring
Hake, Red	South	Index based	Complete	Fall & Spring
Hake, Silver	North	Index based	Complete	Fall
Hake, Silver/Offshore	South	Index based	Complete	Fall
Hake, White	Unit	Model-Based	Major	Fall & Spring
Halibut, Atlantic	Unit	Index based	Low	Fall & Spring
Herring, Atlantic	Unit	Model-Based	Major	Fall & Spring
Herring, River	Unit	Index based	Low	Fall & Spring
Lobster, American	GOM/GB	Model-Based	Major	Fall & Spring
Lobster, American	SNE	Model-Based	Major	Fall & Spring
Mackerel, Atlantic	Unit	Model-Based	Major	Spring
Monkfish	North	Index based	Complete	Fall & Spring

Species	Stock	Assessment Type	Reliance on BTS	BTS Season
Monkfish	South	Index based	Complete	Fall & Spring
Plaice, American	Unit	Model-Based	Complete	Fall & Spring
Pollock	Unit	Model-Based	Complete	Fall & Spring
Pout, Ocean	Unit	Index based	Complete	Spring
Redfish, Acadian	Unit	Model-Based	Complete	Fall & Spring
Scup	Unit	Model-Based	Major	Fall
Shad, American	Unit	Index based	Low	Fall & Spring
Shrimp, Northern	Unit	N/A	Low	Fall
Skate, Barndoor	Unit	Index based	Complete	Fall
Skate, Clearnose	Unit	Index based	Complete	Fall
Skate, Little	Unit	Index based	Complete	Spring
Skate, Rosette	Unit	Index based	Complete	Fall
Skate, Smooth	Unit	Index based	Complete	Fall
Skate, Thorny	Unit	Index based	Complete	Fall
Skate, Winter	Unit	Index based	Complete	Fall
Squid, Longfin Inshore	Unit	Index based	Complete	Fall & Spring
Squid, Northern shortfin	Unit	Index based	Complete	Fall & Spring
Sturgeon, Atlantic	Unit	Index based	Low	Fall & Spring
Wolffish, Atlantic	Unit	Model-Based	Major	Fall & Spring

Primary end users of the BTS data include the NEFSC Ecosystems Surveys Branch, which conducts and manages the survey, as well as other internal NOAA user groups:

- NEFSC Population Dynamics Branch
- NEFSC Population Biology Branch
- NEFSC Ecosystems Dynamics and Assessment Branch
- NEFSC Oceans and Climate Branch
- NEFSC Social Sciences Branch
- NOAA Office of Science and Technology
- NOAA Ocean Acidification Program

It also includes external organizations:

- Mid-Atlantic Fisheries Management Council (MAFMC)
- New England Fisheries Management Council (NEFMC)
- Atlantic States Marine Fisheries Commission (ASMFC)
- Transboundary Resource Assessment Committee (TRAC)
- Canadian Department of Fisheries and Oceans Maritime Region
- Numerous external universities and non-governmental organizations

Table 2. Data collected during NEFSC Bottom Trawl Surveys and examples of data usage.

Type of data	Data Collection Method	Examples of Data Usage
Distribution and abundance of fish and invertebrates	Bottom trawl catches	Stock assessments and supporting publications: Friedland et al. (2023b); van Denderen et al. (2023); du Pontavice et al.

Type of data	Data Collection Method	Examples of Data Usage
		(2022); Adams et al. (2021); Friedland et al. (2021); McElroy et al. (2021); Nazzaro et al. (2021); Friedland et al. (2019); McHenry et al. (2019); Perretti and Thorson (2019); Adams et al. (2018); Deroba et al. (2018)
Life history parameters (e.g., recruitment, age and growth, maturity, fecundity, mortality)	Biological samples and evaluation, including otolith collection, sex and gonad maturity, and status determination.	Stock assessments and supporting publications: Matta and Helser (2024); McBride et al. (2022); McElroy et al. (2022); Wuenschel and Deroba (2019); Wuenschel et al. (2019); Gaichas et al. (2018); McElroy et al. (2016); McBride et al. (2013); McElroy et al. (2013); O'Brien et al. (1993)
Fish and invertebrate taxonomy and systematics	Bottom trawl catches	Galbraith et al. (2022); Bemis et al. (2018); Castro (2011); Collette and MacPhee (2002); Moore et al. (2003); Nakabo and Hartel (1999); Munroe (1998); Munroe (1992); Flescher (1980); numerous museum specimens and collections
Forage fish energy density	Biological samples	Annual State of the Ecosystem Report; Wuenschel et al. (2024)
Food web dynamics	Stomach contents of specimens	Gaichas et al. (2024); Van Beveren et al. (2024); Smith and Rowe (2023); Rowe and Smith (2022); Smith and Smith (2020); Smith and Link (2010)
Active acoustics of pelagic fishes	Active acoustic soundings	Zhang et al. (2024); Jech and Sullivan (2014)
Plankton and oceanographic characteristics of the surface and water column	See EcoMon Survey Mitigation Plan	

In addition to the standardized data collected during the BTS, the BTS accepts special sampling requests from NEFSC scientists, other NOAA programs, universities, and non-governmental organizations. Since tracking of incoming special sample requests began in 2012 and continued through the 2023 survey seasons, a total of 2,205 special sampling requests have been completed for 54 organizations (Table 3). Note that this tracking includes only pre-requested at-sea samples and does not include ad-hoc requests or laboratory-processed samples.

Table 3. Special sample requests received and completed by the Northeast Fisheries Science Center (NEFSC) Bottom Trawl Survey Program from 2012-2023, by organizational affiliation of investigators. Samples are defined as a unique piece of information (or preserved biological sample) collected for each specimen.

Organization	Total Surveys Collecting Special Samples	Total Special Sample Requests
Chesapeake Biological Lab	2	4
College of the Atlantic	3	3
Cornell Museum of Vertebrates	5	7
Cornell University	9	16
Dartmouth College	1	3
Deltona High School	1	1
Everett Public Schools	1	1
Falmouth High School	1	1
Fisheries & Oceans Canada	3	19
Fisheries and Oceans Canada	2	4
Florida Fish and Wildlife Research Institute	2	2
Florida Museum of Natural History	1	2
Gloucester Marine Genomics Institute	2	3
Harvard University	2	2
Louisiana State University	1	1
MADMF	5	5
Marine Biological Laboratory	2	2
Marshfield High School	3	3
Maryland Department of Fish and Game	11	149
Matis	1	2
MIT	1	1
MTSU	1	1
NEFSC	19	1728
New England Aquarium	8	21
NMFS	3	6
NOAA	6	12
North Carolina DMF	1	5
Northeastern University	4	6
Norton High School	2	2
NYSDEC	2	2
Princeton University	2	15
Rockefeller University	2	2
Russian Institute of Fisheries and Oceanography	1	1
Rutgers University	1	7
Shoals Marine Lab	1	1

Organization	Total Surveys Collecting Special Samples	Total Special Sample Requests
SMAST	1	4
Stellwagen Bank National Marine Sanctuary	6	6
Stony Brook University	1	3
The Fish Listener	1	1
UMass Amherst	2	2
UMass Dartmouth	3	13
University of Algarve	2	2
University of Central Florida	1	1
University of Maryland	3	13
University of New England	14	49
University of New Hampshire	1	1
University of Southampton, UK	1	3
University of Washington	1	4
Unknown	7	7
USCG	6	6
USGS	3	3
VIMS	1	1
Virginia Institute of Marine Science	2	2
WHOI	17	44

As mentioned above, the core objectives of the NEFSC BTS are to monitor the biological parameters, oceanographic habitat, and geographic distributions of fish and invertebrates on the Northeast U.S. Continental Shelf in support of stock assessments and ecosystem science. Offshore wind development will impact the ability to complete survey objectives into the future. Notably, the research platform (NOAA Ship *Henry B. Bigelow*; hereafter *Bigelow*) will be unable to sample inside these wind energy areas (WEAs) due to the presence of offshore wind energy infrastructure. In particular, the randomization of station locations will be affected as areas become inaccessible. Standardization of survey gear across the time series would be impacted if supplemental sampling is required in WEAs. While survey scientists are currently assessing the potential impact on operations and data quality, it is likely that to maintain consistent spatial coverage and resolution of the survey, supplemental sampling platforms will be necessary to obtain samples from inside these areas. Such changes will require a modified survey design and statistical analyses that are able to incorporate multiplatform sampling inside and around WEAs.

