

Review of “Vineyard Wind 1 Offshore Wind Energy Project Supplement to the Draft Environmental Impact Statement”

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Editor’s Note¹

This document addresses primarily perceived weaknesses in the SEIS. The editor emphasizes that many issues have been dealt with satisfactorily and these are not addressed, in the main, herein in order to limit document length.

Table 1 prepared by Munroe and Kohut, summarizes the types/scale of wind farms that are reported in the literature. This table points out that the size and scale of what is being considered in the SEIS has not been studied to date and thus the existing literature under consideration in the SEIS may not adequately represent the situation in the US. This constraint limits evaluation of impact across most subject areas.

General Comments:

The SEIS describes a variety of potential impacts on biological, physical, socioeconomic, and cultural resources resulting from proposed development alternatives of the Vineyard Wind 1 project. Resource impacts resulting from wind energy development more broadly throughout the U.S. Atlantic, from North Carolina to Maine, are also included. Impacts are identified as adverse or beneficial and ranked as negligible, minor, moderate, or major. The analysis is extensive across potentially affected resources, though limited in detail for specific resources and impact-producing factors. This lack of detail is often a weakness when examined relative to the potential impacts discussed. Description of expected impacts often identifies a broad range of levels, such that it is difficult to discern anticipated effects with any degree of certainty, for example. As a case in point, in section 3.11, the SEIS states that “cumulative impacts from the presence of structures associated with the Proposed Action when combined with past, present, and reasonably foreseeable activities on commercial fisheries and for-hire recreational fishing are anticipated to range from negligible to major” (section 3.11.2.1, pg. 127 / 3-100).

Key Issue 1: Evaluation of the Totality of impact across the Mid-Atlantic region

Section 1.2.1.1 Reasonably Foreseeable Assumptions quoted here presents an example of the limitations of the SEIS “It is difficult to predict turbine capacity and spacing or other future engineering for planned but currently unscheduled offshore wind awards. For those projects with announced WTG sizes, BOEM assumed an 8 or 12

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MW WTG. BOEM understands that turbine capacity may exceed 12 MW in the future. However, for future procurements and projects underrates potential impacts assuming that 12-MW WTGs will be used—since it is the largest turbine now commercially available (Appendix A).”

The issue faced is the totality of the planned development in the Mid-Atlantic. The SEIS briefly describes the overall plan, but then most of the details, those that exist, do not appear to be comprehensive. Powell et al. (2003) provide a good example of mission creep in evaluating the influence of the Texas Water Plan in its entirety on the health of Galveston Bay. In the case described by Powell et al. (2003), any small change in water distribution in Galveston Bay, which might be posed in an application for permit to e.g., remove small quantities of water from the Trinity River to be used in Houston and discharged into the San Jacinto watershed, would provide very little impact and be approved under that guideline, whereas, in totality, the Texas Water Plan as detailed at that time addressing water redistribution in aggregate would have destroyed much of the oyster resource in Galveston Bay and exerted significant and permanent ecological and economic damage. In the case of the present SEIS, one cannot evaluate the total impact of the proposed development of the Mid-Atlantic Bight as insufficient attention is paid to the impact beyond the Vineyard Wind project, whereas the cumulative impact is the issue of greatest concern.

This issue is exemplified by the absence at the Mid-Atlantic scale of an evaluation of the basic siting plan for wind turbine field development. One does not know if the present profile is optimal in the sense of minimizing ecological and economic damage relative to cost and energy production potential. As a consequence, evaluation of the present plan must be conducted in a vacuum, when alternatives would provide important comparability.

Key Issue 2: Physical oceanographic processes, particularly the influence of flow around/through turbine fields and evaluation of the potential impact on the cold pool

The SEIS includes discussion of physical oceanographic processes that are considered in the various categories of impacts in Chapter 3. This builds on the physical oceanographic summary included in Appendix B of the DEIS. It is critical to consider the physical oceanographic processes and their significant variability across multiple timescales from hours and days to weeks, months, years, and decades. This intense ocean variability drives an equally variable ecosystem from the primary producers (Malone et al. 1988) to the highly migratory fisheries throughout the region. The tight coupling between the ocean conditions and the habitat preference of the commercially and recreationally targeted species lead to a distribution of essential habitat that can significantly vary from season to season and year to year and to sharp gradients across shelf of unusual dimension in comparison to most continental shelves.

Seasonally, this region experiences one of the largest transitions in stratification in our global ocean with cold, well-mixed conditions in the winter months leading to strongly stratified conditions during the summer (Houghton et al. 1982; Castelao et al. 2010). In late spring and early summer, a strong thermocline develops at about 20 m depth across the entire shelf, isolating a continuous mid-shelf “cold pool” of water that extends from Nantucket to Cape Hatteras (Houghton et al. 1982). Local river discharge can augment this thermal stratification across most of the shelf (Chant et al. 2008) and provides pulses of nutrients and other material to the Mid-Atlantic Bight (MAB) shelf. These riverine inputs are only a fraction of the supply from upstream sources delivered by a mean southwestward flow along the shelf (Fennel et al. 2006). In addition, upwelling along the coast occurs annually each summer driven by southwest winds associated with the Bermuda High (Glenn & Schofield 2003; Glenn et al. 2004). Local upwelling can transport cold pool water all the way inshore and to the surface near the coast (Glenn et al. 2004). This upwelled water can drive the development of very large phytoplankton blooms that are advected offshore near the surface by the winds (Sha et al. 2015). The cold pool is dynamic and over its annual lifespan undergoes significant changes in stratification with peak

stratification in the summer and weaker stratification during its formation in the spring and its breakdown in the fall. Additionally, the isolated mass of cold bottom water shifts location, predominately moving toward the southwest as it slowly warms through the season (Houghton et al. 1982).

In general, the additional content in this SEIS now includes considerations of impacts to the cold pool. The SEIS recognizes the importance of local and regional physical oceanographic processes to the habitat and migratory behavior of key species considered in Chapter 3, including ocean impacts to prey targeted by the species of interest. As a result, the same text referencing the cold pool is repeated for each of the relevant categories of species. In each of these sections, the cold pool is mainly discussed in the subsection '*Presence of Structures*'. In these subsections, the report recognizes the dynamic nature of ocean conditions, especially as it relates to timing and location of species habitat and migration. The habitats move and move differently from season to season and year to year. While the seasonality of the cold pool was introduced, the impact of structures on the cold pool focused on the summer months when stratification is at its peak (Houghton et al. 1982; Castelao et al. 2010). The report considers impacts the structures may have on the stratification during the summer months when a strong thermocline isolates the cold pool from the surface as a mechanism that could move nutrient rich cold pool water to the surface, promoting primary productivity.

Given this focus on the impacts during peak stratification in the summer, the SEIS gives less attention to the seasonality of the cold pool beyond a statement that broadly summarizes its formation in spring and ultimate breakdown each fall. During the spring when the cold pool forms and again in the fall when it breaks down, the stratification is reduced (Bigelow 1933; Houghton et al. 1982; Castelao et al. 2010) and perhaps more susceptible to changes in hydrodynamics due to the presence of structures. Of particular sensitivity is the timing and rate of breakdown of the cold pool in the fall. The length of time that bottom water temperature remains high before the winter cooling sets in directly controls the inshore boundary of the boreal community.

The SEIS references studies of hydrodynamic effects of offshore wind turbines on seasonal stratification in the German Bight (Carpenter et al. 2016; Schultze et al. 2020). It should be noted that the seasonal stratification over the summer considered in these German Bight studies is much less than the peak stratification seen in the summer over the Mid-Atlantic Bight. It is much more representative of relatively weaker stratification seen during the formation and breakdown of the cold pool in the spring and fall. Therefore, the results characterizing potential impacts of offshore wind facilities in the German Bight are likely more representative of impacts we might expect from offshore wind facilities during the relatively weaker stratified time periods during the spring and fall rather than the highly-stratified summer months.

