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The Role of Fishery-Independent Bottom Trawl Surveys in Providing Regional and Temporal Context to Offshore Wind Farm Monitoring Studies

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Abstract

Bottom trawl surveys are commonly used to examine potential effects on fishes and invertebrates from offshore wind (OSW) farms in Europe and in the northeastern United States. Because OSW surveys typically occur over a limited spatial footprint, comparison of OSW monitoring results to long-term fishery-independent surveys may provide a regional and temporal context for OSW data sets. We compared results of the Block Island Wind Farm (BIWF) bottom trawl survey (2013–2019) to three fishery-independent bottom trawl surveys (Northeast Area Monitoring and Assessment Program, Northeast Fisheries Science Center, and Rhode Island Department of Environmental Management [RIDEM]) using catch rates of 12 federally managed species. We evaluated temporal trends in annual residual catches for each species calculated within each survey as the difference between the mean annual biomass per trawl and the long-term mean. Regional consistency in relative catches was apparent for species exhibiting synchronous interannual variability among surveys (Black Sea Bass *Centropristis striata*, Scup *Stenotomus chrysops*, Summer Flounder *Paralichthys dentatus*, and Winter Flounder *Pseudopleuronectes americanus*) or a decreasing trend in residual catch rates across the 7-year study period (Little Skate *Leucoraja erinacea*, longfin inshore squid *Doryteuthis pealeii*, and Winter Skate *L. ocellata*). For other species, catches among surveys were asynchronous (Atlantic Herring *Clupea harengus*, Butterfish *Peprilus triacanthus*, and Windowpane *Scophthalmus aquosus*) or anomalous catches in a single year affected the results (Red Hake *Urophycis chuss* and Silver Hake *Merluccius bilinearis*). Monitoring of BIWF occurred during a period with lower-than-average historical catches in a 32-year RIDEM data set for Atlantic Herring, Butterfish, Little Skate, longfin inshore squid, Red Hake, Silver Hake, and Winter Flounder and higher-than-average catches for Black Sea Bass, Scup, and Summer Flounder. There was no evidence that variation in catches near BIWF differed from regional trends in a way consistent with a detrimental impact of OSW farm operation. The regional context provided from multiple bottom trawl surveys varies by species and thus may be limited for interpreting OSW monitoring results.

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Development of offshore wind (OSW) farms in the United States while minimizing impacts to fishery resources is a common goal of state and federal government agencies, environmental interest groups, and fisheries organizations (Petruny-Parker et al. 2015). Bottom trawl surveys (beam and bottom otter trawls) are commonly conducted to assess potential changes to demersal fish and invertebrate communities associated with European wind farms (Lindeboom et al. 2011; Vandendriessche et al. 2015; Degraer et al. 2017). In the United States, trawl surveys are a part of completed (Wilber et al. 2022a, 2022b), ongoing (Ocean Wind, South Fork Wind, and Vineyard Wind), and planned (Revolution Wind and Sunrise Wind) OSW monitoring efforts. Trawl survey tows sample over relatively large distances (typically ~2 km), thus integrating the catch and losing some spatial resolution, but they permit collection of a broad array of organisms, which is useful if multiple species are the subject of concern. In addition, trawl surveys have a broad size selectivity, allowing for juvenile and adult organisms to be sampled effectively (e.g., Garrison and Link 2000). Some northeastern U.S. federal, regional, and state trawl surveys date back several decades, thus providing historical data on temporal fluctuations in relative abundance, distribution, and demographics. To assess potential effects of OSW farms on U.S. fisheries, the Bureau of Ocean Energy Management and some states recommend fisheries monitoring that can include the option of a bottom trawl survey (BOEM 2019; ROSA 2021). It has been suggested that the need for a regional context in which to interpret OSW monitoring results could be achieved through the comparison of OSW monitoring studies to these long-term regional surveys (Methratta 2020; ROSA 2021).

Standardized sampling protocols in OSW monitoring studies are encouraged to facilitate comparisons of results both among OSW projects and with fishery-independent historical data sets. Presently, no clear consensus has been reached among academic and resource management agencies regarding species prioritization or method standardization despite multiple workshops and collaborative guidance documents. In this study, we compared multiple regional fishery-independent data sets to the monitoring data collected during the 7-year (2013–2019) Block Island Wind Farm (BIWF) bottom trawl survey. Examples of previous comparisons of multiple fishery-independent survey results involve stock assessment models (Johnson and van Densen 2007; Pennino et al. 2016; Bell et al. 2021) and studies of fishery species with geographic ranges greater than the extent of a single survey (Chen et al. 2006; O'Leary et al. 2021). Although there is concern over the loss to long-term time series of fisheries-independent information collected at stations located within proposed wind farms, where turbine spacing may restrict access of federal survey vessels (Mann 2021), our study does not address the efficacy of integrating OSW monitoring data into stock assessments.

To briefly summarize the results of the BIWF study, fish and invertebrate abundances exhibited spatial and temporal variation, with significant spatiotemporal variation (i.e., before–after, control–impact [BACI] interaction) in the relative abundance of Black Sea Bass *Centropristis striata*, Little Skate *Leucoraja erinacea*, Windowpane *Scophthalmus aquosus*, and Winter Flounder *Pseudopleuronectes americanus*, none of which was consistent with a detrimental effect of wind farm operation (Wilber et al. 2022b). Because bottom trawl data typically are highly variable (Smith 1996), statistical power for catch rates can be relatively low unless the study design includes sufficient replication. For BIWF monitoring, a 40–63% difference (on average) in catch rates between the two reference areas for the fish examined was observed; thus, only a difference greater than these rates, representing background variation, would be considered ecologically meaningful. High variability in catch rates over a limited spatial extent in the BIWF demersal trawl survey contributed to the relatively high estimated target effect size, despite relatively high temporal replication (i.e., monthly sampling).

