

BEST PRACTICES FOR BASELINE PASSIVE ACOUSTIC MONITORING OF
OFFSHORE WIND ENERGY DEVELOPMENT

by

Jordan Carduner

Dr. Douglas Nowacek, Adviser

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ABSTRACT

Baseline data are critical to assess potential disturbances to the environment. In the absence of baseline data, it is impossible to accurately quantify anthropogenic impacts. Instances in which baseline data were not collected have left critical gaps in knowledge for researchers and environmental managers attempting to comprehend impacts to the environment and mitigate those impacts.

The anticipated proliferation of offshore wind energy projects in the United States represents both a critical data need and an opportunity to apply the lessons of the past. Offshore wind projects are expected to increase significantly in number and magnitude, amplifying their potential impact on the marine environment. This impact can only be accurately measured if the environment is characterized prior to wind farm development, so it can be compared to data collected during construction and operational phases.

Data collection can be particularly challenging in the marine environment. Passive acoustic monitoring (PAM) provides a useful way to track long-term trends in natural biological and human activities at sea because many of these processes and animal behaviors are accompanied by, or depend upon, sound. Thus PAM provides a unique opportunity to track noise levels, biological activities, and to characterize the local marine soundscape before, during and after wind farm development.

This Masters project points to research demonstrating the utility of baseline data collection and reviews the current literature related to the use of baseline PAM at offshore wind projects. Methods for accommodating the limitations of PAM are addressed and best practices are suggested for the use of passive acoustics to effectively characterize the marine environment in relation to future offshore wind development.

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1. Introduction

Baseline data are critical to assess potential disturbances to the environment. In the absence of baseline data, it is impossible to accurately quantify anthropogenic impacts. Instances in which baseline data have been collected prior to environmental change have proven the value of such data [1]. Meanwhile, the cases in which baseline data were not collected have left critical gaps in knowledge for researchers and managers attempting to comprehend the impacts to the environment and mitigate those impacts [2].

The anticipated proliferation of offshore wind energy (OWE) projects in the United States and abroad represents both a critical data need and an opportunity to apply the lessons of the past. Offshore wind projects are expected to increase significantly in number and magnitude, amplifying their potential impact on the marine environment. This impact can only be accurately measured if the environment is accurately characterized prior to wind farm development, so it can be compared to data collected during construction and operational phases. Offshore energy development has been characterized to this point by a lack of baseline data collection and thus an inability to accurately monitor environmental impacts. It remains to be seen whether or not the lessons of the past have been learned and will be applied to the offshore wind industry.

Data collection can be particularly challenging in the marine environment. Some of the more commonly used methods for observation and data collection at sea include vessel-based and aerial visual observation, various types of tagging, active acoustics such as SONAR, and passive acoustic monitoring (PAM). Of these methods, passive acoustic monitoring provides a particularly useful way to track long-term trends in natural biological and human activities at sea because many of these processes and animal behaviors are accompanied by, or depend upon, sound. Despite the utility of PAM for marine environmental assessment, the technology is still not being fully utilized in the monitoring of wind farm development.

2. Noise in the Sea

Unlike light which attenuates rapidly in water, sound has the ability to travel great distances. The ability of sound to be transmitted efficiently in water amplifies the impacts of anthropogenic noise in the sea [3]. Several factors can affect the way sound is transmitted underwater, including depth of source and receiver, salinity, tidal influence, and substrate [4]. While high frequency sound attenuates relatively rapidly, low frequency sound has the ability to propagate over great distances [5].

Noise levels in many of the world's oceans have increased significantly over the past century as a result of anthropogenic sources including shipping, commercial and military activities at sea [6]. These anthropogenic sources of noise in the sea are becoming more intense and widespread, contributing to both increased ambient noise levels and peak sound intensity [5]. One long-term study of ambient ocean sound found an increase of between 3-10 dB off the California coast between 1963 and 2001 [7] while another study in the Northeast Pacific found a 10-12 dB increase in ambient noise from 1964 to 2004, an average increase rate of 2.5-3 dB per decade, associated with increased vessel traffic [8]. Shipping noise in particular has increased the levels of ambient sound throughout the sea, with deepwater ambient noise in the 20-to 200-Hz band increasing 10- to 100-fold since the advent of large-scale industrial shipping [6].

2.1 Impacts on animals

Many marine animals have adapted to the way in which sound propagates in water by developing novel ways of using sound to communicate and forage [6]. These animals have evolved in an ocean filled with natural sources of sound, thus anthropogenic noise introduced to the underwater soundscape can have a profound impact on their fitness and survival. Because many marine animals rely upon sound for communication and hearing, anthropogenic noise sources can have harmful effects on marine life including fish [9], marine mammals [10] and cephalopods [11].

All cetaceans depend on the ability to both send and receive sound for communication, to detect and capture prey, and to gain information about the environment [12]. The low-

frequency calls of mysticetes including the fin whale (*Balaenoptera physalus*) and blue whale (*Balaenoptera musculus*), which are assumed to function as mating calls, have the ability to travel hundreds of kilometers from their source [13]. Some species of beaked whales have developed two distinct click types, one seemingly for target detection and classification and another for prey capture [14]. Weiss et al. found that resident killer whales (*Orcinus orca*), which live in stable matrilineal family groups, each with its own group-specific “dialect” of up to 17 discrete call types, also exhibit “significant changes in vocal behavior depending both on the presence and identity of accompanying whales.” [15]

The extent to which a marine animal is impacted by underwater sound depends on several factors including the animal’s sensitivity level as well as the sound’s particular frequency characteristics, duration, and transmission characteristics in water [16]. High intensity anthropogenic noises in the marine environment include pile driving, military sonar and seismic testing. Despite their relatively short duration, these noises are more likely to have acute impacts such as physical injury or hearing loss on marine animals [16]. Bottlenose dolphins (*Tursiops truncatus*) for instance have demonstrated susceptibility to temporary hearing loss resulting from exposure to mid-frequency sonar [17].

When noise impacts on marine animals are considered, the emphasis is typically on amplitude alone, whereas the broader context of environmental, biological, and operational variables that certainly influence an animal’s response to noise should also be accounted for [18]. Long-term, low frequency noises, such as those that originate from ships and operational wind turbines, can impact marine animals in several ways. Rather than causing injury or short term behavioral responses, these noises can impede the ability of marine mammals to hear, recognize, or interpret sounds, a phenomenon known as “masking” [19]. Other potential impacts include chronic stress and long-term behavioral shifts [20]. Endangered North Atlantic right whales (*Eubalaena glacialis*) have been shown to increase the amplitude of their calls amid increased background noise [1], while Humpback whales (*Megaptera novaeangliae*) have demonstrated a reduced level of communication concurrent with a nearby remote sensing experiment

[21]. Concern is increasing over the risks of chronic exposure to these low intensity noises that represent a constant and increasing presence in the sea [6].

Despite recent research on both the importance of sound to marine organisms and the impact of anthropogenic noise in the marine environment, a great deal remains unknown. The uncertainties regarding how animals are impacted by noise, coupled with the complexity and dynamic nature of the marine environment, underscore the importance of baseline data collection. In order to accurately quantify long-term changes to the environment, measure impacts to marine animals, and develop mitigation strategies, the extent to which noise impacts the marine environment must be measured before, during and after those changes take place.

2.2 Passive Acoustics

Because many marine biological activities are accompanied by sound, acoustic monitoring is useful to track natural biological activity and any changes in that activity as a result of human impacts. Likewise, many anthropogenic activities at sea, such as shipping, construction, and military exercises are accompanied by introduced noise, thus acoustic monitoring represents a useful means to assess and track these activities.

Acoustics is also useful in monitoring ambient sounds in the sea, such as weather and waves. The term “passive acoustic monitoring” refers to the use of received signals to characterize the acoustic environment (as opposed to “active” acoustics, such as SONAR, which entail the transmission of a sound and the monitoring of the echo received) [22].

Passive acoustic monitoring has the potential to mitigate the limitations inherent in visual observation as a means of data collection at sea. The utility of visual data collection in the marine environment is limited to certain conditions: daylight hours, calm sea states, good weather, and alert human visual observers [23]. Visual observations at sea are also limited primarily to the monitoring of species that must surface to breathe, and those that do surface to breathe may do so only occasionally. Passive acoustic recording can operate 24 hours per day in virtually all weather conditions, and is not limited to detection at the surface of the water.

In a study off the coast of New Jersey, researchers performed acoustic and visual (vessel-based and aerial) surveys to assess right whale presence in an area under consideration for OWE development. During 97 days in which both visual observation and PAM were employed, there were 94 days when whales were detected acoustically and not visually, and only one day in which whales were seen but not heard [24]. The results of this study reinforce the utility of PAM in monitoring the marine environment.