The BTS is also particularly sensitive to vessel and gear changes. When vessel and gear changes occur, the catchability of species can be expected to change. Since this is a multi-species survey, measuring the new catchability factors and calibrating to the factors calculated for the *Bigelow* can be time consuming, costly, and imperfect, leading to a reduction in the precision of the time series (Miller et al. 2010).

II. Survey Details

Beginning Year: 1963 fall; 1968 spring

Frequency: Semiannual

Season: Spring (March-May) and Autumn (September-November)

Geographic Scope: Continental shelf and upper continental slope from Cape Lookout, NC, to the western Scotian shelf, including Georges Bank, Gulf of Maine, portions of Canada's exclusive economic zone in water depths of 17 m-366 m.

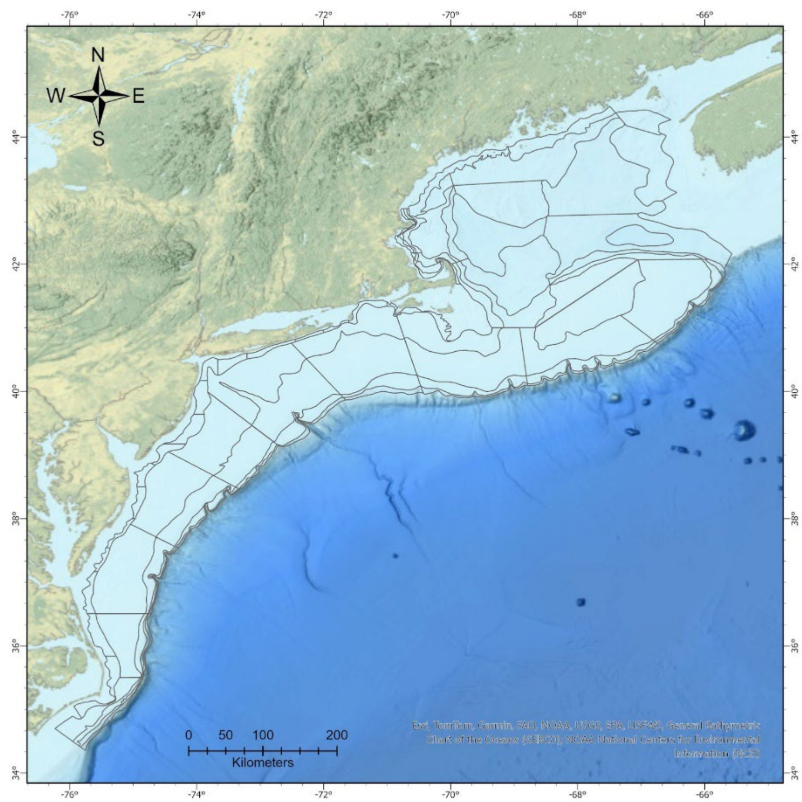

Figure 1. NEFSC BTS strata and complete geographic scope.

Platform: NOAA Ship *Henry B. Bigelow*

Statistical Design: The NEFSC BTS uses a stratified random sampling design. The survey area of interest is divided into strata based primarily on depth and secondarily by latitude, generally related to fish distribution (Grosslein 1969). Strata coverage and the locations of random stations to be sampled within each stratum are determined prior to each cruise. Stations are selected as a single random location, and specific tow locations may commence within a 1-nautical mile (nm) radius of the preselected coordinates. Generally, the number of stations within each stratum is proportional to stratum area but also includes consideration of the overall variability in multispecies distributions and critical management divisions. To assess variability in stratum catch, a minimum of 3 stations are planned within each stratum; a minimum of 2 stations must be successfully sampled.

Random sampling within each stratum produces unbiased abundance indices with measurable statistical precision. Most abundance estimates calculated from BTS data are relative abundance indices rather than absolute abundance indices, which are comparable through time because survey catchability is held constant through calibration and standardization of gear, vessel, and methodology.

Although the stratification and sampling approach have remained constant through time, possible adjustments that would increase data quality and improve efficiency of survey operations have been discussed on several occasions. Azarovitz (1981) recognized that disproportionate sampling occurs where some of the small inshore and offshore strata are sampled relatively more heavily and that this needs to be considered in analyses. In 1986, a group of NEFSC staff performed an evaluation of the BTS program and concluded that modifications to the survey coverage (e.g., eliminating areas south of Cape Hatteras, NC) could be made with minimal loss of information (SWG/NEFC 1988). This recommendation was incorporated into the survey design, resulting in the current footprint. This group also suggested that future work should include identifying other strata where coverage could be reduced, considering modifications to the sampling design and sampling intensity, and evaluating the relationship between sampling intensity and sampling precision across species.

Following those earlier considerations, a BTS restratification plan is currently being developed to reduce the variance in stratum area and allow for more optimal shelf-wide station allocation. The goal of this approach is to reduce overstratification and allow more spatially balanced allocations across strata while ensuring adequate samples to generate measures of within-strata variance. This restratification is focused on collapsing existing strata while maintaining, to the extent possible, existing definitions of fish and shellfish stock boundaries, thus reducing impacts to stock assessments. Computation of survey design efficiency by species and season will be helpful in guiding the potential benefits of reducing the number of strata.

While this ongoing effort to restratify the BTS is not solely focused on mitigating the impacts of offshore wind development, it is anticipated that optimizing the design efficiency will allow for greater flexibility to adapt to a changing, mixed-use landscape.

Methods: The BTS samples stations across the continental shelf ranging in depth from 17 m to the shelf edge at 366 m. Since 2021, stations are sampled in 3 3-week survey cruise legs which typically depart from and return to Newport, RI. Sixty sea days are allocated for the completion of 377 pre-planned stations. Within the survey area, regions are sampled synoptically for maximum comparability.

A standard BTS station consists of a hydrographic profile completed via a vertical CTD cast, an ichthyoplankton and zooplankton sample (at a subset of stations) via an oblique bongo net tow, and a bottom trawl tow.

Oceanographic sampling (addressed by the EcoMon Survey Mitigation Plan) includes a vertical CTD cast at all trawl stations. The CTD is deployed to within 5 m of the bottom and as close to the trawl in time and spatial location as possible, and within 3 hours and 3 nm of the midpoint of the bottom trawl path. CTD casts collect instrument profiles of temperature, salinity, dissolved oxygen, chlorophyll fluorescence, and photosynthetically active radiation.

At a subset of stations, predetermined according to EcoMon allocation criteria, oblique plankton tows allow for the estimation of zooplankton and ichthyoplankton abundance by taxon. For these preselected stations where a plankton tow will occur, a 333 μm mesh 61-cm bongo net is towed in tandem with the CTD cast. The maximum depth rating for the bongo net is 200 meters. For any stations deeper than 210 meters, the bongo and CTD are deployed to 200 meters and a separate CTD cast is completed to within 5 meters of the bottom.

Since 2009, the standardized bottom trawl uses a 3-bridle, 4-seam survey bottom trawl rigged with a rockhopper sweep which is routinely maintained and inspected for quality assurance. A standard tow is 20 minutes long at 3.0 kts over ground and begins when the trawl first touches bottom, as determined by trawl mensuration equipment and interpreted by the winch operator, and ends when the winches are reengaged at haul back. The BTS uses an autotrawl system during all trawling operations to monitor and automatically equilibrate tension in the towing warps, which improves the consistency of gear performance. Tow path and direction is determined by environmental conditions such as wind, current, and the depth contours; tow path is along a consistent depth contour and may follow a nonlinear path to achieve a consistent depth. These standard tow parameters yield an approximately 1-nm tow path.

Aggregate catch weights, individual lengths, weights, and biological samples (e.g., age, sex, maturity, stomach contents, tagging, genetic) for subsampled fish, subsampled invertebrates, and all protected species are collected. Additional biological sampling varies by year and season, including extensive sampling for internal NEFSC scientific studies, as well as external universities and other organizations. Bottom trawl net mensuration data are collected via a suite of Scanmar sensors deployed on the net. These survey data are audited via multistep quality control processes to verify the validity of stations, tows, and sampling data. Station and tow data are validated according to tow validation criteria outlined in Politis et al. (2014); biological sampling data are validated according to the Fisheries Scientific Computer System version 2 (FSCS2) validation requirements preprogrammed prior to each survey (NOAA 2013).

