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Abstract—Fish and macro-invertebrate assemblages were examined in the vicinity of 5 wind energy areas on the northeast U.S. continental shelf by using 2 sampling gears. Collections of fish and macro-invertebrates during the spring of 2014 with a 2-m beam trawl and a standard bottom trawl were compared. Correspondence analysis of proportions of taxa in the catch at sampling stations and estimated individual weights, averaged by taxon, were used to describe the composition of assemblages, and composition of the catch was compared between collections made with the 2 different gears and among different wind energy areas. These comparisons indicated that the 2 gears collected different fish and macro-invertebrate communities. Analysis of the collections by gear type indicated that assemblages varied across several spatial scales. Canonical correspondence analysis was used to examine the relationship between assemblages, sampling programs, and environmental variables to determine which variables and Correspondence analysis dimensions were aligned with stations and were related to the assemblages. Environmental variables explained 20.5% of the variation for the beam trawl stations and assemblages and 28.8% of variation for the bottom trawl stations and assemblages. Our results indicate that assessments of wind energy areas on the northeast U.S. shelf should be conducted by using multiple gear types across multiple spatial and temporal scales.

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Spring occurrence of fish and macro-invertebrate assemblages near designated wind energy areas on the northeast U.S. continental shelf

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Offshore wind farms have been gaining increased interest as a potential source of renewable energy (Wilson et al., 2010; Tabassum-Abbasi et al., 2014). The Bureau of Ocean Energy Management (BOEM) has designated 8 wind energy areas (WEAs) on the northeast U.S. continental shelf between North Carolina and Massachusetts (Bailey et al., 2014). These wind energy areas comprise lease blocks that will be made available for commercial leases and limited research leases (BOEM[1]). Commercial leases allow the leaseholder to ask BOEM for the right to develop wind energy production facilities on the leasehold and undertake a 4-step process of planning and analysis, lease issuance, site assessment, and construction and operations. Limited research leases allow the leaseholder to conduct technological testing and gather data for 5 years. Assessing the environmental impact of offshore wind production is part of the permitting process and is led by BOEM (Federal Register, 2014).

Assessment of the impacts of the location, construction, and energy production of offshore wind farms on fish and macro-invertebrates on the northeast U.S. shelf is in the early stages. However, European countries have been conducting environmental assessments since the early 1990s that have resulted in review articles on the general impacts of, and long-term research needs for, offshore wind farms (Wilson et al., 2010; Lindeboom et al., 2011; Bailey et al., 2014; Bergstrom et al., 2014; Dai et al., 2015; Lindeboom et al., 2015). The reviews have generally concluded there are potentially minor to moderate effects on fish and macro-invertebrate communities. These effects may result from increased anthropogenic noise and electromagnetic fields, increased turbidity, loss or degradation of existing bottom habitats, gains in hard bottom and structural habitats, and the limitation or exclusion of fisheries (Wilson et al., 2010; Bergstrom et al., 2014; Dai et al., 2015;

[1] BOEM (Bureau of Ocean Energy Management). 2017. Renewable energy on the Outer Continental Shelf, 1 p. [Fact sheet; available from website.]

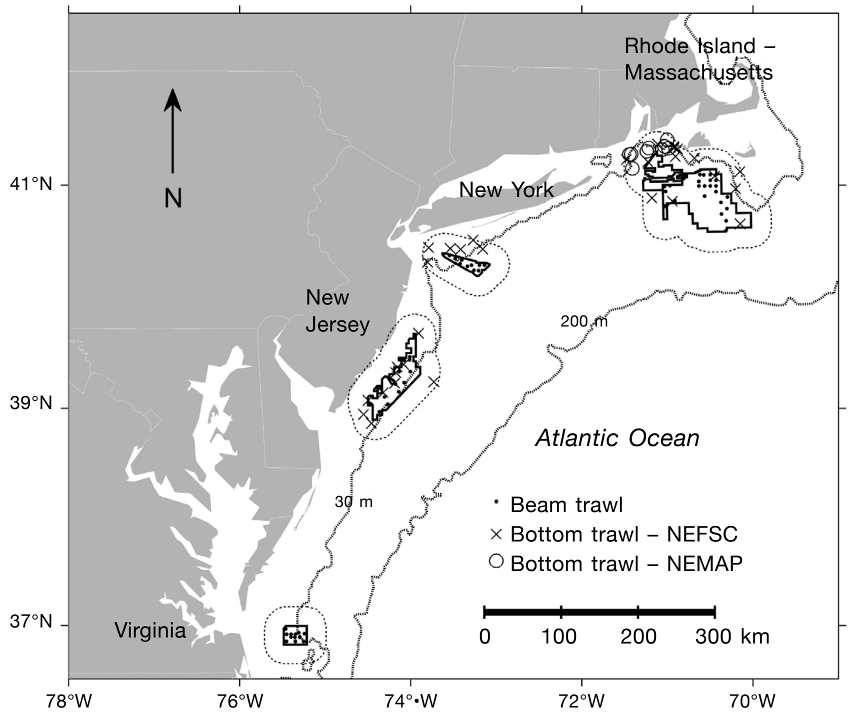

Figure 1

Map of the northeast U.S. continental shelf showing 5 wind energy areas (WEAs) off Virginia, New Jersey, New York, Rhode Island, and Massachusetts where sampling of fish and macro-invertebrates was conducted in the spring of 2014. The Rhode Island–Massachusetts and Massachusetts WEAs were combined because of their close proximity to one another. Collections were made with a beam trawl within lease blocks of each WEA (solid black lines), and collections made with a bottom trawl were selected from inside a 20-km buffer around each WEA (dashed black lines) on the basis of data from surveys conducted by the Northeast Fisheries Science Center (NEFSC) and Northeast Monitoring and Assessment Program (NEAMAP). The 30-m and 200-m isobaths also are shown (dotted black lines).

Lindeboom et al., 2015). These effects all have the potential to modify community structure, including changes in species composition, diversity, and productivity (Bergstrom et al., 2014; Lindeboom et al., 2015).

The reviews highlight the need for before, during, and after construction monitoring to examine ecosystem level effects and the need to continue to track effects over the long term (Lindeboom et al., 2011; Lindenboom et al., 2015). Recommendations also include the use of multiple gear types to examine the entire ecosystem (Wilson et al., 2010), the examination of population-level effects (Bergstrom et al., 2014; Lindeboom et al., 2015), and the implementation of sampling across large spatial scales (Dai et al., 2015; Lindeboom et al., 2015).