Passive acoustics also represents an effective means to characterize anthropogenic noise inputs in the marine environment. The ability of sound to propagate effectively underwater can magnify the environmental impact of activities that involve intense noise levels, such as pile-driving. Thus PAM provides a unique opportunity to track noise levels, biological activities, and to characterize the local marine soundscape before, during and after offshore wind development.

3. Baselines in context

Baselines in environmental data are crucial as they allow for the accurate measurement of change over time. In the absence of accurate baselines, it is impossible to assess anthropogenic changes to the environment and to make informed conservation and management decisions to mitigate those changes. Yet having baseline data in marine science – defined here as data that characterize the environment prior to large scale human intervention – is exceedingly rare. This is likely a result of poor record keeping, the common pool nature of marine resources, and the sheer inaccessibility of many marine organisms and ecosystems until very recently. The lack of accurate baseline data has led to a phenomenon known as “shifting baselines” whereby present day or very recent environmental states and species numbers are accepted as representative of historical conditions and numbers [2] . This can result in underestimation of anthropogenic impacts and can lead environmental managers to base conservation targets on figures that fail to account for actual baseline numbers and conditions.

Where true baseline data in the marine realm do exist, they are generally limited to commercially important fish species. Even these numbers are often inaccurate as they are

inevitably derived from landings data, which are notoriously unreliable as indicators of actual population health [25]. Meanwhile “discontinuous time series, discrete data points or incomplete datasets, inconsistent collection methods, and changes in fishing technology over time” [26] make the comparison between historical and present data problematic.

Passive acoustics is a relatively recent method to monitor the marine environment, but it has already proven a useful means to establish baselines. In the Gulf of Mexico, static PAM recorders deployed by the Littoral Acoustic Demonstration Center (LADC) collected acoustic data in 2001, 2002 and 2007, in an effort to develop individual identification methods for GoM sperm and beaked whale populations [27]. In 2010, the Deepwater Horizon oil rig exploded only 9 miles from one of the locations where PAM data loggers had been deployed in 2007. Following the oil rig disaster, PAM recorders were re-deployed to the same locations, 9, 25, and 50 miles away from the Deepwater Horizon site. Ackleh et al. used the recorded data from all years to extrapolate population density figures for sperm whales, concluding that the estimated sperm whale abundance decreased by a factor of 2 at the recording site nearest the Deepwater Horizon, while abundance increased at the site 25 miles from the well blowout [28]. The baseline PAM data provided the opportunity to investigate how marine mammals were impacted by the disaster, demonstrating that they left the area likely as a direct result of contamination or because of increased vessel traffic in the area [28].

An ongoing study of hormone stress levels in North Atlantic right whales associated with shipping in the Bay of Fundy, Canada, resulted in the “unplanned” collection of baseline data [29]. Data collection was ongoing when the terrorist attacks of September 11, 2001, took place. Immediately following those events, shipping in the area decreased dramatically. Acoustic surveys found that the temporary decline in shipping resulted in a 6 dB decline in underwater noise. Rolland et al. found a reduction in the levels of faecal hormone metabolites related to stress levels that were concomitant with the decrease in shipping noise. Though previous acoustic studies had shown that right whales modify their vocalizations when in the presence of low-frequency noise [1], this study showed

that those altered call patterns are associated with increased stress levels, and established a previously unknown baseline for those stress levels [29].

Because actual baseline data are generally scarce in the realm of marine science, researchers have attempted to fill the data gaps by extrapolating baselines from historical and non-traditional sources such as fisheries archives, molecular markers, paleontological and archaeological records, and interviews with fishers [30] [31]. Luiz and Edwards used quantitative and qualitative measures to analyze historical records from books, naturalists' observations and scientific papers dating back to the 18th century in an attempt to determine whether an extinction occurred in the carcharhinid shark population in the area of St. Paul's Rocks, concluding that the Galapagos shark (*Carcharhinus galapagensis*) had indeed become extinct since the advent of large-scale fishing [32]. McClenahan used historical photographs of the recreational fishery in Florida to estimate changes in size and species composition among reef fish from 1956 to 2007 and found "a major shift in species composition" as well a significant reduction in average fish size, including a 50% decline in the average length of sharks over a 50 year span [33].

Traditional fishing knowledge is often the only source of information on the prior state of many marine ecosystems. Interviews with local fishermen (n=108) in the Gulf of California indicated a reduction in the catch of Gulf grouper (*Mycteroperca jordani*) by as much as 25 times (regression $r(2) = 0.62$, $p < 0.001$) over the span of just three generations [34]. While information from fishers is invaluable in re-creating baselines, evidence suggests that traditional knowledge is also subject to "shifting baselines" as younger generations are less likely to report changes to the environment [35] [34].

The attempts to back-calculate baselines from historical records are necessary because of the absence of actual baseline data. But when the opportunity exists to collect data prior to an anticipated change to the environment, such as that which is likely to accompany OWE development, that opportunity should not be missed.

4. Potential acoustic impacts of offshore wind

Offshore wind projects have the potential to introduce noise to the marine environment via the construction process, turbine operation, and increased vessel traffic due to construction and maintenance. Characteristics of sound transmission from these sources depend on environmental conditions such as depth, salinity, and substrate. Thus the acoustic impacts of these activities will vary by location as well as specifics of the project, e.g., number and size of turbines. Results of modeling and the limited number of sound transmission studies at offshore wind farms provide a starting point for estimating the acoustic impacts of OWE on the marine environment.

4.1 Construction

Offshore wind projects add several types of noise to the marine environment, but pile driving associated with the construction process generally introduces the highest noise levels [36]. The majority of OWE projects throughout the world currently incorporate turbines mounted on single steel piles (“monopiles”) that range in diameter from 3.5 to 6.0 m [37]. Monopiles are popular in OWE construction because of their simple design and well-established installation method. Impact pile driving, in which piles are driven into the seabed by powerful hydraulic hammers, represents one of the loudest potential sources of anthropogenic noise in the marine environment [3]. Pile driving noise results from a quick release of energy when an object hits another, in this case the hydraulic hammer and the pile [38]. The energy then radiates from the impact site through the air, the water column and the seafloor [3]. At a demonstration OWE site in Northeast Scotland, Bailey et al. report that it took 5000–7000 blows from the hydraulic hammer to install each pile during the construction of wind turbines in water 42m deep [16].

Pile driving sounds occur primarily at low frequencies, thus they have the potential to transmit great distances underwater [3]. Recording at the Horns Rev I wind farm, Tougaard et al. found peak energy from pile driving at 160 Hz, though significant energy was also detected up to 100kHz (the upper frequency limit of the T-POD used for recording) [39]. Bailey et al. measured pile driving noise during construction of deep water wind turbines in Scotland’s Moray Firth and found peak energy from 100 Hz to 2

kHz, with significant energy up to 10 kHz [16]. Robinson et al. reported primary frequency content to be around 200-300 Hz, but also reported “frequency components present at high tens of kilohertz [40].” These measurements indicate that pile driving may be detected by animals that communicate and detect sound at both very low frequencies, such as baleen whales and fish, as well as at very high frequencies such as dolphins and porpoises.

The high intensity sound levels produced by pile driving have raised concerns about effects on marine mammals and fish, from disturbance to the potential for injury at close range [41]. In 2011 the UK’s National Policy Statement for Renewable Energy Infrastructure reported that pile driving associated with OWE construction may reach noise levels high enough to cause injury or death to marine mammals [42]. Thomsen et al. estimated the possibility for behavioral response in harbor porpoises could extend up to 20 km from the sound source based on measurements of pile driving noise in the German Bight [43]. Results of a pile driving impact study at the Horns Rev I offshore wind farm showed the zone of behavioral response for harbor porpoises extended more than 20 km from the source, and possibly further [39].

Potential avoidance responses in fish to the extremely high SPLs related to pile driving could impact their ability to effectively locate mates and find food [44]. Based on measurements of pile driving noise and the hearing sensitivities of cod and herring, estimates are that these commercially important species will be able to perceive pile driving noise “at large distances, perhaps up to 80 km from the sound source [43].”

In an effort to measure behavioral responses of marine fish to pile driving, Mueller-Blenke et al. played back pile driving sounds to cod and sole held in net pens and tracked responses with acoustic devices. They found a “significant movement response to the pile-driving stimulus in both species at relatively low received SPLs” ranging from an increase in swimming speed to a freezing response. [44]. A five year baseline study at the Scroby Sands wind farm off the coast of England found a significant decrease in the

herring population during and after the construction period. Monopile construction during the herring's spawning season was posited as responsible for the decline [45].