Carpenter et al. (2016) conducted an analysis of the impact of increased mixing in the water column due to the presence of offshore structures on the seasonal stratification of the German Bight. They offer a conclusion that the current build out of offshore facilities planned in the German Bight is unlikely to alter seasonal stratification dynamics in the region, but could impact the seasonal stratification if the area is developed to a point that it significantly covers the stratified shelf. The amount of overlap to reach this threshold was not defined. What was not included in their analysis and remains an important research topic is the influence of the extraction of wind energy by the offshore turbines on ocean mixing. A critical need exists to understand the influence of large offshore turbines 10s of meters above the sea surface on the wind stress at the ocean surface. This must be quantified to understand the net impact of the turbines on ocean mixing, balancing the loss of wind energy at the ocean surface by the turbines above with the increase in ocean mixing linked to the foundations in the water column below (Carpenter et al. 2016). Additionally, as stated earlier, it is important to consider the impact on the evolution of the cold pool throughout its annual cycle, including its shifting location and evolving stratification. During the less stratified time periods in the spring and fall, when the cold pool forms and breaks down, it is perhaps more susceptible to alterations in water column mixing associated with the structures. Cumulative impacts given multiple wind facilities throughout the region should consider whether the amount of

development would reach the threshold of larger scale impacts on stratification stated in Carpenter et al. (2016)? Will the presence of structures alter the mixing environment enough to change the duration of the cold pool either through earlier or later formation in the spring or breakdown in the fall (Matte et al., 1984)? What impact will this altered timing (if any) have on migration or dynamic habitat of species considered in the SEIS?

Too much attention cannot be given to the cold pool. It is critical to recognize that this body of water permits the extension of boreal species to latitudes well south of those routinely seen worldwide. The cross-shelf temperature gradient, exemplified by the cold pool, is important to many species in the region (Munroe et al. 2013, 2016; Narváez et al. 2015; Sullivan et al. 2000, 2003, 2005, 2006). Boreal species with extended ranges include those supporting major fisheries such as ocean quahogs and sea scallops. Wind-assisted transport and stratification are documented to be important components of larval fish transport from the Slope Sea to the Mid-Atlantic Bight coastal waters (and eventually estuaries) for a number of species (Checkley et al. 1988, Cowen et al. 1993, Hare et al. 1996, Grothues et al. 2002). The cold pool position and especially its areal extent is extremely important to the recruitment of northern, cold-associated fishes such as yellowtail flounder (Sullivan et al. 2005, 2006). The weakening of the cold pool supports the potential of generating the most catastrophic ecological event on the continental shelf the world has ever seen. Given the gravity of a catastrophic shift in cold pool dynamics, great care should be taken to show at high probability that the chance of an impact is vanishingly small. Adequate science leading to that evaluation is not presented in the SEIS and is probably not yet available. This science need is critical.

Key Issue 3: Climate Change

The SEIS mentions climate change a number of times without coming to grips with the seriousness of the problem. The Mid-Atlantic-Northeast continental shelf is increasing in temperature faster than any other area on earth (see Powell et al. 2019 for references). This is built upon a centuries long cooling trend that culminated in the Little Ice Age. Rising temperatures since the end of the Little Ice Age (Moore et al. 2017; Davi et al. 2015; Pace et al. 2018), and the acceleration of temperature rise over recent decades (Nixon et al. 2004; Friedland & Hare 2007; Saba et al. 2016) insert an urgency in the need to utilize all available information to characterize the rapid and multifarious shifts in range for marine species and particularly the biomass dominant species which often also are keystone and/or foundation species.

The SEIS says “The current state of terrestrial and coastal fauna resources is generally stable, although they are subject to disturbance from ongoing activities in the terrestrial and coastal fauna geographic analysis area.” and later “Climate change is altering the seasonal timing and patterns of species distributions and ecological relationships, likely causing permanent impacts of unknown intensity ... The cumulative climate change impacts of the Proposed Action when combined with past, present, and reasonably foreseeable activities on terrestrial and coastal fauna are anticipated to be **minor to moderate**.” The SEIS further states “Thus, the overall cumulative impacts on terrestrial and coastal fauna would likely qualify as **moderate** because the measurable impacts expected would be small and/or the resource would likely recover completely when the impacting agent were gone and remedial or mitigating action were taken.”

But, the SEIS does not integrate the 25-year record of change in biotic composition that can be expected given the recent 25-year history of temperature change on the Mid-Atlantic continental shelf and the ongoing extreme range shifts that are well documented (e.g., Powell et al. 2020a,b). Surfclams provide a good example. Twenty-five years ago, the fishery was primarily located off Delmarva. Now it is off New Jersey and on Georges Bank (Hofmann et al. 2018). The recent range shift includes increasing occupation of the inshore and mid-shelf region of the Long Island shelf, an event that has clearly happened earlier in the history of the Holocene (Powell et al. 2020a) and is now being repeated, as well as the range extension offshore immediately east and south of Nantucket (Powell et al. 2020b). These changes in distribution are not limited to benthic species; concurrent

with recent changes in distribution, the available thermal habitat in the region for many demersal and pelagic fish species is projected to change significantly (Kleisner et al. 2017), with the direction and magnitude of these effects varying by species, and having resultant effects on their availability to fishing fleets and ports. The SEIS future impacts of climate change and the earlier statement that “The current state of terrestrial and coastal fauna resources is generally stable” reflects an inadequate integration of the present state of community reorganization going on within the Mid-Atlantic and northeastern U.S. continental shelves. Evaluation of ecological and economic impacts and impacts on threatened and endangered species based on the assumption that present-day species distribution patterns and the distribution of fishing fleets responding thereto are permanent fixtures is unlikely to be sufficient. Evaluation of impact should consider the 25-year lifetime of wind turbines and the likely dimensions of climate change over that time frame. Projections of the effects of climate change on species distribution and models to evaluate range and distribution shifts of living marine resources in the context of these do exist but do not often consider changes in population dynamics over the lifetime of climate projections in addition to possible species distribution. What can be stated with high probability is that the possibility that a benthic habitat map of today will be valid in ten years is vanishingly small.

The consideration of mussel occupation and filtration on wind turbines offers a good case in point. The SEIS discusses increased wind mixing across the thermocline due to pilings that would bring nutrients up into the photic layer and thereby increase primary productivity, but the SEIS also argues that the increased primary productivity would be consumed by colonizing filter feeders (mussels) and thus not effect finfish or commercially important bivalves. The report suggests that mussel abundance will be high and cites two sources to support increases in mussel presence. One is a social science paper (ten Brink & Dalton 2018) that surveyed fishers about their impressions of the Block Island wind farm. ten Brink & Dalton (2018) report that 9 survey responses noted mussels on the piles, and one spearfisher noted ‘lots’ of mussels. The second source is a report (HDR 2019) that again simply notes an increase in mussel presence (not abundance estimates) on turbines relative to controls. Neither of these sources provide numerical estimates of abundance or biomass of mussels, values that are necessary to estimate filtration capacity of a population of filter feeding mussels (Riisgård 2001; Riisgård et al. 2014) in an array of wind turbines.

The SEIS further cites Slavik et al. (2019) to support the claim that mussels on pilings would have a filtration capacity sufficient to eliminate any possible increases in primary productivity that resulted from enhanced mixing due to pilings. Slavik et al. (2019) used coupled modeling to evaluate impacts of wind farms on primary productivity. They estimated that wind farms add 45% to the regional mussel biomass, and those mussels only marginally impact phytoplankton. Net annual primary production was reduced in their study by only ~8%. Certainly, mussels will filter plankton and other particles from the water, but environmental conditions (temperature, salinity, dissolved oxygen, seston quality and quantity) are known to alter filtration rates (Riisgård et al. 2001; Li et al. 2012). Likewise, refiltration whereby mussels in high density populations filter the same water repeatedly (Yu & Culver 1999; Jones et al. 2011) leads to overestimates of filtration capacity of highly dense populations. Finally, it is common to see local reduction in phytoplankton at a mussel bed, with increases in primary productivity downstream of the mussel population (Norén et al. 1999; Schröder et al. 2014), a process that could be enhanced by turbulence in the wake of a monopile. All of these conditions make it very complicated to estimate the true filtration impacts of a population of bivalves in a natural system (Cranford et al. 2011).