Annual trawl surveys of the northeast U.S. shelf by the Northeast Fisheries Science Center (NEFSC), with the use of standardized bottom trawl gear (ICES[2]; Politis et al.[3]) designed to catch juvenile and adult demersal and semi-pelagic species, provide broad-scale and long-term distribution and abundance patterns of numerous fish and macro-invertebrates (Gabriel, 1992; Lucey and Nye, 2010). However, assessments of smaller noncommercial organisms and prerecruitment stages of fish and macro-invertebrates with the use of smaller research gear, which have smaller mesh sizes for retaining smaller (younger) juveniles, have been conducted only on limited spatial and temporal scales (Steves et al., 1999; Steves and Cowen, 2000; Sullivan et al., 2000; Diaz et al., 2003). The objective for our study was to examine the fish and macro-invertebrate assemblages in the vicinity of BOEM WEAs on the northeast U.S. shelf by comparing the composition of collections made with small-mesh gear and the standardized bottom trawl gear that are routinely used in the 2 long-term annual fish and macro-invertebrate bottom trawl surveys conducted under the NEFSC (Azarovitz, 1981) and Northeast Area Monitoring and Assessment Program (NEAMAP) (Bonzek et al.[4]). Specifically, we examined the proportion of a taxon in catch per station and average weight of individuals collected with 2 types of trawl gear: a 2-m beam trawl and a 4-seam, 3-bridle survey trawl (Bonzek et al.[4]; Politis et al.[3]). We also describe the relationships between the fish and macro-invertebrate assemblages and the explanatory environmental variables.

Materials and methods

Collection of data

Sampling was conducted in the vicinity of 5 WEAs on the northeast U.S. shelf during the spring of 2014 (Fig. 1). Collections were made at night with a 2-m beam

[2] ICES (International Council for the Exploration of the Sea). 2005. Report of the study group on survey trawl standardisation (SGSTS), 16–18 April 2005, Rome, Italy. ICES CM 2005/B:02, 67 p, [Available from website.]

[3] Politis, P. J., J. K. Galbraith, P. Kostovick, and R. W. Brown. 2014. Northeast Fisheries Science Center bottom trawl survey protocols for the NOAA Ship *Henry B. Bigelow*. Northeast Fish. Sci. Cent. Ref. Doc, 14-06, 138 p. [Available from website.]

[4] Bonzek, C. F., J. Gartland, D. J. Gauthier, and R. J. Latour. 2012. Data collection and analysis in support of single and multispecies stock assessments in the Mid-Atlantic: Northeast Area Monitoring and Assessment Program Near Shore Trawl Survey (NEAMAP), 280 p. [Avaliable from website.]

trawl (Kuipers, 1975) with a 0.63-cm-mesh net from 11 March to 12 April 2014. This sampling was restricted to the time of night because the research vessel was used to conduct visual transect surveys of marine mammals and precluded any fishing during daylight hours. Bottom trawl collections were made with a 4-seam, 3-bridle otter trawl net with a dimension of 400×12 cm and with a 2.5-cm-mesh liner (Bonzek et al.[4]; Politis et al.[3]). The nets used by NEFSC and NEAMAP for bottom trawl surveys are not identical, and differences include the sweeps, headline floats, number of both top and belly panels, and the mesh size of some panels (Bonzek et al.[4]; Politis et al.[3]). Samples were collected both day and night from 2 to 20 April 2014 during the NEFSC survey and during the day from 7 to 20 May 2014 during the NEAMAP survey.

Samples were collected with the beam trawl within the BOEM-designated lease blocks of 5 WEAs: Virginia (VA, n=12); New Jersey (NJ, n=13); New York (NY, n=10); Rhode Island–Massachusetts (RIMA); and Massachusetts (MA). Data from 2 BOEM WEAs, RIMA and MA, were combined into a single WEA (RIMA–MA, n=23) because of their close proximity to one another (Fig. 1). Lease blocks were chosen haphazardly to best coincide with visual transect surveys of marine mammals that occurred during daylight hours, and preference was given to those lease blocks that had been sampled during previous surveys with various gears. Both the NEFSC and NEAMAP surveys use a stratified random sampling design. Therefore, samples from within a 20-km buffer around each WEA with the same depth range as that of beam trawl stations (20–60 m) were used for comparison with beam trawl collections. This procedure resulted in bottom trawl samples being available for 3 WEAs: NJ (n=10); NY (n=6); and RIMA–MA (n=23). Unfortunately, no bottom trawl samples were available for comparison with the VA WEA because of a lack of sampling during the NEFSC survey and because the WEA was deeper than the NEAMAP survey area.

Trawl samples were processed on board, and processing was similar for the surveys at the NJ, NY, and RIMA–MA WEAs. Samples were sorted to the lowest practicable taxon, which varied by survey (Suppl. Table). We compared taxa sampled with the beam trawl with taxa sampled with the bottom trawl (Table 1) and found that shrimp were identified to lower taxonomic levels in the beam trawl collections (e.g., caridean shrimp and the white shrimp, *Penaeus setiferus*; Suppl. Table) than in NEFSC bottom trawl collections (e.g., unclassified shrimp; Suppl. Table). These finer taxonomic levels combined for the comparisons by gear type, and those comparisons were made at the highest level of identification (e.g., unclassified shrimp). The total numbers and aggregate weights (measured in kilograms) were available for each taxon and each station. Percent frequency of occurrence was calculated for each taxon, by gear type. The proportion of a taxon in the catch at a sampling station was calculated by dividing the aggregate weight of a taxon by the total weight of all taxa captured at a station. The estimated average individual weight for each taxon (measured in grams) was calculated by dividing the total weight (measured in grams) by the total count for each taxon.

Environmental and habitat sampling was conducted concurrently with trawl sampling. Water temperature and salinity were measured at each trawl station by using either a Sea-Bird Scientific[5] SBE 19 SeaCAT conductivity, temperature, and depth profiler (Sea-Bird Scientific, Bellevue, WA) or Hydrolab MS5 sonde (OTT Hydromet, Kempten, Germany). Bottom water temperature (measured in degrees Celsius) and salinity measurements were taken within 5 m of the bottom. Sediment samples were collected at beam trawl stations by using a 0.04-m^2 or 0.10-m^2 Young-modified Van Veen grab sampler. The Folk (1954) sediment classification system was used to classify beam trawl station sediments into the following categories: 1=muddy sand; 2=sand; 3=sand–slightly gravelly sand; 4=slightly gravelly sand; 5=slightly gravelly sand–gravelly sand; 6=gravelly sand; 7=gravelly sand–sandy gravel.

Statistical analyses

Several statistical analyses were undertaken in order to compare catches across gear types and across WEAs. Correspondence analysis (CA) was used to compare the fish and macro-invertebrate assemblages in relation to gear type and WEA and canonical correspondence analysis (CCA) was used to examine the relationship between assemblages and sampling program and environmental variables. A Student's t-test was used to examine whether the beam and bottom trawls collected individuals of significantly different sizes.