The impacts of pile driving on the marine environment almost certainly extend beyond marine mammals and fish. At Scroby Sands, the decline in the herring population coincided with “a significant decline in foraging success” among the local population of little tern (*Sternula albifrons*), including egg abandonment and failure of chick hatching at a level that had not previously been documented [45]. The results of this study reinforce the importance of assessing ecosystem-wide impacts from OWE construction, rather than looking solely at impacts to a single species.

Another study at Scroby Sands wind farm found a significant decline in the use of a haul out and breeding site by harbor seals (*Phoca Vitulina*) and Atlantic grey seals (*Halichoerus grypus*) that coincided with the construction phase. While turbine construction could not be definitively linked with the abandonment of the site, the absence of other environmental factors led the authors to conclude that either increased vessel traffic or pile driving noise were the likely causes of the decline in seal activity [46].

According to the European Wind Energy Association, monopile construction accounted for 73% of offshore wind substructures built in 2012 [47]. Other, less frequently used construction methods have the potential to mitigate some of the environmental impacts resulting from monopile construction. Vibratory pile driving utilizes unbalanced vibrators, rather than hydraulic hammers, to install small piles. Research has demonstrated that vibratory pile driving may reduce noise impacts by 15-20 dB, though the technique is limited to certain substrates and is only useful with small piles [48]. Gravity-based foundations are generally made of concrete and are secured to the seafloor by the sheer weight of the substructure and ballast. This method does not require pile driving, and environmental impacts are limited to the preparation of the seabed, but the use of gravity-based foundations is limited to depths of less than 10m [49]. Floating support structures are only attached to the seabed with anchor lines, relying on the water

rather than the seabed for support [50]. Because of the minimal impacts to the seabed, this method holds the potential to reduce environmental impacts of OWE construction. Only a few floating support structures are currently in use, including at HyWind in Norway and Portugal's Windfloat project [50]. But as OWE projects move further from shore and into deeper water, where monopile and gravity-based structures are logistically impossible, this method – which can be used at depths of greater than 100m – could represent an increasing share of future offshore wind construction.

Aside from turbine installation, other potential noise sources during the construction process include dredging and rock laying for scour protection, the laying of cable from wind farm to shore, noise from increased vessel traffic, and the installation of other structures such as offshore transformers [51].

4.2 Operation

Underwater operational noise originates primarily from machinery located in the top of the turbine including the gear box and generator [52]. Operational turbine noise is concentrated at low frequencies. Measuring turbine noise at the Horns Rev I wind farm in the Danish North Sea, Betke found sound pressure levels (SPL) concentrated at two spectral lines at approximately 150 Hz and 300 Hz, with no sound detectable above 800 Hz, and a maximum sound level of 122 dB re 1 μ Pa at 100 m from the turbine [53].

Impacts to marine animals from operational turbine noise are likely to be less acute than those resulting from turbine construction [53]. But long-term impacts of operational noise are difficult to assess and could have wide-ranging impacts on marine life and the underwater soundscape. Potential impacts to cetaceans and pinnipeds include behavior modification, masking, or abandonment of critical habitat.

Modeling the acoustic impacts of operational wind farms on three species of fish (Atlantic salmon, cod and goldfish), Wahlberg and Westerberg found that turbines could be detected at a distance of between 0.4 and 25 km depending on species, and that while physical injury was unlikely, the potential for masking communication and orientation

signals remained a possibility [54]. Thomsen et al. found that operational turbine noise could be detectable by dab and salmon up to 1 km and by cod and herring up to 4 km, with the potential for communication masking within these zones [43]. Based on modeled audibility, Tougaard et al. found operational turbine noise seems unlikely to cause behavioral reactions in porpoises unless they are very close to a turbine, but that behavioral reactions in seals is possible within a few hundred meters from a wind farm [52].

Given the current rapid expansion of OWE development, noise generated from operational wind turbines will continue to increase throughout the world's oceans. Wind farms have an estimated operational life span of approximately 30 years [55], thus operational turbine noise has the potential to become a ubiquitous presence in the world's oceans. Acute impacts of noise exposure tend to attract the most research and attention, but "the more significant risk to populations of marine mammals is likely to stem from less visible effects of chronic exposure" to anthropogenic noise inputs in the sea [6].

4.3 Increased vessel traffic

Vessel traffic will inevitably accompany every phase of offshore wind development, from construction to operation to de-commissioning. This vessel traffic, which ranges from large barges required to transport construction materials to small vessels needed to transport crew, will add to the acoustic impacts to the marine environment both within the wind farm site and between the wind farm and land [51]. Underwater noise from these vessels is dominated by propeller noise that results from cavitation [51].

Unlike turbine noise which represents a near-constant presence during operation, vessel noise is intermittent and resulting impacts depend on the number and type of vessels required as well as the quantity of vessel trips necessary [56]. The cumulative impacts of this vessel noise on the marine environment over the 30-year lifespan of an offshore wind farm are difficult to quantify, though studies on cetaceans have demonstrated that vessel noise affects communication and behavior [29] [1].

4.4 Mitigation tools

Several methods may be employed to mitigate pile driving construction noise. Bubble curtains deployed around piles during pile driving absorb sound energy directly and also act as a reflector of sound due to the impedance mismatch between air and water [57]. Bubble curtains have been shown to attenuate sound by up to 14 dB, and have also been effective in reducing behavioral reactions to nearby pile driving activities among captive harbor porpoises [57]. “Soft start” or “ramp up” procedures gradually increase the intensity of impact pile driving, essentially providing an early warning and an opportunity for any animals that are capable to leave the area before high impact pile driving begins [3]. Casings placed directly outside the individual pile, made either of foam or hollow inside, have been demonstrated to reduce SPL by 8 to 14 dB [3].

5. Case studies: Baseline PAM at offshore wind projects

Thus far, peer-reviewed literature on the use of baseline PAM to assess acoustic impacts at OWE developments has been limited to just a handful of studies. These studies examined potential impacts of OWE construction and operation on single species rather than broader changes to the acoustic environment. Because of this specific research focus, all studies utilized data loggers with a narrow frequency band suited to isolate and identify acoustic signals from the species being studied. Studies were thus able to draw conclusions on OWE impacts on specific species, but not on broader changes to the marine environment. Despite these potential limitations, there are valuable lessons to be drawn from this body of research in terms of survey design and methodology.

5.1 Locations

All study locations were located in European waters, not surprising given that Europe has pioneered the development of offshore wind. The scale of the projects ranges from very small (2 turbines) to what was at the time of the study very large (80 turbines). It is worth noting that OWE projects currently in the approval stages in parts of Europe such as the U.K. will make even the largest OWE projects among these studies seem small by comparison. The OWE study sites included the following:

Nysted wind farm is located in the Baltic Sea off the southeastern coast of Denmark. It is comprised of 72 turbines [58], installed at a depth of 6 to 10 meters. Turbines were installed on gravity-based foundations rather than piles, due to the prevalence of sea ice in winter. The use of gravity-based foundations would theoretically mitigate construction-based noise, since most of this noise usually results from the pile-driving process [cite]. However, one of the turbines at Nysted required stabilization with steel sheet piles, which were installed with a vibratory pile driver. The vibrator and the pile driver operated intermittently for between 1.5 to 10 hours over a total of 25 days [59]. Construction on Nysted was completed in 2003.

Egmond aan Zee Windpark was the first major offshore wind farm built in the Dutch North Sea, comprised of 36 turbines over 27 km² [60]. The Dutch government established a formal monitoring program as part of the commissioning of Egmond aan Zee. The monitoring program that ran from construction in 2006 through operation in 2012 included research into the project's impacts on the acoustic ecology of the area, specifically the impacts on harbor porpoises (*Phocoena phocoena*). The turbines at Egmond aan Zee were constructed on monopile foundations, requiring pile-driving.

Horns Rev I was built in 2002 making it the first offshore wind farm in the North Sea. Consisting of 80 turbines, it was the largest OWE in the world at the time of construction [cite]. The wind farm lies 14 km west of the Denmark coast, at a depth of 6-12 meters. Horns Rev I turbines were constructed on monopiles, requiring pile-driving during construction.

Horns Rev II consists of 91 turbines located in the North Sea off western Denmark. When construction finished in 2008 it was the largest OWE project in the world and also the furthest from shore [61]. Turbines were constructed on steel monopiles.