Additionally, the *Bigelow* is equipped with numerous sensors to measure a variety of environmental parameters including a surface water flow-through system. Measurements collected via the flow-through system include dissolved pCO2, as well as temperature and conductivity data via a Seabird TSG 45 and pH via Hydrofia sensors. Additional shipboard sensors collect measurements of dynamic ship position (including heave, pitch, and roll), air temperature, wind speed and direction, and barometric pressure, among other values. Shipboard sensor data are networked, monitored, and recorded by the Scientific Computing System (SCS) a NOAA-developed software for vessel sensor acquisition and quality control (NOAA Office of Marine and Aviation Operations 2023).

Active acoustic sampling data includes continuously recorded multi-frequency data collected across several sounders including:

- Kongsberg EM2040 multi-beam sounder
- Kongsberg ME70 Multibeam sounder
- Kongsberg Simrad EK60 (deprecated)
- Kongsberg Simrad EK80

- Foruno FE800
- Teledyne RDI ADCP

III. Effect of Four Impacts

1. **Preclusion** of NOAA Fisheries sampling platforms from the wind development area because of operational and safety limitations.

   Offshore wind development is expected to preclude the sampling platform, NOAA Ship *Henry B. Bigelow*, from WEAs due to operational and safety limitations. Discussions with the ship operator, NOAA's Office for Marine and Aviation Operations, indicate that the *Bigelow* will likely be precluded from transiting through WEAs in many situations and for mobile gear deployment in all situations.

   Preclusion Impacts on Survey Indices

   Preliminary retrospective analyses of the impact of lost sampling due to WEA preclusion suggest that the loss of trawl samples will decrease precision and could bias indices of abundance for some stocks (Cacciapaglia et al.; forthcoming; Miller et al., forthcoming). Furthermore, these analyses suggest that the impact of preclusion due to WEAs is not consistent across species, season, year, or strata and could affect the ability to detect trends and changes in trends over time (Cacciapaglia et al., forthcoming; Miller et al., forthcoming).

2. **Impacts on the statistical design of surveys** (including random-stratified, fixed station, transect, opportunistic, and other designs), which are the basis for scientific assessments, advice, and analyses.

   The NEFSC BTS currently has a random stratified design where all locations within each stratum have an equal selection probability. This sampling strategy will not be possible in the future as offshore wind development will spatially preclude the BTS from sampling within WEAs in many affected strata; potential sampling locations that fall within active WEAs will have a selection probability of 0, violating the assumptions of random sampling and necessitating new approaches. Given the current offshore wind lease and planning area extent (as of April 2024), 0.1-5,000 km^2 of an individual stratum (representing 0.02-61.0% of the area of a given stratum) will become precluded from random stratified sampling (Figure 2).

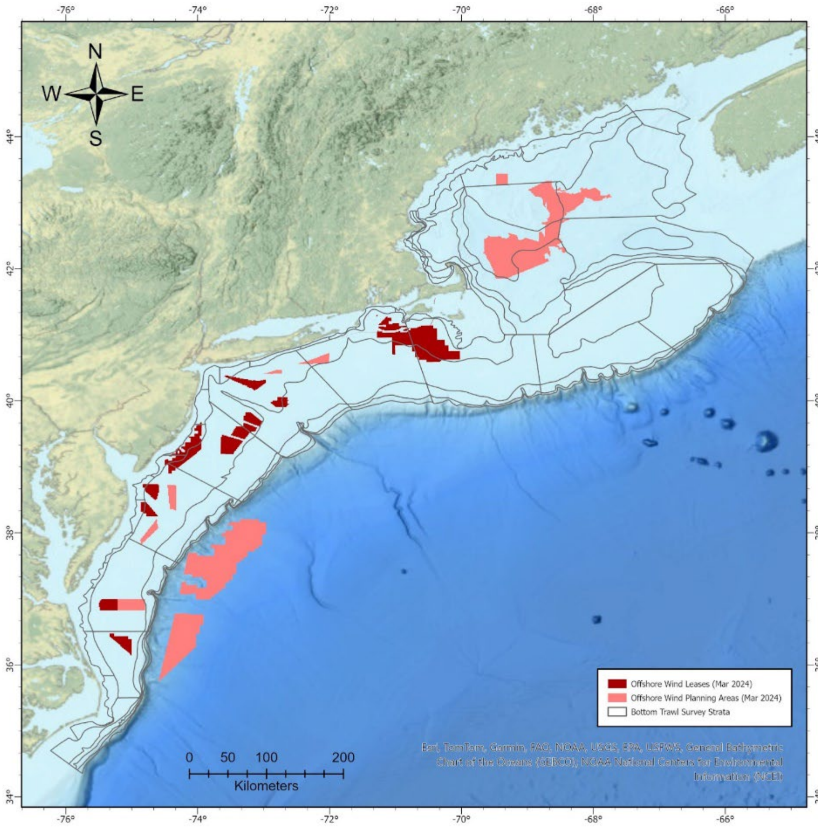

Figure 2. NEFSC BTS has a random stratified design. While not all strata will be impacted by the current (April 2024) extent of planned offshore wind development, random sampling will be precluded in impacted strata, for which 0-61% of total strata area will be impacted.

Losing this information from the affected strata will necessitate the use of either alternate sampling methodologies or inferential methods for stock and ecosystem assessments. Species abundance in inaccessible areas may be inferred from the sampling of adjacent accessible areas if the spatial relationships from earlier periods are maintained in the post-impact period. This, however, is unlikely as wind developments will alter existing habitats and therefore impact communities and spatial structure. Supplemental methods for sampling inside WEAs need to be robust against changing spatial structure and community dynamics, and will require substantial effort to design to allow for successful incorporation into stock and ecosystem assessments.

As described above, data from this survey currently support numerous products for scientific advice, with scopes ranging from ecosystem-wide (e.g., State of the Ecosystem report) to single stocks (e.g., stock assessments). Offshore wind development activities will introduce sources of uncertainty into survey products, including stock assessments and other scientific outputs, because of the varied yet unknown impacts to the marine ecosystem and marine resources. In turn, this will likely translate into increased caution in scientific advice to management.

Analyses are under way to evaluate the specific impacts of offshore wind development on survey design and data products, including external and internal NEFSC projects.

Impacts on Survey Design

Leveraging the NOAA Office of Science and Technology's Distribution Mapping and Analysis Portal (DisMAP) species distribution models, Bottom Trawl Program staff are evaluating the expected impacts of offshore wind development on species-specific sampling. Analyses currently under way include the performance of current stratification across assessed stocks and spatial coherence of potential sampling at the scale of individual WEAs. Further work to assess the impact of lost survey stations on additional species is under way, and a simulation environment is being developed to test station reallocation and survey restratification scenarios.

Impacts on Survey Indices

The NEFSC has a Cooperative Institute for the North Atlantic Region (CINAR) grant agreement with the University of Massachusetts School for Marine Science and Technology (SMAST) to assist Bottom Trawl Program staff to evaluate the impact of lost trawl samples inside WEAs on indices of abundance, both in terms of trends and variability over time. Stations that fell within wind farm areas were removed from survey datasets from 2010-2021, and survey indices were recalculated for 11 taxa (Miller et al., forthcoming). The directionality and magnitude of the resultant change in the stratified mean abundance varied by species, season, and impacted strata (Miller et al., forthcoming).

Impacts on Assessments

Additional studies conducted by the NEFSC Population Dynamics Branch are evaluating the impacts of BTS preclusion from WEAs on stock assessments. Research is ongoing to assess the influence of historical data from stations located in WEAs on index-based assessments. Preliminary results indicate that the impact is dependent on species distribution relative to WEAs and relative proportion of stock biomass encountered by the survey in the WEAs (Cacciapaglia et al., forthcoming).

3. **Alteration of benthic and pelagic habitats and airspace** in and around the wind energy development, requiring new designs and methods to sample new habitats.