The software package "FactoMineR" (Le et al., 2008) in R, vers. 3.2.2 (R Core Team, 2015) was used to perform CA on average proportions and individual weights by a taxon per station to describe proportion of fish and macro-invertebrates and individual size, by station. We conducted 3 analyses: beam and bottom trawl collections combined; beam trawl only collections; and bottom trawl only collections. Beam and bottom trawl stations were analyzed together to examine differences among the collections, by gear type. Assemblage composition in relation to WEA was examined by analyzing beam trawl and bottom trawl samples separately. The inclusion of rare taxa in CA and CCA often leads to assemblage patterns similar to those in data where rare taxa have been removed (Marancik et al., 2005; Walsh et al. 2006) and rare taxa often increase species richness of some assemblages (Marancik et al., 2005) or appear as outliers separate from larger assemblages (Walsh et al., 2006). To simplify our analyses, however, only taxa that had at least a 10% frequency of occurrence were used in the analyses. Percent frequency of occurrence was based on all stations sampled for the

[5] Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1

Percent frequency of occurrence (PFO) and percent contribution of average proportions and average individual weights per station to the first 2 dimensions of correspondence analysis (CA1 and CA2) for fish and macroinvertebrate taxa that had at least a 10% frequency of occurrence in beam trawl and bottom trawl samples collected in the vicinity of wind energy areas on the northeast U.S. continental shelf in the spring of 2014. The *t*-statistics, *P*-values, and degrees of freedom (df) are reported for Student's *t*-tests conducted for 11 taxa that had at least 5% frequency of occurrence in collections made with both gear types. Sizes of individuals sampled were significantly different for the collections made with the 2 gear types (P-values≤0.0045). For the ordination plot of the analysis, see Figure 3.

			Percent contribution of CA1 and CA2		Student's *t*-test		
Classification	Taxon	PFO	Average proportion of taxon per station	Average individual weight per station	*P*-value	*t*-statistic	df
Mollusca	*Placopecten magellanicus*	23.5	1.2	0.3	0.2025	−1.28	83
	Decapodiformes	27.1	0.1	0.1			
Crustacea	Unclassified shrimp	20.0	83.4	0.0	0.1502	−1.45	83
	Homarus americanus	15.3	0.7	0.4			
	Brachyura	47.1	1.1	4.2	0.0404	−2.08	83
Pelagic fish	*Alosa* spp.	30.6	1.1	0.6			
	Clupea harengus	43.5	0.5	0.3			
	Merluccius bilinearis	56.5	1.7	0.2	0.0003	−3.74	83
Demersal fish	*Squalus acanthias*	61.2	9.1	56.8			
	Leucoraja spp.	70.6	6.2	2.1	<0.0001	−6.74	83
	Melanogrammus aeglefinus	14.1	0.7	0.5			
	Urophycis chuss	47.1	2.2	1.2	0.0001	−4.02	83
	Urophycis regia	23.5	0.5	0.8	0.0468	−2.02	83
	Prionotus spp.	27.1	0.0	1.6			
	Myoxocephalus octodecemspinosus	25.9	0.7	3.7	<0.0001	−5.79	83
	Centropristis striata	14.1	0.6	2.0			
	Zoarces americanus	21.2	0.5	4.8	0.0001	−4.14	83
	Ammodytes spp.	10.6	0.6	0.2			
	Scophthalmus aquosus	45.9	0.4	0.6	<0.0001	−7.46	83
	Etropus spp.	38.8	2.2	0.0	0.2847	−1.08	83
	Paralichthys oblongus	11.8	0.1	0.5			
	Paralichthys dentatus	24.7	0.1	1.3			
	Limanda ferruginea	12.9	0.2	1.7			
	Pseudopleuronectes americanus	34.1	0.5	1.9			

combined beam and bottom trawl analyses (Table 1). When the collections made with each gear type were analyzed separately, the percent frequency of occurrence was calculated on the basis of stations sampled with an individual gear (Tables 2 and 3). Therefore, the total number and composition of the taxa used differed in the 3 analyses: comparison by gear type (n=24; Table 1); comparison by WEA of collections made with the beam trawl (n=28; Table 2); and comparison by WEA of collections made with a bottom trawl (n=28; Table 3). Taxa that contributed significantly to the beam trawl (>1%) and bottom trawl (>3%) ordinations were used to describe the different communities that were collected, and the percentage contribution of these taxa to the ordination, which varied by analysis, allowed a clear graphic representation of their relationships.

The R package "vegan" (Oksanen et al., 2015) was used to perform CCA on average proportion of taxa per station, estimated average individual weights for each taxon per station, and 6 explanatory variables for the 2 types of WEA sampling: beam trawl only and bottom trawl only. Both categorical variables (sediment [1 to 7], light [day or night]), and continuous (latitude, longitude, depth, bottom water temperature and salinity) explanatory variables were used, and they differed for each analysis. Continuous variables were standardized to a mean of zero and a standard deviation of one. For the beam trawl analysis, latitude, longitude, depth, sediment, bottom water temperature, and salinity were the categorical variables used. Light was not examined for beam trawl catches because all sampling was done during hours of darkness. For the bottom trawl analysis, latitude, longitude, depth, light, bottom water temperature, and salinity were used. Day-of-year was used in both analyses as a covariable to compensate for seasonality in sample collections. Program (NEFSC

Table 2

Percent frequency of occurrence (PFO) and percent contribution of average proportions and average individual weights per station to the first 2 dimensions of correspondence analysis (CA1 and CA2) for fish and macroinvertebrate taxa that had at least a 10% frequency of occurrence in beam trawl samples collected in the vicinity of wind energy areas on the northeast U.S. continental shelf in the spring of 2014. For the ordination plot of the analysis, see Figure 4.

			Percent contribution of CA1 and CA2	
Classification	Taxon	PFO	Average proportion of taxon per station	Average individual weight per station
Porifera	Porifera	19.0	52.1926	
Ctenophora	Ctenophora	19.0	0.2471	
Polychaeta	Polychaeta	13.8	0.1387	0.0804
Mollusca	Gastropoda	55.2	2.4551	0.0425
	Pleurobranchomorpha	70.7	2.2524	0.0036
	Bivalvia	39.7	6.5778	0.0838
	Placopecten magellanicus	17.2	0.3847	0.1179
Crustacea	Peracarida	29.3	0.4728	0.0140
	Caridea	100.0	11.1031	0.0049
	Penaeus setiferus	10.3	0.5125	0.0332
	Pagurus spp.	46.6	2.1334	0.0332
	Brachyura	37.9	1.3297	11.8286
Echinodermata	*Echinarachnius parma*	58.6	5.7585	0.0084
	Asteriidae	10.3	0.0967	0.0987
Pelagic fish	*Merluccius bilinearis*	24.1	0.3033	0.0032
Demersal fish	*Leucoraja* spp.	41.4	27.4802	37.5870
	Urophycis chuss	25.9	0.4356	0.0004
	Urophycis regia	32.8	25.7295	0.1852
	Prionotus spp.	24.1	4.6438	0.0342
	Centropristis striata	15.5	0.8081	0.1016
	Ammodytes spp.	25.9	0.0737	0.0147
	Gobiidae	20.7	0.1470	0.0194
	Scophthalmus aquosus	17.2	0.2820	0.6746
	Etropus spp.	60.3	3.4550	0.0174

or NEAMAP), coded as a categorical variable, was also used as a covariable to compensate for the difference among trawl nets used for the bottom trawl collections. For each analysis, forward selection of the explanatory variables and analysis of variance (R Core Team, 2015) were used to determine which explanatory variables and dimensions were aligned with groups of stations and were related to the fish and macro-invertebrate assemblages.