Beatrice Wind Farm Demonstrator Project, located in the North Sea off northeast Scotland, consists of just two wind turbines at a depth of 45 meters. Constructed on monopile foundations in 2007, the project was designed as a demonstration to test the

feasibility of commercial OWE development in deep water, and was to be de-commissioned after five years. The turbines are located 24 km from a special area of conservation (SAC) which is home to a resident population of Bottlenose dolphins (*Tursiops truncatus*). Concerns over the turbines' potential impacts on *Tursiops* led Talisman Energy to commission a study with the University of Aberdeen. In 2009, the Crown Estate of the U.K. took the first steps toward approval of a wind farm 11 km from the Beatrice Demonstrator site that will contain between 142 and 277 turbines spanning 131 km² [62].

5.2 Data recorders

All of the published studies we reviewed relied exclusively on the T-POD to record and analyze acoustic data. The T-POD, designed by Chelonia Limited, is a stationary passive acoustic data logger designed specifically to detect the acoustic signals of cetaceans. The device incorporates a hydrophone, an analog processor, a digital timing and logging system and digital memory storage into a submersible housing. It can be programmed to detect specific frequency bands according to the targeted species, with 16 bands available ranging from 9 kHz to 170 kHz. The duty cycle can be set by the user.

The T-POD uses dedicated software to analyze and filter received acoustic data by identifying cetacean clicks, which can be distinguished from other sounds within the same frequency bands based on their unique patterns known as “click trains”. It performs this analysis in real-time and only records data that it identifies as originating from the target species [63].

The majority of the studies reviewed employed T-PODs to collect data specifically on *Phocoena phocoena*. Designers of the studies set frequency ranges accordingly, with the target filter at 130 kHz and a reference filter at 90 kHz [39, 56, 59, 64, 65]. One study attempted to identify OWE impacts on both harbor porpoises and on common bottlenose dolphins (*Tursiops truncatus*), and thus set target frequency bands at both 130 kHz and 50 kHz, in an attempt to capture the respective acoustic signals of both species [66].

The T-POD isolates porpoise signals from other sounds by comparing acoustic signals received in both frequency bands. Signals with significantly more energy within the higher frequency band, and that are shorter than 200 micro-seconds, can reliably be identified as originating either from a porpoise (or from a human-generated sound such as an echo sounder) [56]. Thus the T-POD is particularly well suited to detect porpoise echolocation, as porpoise click trains reliably fall within a relatively narrow frequency band, with the majority of the energy occurring in the range of 120-150 kHz [56]. The T-POD has also been found to be effective at identifying the signals of *Tursiops truncatus* in the wild [67]. T-PODs were employed to measure the presence or absence and the activity level of targeted species.

The T-POD is effective at targeting narrowband and high frequency acoustic signals such as those associated with odontocetes. It is not designed to capture broadband sounds or sounds that occur at low frequencies. These low frequency sounds are characteristic of much of the noise found in the sea including most ambient sound, sounds associated with many fish species, calls associated with most mysticetes, and anthropogenic sound including shipping noise and operational wind turbine noise.

5.3 Methodologies and results

While all studies employed the T-POD as the sole data recording device, study design varied in terms of number of data loggers deployed and the spatial and temporal patterns of deployment. This was partially a result of diverse environmental conditions at the various OWE sites, and partially a result of more recent studies adapting their methods to improve on those that had come before. This review was limited to studies that employed PAM prior to wind farm construction in order to capture baseline data. The majority of studies also recorded acoustic data during and after the construction phase, though some recorded during only construction or only post-construction. All studies employed a control site, so that any changes in species abundance or behavior could theoretically be associated with acoustic impacts related to OWE construction. See Table 1 for a summary of study results.

In attempting to characterize the impacts of the Nysted OWE on harbor porpoises, Carstensen et al. employed a BACI (before-after-control-impact) study. The BACI methodology requires that data be collected both at an impact site and a control site, and both before and after an environmental change [68]. A total of 6 T-PODs were deployed, 3 each within both the impact (wind farm) site and the control site. The 3 data loggers deployed within the impact site were arranged 1.9 km apart from one another in a triangle formation covering the central area of the wind farm. These recorders were at distances of 2.1, 4.0 and 4.0 km from pile-driving activity. The 3 data loggers placed within the control site were deployed in a North-South transect in order to avoid shipping lanes, with 1.9 km spacing between data loggers (total 3.8 km between recorders at the far north and far south) at distances of 15.3, 15.4 and 15.7 km to the pile-driving source. The control site was chosen “to reflect similar bathymetry, bottom features and distance from shore as the impact area [59].” Depths within the wind farm and at the control site ranged from 6-9.5 meters.

The baseline recording period ran for 8 months, from November 2001 to June 2002. Recording during the construction period ran for 17 months, from July 2002 to November 2003. The authors reported a significant decrease in porpoise echolocation activity in the wind farm site relative to the control site during construction activities [59]. The average time between porpoise click trains (the average period of time when no porpoise activity was detected) increased from the baseline period to the construction period at all recorders, but the increase was considerably larger at the recorders located within the wind farm area.

The authors made the assumption that echolocation activity is correlated to porpoise density [59]. Thus they concluded the decrease in echolocation click trains from the “baseline” period to the “construction” period is evidence of porpoises having abandoned the impact area. Whether this was the case or porpoises merely reduced their communication level, results seem to demonstrate significantly altered porpoise behavior correlated to OWE construction activity.

Teilmann and Carstensen followed up in 2012 by publishing updated results from the same study. Data were collected at the site continuously since the first study was published, allowing comparison of porpoise activity before, during and after construction. In total, the study ran for ten years (2001 – 2012) making it the only true long-term study of OWE impacts on the marine environment. This study divided data collection into a baseline period, construction period, and four “operational” periods of approximately the same length. Because the initial study reported a significant decrease in porpoise activity associated with wind farm construction, the authors sought to measure whether porpoise behavior in the years post-construction indicated a gradual acclimatization to the operational turbines [69]. The authors reported a “significant increase in echolocation activity” from the construction period to the four operational periods, particularly within the impact area, though porpoise activity within the impact area has yet to return to the baseline level of activity. There was no obvious pattern of acclimatization, as the second construction period out of four chronological periods contained the highest level of porpoise activity [69].

Scheidat et al. used T-PODs to conduct a B-A-C-I analysis quantifying the effect of the Egmond an Zee windpark on porpoise activity. Baseline data were recorded for one full year (June 2003 – June 2004) prior to wind farm construction. Notably, the study did not record data during wind farm construction. Another two full years of recording (April 2007 – April 2009) were carried out at the site following construction, during normal operation of the wind farm. Thus the authors sought to quantify the impacts of an operational OWE on harbor porpoises.

The study used a total of eight data loggers. Two T-PODs were arranged within the wind farm, at least 260 m from the nearest turbine. Three T-PODs were placed in two reference areas (six total reference T-PODs) approximately 10km North and 10km South of the wind farm. All data loggers were placed at least 1.8 km from one another in order to ensure that data recorded would be exclusive to that particular T-POD. Reference areas were selected to be far enough from the wind farm so that they would not be directly influenced by turbine operation, but close enough that they displayed “similar overall

biotic and abiotic environmental conditions as in the wind farm.” Water depths within the wind farm range from 15–19 m [60]. The authors do not explicitly state the depths at the six control sites.

Results from Scheidat et al. found an overall increase in porpoise activity from baseline to post-construction period inside the wind farm relative to the control area. Because the study did not record data during turbine construction, porpoise response to construction at Egmond aan Zee is impossible to assess. But studies at OWE sites that were constructed with monopile foundations, similar to those used at Egmond aan Zee, have shown a significant decrease in porpoise activity within the impact zone during the construction period [39, 64]. If porpoises at Egmond aan Zee reacted similarly, then results from Scheidat et al. seem to indicate that “either there was little long-lasting construction effect on harbour porpoise distribution...or that recovery after construction occurred fairly quickly.”[65]

Thompson et al. conducted a B-A-C-I study at the Beatrice Demonstrator project to measure impacts of turbine construction and operation on both harbor porpoises and bottlenose dolphins. Researchers deployed 2 T-PODs for 2½ years during baseline, construction, and post-construction operational phases, one located within the construction site and another at a control site 40km away. Data were successfully recorded over 80% of the 2 ½ year period, though the data logger at the impact site had to be moved 1.5 km from its original site in the midst of construction as a result of engineering activity.