But, if we make the assumption that SEIS inferences are correct concerning mussel occupation of wind turbines, the issue remaining is the degree to which these species will remain extant in the region. In 1943, *Mytilus edulis* was found as far south as Beaufort, North Carolina (McDougall 1943). By 1960, the southern boundary of the range had contracted polewards to Cape Hatteras, North Carolina, due to increasing water temperature with increasing abundances and sizes to the north and mortality to the south of Cape Hatteras (Wells & Gray 1960).

Moving forward to 2005, the *M. edulis* population along the entire North Carolina coast no longer persisted year-round owing to increasing water temperatures (Jones et al. 2009). In total, the southern boundary of *M. edulis* had contracted roughly 350 km polewards as the decade of the 2000s neared its end (Jones et al. 2010). The SEIS is silent on the likelihood that mussels will still be present in the Mid-Atlantic in 25 years, but Powell et al. (2019) suggest that continued northward movement will limit distribution south of Cape Cod.

Key Issue 4: Adequacy of the database on finfish and benthic invertebrates

Finfish

In addressing impacts on finfish, the DEIS and SEIS respond to concerns about listed IPFs using information synthesized from peer-reviewed and grey literature, including the recent literature and reports. These data are not uniformly sufficient to evaluate impact. In particular, understanding of the response of electrosensitive fishes to EMF from buried cables comes primarily from physiological research on electrosensitivity and from caging or pond/mesocosm studies that may be influenced by cage-aberrant behavior such as patterned swimming in confined spaces, and a meta-analysis of migratory fish at liberty from telemetry. In particular, the SEIS states “Most exposures are expected to last for minutes, not hours, and the affected area would represent only a tiny portion of the available habitat for most migratory species, many of which travel several miles in a day (CSA Ocean Sciences, Inc. and Exponent 2019).” EMF effects on fish behavior is considered on an area basis, not a blocking basis as in a hurdle to cross during migration. Supporting data are not yet available.

Effects of scale on fish ecology with respect to the density/spacing of turbines is an issue. Turbine pylons and their rock scour revetments will create reefs on what is predominantly a soft-bottom benthic ecosystem. To some fishers, this will be a welcome extension of ongoing efforts to increase production and/or concentration of reef-oriented species such as black sea bass and tautog, and seasonally structure-attracted midwater species such as jacks. A cautionary consideration is that some ‘structure oriented’ fish may not be as reliant on these structures as sometimes thought, and thus positive effects of increases in reef habitat may be uncertain. For example, Fabrizio et al (2013, 2014) found that black sea bass have large home ranges for a “reef” species, and may spend substantial time away from structure, with some exhibiting home ranges up to 4.8 square km. Nieland and Shepherd (2011) found that catches of black sea bass in the NEFSC inshore trawl survey were greater over open bottom than around structure.

Nevertheless, assuming that the reef effect will be important, the scale of the wind turbine build out, and cumulative buildout considering all possible leases, far exceeds that of artificial reef programs. Each reef will have a zone of influence around it that is a function of the foraging behavior of its resident species. This has been well studied in tropical shallow atoll reef systems as the “halo” effect (Madin et al. 2011, Ollivier et al. 2018) wherein lagoonal coral head reef residents graze a well-defined white sand ring into sea grass around their shelters but no further (Gil et al. 2017). The halo extent is constrained by a “landscape of fear” imposed by predators versus a payoff determined by grass density (Brown & Kotler 2004, Downie et al. 2013, Catano et al. 2016. Gil et al. 2017). At high densities of coral heads, the halos of adjacent heads merge (Madin et al. 2011) and standing crop seagrass beds are entirely eliminated and “halos” become continuous, fundamentally changing energy flow and ecosystem function within the atoll. The dynamics are well studied in shallow clear coral reefs because they can be easily seen, including from space (Madin et al. 2011) but much less so in turbid or large marine systems, although Sullivan et al. (2000) is a notable example that is also specific to the region of interest and the cold pool.

However, terrestrial ecology studies are replete with these and terrestrial analogs serve us here; at some point a collection of individual trees becomes a forest (Shrader et al. 2012), which functions different to a savannah and hosts different faunal assemblage and life history patterns (Bowyer & Kie 2006, Boyce 2006, Rietkerk & van de Koppel 2008, Mashintonio et al. 2014, Pirodda et al. 2018). So, at what point do individual small pylon

footprints move from a fractured landscape of scattered reefs to a reef complex with interaction effects? This question is important but little considered in the plans for spacing in the original and alternative models of the SEIS, which appear to be constrained by navigation and efficiency (cable length and routing, wind extraction efficiency). The fact that it matters has been shown in an existing (Alpha Ventus) wind turbine farm in Sheringham Shoal, UK, by telemetry of foraging seals that created a grid-like pattern of direct movement from turbine to turbine as a foraging strategy (Russell et al. 2014). A high density of Fish-Aggregating Devices (FADs), simple floating buoys and lines used to concentrate pelagic thermophilic fishes for easier harvest, has also been demonstrated to substantially change the distribution and abundance of jacks in the Mediterranean Sea (Sinpoli et al. 2019). Monopile reef density effects should at least be modeled based on parameters of fish and mammal movements extracted from a synthesis of telemetry data.

As the SEIS states, ecological impacts to the fish community will not be uniform across species. Habitat models suggest that [summer flounder](#), [butterfish](#), longfin squid, and [spiny dogfish](#) will mostly overlap with wind areas for MAFMC managed species; [Atlantic herring](#), [little skate](#), [winter skate](#), [windowpane flounder](#), and [winter flounder](#) will be the highest for NEFMC managed species (NEFSC 2020). Whether positive or negative, the differential impacts in habitat and productivity across species suggests changes to food web structure, interactions, and ecosystem function that are currently not considered in an integrated fashion in the SEIS. The various direct effects on fish (and other ecological community components) could cumulate to trickle-through effects on fisheries via changes to population dynamics, mortality, and recruitment that go beyond the initial direct impacts associated with habitat changes and/or displacement and mortality. Food web or ecosystem modeling may elucidate the potential magnitude of such changes.

Epibenthos (see in particular page 3-24)

The SEIS discusses impacts to the benthos from wind energy installations. In their evaluation of what the changes and impacts to the benthic community might be from wind farms, the SEIS references only 2 studies that focus on the epibenthic community, not true benthic fauna, or are from ecosystems very different than the U.S. continental shelf. One of these studies, Bergström et al. (2014), includes a review of ecosystems that range from freshwater through ‘near-marine’ coastal systems (none of which reflect the continental shelf, and the benthic community they consider includes epibenthic and true benthic species, although they note that the impacts to the benthic community as a whole is highly uncertain and has been very inadequately studied).

The other study cited by the SEIS (page 3-24), Kerckhof et al. 2019, reports on the ecological succession of the fouling community on wind energy foundations. They find that the intermediate community is the most diverse, but warn that the climax community (which is reached ~9 years after installation) lacks diversity and in the case of the deeper water case, becomes dominated by mussels alone. Kerckhof et al. (2019) caution that the many studies showing increased diversity at wind foundations may reflect the intermediate community, rather than the climax community. Should the climax community condition be considered, wind energy foundations may prove to be much less biodiverse than is being considered now. Regardless, Kerckhof et al. (2019) focuses on epibenthic (fouling) communities, and does not consider the benthic community, despite reference to it in the SEIS to support no change in benthic community in soft sediments over 5 years since turbine foundations are put in. Kerckhof et al. (2019) is the 7th chapter in an extended report about wind farms in the Belgian North Sea (Degraer et al. 2019). A preceding chapter in that peer-reviewed report (Lefaible et al. 2019) did address changes in the benthic community due to the presence of wind turbines. Lefaible et al. (2019), and references therein, indicate changes in the sedimentary habitat (fining of sediments) and an overall shift in the benthic community towards a lower energy community, from what was previously a well-flushed higher energy community. Likewise, the Lefaible et al (2019) report notes changes in the benthos due to increased biodeposition from the increased fouling community (including mussels) on the turbine foundations, a finding

also noted in a number of other studies (Miller et al. 2013; Causon & Gill 2018; Dannheim et al. 2020; Lu et al. 2020). These studies collectively also note that the benthos is a highly understudied ecosystem component and impacts from wind energy installations are therefore highly uncertain, and recommends increased effort to study benthic impacts.