In this study, we examined the relative catch rates of 12 federally managed fishery species that were commonly encountered during the BIWF trawl survey and that are of commercial and/or recreational importance: Atlantic Herring *Clupea harengus*, Black Sea Bass, Butterfish *Peprilus triacanthus*, Little Skate, longfin inshore squid *Doryteuthis pealeii*, Red Hake *Urophycis chuss*, Scup *Stenotomus chrysops*, Silver Hake *Merluccius bilinearis*, Summer Flounder *Paralichthys dentatus*, Windowpane, Winter Flounder, and Winter Skate *Leucoraja ocellata*. The stock assessments of these species estimate varying trends in abundance (Table 1). Our examination of multiple surveys focuses on identifying the following: (1) a negative or positive effect of BIWF operation (i.e., the BIWF catch decreased or increased during the operation time period, whereas catches in other surveys either did not change or exhibited the opposite trend); (2) a temporal context for the 7-year BIWF survey period compared to a 32-year historical record; and (3) instances of no apparent regional or temporal context provided by the survey comparisons.

METHODS

Block Island Wind Farm bottom trawl survey.— Block Island Wind Farm is a pilot-scale facility consisting of five 6-MW wind turbine generators located approximately 5 km southeast of Block Island, Rhode Island, in an area that was historically fished by gillnetters, trawlers, lobster boats, and the recreational fishing community (Tetra Tech Environmental Consultant 2012; McCann et al. 2013).

TABLE 1. Status of each fishery stock as reported in the most recent stock assessment documents (Northeast Fisheries Science Center [NEFSC] stock assessments; noaa.gov; accessed November 20, 2021). Data from the season(s) used in each species' stock assessment were used in the regional context assessment of relative catch rates except where noted.

Species	Stock assessment season	Source	Stock status	Notes within the assessment
Atlantic Herring	Spring and fall	Stock Assessment Workshop (SAW) 65 (NEFSC 2018)	Not overfished, and overfishing is not occurring	Continued poor recruitment suggests that the short- to medium-term prognosis for the stock is likely to be relatively poor.
Black Sea Bass[a]	Spring	Stock Assessment Review Committee (SARC) 62 (NEFSC 2017a)	Not overfished, and overfishing is not occurring	The distribution of Black Sea Bass continues to expand northward into the Gulf of Maine. Current mortality from all sources is lower than recruitment inputs, which has resulted in a spawning stock biomass (SSB) well above the management target.
Butterfish	Fall	2017 update to benchmark assessment (Adams 2018)	Not overfished, and overfishing is not occurring	As of 2012, the stock is considered rebuilt. Additional work has been conducted to incorporate consumptive removals of Butterfish by predators as well as habitat suitability model integration into the assessment.
Little Skate[a] (skate complex)	Spring	New England Fishery Management Council (NEFMC) annual monitoring report (NEFMC 2020)	Not overfished, and overfishing is not occurring	Stock status determination relies on the spring National Marine Fisheries Service trawl survey and the rate of change of the 3-year moving average. The current index is above the 3-year average.
Longfin inshore squid	Spring and fall	SARC 51 (NEFSC 2011)	Undetermined	Because of the species' sub-annual life span, semelparous life history, highly variable recruitment, and lack of fishing mortality reference points, the stock status cannot be determined.
Red Hake	Spring	2017 stock assessment update (Alade and Traver 2018)	Overfished, and overfishing is occurring (southern stock)	The NEFSC trawl survey index has been declining since 2012, but catch has remained relatively stable.
Scup	Spring and fall	SARC 60 (NEFSC 2015)	Not overfished, and overfishing is not occurring	The current SSB is well over target, but recent below-average year-classes and catches above maximum sustainable yield suggest a decrease toward the target unless higher recruitment inputs return.

TABLE 1. Continued.

Species	Stock assessment season	Source	Stock status	Notes within the assessment
Silver Hake	Spring and fall	2017 stock assessment update (Alade and Traver 2018)	Not overfished, and overfishing is not occurring	The northern stock continues to show strong increases in biomass due to strong year-classes. Recruitment remains poor for the southern stock, with the index declining and approaching the management threshold.
Summer Flounder	Spring and fall	SARC 66 (NEFSC 2019)	Not overfished, and overfishing is not occurring	Current mortality from all sources is greater than recent recruitment, which has resulted in a declining stock trend.
Windowpane	Spring and fall	Operational assessment of groundfish stocks (NEFSC 2017b)	Not overfished, and overfishing is not occurring	There has been a "no-possession" rule since 2010, so the model uses estimated discards solely for catch estimates. Survey indices have been increasing since 2000, and fishing mortality and catch rates have been relatively stable. This species is viewed to have low climate vulnerability, and females are showing high condition indices.
Winter Flounder (southern New England/mid-Atlantic)	Spring and fall	Operational assessment of groundfish stocks (NEFSC 2017b)	Overfished, but overfishing is not occurring	The southern New England/mid-Atlantic Winter Flounder stock shows an overall declining trend in SSB over the time series, with current estimates near the time series low. Estimates of fishing mortality have remained steady since 2012, and recruitment has steadily increased since an all-time low in 2013. Current recruitment estimates are above the 10-year average and are the highest since 2008.
Winter Skate	Fall	NEFMC annual monitoring report (NEFMC 2020)	Not overfished, and overfishing is not occurring	The 3-year average index is above the previous 3-year average.

[a]Spring and fall data were used in the Black Sea Bass and Little Skate regional context assessment because catches of both species were relatively high in the fall during Block Island Wind Farm monitoring.