Ultimately the detection of animals at the control site was so low during all recording phases that the site proved useless for comparison. Likewise, dolphin detections were very low at the impact site, leaving only impacts on harbor porpoises to be examined. Impacts on porpoises were largely inconclusive, partially due to the limited utility of the control. The authors concluded that due to the potentially broad spatial scale of the acoustic impacts from OWE, the B-A-C-I design may be too limited to draw meaningful conclusions, recommending that further studies employ a gradient sampling design to

measure impacts at several distances from the OWE site. [66] It was also discovered that other potentially disruptive acoustic events had taken place in the area in July and August 2006, including seismic testing and hydrographic tests. Reliability of results was further limited as impacts of Beatrice on porpoise activity could not be isolated from impacts of the other anthropogenic noises due to a lack of data on source levels and locations for these noise sources.

The study was notable in that it incorporated “ground truthing” in the form of marine mammal visual observers (MMO) in an effort to mitigate some limitations inherent in PAM. The observers were able to confirm that the dolphins in the area were more likely to be common dolphin rather than the *tursiops* that researchers were attempting to detect. This confirmed both the utility of ground-truthing, and the limitation that PAM technology is not yet able to accurately distinguish all individual species.

Brandt et al., studying the impacts of construction on harbor porpoises at Horns Rev II, employed a novel gradient sampling design to overcome the challenges described by Thompson et al. A total of 8 T-PODs were deployed in 6 locations along a transect line extending from within the construction area, across a reef and into the area south of the reef where Horns Rev I wind farm is located [64]. Distance between data loggers was 1.5 to 8 km, while distance from data loggers to wind turbines ranged from 0.5 to 25 km. Data was recorded during a baseline period of 5½ weeks (8 April to 18 May 2008) and then for 5 months during construction (19 May - 14 Oct 2008). Notably, baseline data was recorded during a different season versus construction recording, representing a challenge to accurate comparison between the two periods.

Results showed a significant decrease in porpoise activity from baseline to construction detectable at distances up to 17.8 km. At 2.6 km from the construction site, porpoise acoustic activity ceased entirely during 1 hour after pile driving and remained well below baseline levels for 24 to 72 h at that location. The period of inactivity decreased gradually with distance from the construction site. At 22 km from the site, porpoise activity temporarily increased. Because echolocation was not detected for over 20 hours

following pile driving the construction site, the authors postulate that decreased communication is unlikely to fully explain the change, and that porpoises likely abandoned the area temporarily.

Tougaard et al. conducted a BACI study at Nysted offshore wind farm. Commissioned by the Danish Energy Authority, the study used T-PODs to record data for one year pre-construction (baseline), during the nearly two month construction period, and for two years post-construction. A control site was located 10 km from the impact site. During the pre-construction period, porpoise activity was similar at the control site and impact site. During construction, porpoise presence and acoustic activity “decreased significantly in the wind farm area.” Notably, a smaller yet still significant decrease in porpoise activity was detected within the control site as well.

Data recorded during pile driving indicated that porpoises left the area during piling and returned after a period of up to several days, but that once they returned, their behavior “seemed unaltered when compared to the level of the construction period as a whole.” The authors conclude that it was not pile driving alone that led to a decrease in porpoise abundance during the construction period.

Two years after construction, porpoise presence in the impact area demonstrated a trend toward returning to baseline levels, while acoustic activity in the impact site had completely returned to baseline levels. The authors posit that these trends indicate porpoises have habituated to the operational wind farm. Both activity levels and acoustic communication in the control site also returned to baseline levels.

6. PAM Limitations and Recommendations

Passive acoustic monitoring as a means to characterize the marine environment has inherent limitations. However, these limitations should not be construed as justifications for failing to require PAM as one of several tools to collect data associated with OWE projects. Various means exist to compensate for some of these limitations, which include the following:

1) *PAM is unable to accurately characterize animal abundance.* This limitation stems from the fact that passive acoustics cannot independently verify the number of animals from which vocalizations originate. This is one of the most common criticisms of PAM, but several mitigation techniques exist. Marques et al. used 82 static PAM data loggers to extrapolate Blainville's beaked whale density numbers from acoustic data, accounting for "the probability of cue detection, the rate at which the animals produce cues, and the proportion of false positive detections"[23]. Data recorded with digital acoustic tags (DTAGs) [70], that are temporarily affixed to individual animals and record acoustic data throughout repeated dives, were used to establish cue rates and to supplement data logged on the static PAM recorders by associating vocalizations detected on DTAGs with those received on the fixed hydrophones [23]. Barlow and Taylor used a towed hydrophone array to monitor sperm whale vocalizations, which are particularly distinct, supplementing the acoustic data with visual line transect surveys to estimate sperm whale abundance in a 7.8 million km² survey area. The authors reported that the number of sperm whales detected on line-transect surveys increased substantially as a result of passive acoustic monitoring, although estimation of group size required visual observations [71]. Kyhn et al. adapted point transect sampling methodology used to estimate bird density [72] in developing a novel method for obtaining robust density estimates for porpoises. Supplementing T-POD data collection with visual observers, the authors used the basis of mark-recapture methodology by assigning each visual sighting near a T-POD as a "mark", with simultaneous acoustic detections representing "recapture." The authors report the possibility of a slight negative bias overall "due to missing some occasions when multiple animals were detected in the same snapshot" [73].

2) *PAM is unable to identify to the species level in some cases.* While some cetacean species, for instance the humpback whale (*Megaptera novaeangliae*) and sperm whale (*Physeter macrocephalus*), have vocalization patterns that are distinct enough to determine their species, PAM technology is currently not yet able to distinguish many species from one another. This is especially true for odontocetes; for instance, PAM data is able to identify a dolphin whistle but is not yet able to identify whether the whistle originated from a bottlenose dolphin (*Tursiops* spp.) or a common dolphin (*Delphinus*

spp.). To mitigate this limitation, ground-truthing in the form of visual observers should be employed in an effort to identify the species associated with acoustic data.

3) *PAM is unable to determine whether a lack of acoustic communication is associated with the absence of animals that might otherwise be vocalizing.* This limitation stems from the fact that passive acoustics, when used alone, cannot definitively determine whether a lack of echolocation is simply the result of a reduction in communication among animals, versus a lack of animals present. Again, this is where ground-truthing can compensate for PAM deficiencies, as visual observers are able to determine whether or not marine mammals (that need to surface to breathe) are present. In the case of animals that do not need to surface to breathe such as fish and invertebrates, survey methods to assess fisheries (such as trawls, visual underwater surveys, and active acoustics) can be used to collect data.

Recommendations

Based on the studies above, best practices for baseline PAM studies at OWE project sites include the following:

1) *Data should be collected for at least one full year prior to construction and one full year post-construction.* This is necessary to accurately account for seasonal variations in species abundance and activity rates. Because species composition and density can vary widely from year to year based on factors such as water temperature, currents and prey availability, two years of data should ideally be collected both prior to and after construction to improve reliability of data. Recording for less than one full year on either end severely hampers the reliability of the study.

2) *Data should be recorded during construction.* Data collection during the construction phase is a critical piece of the acoustic picture in terms of OWE impacts to the environment.

3) *Broadband sampling should be utilized in addition to species-specific data collection.* While T-PODs have proven effective at characterizing impacts on porpoises, they fail to capture low to mid-frequency noises from boats, fish, seals and mysticetes. Baseline PAM studies at OWE sites should attempt to characterize the entire marine environment, so that any and all changes to the environment can be fully quantified. Ideally, baseline studies would employ both high-frequency click detectors such as T-PODs as well as broadband data loggers such as the DSG-Ocean. Manufactured by Loggerhead Instruments, the DSG-Ocean is capable of continuous sampling at rates up to 80 kHz. Broadband sampling is inherently data-intensive, thus it may be necessary to record at a duty cycle that captures a snapshot of acoustic activity at all times of day.

4) *Gradient sampling can be useful, Depending on the goal of the study.* Gradient sampling can mitigate some deficiencies of traditional BACI designs, as evidenced by the results of Thompson et al. [66]. Gradient sampling is especially useful in measuring spatial and temporal impacts of OWE projects [64]. For instance, Brandt et al. used such a design to effectively demonstrate the distance at which pile driving impacted the behavior of harbor porpoises [64].

5) *A control site should be located at least 20 km away from the “impact” site.* Tougaard et al. found that porpoises were impacted by pile-driving at a site 20 km away [39], thus the control site must be located at least that far from the impact site to ensure accuracy in results.

6) *The control site should be as similar as possible to the impact site.* To ensure as much as possible that “variation in conditions over time occurs in parallel in the two areas [56],” impact and control sites should be chosen so that they reflect one another in terms of depth, current, tidal impact, and distance from shipping lanes.

7) *If recording is duty-cycled, baseline and post-recording periods should encompass the same diel periods.* Species composition and animal activity can vary throughout the day.