Semi-infaunal and infaunal benthos (see in particular section 3.3.1.1)

The section references the work of Guida et al. (2017) and Green et al. (2010). These are wholly inadequate to describe the biota of the region for the following reasons. 1) The datasets are out of date as substantive changes in faunal distributions have happened since the first half of the 2010 decade. This is discussed in more detail in the previous section on climate change. 2) Unfortunately, studies of the benthos in high energy continental shelf habitats in general have tended to use grab samples to attempt to assess the biological community in the bottom (for example, Lefaible et al. 2019 used a van Veen grab). Neither Guida et al. (2017) nor Green et al. (2010) used gear that adequately sampled the biomass dominants of the continental shelf. Most samples came from grabs. Relatively small grab samplers or even boxcores are insufficient for sampling the majority of large macrobenthic species, particularly those of known commercial importance along the U.S. Atlantic continental shelf (namely surfclams and ocean quahogs). Powell and Mann (2016) and Powell et al. (2017) provide details.

Staff et al (1985) discuss the importance of accounting for biomass, not just numerical abundance, when considering the macrobenthic contribution to marine ecosystems. The biomass dominants tend to be the keystone and foundational species of the community, in addition to being responsible for a substantial fraction of energy flow. In the case of surfclams and ocean quahogs, which are very large-bodied clams and make up the majority of the benthic biomass on the shelf (despite the fact that there may be numerically more worms or other small macrobenthos present), the tools typically used to evaluate the benthic community simply do not adequately account for these species. It has been demonstrated that even a boxcore, which samples to 20 inches depth, is insufficient to assess the clam (both surfclam and ocean quahog) abundance and biomass along the Mid-Atlantic shelf. These two species are not the only species of ecological importance in the macrobenthos. *Ensis directus*, the razor clam, contributes significant biomass in some areas, as do large holothurians. Of importance, these mega-infauna are also long-lived and, therefore, less resistant to ecological impact and less capable of recovery (see later discussion). As an example, Powell and Mann (2016) evaluated the efficacy of a boxcore for sampling the large infaunal clams on the shelf, relative to more appropriate methods like dredge sampling and found that boxcores vastly underestimate the abundance of large-bodied and patchy clams. In the case of surfclams, one of the important commercial species, the chance of a grab sample-based survey, at normal sampling densities, encountering even a single clam is vanishingly small, even though present in commercial quantities. Powell et al. (2017) further evaluated the challenges and shortcomings of estimating benthic biomass accurately for species like clams that tend to be patchy on the bottom, even when using a sampling tool that catches them effectively. Further, survival and growth post-set may be influenced by gradients in food supply that are well documented to occur across filter-feeder communities (e.g., Wildish & Kristmanson 1985, Wilson-Ormond et al. 1997; for diseases, see Bidegain et al. 2016), which can only be inferred if the biomass of the biomass dominants among the filter feeders is accurately known. The lack of studies directly addressing impacts of wind farms on benthos, particularly the biomass dominants, combined with the trend towards underestimation of the large-bodied and commercially important macrobenthos because of inadequate sampling methods, means that little information is available with which to evaluate the baseline and potential impacts of wind energy on benthic structure.

In addition to the seriously limited information on the community composition in the areas in question, the referenced simulations in 3.3.1.1 are all European. The European continental shelf is utterly different from the U.S. shelf, particularly in the relative abundance of very long-lived biomass dominants. A cold pool does not exist there. Such simulations are uninformative. Finally, the SEIS contains no anchorage plan for supporting

vessels. The impact of the biota is in part determined by the number and distributions of supporting vessels and their anchorages, as is the possible deployment of fishing gear (see later discussion).

Impacts to larval dispersal.

The SEIS discusses the potential impact of wind energy areas on larval dispersal only briefly, despite the great importance of this process in structuring and maintaining marine biological communities. In terms of anticipated impacts of wind energy installations on larval dispersal, the SEIS cites Chen et al. (2016) noting the report's findings relative to impacts of wind energy areas on scallop larvae dispersal (SEIS 3rd paragraph page 3-23; SEIS page B-22). The SEIS characterizes the impacts of wind farms in southern New England on scallop larval dispersal as increasing the dispersion of the larval field, but that the wind farms “never... trap or block larvae from settling in habitat previously occupied” and generally are not expected to alter larval dispersal. Unfortunately, the simulations described in the Chen et al. (2016) report are insufficient to evaluate the potential impacts of wind farms on scallop larval dispersal. Rather the particle tracking simulations should be considered a representation of bulk flow and not larval dispersal.

Chen et al. (2016) is a hydrodynamic modeling study designed to evaluate impacts of wind facilities on waves and water flow under extreme conditions (short-term, storm-induced conditions). Particles tracked in what are described as ‘larval experiments’, appear to have no behavior (it is unclear if they are buoyant), and were released at the surface - no complex behaviors nor ontogenetic changes are included. Chen and colleagues note in the report that this approach is insufficient to adequately model larval dispersal which is the result of complex behavior and ontogenic processes (see paragraph 2 on page 41 of Chen et al., 2016), and a number of larval dispersal models have demonstrated that particles without behavior result in significantly different dispersal patterns than those simulated with individually-based behavior (North et al. 2008; Narvaez et al. 2012, Zhang et al. 2015, Daigle et al. 2016; McVeigh et al. 2017; Goodwin et al. 2019). Chen et al. (2016) also note that individual-based models with complex behavior for sea scallop larvae have not been developed. At the time of writing their report, that may have been true; however, since then one such model has been developed and used to simulate dispersal dynamics in the sea scallop stock (Munroe et al. 2018; Hart et al. 2020).

The way that particle tracking was implemented in the Chen et al (2016) report was unusual in terms of the contemporary standard for larval dispersal modeling studies in that only 100 particles were released (typically hundreds of thousands to millions of particles are used in a simulation), and these particles were tracked for 11 days, which represents only about 30% of the larval life span of scallop larvae (Culliney, 1974; Pearce et al., 2004). Likewise, if timing of the simulations were to be reflective of true scallop spawning seasonality (May/June and September: DuPaul et al. 1989; Thompson et al. 2014), results from these simulations may differ greatly (see Zhang et al. 2016 for an example of how strongly season may influence dispersal patterns of clams in the MidAtlantic).

Given that the SEIS bases its conclusions about potential impacts of wind energy installations on larval dispersal on one single report from a study that was not designed to evaluate larval dispersal impacts (Chen et al. 2016), the conclusions reached in the SEIS in this respect must be tentative at best. Future research should focus on commercially important species that extends beyond just scallops, such as other shellfish stocks and fish species that may demonstrate even more complex larval behavior. To this point, wind turbine fields, like oil platforms and forests, redirect flow. Scales vary from large (e.g., Gardiner et al. 2019) to small (e.g., Jumars & Nowell 1984), but the principal of bottom boundary layer effects and primary flow routes within and around structures are comparable. The issue is the degree of influence of these structures and flows on larval transport and settling potential, which would ultimately result in a proportional increase or decrease of community component species, leading to unknown consequences beyond the turbine arrays. Some may overcome Allee effects and produce spawn to influence community structure far downstream (e.g., Hart et al. 2020). Some may

be unable to recruit at all due to increased bypassing flow. An expanded evaluation of the impact of wind turbine development on the benthos is clearly warranted.