Eleven taxa had at least a 5% frequency of occurrence in collections made with the 2 types of gears and the average individual weight per station was analyzed with R (R Core Team, 2015) to determine whether the gears caught significantly different sizes for individual weight. A difference in individual weight among collections, by gear type, was considered significant at Bonferroni corrected *P*-values of ≤0.0045.

Results

Beam trawl samples were dominated by a variety of benthic organisms; the top 5 taxa determined on the basis of their average proportion per station were caridean shrimp, common sand dollar (*Echinarachnius parma*), *Leucoraja* spp., poriferan sponges, and bivalves (Suppl. Table). Demersal and pelagic fish dominated bottom trawl samples; the top 5 were *Leucoraja* spp., spiny dogfish (*Squalus acanthias*), Atlantic herring (*Clupea harengus*), haddock (*Melanogrammus aeglefinus*), and *Peprilus* spp. (Suppl. Table).

Comparison of assemblages by gear type

The analyses for comparison by gear type indicated that the beam and bottom trawl sampled different fish and macro-invertebrate communities. The beam trawl caught significantly smaller individuals, by weight, than the bottom trawl for 6 of the 11 taxa that were tested (Table 1; Fig. 2). The collection of significantly smaller individuals of 6 fish species, *Leucoraja* spp., silver hake (*Merluccius bilinearis*), longhorn sculpin (*Myoxocephalus octodecemspinosus*), windowpane (*Scophthalmus aquosus*), red hake (*Urophycis chuss*), and ocean pout (*Zoarces americanus*), indicated that the beam trawl was more efficient than the bottom

Table 3

Percent frequency of occurrence (PFO) and percent contribution of average proportions and average individual weights per station to the first 2 dimensions of correspondence analysis (CA1 and CA2) for fish and macroinvertebrate taxa that had at least a 10% frequency of occurrence in bottom trawl samples collected in the vicinity of wind energy areas on the northeast U.S. continental shelf during the spring of 2014. For the ordination plot of the analysis, see Figure 5.

			Percent contribution of CA1 and CA2	
Classification	Taxon	PFO	Average proportion of taxon per station	Average individual weight per station
Mollusca	*Placopecten magellanicus*	28.2	0.0011	0.2433
	Decapodiformes	53.8	0.2941	1.0434
Merostomata	*Limulus polyphemus*	12.8	1.5450	22.7470
Crustacea	Unclassified shrimp	15.4	0.0004	0.0554
	Homarus americanus	33.3	1.6580	0.9347
	Brachyura	74.4	0.6235	1.4495
Pelagic fish	*Alosa* spp.	66.7	3.0492	1.3781
	Clupea harengus	94.9	11.7095	0.6319
	Merluccius bilinearis	89.7	0.5675	0.1974
	Stenotomus chrysops	20.5	3.9466	7.2997
	Scomber scombrus	17.9	0.0001	0.0162
	Peprilus spp.	20.5	2.2370	1.0757
Demersal fish	*Squalus acanthias*	43.6	5.2427	33.3815
	Leucoraja spp.	100.0	19.1962	3.1704
	Melanogrammus aeglefinus	28.2	3.1472	1.5533
	Urophycis chuss	64.1	0.2408	2.9577
	Urophycis regia	33.3	0.2033	3.1282
	Prionotus spp.	53.8	0.0293	2.7215
	Myoxocephalus octodecemspinosus	48.7	1.6763	3.9863
	Hemitripterus americanus	15.4	0.0857	14.4757
	Centropristis striata	30.8	2.1206	9.3053
	Zoarces americanus	33.3	1.3455	5.5046
	Scophthalmus aquosus	74.4	0.7544	1.8307
	Etropus spp.	25.6	0.0028	0.0687
	Paralichthys oblongus	25.6	0.4396	3.5277
	Paralichthys dentatus	53.8	0.3313	8.4038
	Limanda ferruginea	28.2	0.3330	3.0043
	Pseudopleuronectes americanus	74.4	0.9314	4.1960

trawl at collecting juveniles (or younger age classes, <2 years old) for some taxa. Conversely, the lack of collections of other abundant demersal fish (e.g., spiny dogfish; haddock; yellowtail flounder (*Limanda ferruginea*); winter flounder (*Pseudopleuronectes americanus*); and summer flounder (*Paralichthys dentatus*)) and a lack of pelagic fish (e.g., *Alosa* spp.; Atlantic herring; Atlantic mackerel (*Scomber scombrus*); and *Peprilus* spp.), regardless of size, indicate that the bottom trawl was more efficient in collecting a number of fish taxa (Suppl. Table).

The variation in catch composition by gear type indicated that CA assemblage structures separated by gear type. Visualization of the first 2 dimensions of the CA ordination described the overall pattern of assemblages associated with each gear type (Fig. 3). The first 2 dimensions explained 30.8% of the variance in assemblages, with eigenvalues of 0.81 and 0.41 respectively. Taxa that contributed significantly (>1%; Table 1) to the ordination highlight the different communities collected by each gear (Fig. 3). The collections made with the 2 gear types separated from each other along the first dimension (Fig. 3A) and average proportion of taxa per station (90.7%) contributed most to the separation of assemblages (Fig. 3B). The beam trawl was stretched along the first dimension and had higher station proportions of unclassified shrimp, brachyuran crabs, sea scallop (*Placopecten magellanicus*), *Etropus* spp., and red hake. The close association of sea scallop and red hake in ordination space may be related to their inquiline relationship, where benthic juvenile red hake live in the mantle of live sea scallop (Able and Fahay, 1998). The collections made with the bottom trawl appear to the left of the origin and had a higher proportion of *Leucoraja* spp., and the bottom trawl was the only gear to sample *Alosa* spp. and spiny dogfish (Fig. 3B). The second dimension aligned with the WEA location, particularly for the collections made with the