Accurate comparison between baseline and post-construction periods requires that the same diel periods be compared with one another.

8) *Ground-truthing in the form of visual observers should be employed to confirm and corroborate results of PAM data collection.* This reduces uncertainties as to whether changes in animal activity are due to abandonment or merely changes in communication, and can mitigate the inability of PAM to identify species [66].

9) *Baseline data collection should look beyond impacts to one particular species.* Most attention thus far has been on direct impacts of OWE to cetaceans, particularly odontocetes. Impacts on other marine mammals, fish and invertebrates should also be explored so that implications of OWE on community structure and trophic interactions can be more accurately understood. Surveys should look beyond single species impacts in order to properly account for impacts to entire ecosystems.

10) *Baseline data collection is critical to assess all potential changes to the marine environment resulting from OWE construction, whether negative or positive.* It has been suggested that the addition of monopiles to support wind turbines could provide a reef effect that would attract invertebrates, demersal fish and even top predators. There is ample evidence that artificial reef structures attract fish and other large marine animals [74], but studies of the reef effects of offshore wind turbines are limited. A study at Nysted found that the recently installed turbines were particularly favorable to blue mussel (*Mytilus edulis*) populations and that blue mussels had the effect of creating local ‘hot spots’ of biological activity within the wind farm [75], while another study concluded that demersal fish abundance was greater in the vicinity of offshore wind turbines than in surrounding waters [76]. Whether wind turbines can substantially improve the biodiversity of a marine area as a result of the reef effect remains to be seen.

7. Policy implications for offshore wind in the U.S.

Offshore wind development in the U.S. is expected to increase significantly in both number and scale over the next several years, magnifying potential impacts on the marine

environment. The U.S. Department of Energy (DoE), in its National Offshore Wind Strategy, has established goals of 10,000 megawatts of offshore wind generating capacity by 2020, and 54,000 by 2030, with plans for offshore wind projects in the Atlantic, Pacific and in the Gulf of Mexico [77]. In March 2012, DoE announced that it was offering \$180 million over the next 6 years to jumpstart research and design of OWE projects in U.S. waters [78]. In November 2012, the Bureau of Ocean Energy Management (BOEM) announced the first ever lease block sales for OWE development on the outer continental shelf (OCS) [79]. These moves signaled that the federal government is moving aggressively toward developing offshore wind energy in U.S. waters. Thus the next few years will be critical in terms of drafting responsive oversight measures for the offshore wind industry.

7.1 Relevant administrative agencies

There are numerous federal and state administrative agencies that play a role in OWE development, monitoring and leasing. The agencies that are most pivotal to offshore wind development include the following:

Bureau of Ocean Energy Management

The Bureau of Ocean Energy Management (BOEM) plays a central role in the development of offshore wind energy in U.S. waters. An agency under the Department of Interior, BOEM performs several functions relevant to offshore wind:

- Identifies potentially suitable areas for offshore wind development based on several factors, including potential wind power generation, the suitability of the substrate for turbine construction, and any potential interference with military activities, obstruction of shipping routes, impacts on fisheries and implications for protected species.
- Ensures wind projects are NEPA compliant. BOEM takes the lead on preparing NEPA documentation, such as Environmental Assessments and Environmental Impact Statements for any proposed offshore wind projects. Through the NEPA process, BOEM is also responsible for informing the public of any potential environmental impacts and seeking public comment on those risks.

- Issues federal leases on the OCS for offshore wind exploration and development. The leasing process must be competitive.

Department of Energy

While the Department of Energy (DoE) does not have permitting power over OWE projects, it does play a significant role in OWE development. The DoE allocates funding incentives for technology research and development, invests in the development of engineering modeling and analysis tools, provides financial support for demonstration projects and performs market analysis and research on wind power markets [75].

DoE also performs analyses to identify the wind power generating capacity of various geographic areas based on modeling and climate data [82]. Maps illustrating wind power potential at various heights are generated from the data produced by these analyses. This data is also used by BOEM as an important part of the analyses of offshore wind farm site suitability.

In 2010, the National Renewable Energy Laboratory (NREL), a project of DoE, released a report on opportunities and barriers to offshore wind development in the U.S. The authors call for a coastal and marine spatial planning process that would “balance competing uses of the OCS such as offshore wind resources and an ecosystem-based vision for the nation’s coastal waters.” Robust coastal and marine spatial planning for offshore wind would help to identify candidate sites based on environmental risks as well as human uses such as fishing. The authors conclude that the marine spatial planning process “is essential for large-scale development of offshore wind” in the United States. [83] Indeed, precautionary management of OWE development will require that agencies work collaboratively to ensure robust oversight measures and to develop adaptive monitoring and management regimes to address challenges that are inherently multi-sectoral.

National Marine Fisheries Service

A branch of the National Oceanic and Atmospheric Administration (NOAA) housed in the Department of Commerce, the National Marine Fisheries Service (NMFS) is significant to the development of offshore wind as it is the agency responsible for protection of fish habitat, marine mammals and any other protected species (such as sea turtles) that could be negatively impacted by OWE development activities such as seismic testing, construction and turbine operation. Federal law requires that NMFS be consulted and must permit any activity with the potential to impact Essential Fish Habitat, or any species covered by the Endangered Species Act (ESA) or the Marine Mammal Protection Act (MMPA).

7.2 Relevant legislation

Several pieces of legislation impact offshore wind development in the U.S., from the protection of marine animals to the designation of control over leases on the OCS. Some of the most significant laws impacting OWE development include the following:

Energy Policy Act of 2005

The Energy Policy Act of 2005 (EPAct) included an amendment to the Outer Continental Shelf Lands Act (OCSLA) that for the first time consolidated jurisdiction over OWE development on the OCS under one agency. Prior to this legislation, the Army Corps of Engineers was responsible for the permitting of any structure – including wind turbines – built in federal waters that held the potential to hinder navigation, as set forth in the Rivers and Harbors Act of 1899. Meanwhile, MMS had jurisdiction over the approval of permitting and leasing for offshore energy development. This led to confusion over which agency had ultimate decision making power over the development of OWE projects.

Amendment 388 of the 2005 EPAct attempted to rectify this uncertainty by consolidating power over offshore wind project approval, siting and leasing on the OCS within MMS/BOEM [84]. The Act also makes clear that other federal agencies with permitting authority relevant to offshore wind development on the OCS retain their jurisdiction. This

is particularly significant in that MMS was routinely permitting the development of offshore oil and gas projects without the prior necessary review and approval of NMFS (and continued to do so for several years following the passage of the EPAct). The Act states unequivocally that despite handing MMS/BOEM responsibility for leasing and approval of OWE projects, agencies charged with upholding the MMPA and ESA retain their full authority to do so. The act also directs MMS/BOEM to consult with other relevant agencies during the leasing and easement process. Finally, the Act mandates that MMS/BOEM must issue leases for wind energy development on a competitive basis [85].

National Environmental Policy Act (NEPA)

Any offshore wind projects proposed by BOEM are subject to the NEPA review process, and BOEM is the agency responsible for taking the lead on NEPA compliance for these projects. Thus any proposed federal wind leases on the OCS must be vetted via the NEPA process for potential environmental impacts. The NEPA process also represents an opportunity for the public to comment on the potential environmental impacts of a proposed project and theoretically to impact the outcome.

It should be noted that despite the federal requirement that projects such as offshore energy development are subject to the NEPA review process, MMS previously provided blanket exemptions from NEPA review for offshore oil and gas activities for years [80]. It remains to be seen whether or not BOEM treats the NEPA review process with the weight it deserves.

Marine Mammal Protection Act (MMPA)

The MMPA prohibits the “take” of marine mammals, with certain exceptions. “Take” is defined broadly, and can range from harassment to injury or death. The “take” of marine mammals is strictly regulated, and any project that is anticipated to result in the “take” of marine mammals, including offshore energy development, must submit an application and receive prior approval from NOAA/NMFS [86].

Endangered Species Act (ESA)

The ESA was enacted to protect and recover species in danger of extinction by prohibiting the “take” of those species. Species may be listed under the Act as either “threatened” or “endangered” on the basis of their biological status and threats to their existence [87]. NOAA/NMFS has jurisdiction over marine species listed under the Act, and some marine mammal species are listed in both the ESA and the MMPA. Like the MMPA, if an offshore energy development project may result in the “take” of any species listed under the Act, NOAA/NMFS must review and approve the potential “take” of those species.