Key Issue 5: Long-lived Biota

The SEIS states in 3.4.2.1. Cumulative impacts of the proposed action: “The Proposed Action would likely result in impacts (disturbance, displacement, injury, mortality, reduced reproductive success, habitat degradation, habitat conversion) that are expected to be local and to not alter the overall character of finfish, invertebrates, and EFH in the geographic analysis area for finfish, invertebrates, and EFH. Some impacts would be adverse.” The SEIS is uninformative as to these adverse impacts. The following train of thought is stipulated numerous times in the SEIS. “Thus, the overall cumulative impacts on finfish, invertebrates, and EFH would likely qualify as **moderate** because a notable and measurable impact is anticipated, but the resource would likely recover completely when the impacting agent was gone and remedial or mitigating action was taken.” The SEIS does not consider the recovery time of the long-lived biomass dominants. The SEIS concludes that “the endangered Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) is the only finfish or invertebrate listed under the Endangered Species Act (ESA) that may be affected by the proposed Project.” This conclusion is not disputed here. The concern raised however is that sensitive species are not just threatened and endangered species. Long-lived sedentary and sessile species have limited rebuilding capacity. Surfclams live for 30-35 years (Powell et al. 2020a). Multi-generational recovery times would be expected if population age-frequencies are expected to return. The oldest ocean quahog aged to date was born in the mid 1700s and the bulk of the present-day stock was born between 1880 and 1940 (Pace et al. 2017, 2018). Recovery periods are extensive, easily 2 to 5 times the expected lifespan of the wind energy field from construction to decommissioning, with multi-generational recovery times anticipated in the range of 200 years. The SEIS provides little evaluation concerning the potential permanence, in normal human life span scales of time, of the impact of wind energy development. Centuries long impacts may be anticipated in some regions. Long-lived sedentary or sessile biota are not biomass dominants everywhere and a thorough review of benthic habitats in the Mid-Atlantic would be illuminating. Given these permanent impacts, every effort should be made to develop areas that do not now and are not expected in the future to support biomass dominants with vicennial or greater life spans. Such siting evaluations are not available.

The SEIS considers that decommissioning and removal at the end of the project life span will occur. Such has not always been the case as exemplified for example, by Gulf of Mexico oil platforms. These case studies should be reviewed and if applicable, the SEIS should evaluate the influence of wind energy development if decommissioning and removal does not occur.

Key Issue 6: Fishing, surveys, and stock assessments

The SEIS (section 3.13) anticipates that turbine spacing of e.g., 1x1 NM may prevent fishing and transit. Larger transit lanes may improve vessel transit if directionality is properly anticipated. The SEIS describes transit lane plans for today’s vessel use but does not contemplate the potential that future transit operations may require directionality incompatible with the present-day scenario (see earlier discussion of climate change). The underwater turbine linkage maps show a poorly constructed plan if facilitation of fishing vessel operations is desired. Figure ES-1 (DEIS) is an example. Alternative cable distributions, if feasible, do not seem to have been considered.

The most important indirect impact on the economics of fishing is the possible feedback from impacts on marine mammals. Likely consequences of WDAs impacts on marine mammals include:

- Direct effects of increased entanglements of MMs in commercial fisheries including loss of fishing time and additional costs associated with handling/reporting requirements, as well as gear repairs or replacement.

- Increased mortality/serious injury (MSI) in commercial fisheries which may elevate fisheries' classification to categories (I and II) that trigger deployment of observers and potentially, if $MSI > PBR$, trigger establishment of Take Reduction Teams and development of Take Reduction Plans. These monitoring and mitigation measures imposed by the MMPA represent additional costs for NMFS and commercial fishing operators.
- Delay in the recovery of stocks, in particular of Right Whales, caused by the combined IPFs impacts, translates into costs to maintain or expand measures to reduce bycatch, which would be sustained by NMFS and the commercial fisheries operators. Declines in stocks to levels that warrant changes in stock status (depleted under MMPA or threatened, endangered under the ESA) could also lead to additional costs associated with new bycatch reduction measures if warranted.

The feedback of turbine emplacement on stock assessments potentially is the most important economic impact. An important issue is the degree to which adverse impacts would accrue to the science conducted by NMFS and the various states. This would include fisheries independent surveys, but also other science activities conducted by NMFS, such as endangered species monitoring and other physical and biological assessments including essential fish habitat assessments in the region. The SEIS broadly lists what these effects are likely to be and categorizes them as major. The logic used in the SEIS for major impact is that surveys will be impaired, uncertainty will increase, and quotas will be lowered (or eliminated). The SEIS notes that surveys within the turbine field are unlikely and that this will increase uncertainty in assessments, but without any estimates of effect. For some species, the actual impact would begin with a contraction of the total stock. Simply put, the only recourse in the assessment would be to assume that no stock exists in unsurveyed areas. The example of the region east of Nantucket and the clam survey is a good example. Here, the fishery has caught clams for many years, yet the region is not surveyed and those clams are not, therefore, included in the stock estimate. The wind turbine field would also be debited from the stock footprint. Consequently, estimated stock carrying capacity would be reduced. As the target and threshold reference points are directly related to carrying capacity, these also would be reduced. This would reduce the Overfishing Limit (OFL) and ultimately the Allowable Biological Catch (ABC). Consequently, the possibility of an overfished state or that overfishing occurred would increase. Quota reductions would be a likely result.

It is important to realize that any unknown generates additional uncertainty that ultimately favors a quota reduction. It is important to realize that this impact is perpetual. That is, the economic damage is realized each year that the turbine field exists and restricts survey completeness. Thus a single year compensation package cannot mitigate the adverse economic impact. It is important to realize that long-term recovery after decommissioning might result in decadal and longer impacts on fishing of long-lived species, a timeline and effect level not contemplated in the current SEIS. Importantly, the SEIS does not show any estimates of effect of reductions in spatial footprint of monitoring on uncertainty in governance (quota calculations considering risk policy), even though simulations using Management Strategy Evaluation (MSE) technology are readily possible with today's software that would enable one to quantify the potential damage. As yet, then, we do not know how assessment models may respond to changing survey (and landings) inputs relative to defined reference points. It is important to note that under the MAFMC risk policy, increases in uncertainty in estimates of stock status and factors affecting population and ecosystem dynamics result in more precautionary advice when deriving ABCs.

In summary, the SEIS discusses impacts of wind energy areas to managed fisheries and notes these impacts will be among the greatest impacts of the project. The SEIS correctly indicates that impacts owing to inability of federal fisheries management agencies to conduct annual stock surveys within the wind area footprint will be major. However, the SEIS does not address the scale and scope of these impacts. Given the size and location of these wind leases, which overlap with important portions of many economically and culturally important stocks,

the effect on scientific advice to inform management resulting from an inability to survey may be one of the biggest anticipated impacts of the wind project - but the scale of the consequences is not known. It is likely that the magnitude of the effect will vary by species, and that this uncertainty will be further compounded for fished species that are experiencing distribution shifts (both among and within years) due to climate change as the proportions of stocks being available/unavailable to monitoring will change as the spatial footprint of wind farm development changes (increases) over time during regional deployment, also exacerbating dynamic changes to biological reference points. This important information should be prioritized and addressed using management strategy evaluations and other modeling approaches. A benefit to doing this work would also be to demonstrate the value associated with developing alternative monitoring techniques and technologies within wind farm areas to mitigate scientific survey reductions.

Key Issue 7: Marine mammals

Cumulative impacts as defined in the SEIS refer strictly to the combined Vineyard Wind (VW) and future offshore wind energy developments. Despite SEIS conclusions that refer to “all the IPFs together, little formal qualitative and no quantitative analysis combines the impacts from the complete collection of sub-IPFs exists, as noted much earlier under the General Comments section. Thus, assessment of the cumulative impacts that result from integrating impacts from all IPFs remains undetermined. This is a significant omission for stocks of marine mammals (MMs) that already show signs of decline or very slow recovery such as the four ESA listed stocks (also strategic under status and the MMPA) and the additional seven MMPA strategic stocks (Hayes et al. 2019). In addition, in the analyses of each individual impact, the SEIS often justifies negligible or no impacts based on the premise that a small increase in the impact has little or no effect given the current level of disturbance from other sources. This approach is unwise for slow growing populations and discounts the cumulative nature of stressors that directly and indirectly decrease population growth, as is generally the case for MMs, or that impede growth to sustainable levels, as is typically the case for ESA listed species (NASEM, 2017). Since this SEIS is precedent-setting in methodology for assessing offshore wind energy impacts on marine mammals and considering the large spatial and temporal extent of these WDAs activities, foregoing a proper cumulative impact assessment that integrates the sub-IPFs and IPFs is unfortunate. A formal cumulative impact assessment that explicitly integrates the sub-IPFs and IPFs is needed to adequately assess impacts on MMs.