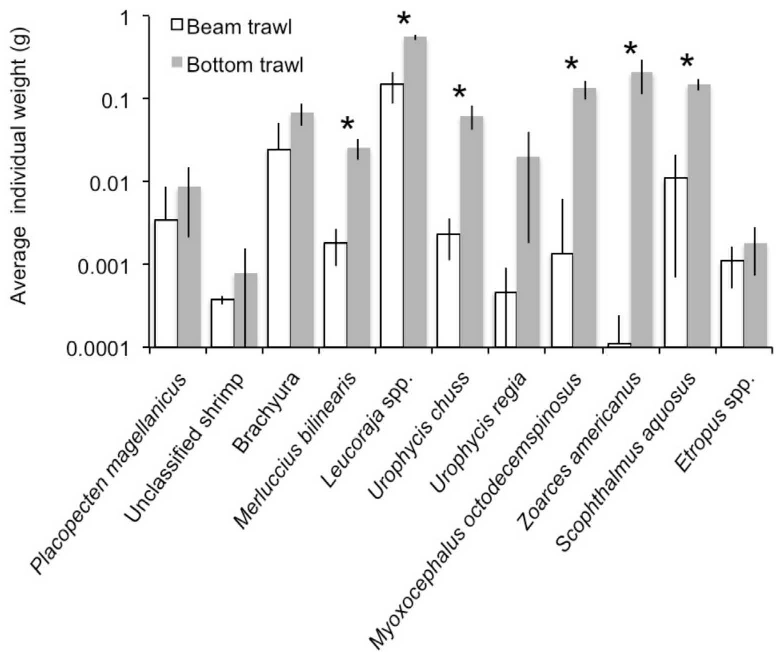

Figure 2

Average individual weight (g) of taxa that had at least a 5% frequency of occurrence in collections made with the beam and bottom trawls on the northeast U.S. continental shelf in 2014. A Student's t-test was used to examine whether the sizes of individuals were significantly different between the collections made with the 2 gear types. An asterisk (*) indicates a taxa for which a difference in individual size between collections by gear type was considered significant (Bonferroni corrected P-value: $\leq$0.0045). Error bars indicate standard errors of the means.

bottom trawl (Fig. 3A). Both average proportion of taxa per station (76.6%) and average individual weights by taxon (23.4%) contributed to assemblage variation (Fig. 3, B and C). The beam trawl collected significantly smaller individuals of most taxa, and the bottom trawl stations in the NJ WEA had spiny dogfish with larger average individual weights (Fig. 3C).

Comparison of assemblages by wind energy area

The separate analyses of collections made with each gear type indicated that the fish and macro-invertebrate communities varied across several spatial scales and that assemblage varied among and within WEAs. Four CA dimensions explained at least 50% of the variation in average proportion of a taxon per station and estimated average individual weight of a taxon per station for analyses of both the beam and bottom trawl collections. Again, the first 2 dimensions described the overall pattern of assemblages associated with each gear type (Figs. 4 and 5).

The first 2 dimensions of the CA for the beam trawl described 30.2% of the variance in assemblages with eigenvalues of 0.72 and 0.64 respectively. Taxa that contributed significantly (>1%; Table 2) to the ordination highlight the different communities across the large spatial scale (north to south) and within WEAs (Fig. 4). The 3 northern WEAs (RIMA–MA, NY, NJ) were distinct from the VA WEA, and separated along the second dimension (Fig. 4A), and average proportion of taxa per station (85.3%) contributed most to the separation in assemblage structure (Fig. 4B). The VA WEA had higher proportions of spotted hake (*Urophycis regia*), *Prionotus* spp., *Etropus* spp., *Pagrus* spp., gastropods, bivalves, and brachyuran crabs (Fig. 4B). The northern WEAs overlapped each other, but did show some separation along both dimensions, particularly for the RIMA–MA WEA (Fig. 4A), indicating variation of communities at smaller spatial scales (e.g., within WEAs). Both average proportion of taxa per station (63.7%) and average individual weights of taxa per station (36.3%) contributed to the variation (Fig. 4, B and C). Stations in the lower left quadrant (Fig. 4A) had higher proportions and larger average individual weight of *Leucoraja* spp. (Fig. 4, B and C). The stations on the lower right quadrant of the ordination, located mostly in the RIMA–MA WEA (Fig. 4A), had higher proportions of poriferan sponges and larger average individual weight of brachyuran crabs (Fig. 4, B and C). Stations near the origin (Fig. 4A) had higher proportions of caridean shrimp, common sand dollar, and species of the order Pleurobranchomorpha (Fig. 4B). Both the sea scallop and the red hake are close in ordination space near the origin, but are not labeled.

The first 2 dimensions of the CA for the bottom trawl explained 32.5% of the variance in assemblages, with eigenvalues of 0.47 and 0.27, respectively. Taxa that contributed significantly (>3%; Table 3) to the ordination highlight the differences among the assemblages (Fig. 5). The NY and NJ WEAs were distinct from the RIMA–MA WEA, and separated along the first dimension (Fig. 5A). Average individual weight of a taxon per station (85.8%) contributed most to the separation in assemblage structure along the first dimension (Fig. 5C). Larger individuals of horseshoe crab (*Limulus Polyphemus*), and spiny dogfish were caught in the NY and NJ WEAs, and larger individuals of longhorn sculpin, ocean pout, sea raven (*Hemitripterus americanus*), and yellowtail flounder were caught in the RIMA–MA WEA (Fig. 5C). Additionally, the RIMA–MA WEA had higher station proportions of scup (*Stenotomus chrysops*) and haddock than the NY and NJ WEAs (Fig. 5B). Variability in assemblage structure also occurred