Concern over the potential effects of construction and operation of BIWF on demersal fish and invertebrates led Deepwater Wind Block Island, LLC to conduct a bottom trawl survey covering baseline (2013 and 2014), construction (parts of 2015 and 2016), and operation (2017–2019) time periods. This survey was conducted within the wind farm and in two nearby reference (REF) areas with similar habitat characteristics (Figure 1) using a BACI study design (Underwood 1992; Smith et al. 1993). Sampling was conducted monthly at a subset of six trawl locations in each of three areas corresponding to REF areas east and south of Block Island, which averaged 15 km^2, as well

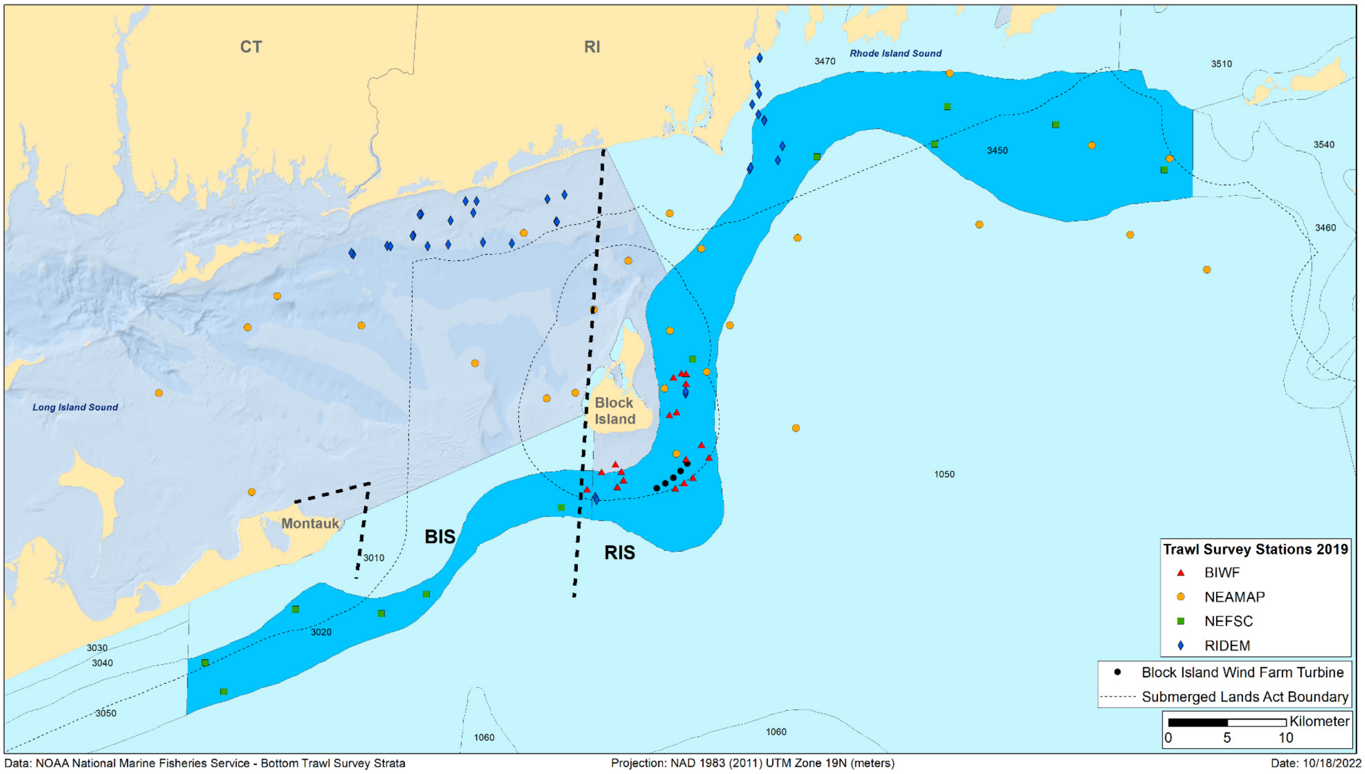

FIGURE 1. Example station locations for a single year of sampling in the Block Island Wind Farm (BIWF; red), Northeast Area Monitoring and Assessment Program (NEAMAP; yellow), Northeast Fisheries Science Center (NEFSC; green), and Rhode Island Department of Environmental Management (RIDEM; blue) bottom trawl surveys. The NEAMAP stations were subsampled by depth strata within Block Island Sound (BIS) and Rhode Island Sound (RIS), which are delineated by dotted lines. The NEFSC depth strata 3,020 and 3,450 are depicted by the blue contour. Two of the six trawl locations in each BIWF area were randomly selected for sampling each month. A more detailed depiction of the BIWF trawl lines is provided by Wilber et al. (2022b).

as a 21-km^2 area near the wind farm, designated as the area of potential effect (APE). Two trawl lines within each of the two REF areas and the APE were randomly selected for sampling each month. Data from trawls conducted during March–May and September–October (2013–2019) were used in our study to obtain a data set with seasonal coverage comparable to the spring and fall sampling conducted in the regional surveys described below.

Regional fishery-independent surveys.— Data from fishery-independent surveys were subsampled to include stations across a spatial extent that was broad enough to provide a regional/ecosystem context, defined as greater than 1,000 km^2 (ROSA 2021), but not so broad as to include areas with substantially different fish communities or environmental conditions. The approximate area sampled by the stations depicted in Figure 1 was 1,920 km^2. Data sources and the methods used to select stations are described for each trawl survey.

The Northeast Area Monitoring and Assessment Program (NEAMAP) nearshore trawl survey is led by the Virginia Institute of Marine Science and is conducted during the spring and fall in shallow coastal waters to complement the Northeast Fisheries Science Center (NEFSC) bottom trawl survey, which samples deeper habitat (Figure 1). The NEAMAP survey was developed to address the gap in fishery-independent survey coverage due to research vessel size restrictions (Bonzek et al. 2017). The NEAMAP trawl survey sampling in Block Island Sound (BIS) and Rhode Island Sound (RIS) started in fall 2007, and data collected from stations within depth strata 3 and 4 (Table 2) in these areas from 2013 to 2019 are included in our study.

The NEFSC bottom trawl survey has been conducted in the spring (March–May) and fall (September and October) since the 1960s, with a gear and vessel change occurring in 2009 (Bell et al. 2021). The NEFSC data for strata 3,020 and 3,450 (Table 2) from 2013 to 2019 are used in this study. The time period used for the NEAMAP and NEFSC surveys is consistent with the years of sampling for BIWF monitoring.