Although for several of the IPFs, adverse impacts on behavior, essential biological activities (e.g., foraging, breeding and migration) and habitat utilization are described, the SEIS is limited in its consideration of the combined IPFs effects on potential decreases in individual fitness and population growth. A simulated harbor porpoise population subject to noise from wind turbines (mirroring the existent and planned wind turbines in the Inner Danish Waters) and shipping, plus bycatch rates of 4% suffered a substantial decrease and increasing bycatch rates over 10% led the population to extinction. These findings suggest that cumulative impacts of wind farms, shipping and bycatch are additive (Nabe-Nielsen et al. 2014). Given the large spatial extent of the combined VW/future WDAs which, for some MM stocks, covers either their entire range or significant portions of their foraging habitat (e.g. cold pool), mating and/or breeding grounds (Hayes et al. 2019; Roberts et al. 2016), and the persistence of these disruptions over decades, particularly those that result from operations and maintenance, it seems improbable that decreases in fitness and population growth would not occur and it is, therefore, extremely important to show a high probability that they will not occur. Note that general methodological obstacles or difficulties in teasing apart effects that cause decreases in individual fitness and population growth or lack of studies are not *per se* a justification to conclude that those impacts would not be likely or that mitigation is feasible. Note also that under “Irreversible impacts” (“ [p. D-10, Table D.4-1]) these outcomes were only considered for the four ESA listed species rather than all protected MM species that occur in the area and it was considered that mitigation would reduce or eliminate such effects (see comments on

mitigation that follow).

The potential perturbation of the cold pool, which was considered as a potential adverse impact on foraging opportunities for MMs under “presence of structures”, does not seem to have been taken into account when concluding the overall magnitude of impacts on foraging opportunities under this IPF to be “moderate beneficial”. Note that for some MM species, disruption of these large-scale oceanographic features that support not only foraging but also mating, breeding, and long-distance migration patterns, could have devastating effects at the individual and population levels (e.g. high metabolic costs and reproduction costs) or at the species level (i.e. evolutionary bottlenecks). This reiterates a general concern about the cold pool as potentially the most serious ecological impact of wind turbine development, likely with ecosystem-level impacts, if its modification at any degree took place. In addition, the net effect of foraging opportunities created by the presence of structures has yet to consider predation (e.g. by sharks and, by birds of prey, coyotes, etc. on seal pups in rookeries) and competition (among MMs and with non-MM species), both likely to occur concomitantly with increases in various prey and MMs. This could carry adverse impacts, i.e. increase mortality, injury, stress levels of MMs or avoidance of WDAs. An increase in sharks along the U.S. northeast Atlantic where seal rookeries occur has been reported (Moxley et al. 2020) and a similar effect would be expected if seals and other MMs are attracted to WDAs. Also, if foraging sites move further from the rookeries, it is also likely that the risk of predation increases for the nursing females and for the unprotected pups (Moxley et al. 2020).

The likely substantial intensification of MM-fisheries interactions with a potential significant increase in MM mortalities and serious injuries (MSI) inside and outside the WDAs (VW and future WDAs) due to entanglement (directly, in active fishing gear and indirectly, in lost gear) is not adequately considered. This results primarily from the lack of a formal analysis (even qualitatively) of the expected cumulative impacts on MMs stocks from three likely scenarios: 1. reduction in fishing area for some commercial fisheries due to safety considerations; 2. shift of some coastal recreational fisheries to the WDAs offshore areas and 3. an actual overall increase in recreational fisheries in the region. These scenarios result in increased density of fishing gear in the water, particularly around WDAs, which is a significant factor in elevating the risk of entanglements. The shift of recreational fisheries from nearshore to offshore areas and the displacement of recreational and commercial fisheries from WDAs are referred to as potentially increasing interactions with fishing gear but inconsistently and incompletely: first claiming that the shift in recreational fisheries would not change the overlap with MM distributions, while later in the same paragraph acknowledging the potential for different species to be affected. Yet, aside from the North Atlantic right whale stock (NARW), no attempt is made to identify the MM stocks that are more likely to be impacted based on their distribution, foraging habits and existing estimates of MM stock bycatch by type of commercial fishery. Importantly, the increased MSI expected from increased density of fishing may act as an effective lethal (or serious injury) trap for MMs that are attracted into the WDAs to forage. This possibility requires increased scrutiny. The SEIS also states that “Abandoned or lost fishing gear may get tangled with foundations, reducing the chance that abandoned gear will cause additional harm to marine mammals and other wildlife, [...]”, but this is not a reasonable expectation considering the expected increase in MM prey species and foraging MMs inside WDAs (reef effect), i.e. nets would continue to capture wildlife and MMs and at a higher rate than in areas with lower density of prey and MMs. In addition, entanglements could be increased inside WDAs because the ability of MMs to detect the nets and lines would likely be reduced compared to outside WDAs. Importantly, the expectation that “[...] entanglement and ingestion of debris, is not considered a new impact-producing factor but rather a change in the distribution of this factor if inshore fishing effort is moved offshore [...]” ignores the potential increase in MM mortalities or serious injuries from entanglements resulting on one hand from the increase in magnitude in fisheries interactions and on the other hand from the increase in WDA-related lines, cables, etc. whether in use or lost. In summary, all of the above adverse impacts were ranked as moderate, when they should have been elevated to major. The lower level of impact assumed may in part explain why population-level impacts were

not considered.

Several conclusions on lower impacts of IPFs on MMs were contingent on minimization/mitigation measures. However, at this time, plans for minimization/mitigation of impacts are only available for VW and, except for the approved IHA for VW's HRG and G&G surveys, are vague and either not binding or have yet to be finalized, approved, and funded. Best Management Practices (BMP) (p. A-19, Table A.5) are also very general, lacking specific requirements with performance measures or references to standard protocols. So, for the purposes of this SEIS, it cannot be ascertained which mitigation measures will be in place, whether adequate survey standards will be required and which mechanism(s) will be implemented to enforce them. These uncertainties preclude evaluation of how effective mitigation may (or not) be in reducing or eliminating impacts. Finally, for minimization/mitigation and monitoring surveys and adequate automation and integration of data collected from GPS and other devices using customized software must be available to maximize acquisition of relevant information and ensure consistency, integrity, transparency, accuracy and rapid data dissemination and reporting. In addition, all data collected should be made available on a public online repository no later than three months after the survey to allow implementation of adaptive management and independent review.

Ongoing conservation efforts to protect and recover MM stocks are likely to be considerably hindered by the proposed offshore wind energy development because for two reasons. 1) Identifying the origin of entanglements from stranded carcasses, scarred or mutilated live animals is already a significant challenge to the management of MM-fisheries interactions (Hayes et al. 2019; Knowlton & Kraus 2001; Pace et al. 2014; Robbins & Matilla 2004). The emergence of offshore wind energy will add a new possible source of entanglements from construction and operations that could be difficult to trace and could be mistakenly attributed to fisheries interactions. The magnitude of this phenomenon is not likely to be trivial considering the large spatial and temporal extents for these activities. 2) Decreasing vessel-based surveyed area from historical levels (NEFSC and SEFSC, 2018) may compromise the ability to estimate MM stock abundance and characterize distribution, habitat utilization patterns, movements, and trends in abundance of MM stocks. In turn, this affects the ability to accurately evaluate the impact of estimated bycatch levels on the various MM stocks and to evaluate the efficacy of existing bycatch reduction measures or the need for additional measures. This is significant since bycatch is the dominant threat for the MM stocks that occur in the WDA area (VW and future WDAs) (Hayes et al. 2019).