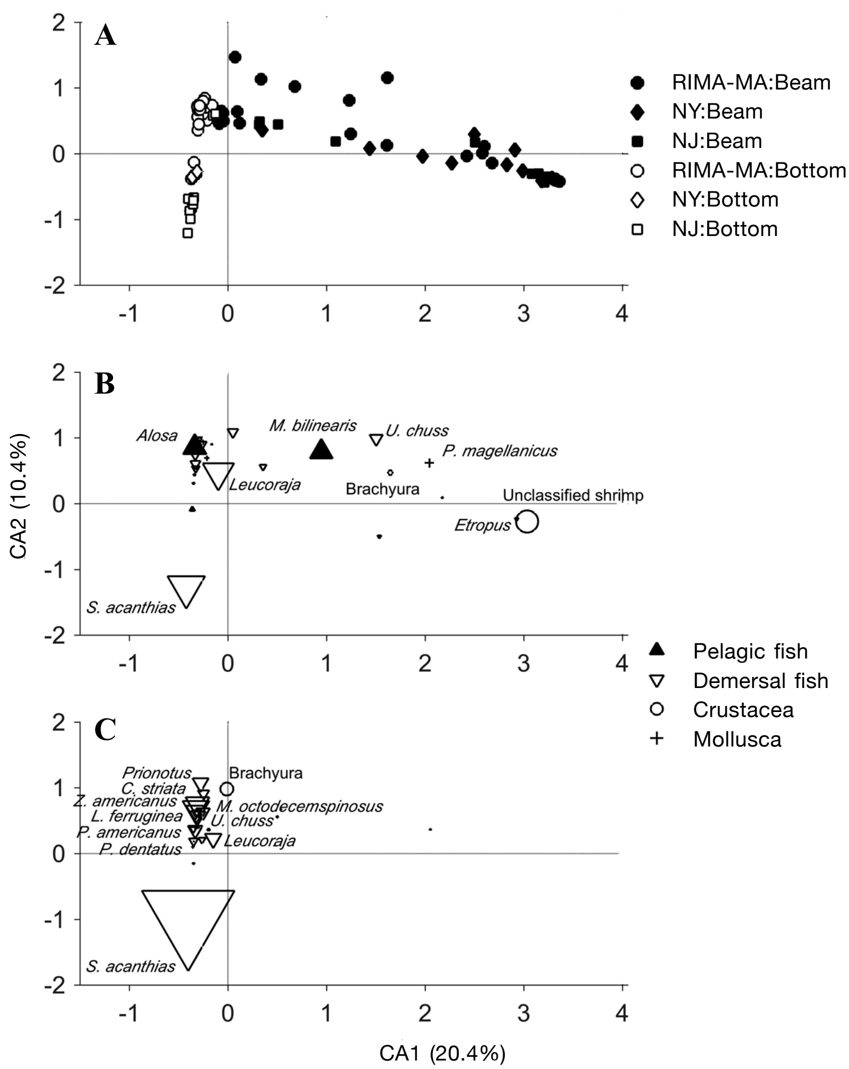

Figure 3

(**A**) Correspondence analysis ordination plots, showing the scores and variance explained for the first and second dimensions (CA1 and CA2), of the sampling stations at 3 wind energy areas, Rhode Island–Massachusetts and Massachusetts (RIMA-MA), New York (NY), and New Jersey (NJ), by using fish and macroinvertebrate taxa that occurred in at least 10% of the collections made in 2014. Beam trawl is represented by a solid symbol and bottom trawl by an open symbol. The size of the symbols are scaled to the contribution of each taxon to the ordination and are shown by taxon classification for (**B**) average proportion of a taxon per station and (**C**) average individual weight of a taxon per station. Taxa that contributed more than 1% to the ordination are labeled (For names of taxa, see Table 1).

within the RIMA–MA WEA (Fig. 5A). The stations of the RIMA–MA WEA separated along the second dimension (Fig. 5A), and both the average proportion of taxa per station (47.5%) and average individual weights of taxa per station (52.5%) contributed to the variation in assemblage structure (Fig. 5, B and C). Stations in the upper right quadrant (Fig. 5A) had higher proportions of scup and haddock (Fig. 5B), and larger individuals of numerous taxa, such as scup, sea raven, spotted hake, fourspot flounder (*Paralichthys oblongus*), black sea bass (*Centropristis striata*), and summer flounder (Fig. 5C). The other assemblage (in the lower right quadrant) had higher proportions of *Leucoraja* spp., Atlantic herring, and *Alosa* spp. (Fig. 5B), and larger individuals of longhorn sculpin, ocean pout, yellowtail flounder, winter flounder, and *Leucoraja* spp. (Fig. 5C).

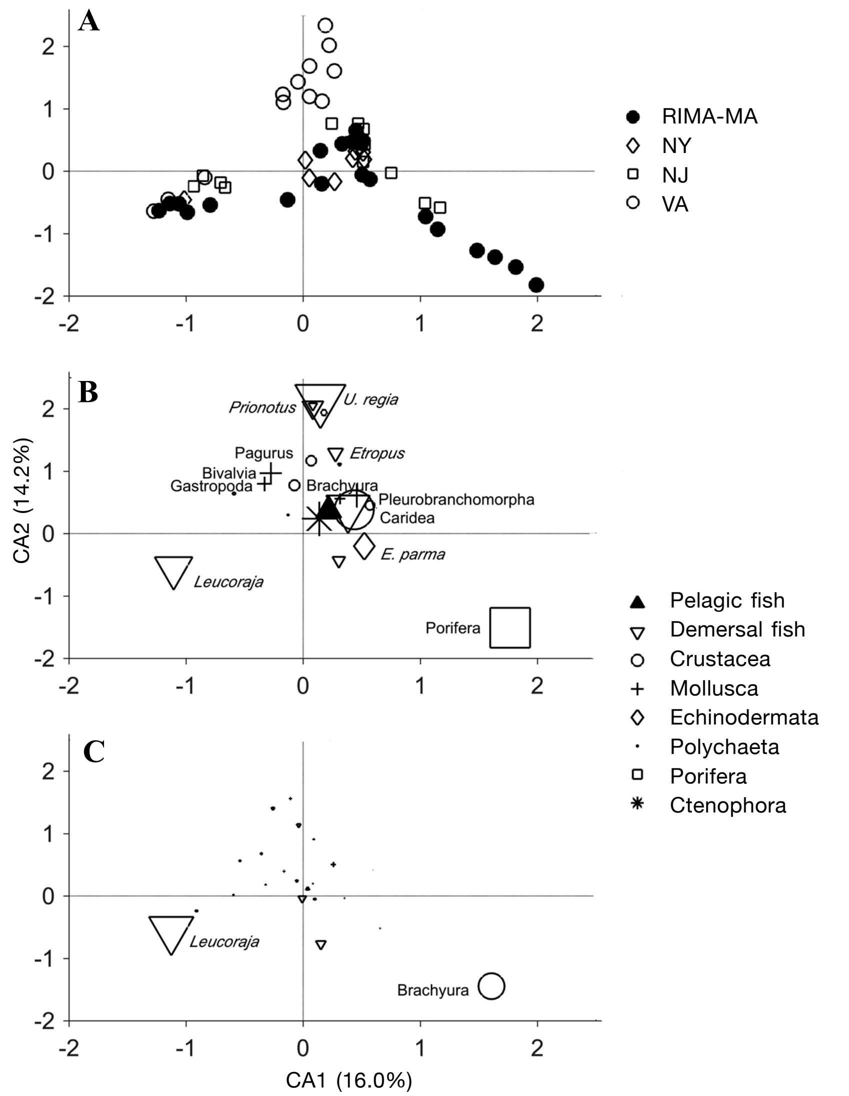

Figure 4

(**A**) Correspondence analysis ordination plots, showing the scores and variance explained for the first and second dimensions (CA1 and CA2), of the sampling stations at 4 wind energy areas, Rhode Island-Massachusetts and Massachusetts (RIMA–MA), New York (NY), New Jersey (NJ), and Virginia (VA) by using fish and macro-invertebrate taxa that occurred in at least 10% of the collections made by beam trawl in 2014. The size of the symbols are scaled to the contribution of each taxon to the ordination and are shown by taxon classification for (**B**) average proportion of a taxon per station and (**C**) average individual weight of a taxon per station. Taxa that contributed more than 1% to the ordination are labeled (For names of taxa, see Table 2).