The Rhode Island Department of Environmental Management (RIDEM) has conducted a spring (April and May) and fall (September and October) bottom trawl survey in state waters since 1979. Stations in BIS and RIS

TABLE 2. Characteristics of fishery-independent bottom trawl surveys examined in this study (NEAMAP = Northeast Area Monitoring and Assessment Program; NEFSC = Northeast Fisheries Science Center; RIDEM = Rhode Island Department of Environmental Management). The number of annual trawls is provided in parentheses in the Survey column, and approximate locations are depicted in Figure 1 (BIS = Block Island Sound; RIS = Rhode Island Sound). All surveys used a 20-min tow duration. The sample size for Block Island Wind Farm (BIWF) is derived from two monthly samples per area over three areas during 5 months/year (i.e., March–May for spring; September and October for fall).

Survey	Years analyzed	Coverage	Depth range (m)	Vessel	Gear
BIWF (*n* = 30)	2013–2019	Two reference areas and the area around wind farm (area of potential effect)	18–40	F/V *Virginia Marise* (21.95 m [72 ft])	412- × 12-cm, four-seam whiting trawl with 167.64-cm (66-in) Thyboron otter doors and a 2.54-cm (1-in) knotless cod end liner (Wilber et al. 2022b)
NEAMAP (*n* = 26)	2013–2019	Depth strata 3 and 4 in BIS and RIS	>18	F/V *Darana R* (27.43 m [90 ft])	Four-seam, three-bridle, 400- × 12-cm net with a cookie sweep and 2.54-cm (1-in) knotless liner in the cod end. The doors are 167.64-cm (66-in) Thyboron type IV (NEAMAP gear, Virginia Institute of Marine Science; vims.edu).
NEFSC (*n* = 12)	2013–2019	Depth strata 3,020 and 3,450	21–44	*Henry B. Bigelow* (63.70 m [209 ft])	Four-seam, three-bridle bottom trawl with a rockhopper sweep (Politis et al. 2014)
RIDEM (*n* = 20)	1988–2019	Depth strata 5, 6, 9, and 10 in BIS and RIS	18–36	R/V *John H. Chafee* (15.24 m [50 ft])	Two-seam trawl, 533.40- × 11.43-cm (210.0- × 4.5-in) fishing circle, 12.19-m (40-ft) headrope, 16.76-m (55-ft) footrope, 11.43-cm (4.5-in) mesh body, 5.08-cm (2-in) mesh in the cod end, with a 6.35-mm (0.25-in) octagonal knotless liner. Headrope has seven 20.32-cm (8-in) light-duty trawl floats evenly distributed over the length. Thyboron type IV, 111.76-cm (44-in) steel trawl doors (RIDEM coastal trawl survey; ri.gov)

were included in 1988, and two stations near Block Island were added in 2012. Data from stations located in strata 5, 6, 9, and 10 were used in our study (Table 2), which includes BIS and RIS stations sampled from 1988 through 2019. The RIDEM trawl survey provides the longest data set with a consistent vessel and gear sampling protocol; therefore, it is used to provide a historical context for comparison of annual catches that occurred during BIWF monitoring.

Data treatment.— We examined temporal trends in relative abundance for each of the 12 species in each survey by plotting residual catches—that is, the difference between the annual arithmetic mean biomass per trawl and the 7-year (2013–2019) arithmetic mean biomass per trawl within each survey over time. The BIWF residual catches were used to represent annual fluctuations from the long-term mean and were calculated separately for the APE and the combined REF areas for BIWF data. Seasonal data included in these evaluations (i.e., spring, fall, or spring and fall averaged) were based on the season used in each species' stock assessment (Table 1), with two exceptions. Spring monitoring data were used in stock assessments for Black Sea Bass and Little Skate; however, catches of these species were relatively high in the fall during BIWF monitoring, so spring and fall data were used here to better capture temporal fluctuations. Although seasonal data were used in this assessment, the temporal unit is a year; therefore, the data are referred to as annual residual catches. We assessed temporal trends in two ways: (1) a short-term regional context and (2) a longer-term context. For the short-term regional context, annual residual catches were compared among the surveys over the 7-year period in which the BIWF bottom trawl survey was conducted. For the longer-term context, annual residual RIDEM catches were plotted over a 32-year period (1988–2019) and the relative catches during the BIWF monitoring study (2013–2019) were noted.

The regional context was further explored using Spearman's rank correlations (with coefficient ρ) conducted individually for each species to compare the annual relative catch data (deviation from the mean) among all surveys. Spearman's rank correlations assessed the similarity of rankings of annual relative catches, which may differ even when the temporal fluctuations of catches in two surveys appear synchronized. An increase in catch from 1 year to the next will produce a higher rank in the latter year regardless of the magnitude of the change in catch. In this way, Spearman's rank correlation is not affected by extreme values, and the ranks are the same whether residual catch or the observed catch is correlated, but the rank correlation is also sensitive to small changes in catch that can mask the larger trend. For instance, two series of residual catches with signs in common during the same years (i.e., positive or negative) may vary slightly in magnitude, thus affecting rankings and Spearman's correlation results. Therefore, these tests assessed the strength of cooccurring temporal trends in relative annual catches between surveys in terms of both direction and relative magnitude during the 7-year study period.

RESULTS

The range of the residual catches is a function of the relative biomass and availability of a species. For instance, Butterfish, Little Skate, Scup, and Winter Skate consistently had the greatest relative abundances in the BIWF survey (Wilber et al. 2022b) and exhibited the greatest ranges in their individual residual catches depicted as deviations from means (Figure 2). The scale of the residual catches, therefore, is less a reflection of the relative variability in annual catches among species and more a reflection of the differences in the relative abundance among species.

Regional Context

Evaluations of the BIWF residual catch plotted against the residual catches of the NEAMAP, NEFSC, and RIDEM surveys from 2013 to 2019 (Figure 2) were subjectively characterized into one of four categories as follows: (1) interannual variation in relative catches was fairly synchronous among surveys, with no temporal trend (Black Sea Bass, Scup, Summer Flounder, and Winter Flounder); (2) a decreasing temporal trend was apparent in most surveys (Little Skate, longfin inshore squid, and Winter Skate); (3) an outlier high annual catch was recorded in most surveys (Red Hake and Silver Hake); or (4) residual catches were not synchronized among surveys (Atlantic Herring, Butterfish, and Windowpane).