To summarize, the uniqueness of the proposed wind energy development, unprecedented in terms of the large spatio-temporal footprint and the exceptionally large number of protected MM stocks affected (~15), requires further evaluation of impacts on individual MM stocks, especially regarding individual fitness and population-level impacts, to establish whether a delay in recovery or a decline to levels that would warrant a downgrade in stock status (under the MMPA or the ESA) is probable for any of the stocks. For these slow-growing populations that are already adversely impacted by multiple factors, further evaluation should explicitly account for the detrimental impacts caused by: 1) any incremental increase in frequency/intensity of a given IPF relative to current levels from other sources (e.g, shipping, fishing), and 2) cumulative effects of all subIPFs for the proposed WDAs (VW and future) combined with projected levels of non-WDA sources. In particular, greater scrutiny at stock-level is needed for: 1) the expected increase in mortality/serious injury for each individual stock from changes in interactions with fisheries; 2) the impacts on foraging and breeding areas, as well as on migratory and other seasonal movement patterns, and 3) how WDAs might hinder existing MM management and conservation efforts.

Key Issue 8: Economics

This review focuses on 3.7 *Demographics, Employment, and Economics*, 3.11 *Commercial Fisheries and For-Hire Recreational Fishing*, 3.12 *Land Use and Coastal Infrastructure*, relevant material in Appendices

(primarily Appendices A and B)

Revenue Exposure: Revenue exposure as described in the document “quantifies the dockside value of fish reported as being caught in individual wind lease areas” (section 3.11.1.1, pg. 124 / 3-97). It is mentioned that “the revenue exposure estimate is a very conservative estimate of actual impacts,” as actual impacts depend on a variety of factors, including “the potential for continued fishing to occur within the footprint of the wind lease area” and “a vessel’s ability to adapt by changing where it fishes” (section 3.11.1.1, pg. 124 / 3-97). This description appears to miss exposure of revenues occurring outside of wind lease areas arising due to potential changes in vessel transit routes that make certain areas no longer profitable to fish. If vessel transit to or from fishing grounds is impacted by the presence of wind energy structures, revenues occurring in locations outside wind lease areas, that are reached via transit through lease areas, might be considered exposed to wind energy development. As detailed earlier, the potential economic impact of quota reductions pursuant to decreased survey capability cannot be underestimated. An economics-based MSE is essential to evaluate the probability of quota reduction and the long-term recovery effects after decommissioning due to impacts on long-lived commercially important species, particularly those that are sedentary or sessile in life style.

Shore-Based Industries: Commercial fisheries rely on a variety of shore-based supporting and value-added industries. Fishing ports are home to ancillary services such as vessel and gear maintenance as well as seafood product processing, sales, and distribution. In Massachusetts and Rhode Island, total economic impacts arising from direct, indirect, and induced impacts associated with over \$600M in commercial fishery landings are ~\$2.6B, including ~\$1.3B in value-added impacts. Including all states considered as potentially affected by future offshore wind activities (Maine to North Carolina), total economic impacts associated with the nearly \$2B in commercial landings during 2016 were estimated at ~\$7.9B, with ~\$3.9B in value added impacts (NMFS 2018; estimates do not include impacts associated with imports). Growth in the offshore wind energy industry is expected to increase economic activity and investment in ports utilized during construction, operation, and decommissioning phases (section 3.7 *Demographics, Employment, and Economics*). Increased competition for onshore facilities, services, and labor could increase market prices, raising costs and reducing competitiveness of commercial fishing and seafood businesses (note that labor impacts could extend to commercial fishing vessel crew). These points are acknowledged in a general and relatively limited capacity in sections 3.7 (*Demographics, Employment, and Economics*) and 3.12 (*Land Use and Coastal Infrastructure*). Port utilization impacts specific to the fishing industry included in section 3.11 (*Commercial Fisheries and For-Hire Recreational Fishing*) are described as primarily due to increased vessel traffic and congestion, however.

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Table 1

Observational studies

Location	Water depth	Temperature	Turbine array	Turbine size	Turbine foundation	Megawatts	Scour Protection	Study details	Study
German Bight, North Sea	• Site 2: depth 40 m		<ul style="list-style-type: none"> • Site 1: DanTysk OWF, Area 19 km × 5 km • Site 2: 80 turbines with area 41 km² • Set C: Global Tech I OWF 		• Set B: tripod foundations			<ul style="list-style-type: none"> • Observational: surface drifter data, 3 sites • Simulations: PELETS 	Callies et al., 2015
Denmark, North Sea and Baltic Sea	<ul style="list-style-type: none"> • Horns Rev: 5 - 15 m • Nysted: 6 -9.5 m 		<ul style="list-style-type: none"> • Horns Rev: 80 turbines, 14-20 m offshore, 560 m between turbines • Nysted: 72 turbines, 867 m E/W and 481 m N/S between turbines 	<ul style="list-style-type: none"> • Horns Rev: hub height 70 m, rotor diameter 80 m • Nysted: hub-height 68.8 m, rotor diameter 82.4 m 		<ul style="list-style-type: none"> • Horns Rev: 2 MW • Nysted: 2.3 MW 		<ul style="list-style-type: none"> • Observational: Satellite synthetic aperture radar • Multi-turbine study 	Christiansen et al., 2005
Belgian part of the North Sea (BPNS)		<ul style="list-style-type: none"> • May 2011:13.1-13.3°C •June 	• 6 total turbines, 500m apart at depth of 22.5 at MLWS		<ul style="list-style-type: none"> • Gravity based foundations • Diameter - 23.5 m 		<ul style="list-style-type: none"> • Scour protection system (boulders) consisting 	<ul style="list-style-type: none"> • Sampling taken around 1 of 6 turbine foundations 	Coates et al., 2013

		2012:13.5 - 13.6°C						of filter layer (crushed gravel) [diameter of 55.5m] & upper armour layer (quarried rock) [diameter 51m]		
Belgian part of the North Sea (BPNS)			C-Power wind farm					<ul style="list-style-type: none"> • Scour protection: filter layer (48m diameter); armour layer (diameter of 44m) 	<ul style="list-style-type: none"> • Observational: sampling, Multi-turbine study 	De Troch et al., 2013
Southern Baltic Sea	18 m	Surface - 12 °C	<ul style="list-style-type: none"> • 21 pitch-controlled Siemens turbines • Triangles arrangement of turbines 	<ul style="list-style-type: none"> • Hub height: 67m • Rotor diameter: 93m 	Monopiles	2.3 MW		<ul style="list-style-type: none"> • Observational (EB1 farm) and modeling: LES model PALM • Multi-turbine study 	Dorenkamper et al., 2015	
Western Coast (Irish Sea), UK			<ul style="list-style-type: none"> • Walney site: 327 wind turbines (various characteristics) • Crosby Site: mainly Burbo 	<ul style="list-style-type: none"> Hub height ranges from 83.5m to 105m 		3.6 MW - 8.25 MW		<ul style="list-style-type: none"> • Observational: Meteorological data (wind and precipitation) • Multi-turbine study 	Fahel et al., 2020	