Environmental relationships

Environmental variables were related to the station groups and associated fish and macro-invertebrate assemblages for both beam and bottom trawls. Forward selection of the explanatory environmental variables indicated bottom salinity was not significantly related to the assemblages sampled by either gear and was removed from the analyses. The 5 remaining environmental variables, which differed among gears used for sampling, resulted in the first 2 CCA dimensions significantly aligning with the station groups (Fig. 6). The unconstrained variance explained the most variability of each ordination, 75.8% and 56.0% for the beam and bottom trawls, respectively. The environmental variables explained 20.5% of the variation for the beam

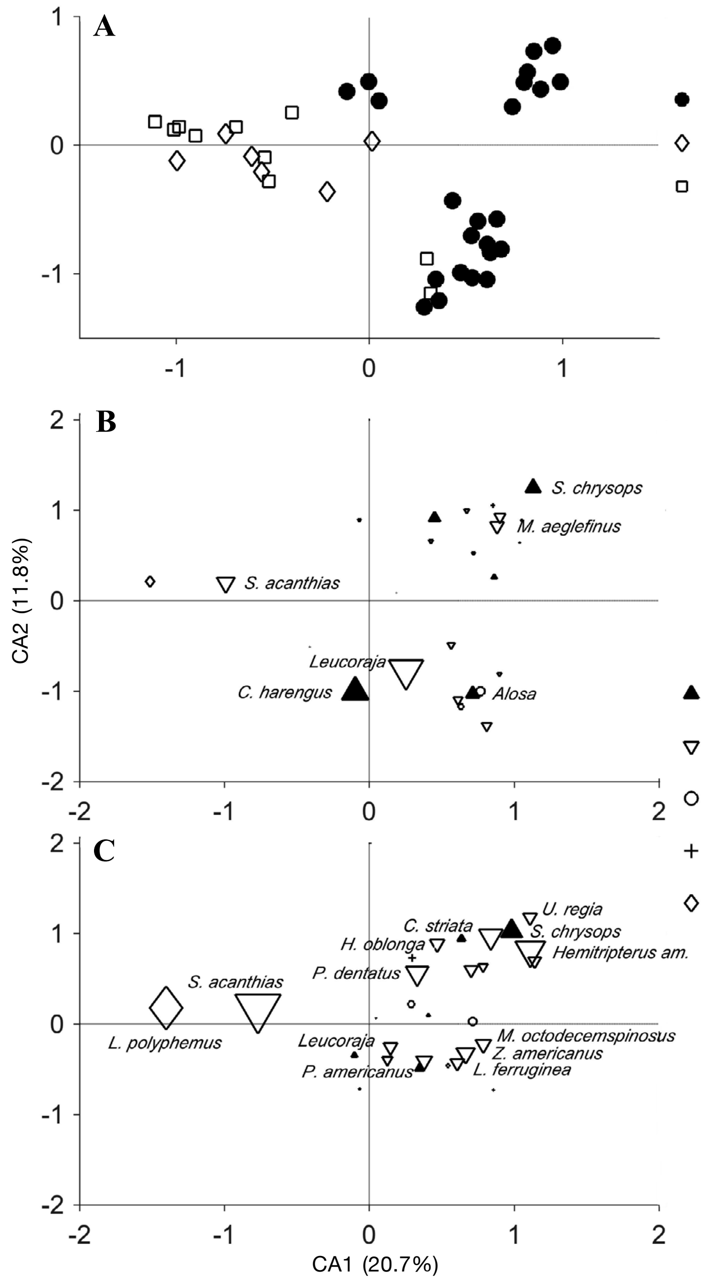

Figure 5

(**A**) Correspondence analysis ordination plots, showing the scores and variance explained for the first and second dimensions (CA1 and CA2), of the sampling stations at 3 wind energy areas, Rhode Island–Massachusetts and Massachusetts (RIMA–MA), New York (NY), and New Jersey (NJ), by using fish and macro-invertebrate taxa that occurred in at least 10% of the collections made with a bottom trawl in 2014. The size of the symbols are scaled to the contribution of each taxon to the ordination and are shown by taxon classification for (**B**) average proportion of a taxon per station and (**C**) average individual weight of a taxon per station. Taxa that contributed more than 3% to the ordination are labeled (For names of taxa, see Table 3).

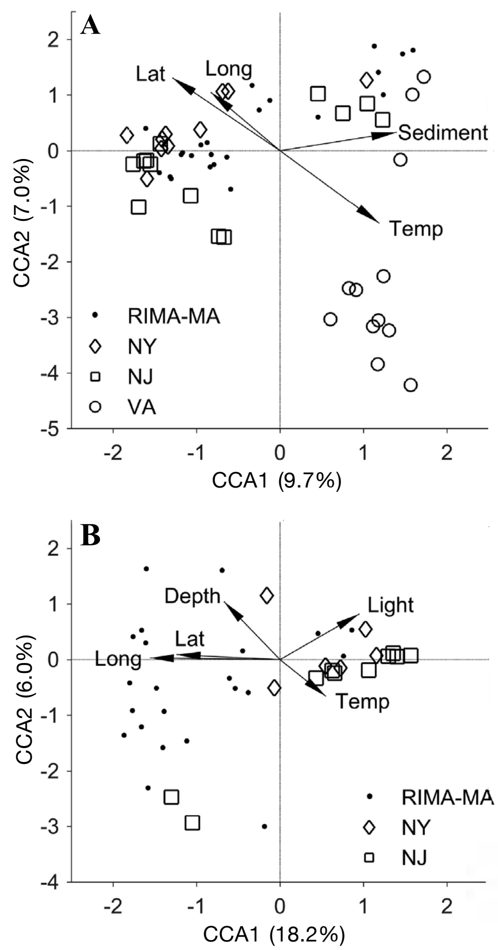

Figure 6

Canonical correspondence analysis (CCA) ordination plots, showing the scores and variance explained for the first and second dimensions (CCA1 and CCA2), of the sampling stations for each wind energy area, Rhode Island–Massachusetts and Massachusetts (RIMA–MA), New York (NY), New Jersey (NJ), and Virginia (VA), by using fish and macro-invertebrate taxa that occurred in at least 10% of the collections made in 2014 with a (**A**) beam trawl and (**B**) bottom trawl. The arrows depict the gradient of each explanatory variable.

trawl station groups and assemblages and 28.8% for the bottom trawl station groups and assemblages. Finally, covariables explained smaller proportions of the variance, with day of year explaining 3.7% and 3.1% for the beam trawl and bottom trawl, respectively. For the bottom trawl analysis, program (i.e., NEFSC vs. NEAMAP) explained 12.0% of the variance. For beam trawl station groups and assemblages, latitude (F=2.57, df=1, P≤0.006), longitude (F=3.94, df=1, P≤0.001), sediment (F=4.10, df=1, P≤0.001), and bottom water temperature (F=1.94, df=1, P≤0.040) were significantly correlated for the beam trawl station groups and assemblages (Fig. 6A). For the bottom trawl station groups and assemblages, all 5 remaining variables—latitude (F=4.87, df=1, P ≤ 0.001), longitude (F=2.92, df=1, P≤0.005), depth (F=2.25, df=1, P≤0.011), bottom water temperature (F=2.05, df=1, P≤0.019), and light (F=3.82, df=1, P≤0.001—were correlated (Fig. 6B). Thus, the station groups in ordination space were similar but not identical among the CAs and CCAs in the comparisons of the separation of WEAs in Figure 6 with those in Figures 4 and 5.