The patterns in the residual catch values were also compared between the five data sources for a total of 10 possible pairwise Spearman's rank correlations for each species, yielding 120 total tests. A Spearman's ρ of 0.70 was used as the threshold for identifying the strongest correlations. We note that this threshold is somewhat subjective and was used simply to highlight the strongest associations. If we were reporting the statistical significance of these correlations, ρ values greater than 0.714 would be flagged as statistically significant for a one-tailed α of 0.05 and a sample size of 7. However, we are not reporting statistical significance because sample sizes (n = 7) were too limited to warrant this level of scrutiny. Twenty of the tests had ρ values greater than 0.70, indicating strong associations in the temporal patterns between data sources; two comparisons yielded a strong negative correlation ($\rho \leq -0.70$). The 10 species with strong positive correlations included Atlantic Herring (n = 1), Black Sea Bass (n = 2), Butterfish (n = 1), longfin inshore squid (n = 1), Red Hake (n = 3), Scup (n = 1), Summer Flounder (n = 1), Silver Hake (n = 6), Windowpane (n = 1), and Winter Skate (n = 3; Supplementary Material available separately online).

Temporal Context

The RIDEM residual catches during the BIWF monitoring time period were categorized relative to the long-term data set (Table 3; Figure 3) as (1) mostly lower than the historical mean (Atlantic Herring, Butterfish, Little Skate, longfin inshore squid, Red Hake, Silver Hake, and Winter Flounder); (2) mostly higher than the historical mean (Black Sea Bass, Scup, and Summer Flounder); or (3) lacking an apparent clear temporal trend (Windowpane and Winter Skate). Variation in catches was similar for Windowpane and Winter Flounder, with low catches in the early 1990s, higher catches in the late 1990s, and subsequent declines for both species until the early 2000s.

DISCUSSION

A comparison of BIWF monitoring results to temporal variation in regional fishery-independent surveys provides an additional approach to detecting potential effects from wind farm construction and operation beyond the BACI analyses. For instance, the BIWF Black Sea Bass catch rates increased between the baseline and operation time periods at the APE by nearly an order of magnitude while remaining relatively constant at a REF area (Wilber et al. 2022b). This significant BACI contrast is interpreted as an artificial reef effect for this shelter-oriented species. However, the historical context provided by the RIDEM survey illustrates that the artificial reef effect is superimposed on a regional increase in Black Sea Bass abundances. The decrease in catch rates of Little Skate

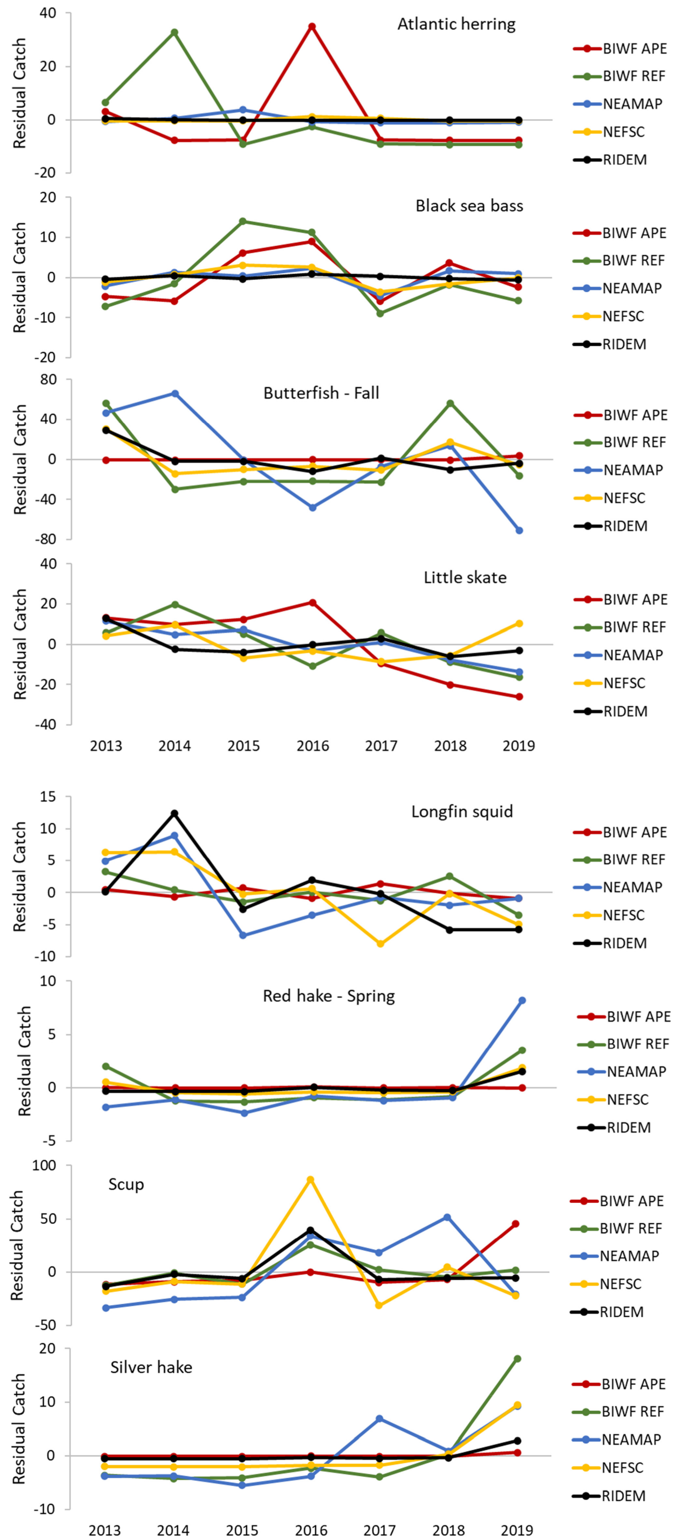

FIGURE 2. Interannual variation in the residual catches (deviation from the long-term mean) of 12 federally managed species collected in four fishery-independent bottom trawl surveys (Block Island Wind Farm [BIWF], Northeast Area Monitoring and Assessment Program [NEAMAP], Northeast Fisheries Science Center [NEFSC], and Rhode Island Department of Environmental Management [RIDEM]). Residual catches for the BIWF area of potential effect (APE) and the reference (REF) areas are depicted separately.