   Offshore wind development will alter benthic habitats and oceanographic characteristics, which will likely impact productivity and distributions of some species (Methratta and Dardick 2019). Full impacts should be considered over the lifespan of individual developments (i.e., construction, operation, and decommissioning), as well as through a landscape perspective, considering cumulative impacts of multiple developments within the region.

   Habitat impacts of construction are expected to have broad-scale effects. Placement of scour protection and cabling are expected to result in local-scale movements and smothering. Pile driving and other drilling activities will introduce sound impacts over larger areas; however, some of the sound impacts may be dampened through the use of bubble curtains. Construction activities during survey periods that alter movements and behaviors of species captured by the BTS may affect the availability and catchability in the proximate area.

   Operation during the lifetime of wind energy installations may also impact species distribution and abundance. The placement of scour protection and turbine foundation will introduce hard bottom and intertidal habitat areas, which can be expected to introduce changes to species distribution, abundance, and biomass. Reef effects due to the introduction of habitat structure may serve as fish aggregating devices for some species; turbine installation may serve as a dispersive force for other species.

Additionally, studies have evaluated the impact of electromagnetic fields generated by wind turbines and associated cabling and found differential aggregative and dispersive impacts by species (Hogan et al. 2023). Lastly, warm water outflow from substation open-system cooling has the potential to dramatically change local community composition. Without increased spatial resolution of sampling, the accuracy of survey indices could decrease. Decommissioning of turbines following their lifespan will further alter benthic habitat. Complete removal of installed structures will disrupt established reef effects and communities and could cause landscape-wide reorganization of spatial distribution across suitable habitat patches.

In addition to the consideration of impacts at the individual development scale, it is critical to assess potential impacts through a landscape perspective, considering full scale regional buildout over time. This has the potential to create many discrete habitat patches for structure-affinitive species and may result in improved habitat connectivity and redundancy. For structure-avoidant species, the opposite may be true; the presence of WEAs may create habitat fragmentation. In both cases, regional scale changes in species distributions (affecting range and center of gravity) may become evident. Habitat changes due to wind development, as discussed above, will necessitate caution in interpretation of survey data. If species are displaced during construction or decommissioning, or if species aggregate around turbines at too fine a spatial resolution for the survey to representatively sample, the sampling resolution of the survey will be insufficient, and care should be taken with interpretation of the survey data.

4. **Reduced sampling productivity** caused by navigation impacts of wind energy infrastructure on aerial and vessel surveys.

   The transit path for station completion within regions is based on transit efficiency between stations and affected by logistic concerns such as prevailing weather conditions, sea state, and stations left to sample after previous cruise legs. For example, if offshore stations have too large of a swell to sample, inshore stations will be sampled until the swell subsides. Transits between stations would be most efficient if the vessel were able to cross offshore wind developments, particularly in areas offshore of New Jersey where there is a high density of WEAs along a north-south axis and survey stations both east and west of the developments.

   Conversations with commanding officers of the *Bigelow* and chief scientists of the BTS led to the conclusion that transiting across wind developments would be risky in poor weather conditions. In this situation, it would thus be necessary to transit around WEAs or make station selection decisions that would reduce the efficiency of the survey (effectively requiring a reduction in the number of stations, more survey days to complete the survey, or more flexibility in the allocation of stations) and violate the assumptions of random station allocation.

IV. Mitigation Planned, as per Six Elements

1. *Evaluation of survey designs*

Preliminary evaluations assessed the impact of removing stations inside of WEAs. It was confirmed that the removal of these stations impacted stratified mean abundance indices. Therefore, the impacts of offshore wind development on the design and operation of the BTS will need to be mitigated. In order to appropriately mitigate a survey of this consequence, several questions need to be addressed regarding survey design (Table 4). Many of these mitigation decisions are dependent upon operational and safety considerations of operating trawl gear within WEAs.

In addition to impacts to abundance indices, downstream impacts on derived products, including stock and ecosystem assessments, are essential to consider. Ongoing projects are developing spatially-explicit models to explore the impact of scenarios likely to occur due to the development of offshore wind. A management strategy evaluation (MSE) model is planned to test the efficacy of explicitly including an offshore wind area in stock assessment models and to evaluate the degree to which survey design accounting for WEAs can improve the accuracy of model estimates.

Lastly, research is required to develop a better understanding of the relationship between change in approximated transit times and the number of sampling days required. Analyses are recommended to estimate changes in transit time under ideal conditions using optimal path analysis simulations. Such analyses should be interpreted cautiously, however, as they cannot account for in situ logistical and operational constraints (e.g., weather, oceanographic conditions, dynamic management rules, vessel traffic, fixed gear impediments) and should thus only be used to generate rough estimates of changes in transit times.

Table 4. Identified research questions relevant to the development of offshore wind mitigation solutions for the Northeast Fisheries Science Center (NEFSC) Bottom Trawl Survey (BTS).

Question		Potential Impacts	Mitigation Strategies
Survey Design	What is the best supplemental sampling design inside WEAs which is able to be calibrated to the BTS? -Perimeter sampling around WEAs -Scaled bottom trawl survey gear and protocols at random stations inside WEAs -Scaled bottom trawl survey gear and protocols at fixed stations inside WEAs -Alternative sampling gear for integration with BTS survey What are the impacts of uncalibrated supplemental sampling inside WEAs?	-Reduced sampling efficiency -Reduced survey and index precision -Lack of resolution could cause imperfect detection of distributional change versus abundance change -Without calibration (design or model-based), potential for incomplete survey of stocks -Supplemental survey methods without biological sampling capabilities (e.g., optical methods) would require increased biological sampling rate elsewhere (i.e., more stations rather	-Simulation studies to assess if perimeter sampling of WEAs will allow inference distribution and abundance inside unsampled WEAs, considering marine protected area spillover literature, metapopulation dynamics (source/sink), basin modeling, and spillover effects -Design-based experimental calibration studies for gear and vessel modifications -Model-based calibration studies for alternative gear(s)

Question		Potential Impacts	Mitigation Strategies
	Does the current survey schedule and spatial footprint appropriately accommodate expected changes in both the distribution and timing (seasonal and diel) of sampled species? Do we know enough about individual species interactions/responses to turbines and associated infrastructure operation to understand impacts to survey design and respond appropriately?	than increased sampling in existing stations to prevent bias) -Turbine arrays and intra-array cables will limit options for tow length and direction -Adequate spatial and temporal overlap necessary between BTS and supplemental survey to allow for model-based index standardization	-Simulation studies to assess survey performance under scenarios anticipated ecological change -Behavioral studies outside the scope of the BTS to assess species interactions and responses to turbines and associated infrastructure -Continued monitoring with periodic assessments of the match-mismatch of survey design to stock biology
	Is existing survey stratification and station allocation appropriate for ongoing use in the context of offshore wind development? What is the sample size required for detection of ecological (e.g., distributional) and biological (e.g., age composition, life history) trends while accounting for disrupted sampling design impacts?		-Ongoing collaboration with Population Dynamics Branch to restratify and assess optimal allocation methods (e.g., spatially balanced sampling with Generalized Random Tessellation Stratified [GRTS]) -Increased sampling rate within WEAs -Assess sampling rates outside WEAs to ensure spatial overlap with supplemental sampling and ability to detect abundance and distribution changes (likely less impact under spatially balanced sampling approach) -Simulation studies to assess required sample size and impacts on CV -Periodic pilot studies to assess for adequate sampling under continued wind development scenarios
Survey Operations	What are appropriate sampling gears/protocols (including the requirement of autotrawl systems) for supplemental sampling inside WEAs?	-Potential for sampling bias in length structure and other biological parameters due to use of alternate gears/protocols - All remote sensing modalities: lack of biological sampling capabilities -Optical methods: decreased precision in species identification and	-Scaled BTS gear and protocols to minimize catchability differences -Analysis of gear performance and catchability (species- and size-specific) of BTS and supplemental sampling gear