The variable of location on the northeast U.S. shelf, defined by latitude and longitude, correlated most with station groups and assemblages for the beam and bottom trawl collections. Most VA WEA stations from the beam trawl collections separated from the northern WEAs along the first and second dimensions (Fig. 6A), and aligned with latitude and longitude, and explained 45.1% of the environmental correlation. Bottom water temperature explained 8.8% of correlation and aligned opposite latitude and longitude (Fig. 6A), indicating that the spring bottom temperature was lower in the northern WEAs. Sediment explained the final 31.4% of the environmental correlations for the beam trawl collection and aligned with the first dimension and variability in the northern WEAs stations (Fig. 6A).

Latitude and longitude combined explained most of the environmental variability (59.2%) for the bottom trawl station groups and assemblages, and aligned with the first dimension (Fig. 6B). The importance of the remaining 3 environmental variables (depth, light, and bottom water temperature) ranged from 14.4% to 12.9%. Bottom water temperature and depth opposed each other (Fig. 6B), with temperature decreasing with increasing depth. Light aligned near the middle of the 2 dimensions (Fig. 6B), and was related to day-night variability in bottom trawl collections. Daytime collections were spread throughout the ordination space, whereas nighttime collections were clustered in the lower left quadrant (data not shown).

Discussion

The differences in the identified fish and macro-invertebrate assemblages in the collections made with the 2 gear types highlight the importance of employing multiple types of gears for environmental assessments (Wilson et al., 2010). The beam trawl collected a higher proportion of juvenile fish, small noncommercial fish, and small macro-invertebrate prey species than the bottom trawl (Suppl. Table; Figs. 2 and 3). The diversity of the beam trawl samples may be the reason why the ordinations for those stations were more variable than the bottom trawl stations. In contrast, the bottom trawl caught a higher average proportion of and larger (i.e., older) demersal and pelagic, commercially important fish and fewer macro-invertebrates per station (Suppl. Table; Figs. 2 and 3) and generally had lower variability in ordination space. Average proportion of taxa per station drove assemblage structure defined by the beam trawl samples (Fig. 4) because the beam trawl caught a smaller size range of individuals. Average individual weights by taxon per station were more important to assemblage structure for bottom trawl samples (Fig. 5).

Sampling season and variation in mesh sizes of nets may account for some of the differences in the comparisons of assemblages for the 2 gear types. Beam trawl sampling occurred earlier in the spring than bottom trawl sampling, and the beam trawl had a smaller mesh. Additionally, variability in sampling time of day (lack of day samples for beam trawl collections) may have influenced our analyses. Other research on the northeast U.S. shelf has shown that gear type and mesh size of nets influence species and size in composition of catch (Vasslides and Able, 2008; Slacum et al., 2010; Malek et al., 2014). Beam trawls often catch more demersal taxa and otter trawls catch more pelagic taxa (Vasslides and Able, 2008; Malek et al., 2014). Malek et al. (2014) also found that a beam trawl caught smaller individuals than an otter trawl equipped with a net of the same mesh size. Assessments of WEAs would clearly benefit from the use of gears, such as beam trawls, that collect smaller individuals of both fish and macro-invertebrates, allowing a more comprehensive understanding of the potential impact of developing wind farms, because the combination of beam trawls with bottom trawls provides a more complete view of demersal communities than bottom trawls alone.

Fish and macro-invertebrate assemblages varied spatially on the northeast U.S. shelf for both gear types, and latitude and longitude were important explanatory variables. The VA WEA is the farthest distance from the other WEAs and had the least overlap in assemblage composition for the beam trawl stations (Fig. 4). The NJ and NY WEAs were the closest to each other, and had the most overlap in assemblages for the bottom trawl stations (Fig. 4), and both also overlapped with portions of RIMA–MA for beam trawl stations (Fig. 3). Regional variation in assemblage structure on the northeast U.S. shelf, following a south to north gradient, has been described for both fish (Gabriel, 1992; Lucey and Nye, 2010) and macro-invertebrates (Wigely and Theroux, 1981; Theroux and Wigely, 1998; Hale, 2010). Consequently, impacts of WEAs spread along the shelf may become additive for assemblages that span large distances (i.e., 50–100 km). Therefore, impact assessments need to take a more holistic ecosystem-scale approach.

Assemblage structure varied within WEAs, and may be due to the effect of habitat conditions on species distributions. The explanatory habitat variables, sediment, depth, and bottom water temperature, correlated with assemblage structure in the beam trawl and bottom trawl collections (Fig. 6). The lack of daytime beam trawl sampling may have influenced our results because some species have been found to exhibit diel patterns of microhabitat use on the northeast U.S. shelf (Diaz et al., 2003); consequently additional round-the-clock sampling may lead to the discovery of different habitat relationships than those we report here. Nevertheless, taxon-specific relationships with habitat on the shelf have previously been shown for fish and macro-invertebrates and were most closely associated with sediment characteristics (Wigely and Theroux, 1981; Theroux and Wigely, 1998; Methratta and Link, 2006, 2007), depth (in both the cross-shelf and shoal formations) (Viscido et al., 1997; Steves et al., 1999; Methratta and Link, 2007; Vasslides and Able, 2008; Slacum et al., 2010), and bottom water temperature, particularly with seasonal temperature changes (Steves et al., 1999; Malek et al., 2014). Hale (2010), in examining estuarine and near shore sample locations, also showed that salinity was related to macro-invertebrate assemblages. The RIMA–MA WEA covered the largest area and had the most diverse assemblages for both beam and bottom trawl collections (Figs. 4 and 5). This finding may be related to greater heterogeneity in habitat types within this combined WEA. Impact assessments within and among WEAs need to take into account habitat variability.

Our study provides a “snapshot” of the springtime assemblages for the northeast U.S. shelf. Seasonality, as defined by day of year, explained a small proportion (<4%) of the variability in fish and macro-invertebrate assemblage structure for both the beam and bottom trawl collections. Other research on the northeast U.S. shelf has documented the existence of seasonal assemblages. Steves et al. (1999) identified 3 seasonal assemblages for recently settled juvenile fish: winter–spring, summer, and fall. Malek et al. (2014) identified summer and fall assemblages from beam trawl and otter trawl collections in Rhode Island Sound that remained stable across years. Therefore yearlong temporal sampling of WEAs will be needed to assess the entire assemblage structure, especially considering the complex life history (e.g., multiple life stages with various habitat needs) of many of the shelf species of both fish and macro-invertebrates.

Overall, our results and previous research indicate that effects of WEAs will need to be critically assessed for WEAs on an individual basis. Additionally, effects should be evaluated across multiple spatial and temporal scales to determine population-level effects on resident fish and macro-invertebrates (Bergstrom et al., 2014; Lindeboom et al., 2015). Many species use large areas during their life span (e.g., egg, larval, juvenile, adult stages), often make long-distance seasonal migrations (Secor, 2015), and therefore small-scale effects (on the scale of individual WEAs) may have additive effects (Bergstrom et al., 2014; Dai et al., 2015) on populations of commercially and ecologically important fish and macro-invertebrates.

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