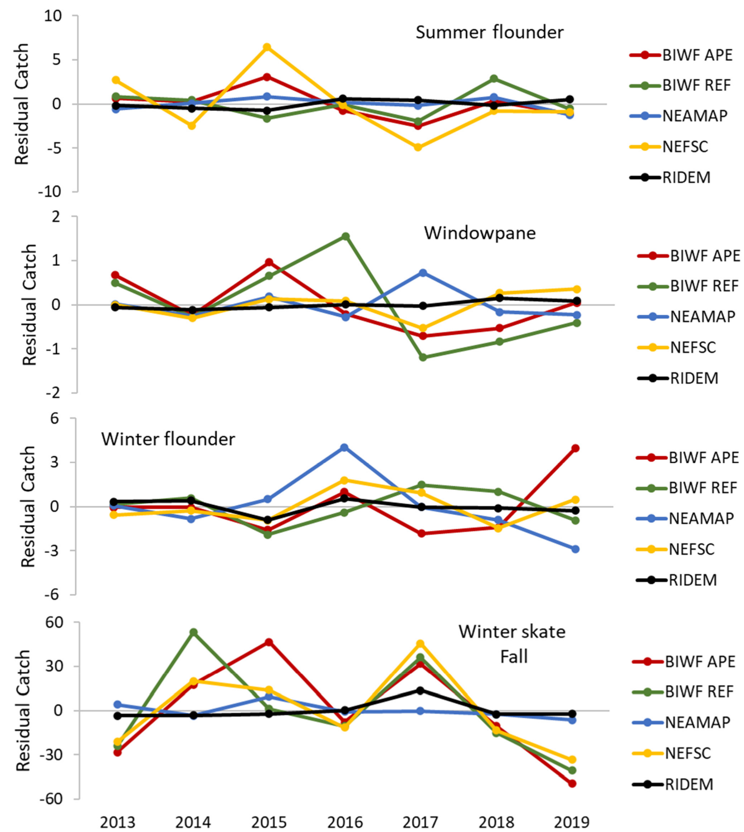

FIGURE 2. Continued.

between baseline and operation time periods only at one REF area (Wilber et al. 2022b) was consistent with declining catches in the region over the same period. The significant Windowpane and Winter Flounder BACI contrasts (Wilber et al. 2022b) reflected substantial spatiotemporal variation that was similar to the asynchronous regional fishery-independent survey results for Windowpane and the weak synchrony for Winter Flounder. Asynchrony among regional surveys may result from changes in distribution patterns from year to year, with surveys that sample in different locations intercepting relatively high fish densities in different years as distributions change. Asynchrony also may result from the highly stochastic nature of catching fish that belong to schooling species. Hence, intrinsic to any comparison of OSW trawl survey results to regional surveys is the confounding feature that potential differences in relative abundance patterns may be an artifact of the different spatial distributions of the

TABLE 3. General comparisons among the Block Island Wind Farm (BIWF), Northeast Area Monitoring and Assessment Program (NEAMAP), Northeast Fisheries Science Center (NEFSC), and Rhode Island Department of Environmental Management (RIDEM) surveys during the time period of the BIWF study (2013–2019) crossed with the trend from the full RIDEM survey (1988–2019) by species.

	Regional context (2013–2019)			
Temporal context (1988–2019): RIDEM catch from 2013 to 2019 relative to 32-year history	(1) Synchrony among surveys; no temporal trend	(2) Decreasing temporal trend	(3) Outlier in annual catches	(4) No synchrony among surveys
(1) Lower	Winter Flounder	Little Skate, longfin inshore squid	Red Hake, Silver Hake	Atlantic Herring, Butterfish
(2) Higher	Black Sea Bass, Scup, Summer Flounder			Windowpane
(3) Unclear		Winter Skate		