Question		Potential Impacts	Mitigation Strategies
		length/weight estimation (e.g., due to optical lensing, turbidity, nighttime sampling, and light attraction)	
	What is the appropriate, logistically feasible, and operationally safe sampling schedule (i.e., 24 hour sampling vs daylight sampling)? If multiple vessels are involved in supplemental sampling, what sampling schedule would minimize confounding effects between vessel and schedule?	-Inability to calibrate supplemental sampling to nighttime BTS sampling -Introduction of new uncertainty and confounding factors -Interaction effects between vessel and time-of-day preventing ability to determine diel patterning of catches	-Analyze daylight impacts on survey catches and diel catchability impacts -Operationalize moving schedule of day/night operations per supplemental survey vessel
	What is the time and station loss associated with increased transit times in/around WEAs (i.e., how many extra sea days are required to accomplish the current sampling load of 377 stations)?	-Increased transit time between stations, likely impacts to station completion rate -Decreased station completions could result in increased variance, inability to calculate stratified variance, or insufficient station overlap to standardize and integrate supplemental sampling data to BTS	-Adjust allocated sea days to account for changes in transit times -Allocate additional required sea days for BTS sampling to NOAA Ship *Pisces* -Restratification to prevent continued overstratification and allow greater flexibility in station allocation
	What are the operational constraints of sampling around monopile and jacket turbines?	-Potential for use of modified trawl gear (scaled version) -Alternative proposed methodologies are also problematic (eDNA: pseudopresence data only; Acoustics: not species-specific; Optical: selectivity in poor visibility)	-Increased perimeter sampling around WEAs to infer abundance and distribution inside WEAs -Integrate data from alternative design(s) and gear(s) through design- or model-based calibration and index standardization
	What are the operational constraints of sampling in floating WEAs in the Gulf of Maine?	-Less potential for use of modified trawl gear, increased reliance on perimeter sampling and use of alternative methods -Alternative proposed methodologies are also problematic (eDNA: pseudopresence data only; Acoustics: not species-	-Increased perimeter sampling around WEAs to infer abundance and distribution inside WEAs -Integrate data from alternative design(s) and gear(s) through model-based calibration and index standardization

Question		Potential Impacts	Mitigation Strategies
		specific; Optical: selectivity in poor visibility)	
Data Quality and End Use	What level of spatial overlap is needed between existing and supplemental sampling to ensure usability of supplemental data series for consistent and reliable incorporation into abundance indices (e.g., through model-based methods) and stock assessments?	-Insufficient spatial and temporal overlap will result in inability to standardize supplemental sampling to BTS data and therefore will not be a usable source of data for quantitative inference of relative abundance -Lack of continuous spatial and temporal overlap will prevent assessment scientist from being able to assess changes in catchability and performance of calibration over time	-Simulation studies to assess required spatial and temporal overlap in supplemental sampling, including sensitivity analyses to assess impact of temporal offset of sampling and degree of spatial autocorrelation to station proximity required -Continued monitoring and adjustment of station allocation throughout the project lifespan
	What alternative sampling modalities (e.g., gears and statistical designs) may be combined for assessment purposes? What is the best method for data integration and index standardization?	-Data requirements for design-based calibration across multiple species are substantial -Incompatible gears and designs may not be able to be integrated in a biologically meaningful scale (i.e., imprecision in resulting indices may be too wide)	-Analyses and simulations on species- and size-specific gear selectivity and repercussions of selectivity biases on data integration and modeling products -Calibration of data through model-based or design-based methods
	What are the type and level of impacts likely to result if nighttime sampling cannot occur within WEAs?	-Lack of integration with existing 24-hour models and data sources may result in ineffective WEA sampling, unable to be used in assessment models	-If nighttime mobile gear sampling is deemed impossible due to safety concerns, integration of alternative sampling methods that are able to operate at night might be required
	What is an acceptable decrease in survey precision with regard to impacts on assessment-related data products?	-Potential loss of precision in assessment models, particularly for low abundance stocks/species	-Sensitivity analyses to assess the impact of survey indices' precision on stock assessment results
	How will the increasing and disparate data streams be managed, housed, processed, and QA/QCed? -Funding	-Lack of resources to manage disparate data streams resulting in inability to integrate into standardized indices	-Collaboration with Population and Ecosystems Monitoring and Analysis Division data management team and Information Technology Division to

Question		Potential Impacts	Mitigation Strategies
	-Support -Methodology		develop and implement data management protocols
	How much of an aggregative or dispersive effect would turbines need to have for impacts to be evident in BTS trends?	-Inability to capture within-WEA dynamics using only BTS indices, requiring successfully integrated supplemental sampling methodologies	-Simulations based on different stock areas and WEA areas, along with different precision of the survey outside the WEA

2. ***Identification and development of new survey approaches***

With offshore wind development preventing random sampling from areas of the spatial survey frame, as well as preliminary analyses suggesting the historical survey stratification may be suboptimal, 4 strategies are being used to assess and develop mitigation approaches: (1) optimizing BTS performance outside of WEAs in regions that will remain accessible; (2) addressing data gaps from areas inside of WEAs where the BTS will be precluded; (3) planning for lost transit efficiency; and (4) testing of alternative survey methods.

As described in Section III, we anticipate that habitat changes introduced by wind energy development have the potential to increase variance in the data we collect (Methratta and Dardick 2019). Furthermore, the specific locations, turbine spacing, types of foundations, and overall area of development are not known. Therefore, for the purpose of this mitigation plan, we are assuming that supplemental sampling (sampling methods that can occur inside of wind development areas) will be needed to provide adequate information on spatial, temporal, and life history trends for assessed stocks.

Optimizing BTS Design and Performance

An essential component of the mitigation strategy will require optimizing station allocation across the BTS footprint. As discussed in Section II, this will require restratification to condense the existing strata into fewer, larger, more spatially consistent regions. By correcting the current overstratification of the survey, we will have more flexibility to allocate survey effort in a more spatially consistent manner across the survey frame and ensure allocation of effort in areas where it is necessary for effective calibration.

In addition to restratification, a spatially balanced sampling design will be evaluated relative to stratified random sampling. Spatially balanced sampling designs have been shown to be more efficient (i.e., lower variance for a given level of sampling effort; Dumelle et al. 2022; Dumelle et al. 2023) and to improve performance in fishery-independent surveys relative to non-spatially balanced designs (Cheng et al. 2024). A spatially balanced sampling approach may offset some of the losses in precision due to preclusion and allow for more targeted responses to excluded areas. In particular, we plan to assess the use of the Generalized Random Tessellation Stratified (GRTS) sampling design in the areas still accessible to the survey (Stevens and Olsen 2004).

GRTS allows for variable inclusion probabilities while retaining desirable properties of design-based inference, thus allowing the flexibility to increase the likelihood of sampling areas surrounding untrawlable bottom (e.g., WEAs) by increasing relative inclusion probabilities along their perimeter to ensure spatial overlap of sampling between the BTS and supplemental surveys. Perimeter sampling around and supplemental sampling within WEAs may offset potential bias of future surveys and allow for continuation of design-based inference. Otherwise, future efforts may require model-based approaches to derive indices. Application of model-based approaches to historical data may induce wide variations in perceived abundance trends for many species.

Preliminary analyses that evaluated the use of exclusively relying on perimeter sampling to infer abundance inside WEAs found that it is only effective if the species density at the boundary is representative of the density within, an assumption that fails as WEA area increases. Existing planned development areas are larger than perimeter sampling alone can effectively sample.

Addressing Data Gaps

In addition to optimizing survey performance in accessible regions, program staff are evaluating options to address data gaps caused by preclusion. Changes to the survey design discussed above will likely need to be coupled with supplemental sampling inside WEAs to maintain accurate estimates of abundance and distribution. Supplemental sampling inside WEAs should be designed to be integrated with BTS data as much as possible, either through in situ design-based experimental calibration or model-based index standardization. Further, any supplemental sampling should be able to capture fine-scale changes in abundance, distribution, and size/age structure, which will most likely require the ability to take biological samples.

Scaled Bottom Trawl Survey

The most easily transferable supplemental sampling modality would be a scaled version of the BTS gear and protocols (including the use of autotrawl systems), operating on one or more vessel platforms that are able to trawl inside of the wind development areas. Bottom trawling is the preferred sampling modality in order to maximize efficiency (number of species and individuals sampled) and maintain biological sampling for age and growth, energetics, and food web studies. A scaled version of the existing BTS gear would likely minimize gear effects and selectivity differences; however, both would require additional study. This supplemental bottom trawl survey should collect baseline data and be calibrated to the *Bigelow*. Ideally, the supplemental sampling will have spatiotemporal overlap with sampling in the standard trawl survey for at least 5-10 years prior to wind farm development. Currently, the feasibility of bottom trawl operations within WEAs is unclear; initial trawl experiments inside WEAs have been successful (e.g., Zemeckis et al. 2024), but the limits on sampling platform size, weather, safety, and station allocation are currently unclear. As more information becomes available, alternative sampling designs (i.e., fixed or random stations) will be simulated and tested.