			Bank Wind Farm				
German EEZ, North Sea	40 m	July 2014: SST 18.5°C - 19.5°C	<ul style="list-style-type: none"> • 80 turbines located 100 km offshore <ol style="list-style-type: none"> 1. Global Tech I 2. BARD Offshore I 	<ol style="list-style-type: none"> 1. GTI: Tripod 2. Bard: Tripile 	Turbines not operational during study	<ul style="list-style-type: none"> • Observational: ROTV TRIAXUSsystem. • Multi-turbine study 	Floeter et al., 2017
Southern German Bight, North Sea	33.5 m		Extrapolated results to 5000 prospective wind-power foundations		Offshore research platform FINO 1: similar in size & shape to the common jacket type foundations of wind turbines in the German Bight.	<ul style="list-style-type: none"> • Multi-turbine study 	Krone et al., 2013
Southern German Bight, North Sea	<ol style="list-style-type: none"> 1. Alpha ventus: 27- 29 m 2. Riffgat: 20 - 23 m 		<ol style="list-style-type: none"> 1. Alpha ventus-12 turbines (6 studied) 2. Riffgat-30 turbines 	<ol style="list-style-type: none"> 1. Alpha ventus-6 tripod, 6 on jackets 2. Monopiles (Diameter 6.5 - 7.5 m) 	<ol style="list-style-type: none"> 2. Scour protections of natural rock (Diameter 28 – 31 m; height 1m) 	<ul style="list-style-type: none"> • Multi-turbine study 	Krone et al., 2017
The Narrows, a tidal channel linking Stranford Lough with the Irish Sea	25miles m		<ul style="list-style-type: none"> • Monopile structure (3m diameter), 27 m long crossbeam. <ol style="list-style-type: none"> 1. Walter's Rock 2. SeaGen 3. Routen Wheel 	<ol style="list-style-type: none"> Quadropod foundation fixed on the seabed 		<ul style="list-style-type: none"> • One turbine studied at each site 	Lieber et al., 2019

									•Rotors removed for study	
Plymouth University COAST basin	Basin : 0.5 m deep		Basin: 15m long, 10m wide,	Pile diameter 5m	Scale model monopile				• Controlled experiment • Scale monopile	Miles et al., 2017
Thorntonbank, Belgian part of the North Sea (BPNS),	18-24 m		<ul style="list-style-type: none"> • 54 wind turbines • Distance between turbines: 500-800m • Surface area of farm: 18km² • Surface area of hard substrate: ~1600m² 		<ul style="list-style-type: none"> • 2 types: 1.concrete gravity based (6 turbines) 2. steel jacket foundation with four legs (48 turbines) • Diameter 14 m 		<ul style="list-style-type: none"> • Pebbles and rock • Max. radius 19 m 	• Multi-turbine study	Reubens et al., 2013	
Dutch offshore wind farm Egmond aan Zee, North Sea	17-21 m		<ul style="list-style-type: none"> • 36 Vesta V90 wind turbines (4 rows) • Diameter - 4.6m • Spacing: 650m -1km • Surface area of farm: ~40km² 		• Steel monopile	Total installation: 108 MW	<ul style="list-style-type: none"> •Revetment filter layer: small sized rocks & top layer of heavy rocks •Diameter ~25m 	<ul style="list-style-type: none"> • Multi-turbine study • Farm & surrounding safety zone (500 m) closed to shipping activities 	van Hal et al., 2017	

Modeled studies

Location	Water depth	Temperature	Turbine array	Turbine size	Turbine foundation	Megawatts	Scour Protection	Study details	Study
Lake Erie, USA	3 depths used:	• Day 90–uniform temp. (4°C)	Rectangular grid spacing	Hub height: 100m				“Infinite Extent Wind Farm” • Model: COHERENS	Afsharian et al., 2019

10 m, 25 m, 60 m • Temp. past day 90 differ by depth (max DOY 200-250) (~ 21- 25°C)

Hypothetical large wind farm	20m		5km footprint			<ul style="list-style-type: none"> • Model: MITgcm general circulation 	Broström, 2008
Eastern Irish Sea, south-western UK shelf	30m	Surface: 3 - 20°C	242 turbines	Monopile, 5 m diameter		<ul style="list-style-type: none"> • 3D unstructured grid model (FVCOM) • Multi-turbine study 	Cazenave et al., 2016
Theoretical OWF in the North Sea	SWAN: 20m Accoustic model: varies, 45-50m & 25m		<ul style="list-style-type: none"> • GETM: small wind farm • SWAN: array and farm layouts for 5 scenarios 	SWAN: 10m diameter turbine pile	SWAN: 5 MW (24 MW total capacity) Accoustic model: 5 MW	<ul style="list-style-type: none"> • Models: GETM-ERSEM-BFM, SWAN, and an acoustic energy flux • Multi-turbine study 	van der Molen et al., 2014
Gulf Coast and East Coast, USA			<ul style="list-style-type: none"> • Area spacing: 28 D² or 56 D² • Installed density: 8.39 or 16.78 (W/m²) • Number of turbines: 78,286 - 543,442 	100m hub height	5.0 or 7.58 MW	<ul style="list-style-type: none"> • Models: GATORGCMOM, GFDL, HWRF 	Jacobson et al., 2014
Eastern Lake Ontario, Kingston Basin	26 m		Simulated wind farm 130km ² area	Monopile foundation represented within model as a dry point (land),		<ul style="list-style-type: none"> • Model: Coupled wave and hydrodynamic • Multi-turbine study 	McCombs et al., 2014

				reducing wave energy					
Simulation, coast of Texas 200 m & Louisiana			<ul style="list-style-type: none"> • Wind farms are modelled using the Fitch wind farm parameterization • Enercon 126 turbines • 5 cases with different layouts used 	<ul style="list-style-type: none"> • Diameter 126 m 	7.5 MW		<ul style="list-style-type: none"> • Multi-turbine study Simulation 		Pan et al., 2018
Bay of Seine 22-31m			<ul style="list-style-type: none"> • Proposed total area of 50 km² • 10-16km offshore, 75 turbines & converter station • Footprint - 0.342 km³ or 0.70% of area 				Ecopath model - Raoux et al., 2017		Raoux et al., 2018
Havsul region, Møre coast			70 turbines (two designs tested)	<ul style="list-style-type: none"> • Diameter - 120m • Height - 90m 			Wake model		Segtnan et al., 2015

Combined studies

Location	Water depth	Temperature	Turbine array	Turbine size	Turbine foundation	Megawatts	Scour Protection	Study details	Study
German Bight	40 m	<ul style="list-style-type: none"> • Observed range: 14- 22°C 	Distance between turbines:		<ul style="list-style-type: none"> •Bard 1: "tripile" •Global Tech 1: 	•Bard 1: 3 MW		•Combination of idealized modeling and in situ measurements	Carpenter et al., 2016

		<ul style="list-style-type: none"> • Bard 1: 866m • Global Tech 1: 733m 	<ul style="list-style-type: none"> • Length of farm: <ul style="list-style-type: none"> • small 8km • large 100km 	<ul style="list-style-type: none"> • “tripod” foundation 	<ul style="list-style-type: none"> • Global Tech 1: 15 MW 	<ul style="list-style-type: none"> • TRIM-NP hydrodynamic model • Observations: glider, mooring, ADCP GETM 		
US East Coast	varying: $\geq 30\text{m}$, 31-50m, 51-200m	10 diameters square spacing	Rotor diameter: 126m	<ul style="list-style-type: none"> • $\geq 30\text{m}$: monopiles/gravity • 31-50m: multi-leg • 51-200m: floating 	5 MW	<ul style="list-style-type: none"> • Model (WRF) and observational (buoys, offshore towers) • Multi-turbine study 	Dvorak et al., 2013	
Nysted offshore wind farm, Danish part of W. Baltic Sea	6-9.5m	<ul style="list-style-type: none"> • Observed: 8-20°C • Modeled : 0-24°C 	<ul style="list-style-type: none"> • 72 turbines in an 8x9 grid • Spacing: 850m (E-W) & 480 (N-S) • Total area of 28km² 	<ul style="list-style-type: none"> • Conical with cylindrical shaft • Diameter - 4.24 m; height - 3m; base - 16m wide hexagonal 	<ul style="list-style-type: none"> • Basement filled with gravel and stones. Upper median diameters 0.70m. 	<ul style="list-style-type: none"> • Scour protection stones with thickness of 0.27-1.10m placed around foundation • Outer diameter: 25m 	<ul style="list-style-type: none"> • DEB-model coupled to a small-scale 3D hydrodynamicbiogeochemical model (validated against field measurements) 	Maar et al., 2009