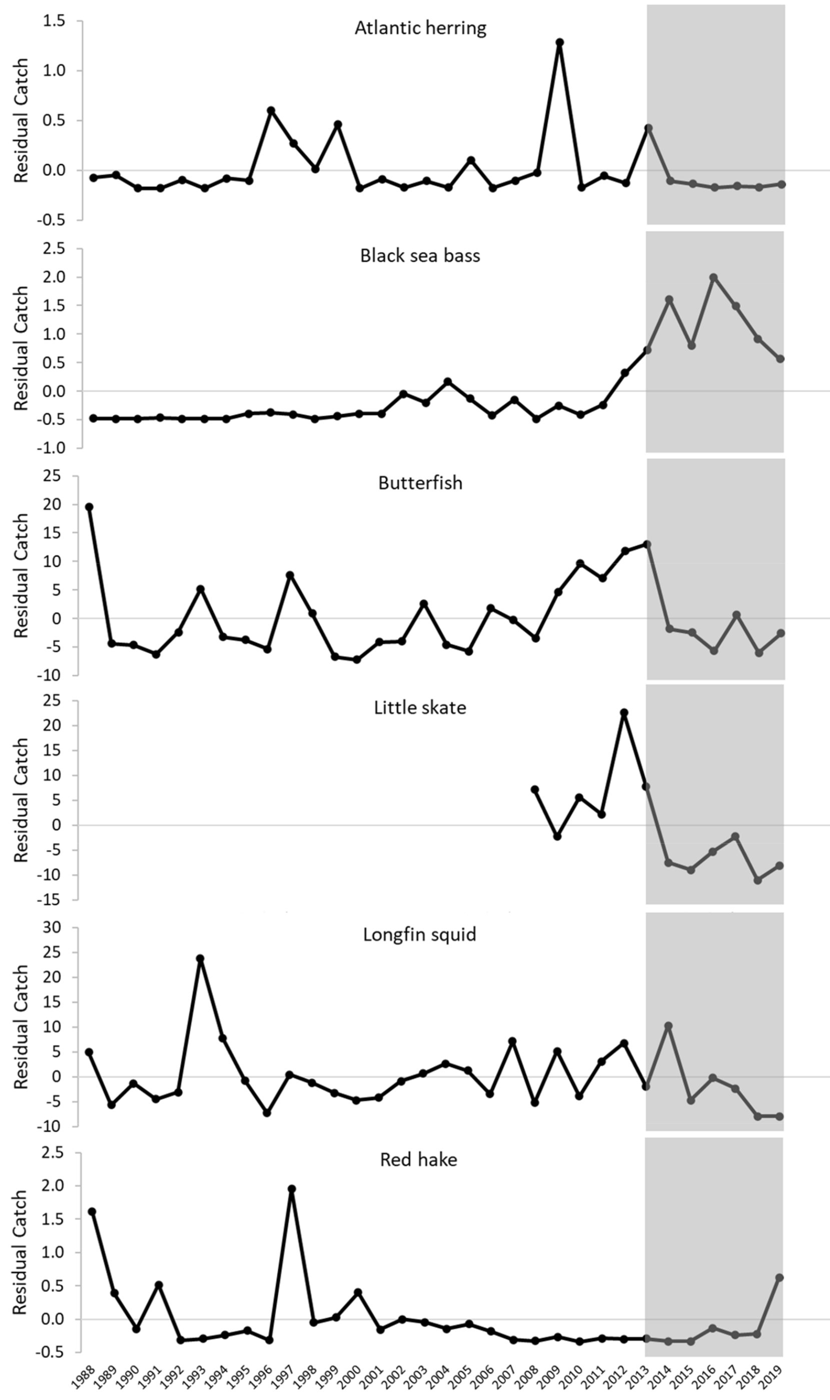

FIGURE 3. Interannual variation in the residual catches (deviation from the long-term mean) of 12 federally managed species collected in the Rhode Island Department of Environmental Management (RIDEM) survey is depicted, with the shaded rectangle (2013–2019) representing the time period when Block Island Wind Farm bottom trawl monitoring occurred. Little Skate and Winter Skate were identified to species in the RIDEM survey starting in 2008.

surveys and the availability of the resource. Therefore, rather large differences in catches near a wind farm may be required to be interpreted as an impact, given the caveats that explain background variation among multiple surveys that are intended to provide a regional context for monitoring results.

Providing context to OSW bottom trawl monitoring results with regional fishery-independent surveys has been

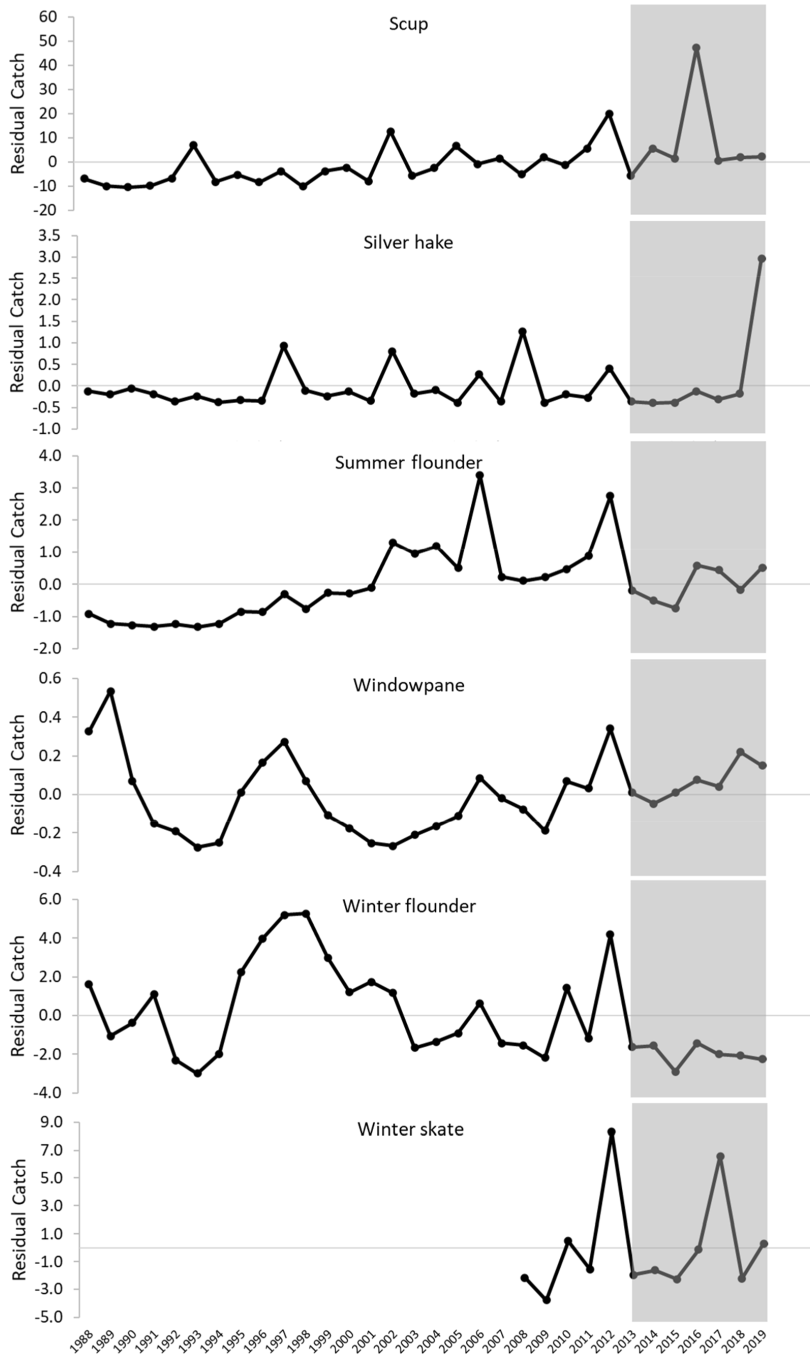

FIGURE 3. Continued.

requested because of the highly variable nature of bottom trawl survey data (Smith 1996; Frisk et al. 2011; Sagarese et al. 2016). Sampling with a trawl net has the potential for large catches because gear saturation rarely occurs, and the catch data can be highly skewed due to a few very large catches caused by patchy fish and invertebrate distributions. Bottom trawl monitoring can be costly, both economically and ecologically (McConnaughey et al. 2020); therefore, baseline and operation time periods are commonly limited to several years, and if either time period includes an anomalous year in terms of catch, the interpretation of possible effects from the wind farm may be improved by assessing multiple contemporaneous surveys.