Alternative Supplemental Sampling Methods

Due to the uncertainty of being able to operate mobile gear in WEAs, other sampling modalities will be evaluated, as well. These may include acoustics, trap-video, hook and line surveys, and eDNA (for more information about potential supplemental methods, see the relevant Survey Mitigation Plans). All of these methods would require the development of model-based tools for index standardization to the BTS.

Planning for Lost Transit Efficiency

To determine the amount of survey effort that will be available for redistribution across the sampling frame, we also consider the potential loss of transit efficiency between sampling stations. Because the *Bigelow* may not be able to transit through WEAs in many conditions, this could impact the efficiency of the transit routes between stations and increase transit times. Analyses are planned to inform the potential delay introduced by transit inefficiencies; however, it will be assumed that some amount of impact is anticipated and should be mitigated.

Pending the results of the transit efficiency analysis and the restratification and reallocation design assessments, we will evaluate if additional sea time is needed to complete the BTS. Should more days be required and the *Bigelow* is unavailable, it is possible to use a sister ship, such as the NOAA Ship *Pisces* (hereafter *Pisces*), to complete the additional sea days required. In the past, the *Pisces* has been used as a substitute sampling platform when the *Bigelow* has been unavailable.

Testing of Alternative Survey Methods

As mentioned above, the NEFSC funded the University of Massachusetts SMAST through CINAR to develop a simulation framework to assess alternative sampling designs. Such a simulation framework may prove useful for determining the most appropriate supplemental survey design by evaluating the hypothesized ability to capture changes in abundance and distribution in the BTS time series.

To assess the performance of proposed alternative sampling designs, analyses will compare the performance of (1) status quo; (2) current survey design with WEA preclusion; (3) restratification and reallocation with WEA preclusion; and (4) hybrid sampling design(s) with updated stratification and allocation with supplemental sampling inside areas inaccessible to the *Bigelow* (i.e., WEAs).

3. *Calibration and integration of new survey approaches*

For the new survey approaches being discussed to have immediate utility in stock and ecosystem assessments, it will be essential to ensure their ability to be calibrated to the existing BTS time series. Calibration informs how time series are related and how to scale them relative to each other. Without calibration, the relationship between time series can only be revealed with time, often several years; the goal of calibration is to accelerate the understanding of that relationship so that datasets can be joined for continued analysis. This is particularly critical because for many assessments, the BTS provides essential indices of abundance and biomass (Table 1). Because of its lengthy time series, BTS indices are often used in models as the reference against which alternative indices are evaluated to estimate relative catchability and provide an estimate of scaling. Thus, calibrating supplemental sampling indices to the BTS time series would allow their use as a combined continuous time series in the stock assessments.

By calibrating between gears and sampling methodologies, we allow for an accounting of differences in catchability and selectivity between different gears. Calibration may lead to the development of conversion factors which describe the expected differences in catch responses for the calibrated gear types when sampling the same sampling unit. This allows for the blending of catch datasets and adds utility to each time series. By calibrating gears used in a newer time series (e.g., supplemental sampling) to gears used in the original time series (i.e., BTS), we can build abundance estimates using both datasets. Critically, calibrations will vary by species, as such analyses must be performed on a species-specific basis.

If active (mobile gear) approaches are used, calibrating measures of selectivity and catchability for each gear can be based on covariates that describe sampling effort (e.g., gear geometry, towing speed) and by opportunistically or experimentally paired survey sampling. If passive (fixed gear) approaches are used (e.g., traps or longlines), calibration to the BTS is difficult since passive gears are limited by the volitional activities (e.g., movement, hunger) of the species of interest. Additionally, comparing sampling effort between active and passive gears is challenging. The BTS estimates sampling effort in units of swept area, which is not possible to estimate for passive gears. However, model-based standardization of passive gear to the BTS is possible and would require multiple years of data to be effective.

In the context of BTS mitigation, without appropriate calibration to the BTS, alternative sampling methods will be treated as a separate time series. In that case, it is likely that the new time series will not be usable in stock assessments for approximately 10 years (i.e., until the time series is long enough to show relative trends and estimate both selectivity and catchability for a given stock, and its relationship to existing data sources is statistically observable). For example, following the development of the Gulf of Maine Bottom Longline Survey, it took 7-10 years of data collection before the time series could be considered for incorporation into stock assessment, depending on the stock and the assessment type. Even so, the incorporation of a new, uncalibrated time series into an assessment model will introduce new sources of uncertainty and may result in less precise estimates of abundance.

Below, we discuss the approaches being developed to ensure data compatibility for the design changes proposed.

Optimizing BTS Design and Performance

The proposed optimizations include restratification and reallocation. For historical data, restratification would require the imposition of a post-stratification correction on the time series (i.e., samples collected under previous stratification scheme). In contrast, using a GRTS approach for allocation of future stations will not require the imposition of a design penalty as GRTS is a form of random sampling where 2-dimensional space is mapped into 1-dimensional space and subsequently randomly sampled (Dumelle et al. 2022) .

Addressing Data Gaps

To address data gaps caused by preclusion from WEAs, it will be necessary to incorporate supplemental sampling. Obtaining supplemental sampling on a different platform, whether using bottom trawl or other gear(s), will require calibration to allow for the standardization of derived indices of abundances with the NEFSC BTS time series, which is essential for its expeditious utility in stock assessment models. Specific approaches and methodologies will be dependent upon the type of supplemental sampling deemed scientifically appropriate and operationally feasible. Due to the dynamic nature of expected changes in the ecosystem and resulting challenges associated with its sampling, we anticipate increased uncertainty in the resulting data. Therefore, it is essential for end users to be cognizant of assumptions made in the development of calibration models and their implications for the interpretation of subsequent model results.

Temporal and Spatial Overlap

For all supplemental sampling designs, it will be critical to use either design- or model-based calibration methods to standardize supplemental sampling data to the BTS time series. For both approaches, it is essential to maintain spatial and temporal overlap with BTS sampling for the life of the surveys to ensure the development and continued refinement of robust calibration factors (ICES 2023). This spatial and temporal overlap is especially critical if modeling methods are used to estimate differences in catchability or combine individual surveys into an aggregate index, which has recently been completed for several stocks (Hansell and Curti 2023).

Design-Based Calibration

The calibration of mobile gears has established and widely accepted methods and thus would be relatively straightforward. Design-based calibrations would require in situ experimental work, with side-by-side tows conducted over representative bottom types (Miller et al. 2010). Experimental comparisons would allow for the calculation of design-based calibration factors between mobile gears for each species or taxonomic unit that had adequate catches. Although such calibration methods are conceptually and analytically straightforward, they are also high effort (requiring simultaneous availability of both sampling platforms) and thus typically finite, which makes it challenging to achieve a high enough sample size and properly capture temporal variability (ICES 2023). Also, the greater the differences in gear and vessel types, the harder it is to calculate reliable calibration factors. This kind of paired effort often results in a single estimated calibration factor that is used to transform catches prior to analysis, which is suboptimal as it does not propagate uncertainty in the estimated calibration factor (ICES 2023).

Model-Based Calibration

Model-based index standardization approaches would not necessarily require side-by-side experimental tows but would require substantial spatial and temporal overlap of sampling stations for each survey to allow the model to estimate differences in catchability and selectivity (ICES 2023). Such a model-based approach would likely require some investment of sampling effort in overlapping frames during the early years of the survey to establish the model with continued (but reduced) calibration sampling efforts throughout the lifetime of the projects.

This is particularly important should passive gears (e.g., longline, gillnet, trap) or remote sensing methods (e.g., optical or acoustic) be used. These alternative methods are strongly dependent on fish behavior (e.g., movement, hunger) or detectability (He 2011), thus presenting a challenge for calibration to active gear. The ability to calibrate other types of survey modalities (i.e., modalities that have measures of sampling effort that are not comparable to swept area) to the BTS will require a significant investment of resources for derivation of appropriate calibration measures.