Coastal Zone Management Act (CZMA)

The CZMA is a federal Act that encourages states to develop plans for coastal zone management and allocates federal funding to support the implementation of these plans. It also provides states the authority to review federal activities, licenses and permits that have potential impacts on states’ coastal zones through the process of consistency determinations. The Act mandates that all activities on the OCS in federal waters be “consistent to the maximum extent practicable with federally approved state coastal zone management programs.”

Any activity, including offshore energy development, that would directly impact the coastal zone of states must be accompanied by a written consistency determination to the affected state’s coastal zone management agency for review. States then have the opportunity to review and comment on the consistency determination. However, a Supreme Court ruling in 1984 significantly hindered the ability of states to limit offshore energy development in federal waters. In the case *Secretary of Interior vs. California* the Court ruled that federal OCS lease sales do not directly affect the coastal zone under the terms of the CZMA and are thus not subject to consistency review under the CZMA [88].

State-level coastal management acts

Though states cannot veto a CZMA consistency determination, individual states generally enact their own forms of legislation governing activities in state waters (within

3 nautical miles of the coast) such as North Carolina's Coastal Area Management Act. Offshore wind farms proposed within state waters would be governed by these pieces of legislation. In addition, any facets of offshore wind farms in federal waters that must pass through state waters, such as cables and vessel traffic, also fall under the jurisdiction of state law. State-level legislation can also include stringent requirements for activities that take place offshore, to ensure that any federal plan for OWE development must take those requirements into account when drafting a consistency determination for offshore wind leasing and development.

As the first offshore wind turbines are set to be built in U.S. waters over the next few years, a unique opportunity currently exists to ensure robust, multi-sectoral monitoring and regulation of offshore wind development from the outset.

8. Conclusion

In December 2012, three OWE developers and several non-governmental organizations announced an agreement on measures to reduce impacts of offshore wind development on critically endangered North Atlantic right whales. The voluntary measures seek to mitigate impacts of seismic testing and weather tower construction in the Mid-Atlantic Wind Energy Area, recognizing that this region overlaps a critical right whale migration corridor [89]. Although the measures in this agreement were within the range of alternatives contained in the Mid-Atlantic Environmental Assessment (EA) released by BOEM, they went above and beyond the requirements for mitigation contained in the EA. This represented a sign that the wind industry is amenable to environmental impact mitigation if the need for mitigation is supported by baseline data.

Two months later, in a further sign of the industry's willingness to mitigate environmental impacts, OWE developer Deepwater Wind announced voluntary measures to protect right whales off the coast of Rhode Island. . The company had announced plans to begin construction on a demonstration-scale wind project in Rhode Island Sound in April of 2014 or 2015, but voluntarily adjusted those plans as a result of historical sightings data that demonstrate the whales are active in the area throughout the month of

April [90]. While PAM data was not used to inform this particular decision, the early involvement of the industry in the coastal and marine spatial planning (CMSP) process in Rhode Island was largely responsible for Deepwater Wind's voluntary agreement to delay construction despite the added cost and significant inconvenience [91].

Meanwhile, trends in the OWE industry indicate that wind farms, until recently confined to shallow coastal waters, will continue to move further from shore and into deeper waters as both turbine and transmission technology improve [47]. As offshore wind projects move into deeper waters where monopile foundations are not logistically feasible, the traditional turbine construction method of pile driving will inevitably become less utilized. Technological advances in OWE foundation methods, such as floating wind farms, may hold the best hope for mitigating the environmental impacts of offshore wind construction. In the short term, the incorporation of acoustic monitoring into the CSMP process may be the best way to ensure the thorough collection of environmental data and the accurate characterization of the marine environment prior to, and following, offshore wind farm construction.

Table 1: Summary of reviewed baseline PAM studies

Author(s)	Wind farm location	Construction type	Deployment duration	Survey type	Results	Additional Notes
Teilman & Carstensen et al.	Nysted (Denmark)	Gravity base (one vibratory pile)	10 yrs (baseline 8 mo.)	BACI	Decreased porpoise activity in impact area during construction.	Stated assumption that echolocation activity is correlated to porpoise density, no ground-truthing to verify.
Scheidat et al.	Egmond aan Zee (Netherlands)	monopile	3 yrs (1 yr baseline)	BACI	Porpoise acoustic activity significantly higher inside the wind farm vs. control areas post-construction.	No recording during construction phase. Used historical sightings data to compare expected porpoise numbers.
Brandt et al.	Horns Rev II (Denmark)	monopile	6 months (5 weeks baseline)	Gradient sampling	Negative effect of construction on porpoise acoustic activity detectable to a distance of 17.8 km.	Gradient sampling allowed estimate of distance at which pile driving noise no longer negatively affected porpoise activity.
Thompson et al.	Beatrice (Scotland)	tri-pile	1.5 yrs.	BACI	low detections rates in both impact and control sites, other anthropogenic noises in area during study led to inconclusive results	employed ground-truthing in the form of visual surveys: 20 km transect lines through the impact area during PAM study.
Tougaard et al.	Nysted (Denmark)	Gravity base (and one vibratory pile)	3+ yrs (1 yr baseline)	BACI	porpoises clearly abandoned impact general area during construction.	

References

1. Parks, S.E., et al., *Individual right whales call louder in increased environmental noise*. Biol Lett, 2011. **7**(1): p. 33-5.
2. Pauly, D., *Shifting Baselines: The Past and the Future of Ocean Fisheries* Vol. 1. 2011: Island Press.
3. Gedamke, J., *Overview and Summary of Recent Research into the Potential Effects of Pile Driving on Cetaceans*, NMFS, Editor 2011.
4. Urick, R.J., *Principles of Underwater Sound* 1983: McGraw Hill.
5. Hildebrand, J.A., *Anthropogenic and natural sources of ambient noise in the ocean*. Marine Ecology-Progress Series, 2009. **395**: p. 5-20.
6. Tyack, P., *Implications for marine mammals of large scale changes in the marine acoustic environment* Journal of Mammalogy, 2008.
7. Andrew, R.K., et al., *Ocean ambient sound: Comparing the 1960s with the 1990s for a receiver off the California coast*. Acoustics Research Letters Online, 2002. **3**(2): p. 65.
8. McDonald, M.A., J.A. Hildebrand, and S.M. Wiggins, *Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California*. J Acoust Soc Am, 2006. **120**(2): p. 711.
9. Slabbekoorn, H., et al., *A noisy spring: the impact of globally rising underwater sound levels on fish*. Trends Ecol Evol, 2010. **25**(7): p. 419-27.
10. Nowacek, D., L. Thorne, and D. Johnston, *Responses of cetaceans to anthropogenic noise*. Mammal Review, 2007.
11. André, M., et al., *Low-frequency sounds induce acoustic trauma in cephalopods*. Frontiers in Ecology and the Environment, 2011. **9**(9): p. 489-493.
12. David, J.A., *Likely sensitivity of bottlenose dolphins to pile-driving noise*. Water and Environment Journal, 2006. **20**(1): p. 48-54.
13. Stafford, K.M., C.G. Fox, and D.S. Clark, *Long-range acoustic detection and localization of blue whale calls in the northeast Pacific Ocean*. Journal of the Acoustical Society of America, 1998. **104**(6): p. 3616-3625.
14. Johnson, M., et al., *Foraging Blainville's beaked whales (Mesoplodon densirostris) produce distinct click types matched to different phases of echolocation*. Journal of Experimental Biology, 2006. **209**(24): p. 5038-5050.
15. Weiss, B.M., et al., *Intra- and intergroup vocal behavior in resident killer whales, Orcinus orca*. J Acoust Soc Am, 2007. **122**(6): p. 3710-6.
16. Bailey, H., et al., *Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals*. Mar Pollut Bull, 2010. **60**(6): p. 888-97.
17. Mooney, T.A., P.E. Nachtigall, and S. Vlachos, *Sonar-induced temporary hearing loss in dolphins*. Biol Lett, 2009. **5**(4): p. 565-567.
18. Ellison, W.T., et al., *A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds*. Conserv Biol, 2012. **26**(1): p. 21-8.
19. Clark, C.W., et al., *Acoustic masking in marine ecosystems: intuitions, analysis, and implication*. Marine Ecology Progress Series, 2009. **395**: p. 201-222.