Some species examined in this study shared a common combination of regional and temporal trends in residual catch rates. The similar long-term fluctuations of Windowpane and Winter Flounder in the RIDEM survey may reflect their connected associations through fishing and management practices. The Windowpane is a thin-bodied flatfish whose discard is required in southern New England (Anderson and Weissman 2021; Bell et al. 2021). Because the Windowpane is regulated as bycatch, landings in associated target fisheries, such as those for Winter Flounder, Black Sea Bass, Scup, and Summer Flounder, can be affected. Catches of Black Sea Bass, Scup, and Summer Flounder were synchronous among surveys, and RIDEM catches during the BIWF monitoring period were higher than the historical average. These three species share the characteristic of expanding their ranges poleward due to warming ocean temperatures (Perretti and Thorson 2019; Bell et al. 2020; McMahan et al. 2020). Red Hake and Silver Hake catches during the BIWF survey were lower than the historical RIDEM average, and an anomalous high-catch year (2019) was recorded in three of four surveys. Similar temporal trends for hake catches were not surprising given that they share similar niches, have the same fisheries management plan, and are frequently caught together (NEFSC 2017b). Little Skate and longfin inshore squid catches were lower than the historical average during the BIWF survey, and catches decreased within the BIWF survey period for most surveys. Interannual variation in Atlantic Herring and Butterfish catches was not synchronized among surveys, and catches during the BIWF survey period were lower than their respective historical averages. Catches of Atlantic Herring and Butterfish can be highly stochastic, and these species are not strictly demersal, which may contribute to the sporadic nature of their catches, resulting in asynchrony among demersal trawl surveys.

For some species (i.e., Scup and Winter Flounder), interannual variation in residual catches was relatively synchronous; however, only one correlation had a ρ value above 0.70, which indicates that the relative magnitude of synchronous fluctuations in catches resulted in different rankings among surveys. Spearman's rank correlations may be better suited to assessing the correspondence between relative catches in two surveys over a time period longer than 7 years, as residuals would reflect the trajectory of long-term trends rather than short-term interannual variation. Because OSW monitoring study durations in the United States are unlikely to exceed 7 years, it should be acknowledged that qualitative assessments may be the only means to view OSW monitoring results in the context of regional temporal trends that are apparent in other fishery-independent trawl survey data. These assessments, together with the statistical evaluation of OSW monitoring data (e.g., BACI contrasts of catch and community structure), can contribute to an understanding of OSW farm impacts.

A challenge for documenting potential effects of the developing OSW industry on northeastern U.S. fisheries is to partition these effects from those of underlying climate-related changes in fisheries distributions (Nye et al. 2009; Hare et al. 2016) and migration phenologies (Langan et al. 2021). For instance, the northern and eastern shifts in some species' distributions related to climate change suggest that the catches of fishery species near their northern range limit (e.g., Black Sea Bass, Summer Flounder, and Scup) will increase coincident with OSW expansion, whereas catches of fishery species at the southern or western extent of their ranges (e.g., American lobster *Homarus americanus*, Winter Flounder, and Atlantic Cod *Gadus morhua*) will decrease (Mann 2021). Monitoring by using bottom trawl surveys can provide valuable information on demersal fish and invertebrate communities near an OSW farm and, when coupled with regional surveys, regional shifts in distributions may become apparent. Limitations of trawling as a monitoring method, however, include low statistical power for some species' catch rates in BACI designs, catch mortality, and the environmental effects of bottom disturbance, including aqueous CO_2 emissions from increased carbon metabolism following sediment disturbance (Atwood et al. 2020; Sala et al. 2021).

At BIWF, assessment metrics other than catch rates included fish stomach content analysis, morphometric indices of condition, and stomach fullness for flounders and gadids (Wilber et al. 2022a). Other ways in which samples collected during bottom trawl surveys can be leveraged to examine mechanisms of impact or reduce ecological costs include coupling trawl surveys with environmental DNA sampling (Stoeckle et al. 2021; Rourke et al. 2022) to facilitate a change to less-extractive monitoring methods in the future. Additionally, biochemical assessments of fish lipid stores, protein content, or stable isotope analysis can provide real-time indicators of condition (Davidson and Marshall 2010; McPherson et al. 2011; Mavraki et al. 2020), and tagging studies using acoustic telemetry can provide information on fish presence, persistence, residency, and movements over extended time periods (Ingram et al. 2019; Zemeckis et al. 2019). Education and outreach efforts are needed to ensure that results generated by less-traditional monitoring methods are trusted and accepted by fisheries interest groups and resource managers.

Balancing the interests of science, commercial and recreational fishing industries, offshore renewable energy development, and other ocean users in the design and execution of fish and invertebrate surveys requires attention to regional and temporal context and the suitability of a sampling approach to address primary questions. Social and commercial interest in the abundances of fish and invertebrates in the vicinity of offshore infrastructure will continue throughout the life cycle of each project. This interest, combined with regulatory requirements, compliance monitoring agreements, and availability of stock assessment information, can drive the primary questions. These include concern over potential changes to fish/invertebrate community composition, migratory routes, trophic dynamics, and benthopelagic coupling. Use of commercial harvesting techniques, such as bottom trawls, can address a subset of these questions, but interpretations are limited based on the distribution trajectories of individual species that are related to climate change as well as biological factors, such as shifting predator–prey dynamics. Future monitoring may benefit from relying less on trawl surveys that typically collect highly variable catch rate data and instead examining potential modes of impact or using less-extractive methods, such as environmental DNA, acoustic telemetry, video sampling, and diver surveys.

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SUPPORTING INFORMATION

Additional supplemental material may be found online in the Supporting Information section at the end of the article.