Planning for Lost Transit Efficiency

Decreased transit efficiency, as discussed above, may result in the need to reassess the sea day allocation of the BTS on the *Bigelow*, in which case, studies should evaluate potential phenological impacts due to extending the timing of the BTS. Phenological correction factors may be developed to account for variation on survey timing (Foley et al. 2020); however, such corrective measures will further increase uncertainty in data products.

Alternatively, leveraging the *Bigelow*'s sister ship, the *Pisces*, may allow for a relay approach for continued monitoring during the survey windows (e.g., the *Pisces* could deploy between *Bigelow* legs). Due to the similarity in vessel design, performance, and operation, vessel effects would likely be minimal and could be quantified as catchability covariates rather than through vessel calibrations experiments (ICES 2023).

4. *Development of interim provisional survey indices*

The goal of this survey mitigation plan is to maintain the integrity of the existing 60-year, fishery-independent survey time series and derived indices of abundance. Some of the mitigation actions described above will require the development of alternate calculations and calibrations for indices; however, the ultimate goal is to require no interim provisional survey index but rather a comparable time series. This is especially critical because the BTS underpins several stock assessment models (Table 1) and serves as the primary fishery-independent index to which other surveys are scaled. A continuous interruption in the BTS indices or unmitigated and uncalibrated change to survey design and time series would result in substantial impacts to stock assessments, especially their measures of uncertainty and variability. It is therefore essential to ensure appropriate and continuous calibration rather than the development of interim and independent survey products.

While specific mitigation measures are under development, BTS stations that fall within active wind lease areas (i.e., operational turbines or leases under active construction) will be reallocated within the same strata. To date (through the Spring 2024 BTS), no stations have been reallocated due to spatial conflict with WEAs. As buildout of wind energy facilities continues, the likelihood of future spatial conflict increases, and the statistical impacts of systematic exclusion of this structured and disturbed habitat must be considered. In collaboration with stock assessment scientists, research will be conducted to assess the impact of these short-term systematic biases on indices of abundance, while permanent mitigation methods are being developed.

5. *Wind energy monitoring to fill regional scientific survey data needs*

Wind energy developers are required to conduct fisheries monitoring surveys to assess the impact of development on the fisheries resources in WEAs. Some studies have attempted to maintain consistency by using the NEAMAP Southern New England-MidAtlantic survey as a design template (Methratta et al. 2023). However, trawl survey catches are known to be sensitive to non-standard elements including vessel, bridle angle, and even the specific net (Weinberg and Kotwicki 2008), so more standardization is required. Furthermore, developer monitoring studies are designed as impact assessment studies over relatively short time frames (Methratta et al. 2023). While it is possible to coordinate regionally across wind farms to accomplish a survey that meets assessment needs, there is currently no regionally consistent, scientifically designed survey that could be integrated with the existing BTS to produce reliable abundance estimates and validated biological samples for life history parameterization required by assessment models. There are 2 efforts under way related to developing a more coherent, regional approach. First, the creation of wind energy development fisheries monitoring standards to ensure that these efforts are consistent across projects. Second, consistent with the Federal Survey Mitigation Strategy, NOAA, BOEM, and wind energy developers are discussing the development of a regional bottom trawl survey mitigation approach.

Determination of specific monitoring efforts required is dependent on the results of the analyses described in this plan. However, increased monitoring activities outside of the scope of the BTS will be necessary in and around WEAs to determine the scale of biotic and abiotic habitat alteration and associated finfish and invertebrate abundance, distribution, age composition, and life history parameter changes. Such monitoring efforts would be informative for the design of supplemental survey approaches and should include investigations of physical and oceanographic habitat changes; turbines and associated structures as aggregation and dispersion mechanisms; changes to species movement, distribution, and life history; and density gradient effects.

In particular, understanding abundance and density gradients surrounding turbines and associated structures would allow for better interpretation of the relationships between supplemental sampling modalities. Transect designs might be useful for establishing baseline data on gradient effects which may be compared to alternative sampling methods to assess relative catchability. Additionally, synoptic data from within and around WEAs will be necessary to determine the spatial autocorrelation and coherence of species abundance and distributions. Notably, perimeter samples collected via BTS will exploit spatial coherence and are likely to work better for mobile than sessile species but will be compared to measurements captured via supplemental gear and vessels. Such analyses will inform the extent of supplemental sampling to address data gaps in the BTS data set due to preclusion from WEAs.

Fishery monitoring efforts conducted by wind developers may help to inform our mitigation actions. Specifically, developer monitoring activities may aid in understanding of the limitations associated with operating mobile gear inside wind farms. They could also inform the design of supplemental survey approaches by improving our understanding of abundance and density gradients surrounding turbines which would allow for better design of alternate sampling and interpretation of resulting data.

Lastly, efforts to address the larger-scale ecological impacts of region-wide, cumulative offshore wind development should also be developed but are outside of the scope of this survey mitigation plan. Specifically, understanding the regional-scale ecological impacts of offshore wind development on productivity (e.g., Daewal et al. 2022) and species distributions (e.g., Buyse et al. 2022) should be a priority.

6. ***Development and communication of new regional data streams***

Key NEFSC constituents have been involved in the creation of this mitigation plan, including representation from the Ecosystems Surveys Branch, NEFSC Leadership, Population Dynamics Branch, Offshore Wind Ecology Branch, and Population Biology Branch. Internal reviews have been conducted by members of the Cooperative Research Branch, Population Dynamics Branch, and NEFSC Leadership Team.

Additional constituents who should be consulted in the adoption of the BTS mitigation plan include the Greater Atlantic Regional Fishery Resource Office (GARFO), regional fisheries management groups (e.g.,TRAC, NEFMC, MAFMC, ASMFC), and advisory panels (e.g., Northeast Trawl Advisory Panel [NTAP]). Additional review processes will be developed in consultation with these groups and regional stakeholders as needed.

Continued collection of BTS data in and of itself should not increase data management needs. The addition of mitigation surveys, either with mobile, fixed, or remote sensing methods, will increase data management needs in a variety of ways and this must be considered in the costs of these surveys.

We also anticipate increased demand for improved public dissemination of the data and increased demand for analytical products not traditionally generated for these survey data. Systems for improved public dissemination of data, consistent with the NOAA Public Access to Research Results Plan, need to be developed (De La Beaujardière and Kaske 2015). This will become increasingly important as ecosystem-scale changes in suitable habitat and species distribution in response to WEA development are likely, creating an increased need for metadata and submission to data archives beyond what is currently done.

The use of additional platforms to collect trawl survey data from inside WEAs will increase IT support needs. Specifically, if the NEFSC implements and executes a portion of trawl sampling on a smaller vessel(s), additional technical support staff will be required to prepare, set up, and maintain data collection hardware and software. If these trawl samples are collected outside of the NEFSC, a clear plan to collect, transfer, audit, and manage these data will need to be developed to ensure data integrity and accessibility for NEFSC scientists.

The use of modalities other than bottom trawl for supplemental survey data would further increase IT support needs, which would be highly dependent upon the specific methodology employed. The use of alternative gear types would require examination of existing data collection platforms and data management structures to ensure compatibility; any remotely sensed data would require substantial investment in data storage and management infrastructure.

Other research outside the scope of the BTS aimed at better understanding ecological impacts of wind development will require increased data management resources. These efforts are outside of the scope of the BTS objectives; therefore, their data management and IT needs will be addressed elsewhere.

V. Proposed Schedule for Implementation

Table 4: Proposed schedule for Bottom Trawl Survey (BTS) mitigation implementation. Checkmarks denote completed activities or achieved milestones.

Element	Task	Activities	Milestones
IV.1	Evaluate impacts of BTS station loss and transit costs due to WEAs	☑ Solicit stakeholder input on research needs ☑ Evaluate WEAs' impact on calculated indices of abundance and index-based stock assessments ☐ Develop spatially explicit assessment model to explore WEA impacts of species distributions and sampling ☑ Evaluate the performance of existing bottom trawl survey stratification design ☐ Develop optimal path simulations to evaluate impacts on transit times	☑ Hold stakeholder workshops to generate research needs and identify species of concern ☐ Estimate anticipated changes in precision of abundance estimates for species identified by stakeholders ☑ Estimate impacts on index-based assessments ☐ Develop spatially explicit assessment modeling framework as a sandbox environment for hypothesis testing ☑ Calculate appropriate performance metrics for existing stratification ☐ Compare estimated transit times with and without WEA presence
IV.2	Develop and test alternative survey designs	☐ Restratify BTS into condensed existing strata ☐ Assess feasibility and operationalization of GRTS allocation ☐ Assess supplemental sampling designs, including gear and sampling design (with BTS spatial and temporal overlap)	☐ Create shapefiles of proposed new stratification design ☑ Hold workshop with Population Dynamics Branch for feedback on stratification design ☐ Compare estimates of variance between current and proposed survey designs for a variety of species distribution scenarios ☐ Determine efficacy and bias of GRTS with high-intensity perimeter sampling ☐ Assess difference in simulated index estimates between no additional sampling and supplemental WEA sampling

			☐ Develop review process to implement GRTS
IV.3	Execute calibration studies	☐ Determine efficacy of design-based or model-based calibration between *Bigelow* and supplemental sampling, particularly in regard to assessed species with high reliance on BTS products ☐ If design-based calibration is used, design side-by-side calibration experiment ☐ If model-based calibration is used, determine spatial and temporal sampling requirements for optimal data integration ☐ Repeat process periodically, as needed, to assess calibration performance	☐ Determine poststratification penalty and recalculate historical indices ☐ Determine appropriate calibration methodology ☐ Design calibration study ☐ Execute calibration study ☐ Calculate conversion factors or construct index-standardization models ☐ Hold workshop with Population Dynamics Branch to review calibration
IV.5	Implement mitigated sampling design	☐ Implement new stratification and GRTS allocation ☐ Begin supplemental sampling (if required) and generate standardized indices of abundance ☐ Recalculate historical indices	☐ Implement GRTS algorithm in existing station selection tools ☐ Contract with supplemental sampling vessel(s) ☐ Conduct pilot studies as needed to establish standard sampling protocols ☐ Make audited supplemental sampling data collected from within WEAs available in NEFSC database ☐ Integrate supplemental sampling with BTS data in internal NEFSC workflows
IV.6	Communicate changes and anticipated impacts of mitigation actions	☐ Peer review of proposed survey redesign ☐ Communicate proposed survey design changes to stakeholders	☐ Constitute a panel of experts and conduct a review ☐ Inform regional councils and stakeholders of survey design changes

VI. Links to Other Surveys

Several linkages to other surveys are anticipated. Biological and physical oceanographic data are collected for the BTS in collaboration with the EcoMon survey, and mitigation protocols are being developed in collaboration with the NEFSC Oceans and Climate Branch. The Scallop Survey and Hook and Line Survey are both evaluating the use of GRTS spatially balanced sampling methods as a component of their mitigation efforts.

Additional linkages to other surveys may emerge as we better define the need for supplemental sampling using alternative methods inside WEAs. These surveys may include the Gulf of Maine Bottom Longline Survey, Northern Shrimp Trawl Survey, as well as the proposed Hook and Line, Trap/Video, and eDNA surveys, surveys instituting acoustic methods, and others. Notably, some of these surveys (e.g., Gulf of Maine Bottom Longline, Hook and Line, Trap/Video, and Northern Shrimp Trawl Survey), although using alternative sampling gears, would be able to provide some assessment products typically provided by the BTS (e.g., otoliths, maturity, stomach contents). Other methods relying on remotely sensed data (e.g., optical and acoustic data, eDNA) would allow for the determination of presence and pseudoabsence (i.e., inferred absence supplementing presence-only datasets where a lack of detection might not mean true absence) as well as species diversity and might allow for estimation of biomass trends from ex situ experiments (although more in situ work is needed to determine the feasibility).

VII. Adaptive Management Considerations/ Opportunities

A major goal of the present approach is to limit the necessity of future modifications of the survey and allow for adaptive response to future changes in accessibility, distributions, and habitats of the Northeast Continental Shelf. By leveraging a GRTS sampling design, this plan allows for flexibility of station allocation so that sampling effort can be modified over time as WEAs are built out and decommissioned without requiring restratification of the entire sampling frame. In many instances, the final siting and design of wind structures remains unknown, particularly in areas designated for floating wind turbines. The particular design decisions at regional, WEA, lease, and turbine scales may have major implications for survey operations. As such, BTS staff will continue to monitor the status of WEA development, periodically reassess the performance and revise the survey design, and develop new analytical tools, as needed.

This mitigation plan also outlines potential opportunities for integrating supplemental sampling in WEAs to address data gaps. As in ecological communities, redundancy improves resilience to stochastic events. The incorporation of supplemental sampling (e.g., NEFSC 2024) in a standardized and scientifically rigorous manner presents an opportunity to improve the BTS’s resilience to unanticipated effort reductions (ICES 2023).

VIII. Statement of Peer-Review Plans

The proposed BTS redesign will be peer reviewed by an external expert panel made up of scientists with specific expertise and experience in statistical design of fishery-independent surveys and fish stock assessment. The specific makeup of the panel will be determined by the NEFMC, the MAFMC, and the ASMFC.

Additionally, analyses conducted as part of this mitigation effort may be published in peer-reviewed journals and/or presented at scientific conferences.

IX. Performance Metrics

Mitigated surveys should produce assessment models that minimize bias and have similar variances to historical estimates. The magnitude of bias will depend on the magnitude of changes in density within excluded areas and the ability of alternative designs to estimate these differences. Here, we propose using perimeter stations and supplemental sampling approaches to infer potential changes in density. Both approaches depend on the degree of autocorrelation measured over the scale of areas inaccessible to the *Bigelow*, generally at the scale of tens of kilometers.

Estimation of Bias

Undetected impacts on fish density and distribution changes due to changing behavior or habitat preferences will increase bias. Similarly, reliance on alternative methods for sampling within exclusion areas will increase bias if calibrations are not properly estimated. Variances of the total (biomass or abundance) will reflect the joint sampling error effects of each sampling method and would be expected to increase the total variance of the estimate.

The potential magnitude of such changes can be approximated by reviewing historical data. In particular, stations within closed areas can be excluded from computations to derive “counterfactual” estimates of bias and precision. Similarly, estimates from excluded areas could be multiplied by some scalar $\underline{a}$, where ($0<\underline{a}<b$) to test for the effects of changes in density within WEAs. A final level of analyses would be to examine the influence of changes on the slope between successive years. Most stock assessments use surveys as measures of trend rather than scale. Comparison of smoothed estimates of trend could help identify the implications of consistently biased estimates of relative abundance.

Simulations of sampling strategies using hypothesized scenarios of spatial abundance patterns will also be useful in understanding the performance of our survey moving forward. In addition to measures of relative bias and variance, simulations can evaluate the ability to estimate true bias since the true population size is known. Thus, measures of coverage rate can be used to determine how well measures of uncertainty include the true mean. Additionally, sensitivity analyses could assess the uncertainty that results from failure to sample in WEAs, as well as the impacts of increased CV.

Coefficient of Variation

The CV for estimates of abundance is an oft-used metric in stock assessments. The impact of integrating multiple data sources on CVs will depend on how much variance is associated with each time series, in addition to the uncertainty in the relationship between them.

Operational Feasibility

A successful mitigation plan will be one that maintains the survey time series, produces models with acceptable performance metrics, and is feasible to conduct. This plan describes several actions to ensure the BTS time series is maintained while increasing adaptability to future changes. However, the cumulative impacts of offshore wind development may increase the spatial and temporal variability of some species to the point that the number of stations necessary to accurately model abundance and distribution trends with acceptable performance metrics will be larger than we can feasibly sample. While keeping our mitigation efforts feasible is a critical consideration in what we are proposing in this plan, we are primarily concerned with NMFS's mandate of the long-term biological and economic sustainability of marine fisheries under the Magnuson Stevens Fishery Conservation and Management Act; therefore, we have designed our plan to prioritize understanding the biological and ecological state of the fisheries in the face of offshore wind development before considering the feasibility of what is required under NMFS's current federal budget.

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