20. Merchant, N.D., et al., *Assessing sound exposure from shipping in coastal waters using a single hydrophone and Automatic Identification System (AIS) data*. Mar Pollut Bull, 2012. **64**(7): p. 1320-9.
21. Risch, D., et al., *Changes in Humpback Whale Song Occurrence in Response to an Acoustic Source 200 km Away*. Plos One, 2012. **7**(1).
22. Nowacek, D., *Methods in Marine Bioacoustics: Duke University Marine Laboratory course 2012*.
23. Marques, T.A., et al., *Estimating cetacean population density using fixed passive acoustic sensors: an example with Blainville's beaked whales*. J Acoust Soc Am, 2009. **125**(4): p. 1982-94.
24. Whit, A. and e. al., *North Atlantic right whale distribution and seasonal occurrence in nearshore waters off New Jersey, USA, and implications for management*. ESR, 2013. **20**: p. 59-69.
25. Guénette, S. and D. Gascuel, *Shifting baselines in European fisheries: The case of the Celtic Sea and Bay of Biscay*. Ocean & Coastal Management, 2012. **70**: p. 10-21.
26. Alexander, K., et al., *Catch Density: A New Approach to Shifting Baselines, Stock Assessment, and Ecosystem-Based Management*. Bulletin of Marine Science, 2011. **87**(2): p. 213-234.
27. Ioup, G.E., *Analysis of bottom-moored hydrophone measurements of Gulf of Mexico sperm whale phonations*. Proceedings of the 23rd Annual Gulf of Mexico Information Transfer Meeting, New Orleans, 2005: p. 109-136.
28. Ackleh, A.S., et al., *Assessing the Deepwater Horizon oil spill impact on marine mammal population through acoustics: endangered sperm whales*. J Acoust Soc Am, 2012. **131**(3): p. 2306-14.
29. Rolland, R.M., et al., *Evidence that ship noise increases stress in right whales*. Proc Biol Sci, 2012. **279**(1737): p. 2363-8.
30. McClenachan, L., F. Ferretti, and J.K. Baum, *From archives to conservation: why historical data are needed to set baselines for marine animals and ecosystems*. Conservation Letters, 2012. **5**(5): p. 349-359.
31. Lotze, H.K. and B. Worm, *Historical baselines for large marine animals*. Trends Ecol Evol, 2009. **24**(5): p. 254-62.
32. Luiz, O.J. and A.J. Edwards, *Extinction of a shark population in the Archipelago of Saint Paul's Rocks (equatorial Atlantic) inferred from the historical record*. Biological Conservation, 2011. **144**(12): p. 2873-2881.
33. McClenachan, L., *Documenting loss of large trophy fish from the Florida Keys with historical photographs*. Conserv Biol, 2009. **23**(3): p. 636-43.
34. Sáenz-Arroyo, A., et al., *Rapidly Shifting Environmental Baselines among Fishers of the Gulf of California*. Proc Biol Sci, 2005. **272** (1575): p. 1957-1962.
35. Bender, M.G., S.R. Floeter, and N. Hanazaki, *Do traditional fishers recognise reef fish species declines? Shifting environmental baselines in Eastern Brazil*. Fisheries Management and Ecology, 2013. **20**(1): p. 58-67.
36. Madsen, P.T., et al., *Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs*. Marine Ecology-Progress Series, 2006. **309**: p. 279-295.

37. *The monopile - close to a monopole*. 2012 [cited 2013 Feb 18 2013]; Available from: <http://www.lorc.dk/offshore-wind/foundations/monopiles>.
38. Popper, A.N. and M.C. Hastings, *The effects of anthropogenic sources of sound on fishes*. J Fish Biol, 2009. **75**(3): p. 455-89.
39. Tougaard, J., et al., *Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (Phocoena phocoena (L.))*. J Acoust Soc Am, 2009. **126**(1): p. 11-4.
40. Robinson, S.P., et al., *A methodology for measurement of radiated noise from marine piling*. 2009.
41. Southall, B.L., et al., *Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations*. Aquatic Mammals, 2007.
42. *National Policy Statement for Renewable Energy Infrastructure* D.o.E.a.C.C. (UK), Editor 2011.
43. Thomsen, F., et al., *Effects of offshore wind farm noise on marine mammals and fish*, 2006, COWRIE Ltd.
44. Mueller-Blenke, C., et al., *Effects of pile driving noise on behaviour of marine fish*, 2010, COWRIE
45. Perrow, M.R., et al., *Effects of the construction of Scroby Sands offshore wind farm on the prey base of Little tern Sternula albifrons at its most important UK colony*. Mar Pollut Bull, 2011. **62**(8): p. 1661-70.
46. Skeate, E.R., M.R. Perrow, and J.J. Gilroy, *Likely effects of construction of Scroby Sands offshore wind farm on a mixed population of harbour Phoca vitulina and grey Halichoerus grypus seals*. Mar Pollut Bull, 2012. **64**(4): p. 872-81.
47. Arapogianni, A., *The European offshore wind industry - key trends and statistics 2012, 2013*, European Wind Energy Association.
48. Elmer, K.H. and e. al., *Measurement and Reduction of Offshore Turbine Construction Noise*, in *DEWI Magazine (Germany)*2007.
49. *The gravity-based structure: Weight matters*. 2011 March 28, 2013]; Available from: <http://www.lorc.dk/offshore-wind/foundations/gravity-based>.
50. *Floating support structures*. 2011 March 28, 2013]; Available from: <http://www.lorc.dk/offshore-wind/foundations/floating-support-structures>.
51. Nedwell, J. and D. Howell, *A review of offshore wind farm related underwater noise sources*, 2004, COWRIE.
52. Tougaard, J., O.D. Henriksen, and L.A. Miller, *Underwater noise from three types of offshore wind turbines: estimation of impact zones for harbor porpoises and harbor seals*. J Acoust Soc Am, 2009. **125**(6): p. 3766-73.
53. Betke, K., *Measurement of underwater noise emitted by an offshore wind turbine at Horns Rev*. 2006.
54. Wahlberg, M. and H. Westerberg, *Hearing in fish and their reactions to sounds from offshore wind farms*. Marine Ecology Progress Series, 2005. **288**.
55. Kikuchi, R., *Risk formulation for the sonic effects of offshore wind farms on fish in the EU region*. Mar Pollut Bull, 2010. **60**(2): p. 172-7.
56. Tougaard, J., *Final report on the effect of Nysted Offshore Wind Farm on harbour porpoises*, 2005.

57. Lucke, K., et al., *The use of an air bubble curtain to reduce the received sound levels for harbor porpoises (Phocoena phocoena)*. J Acoust Soc Am, 2011. **130**(5): p. 3406-12.
58. *Nysted: Introduction to the wind park*. Feb. 21 2013]; Available from: http://www.dongenergy.com/Nysted/EN/About_the_park/Introduction/Pages/Introduction.aspx.
59. Carstensen, J., O.D. Henriksen, and J. Teilmann, *Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs)*. Marine Ecology-Progress Series, 2006. **321**: p. 295-308.
60. NordZeeWind, *General Report, Document No OWEZ R 141 20080215*, 2008, OffshoreWindfarm Egmond aan Zee.
61. *Horns Rev 2: About the project*. Feb. 25, 2013]; Available from: http://www.dongenergy.com/hornsrev2/en/about_horns_rev_2/about_the_project/pages/about_the_project.aspx.
62. *Beatrice wind farm: Project information*. Feb. 04, 2013]; Available from: <http://www.sse.com/Beatrice/ProjectInformation/>.
63. *Cehlonia Ltd.: About the TPOD*. Dec. 15, 2012]; Available from: http://www.chelonia.co.uk/about_the_tpod.htm.
64. Brandt, M.J., et al., *Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea*. Marine Ecology Progress Series, 2011. **421**: p. 205-216.
65. Scheidat, M., et al., *Harbour porpoises (Phocoena phocoena) and wind farms: a case study in the Dutch North Sea*. Environmental Research Letters, 2011. **6**(2): p. 025102.
66. Thompson, P.M., et al., *Assessing the responses of coastal cetaceans to the construction of offshore wind turbines*. Mar Pollut Bull, 2010. **60**(8): p. 1200-8.
67. Philpott, E., et al., *Using T-PODs to investigate the echolocation of coastal bottlenose dolphins*. Journal of the Marine Biological Association of the UK, 2007. **87**(01): p. 11.
68. Stewart-Oaten, A., W. Murdoch, and K. Parker, *Environmental impact assessment: "Pseudoreplication" in time?* Ecology, 1986. **67**(4): p. 929-940.
69. Teilmann, J. and J. Carstensen, *Negative long term effects on harbour porpoises from a large scale offshore wind farm in the Baltic—evidence of slow recovery*. Environmental Research Letters, 2012. **7**(4): p. 045101.
70. *DTAG: A Digital Acoustic Recording Tag*. Nov. 25, 2013]; Available from: <http://www.whoj.edu/page.do?pid=39337>.
71. Barlow, J. and B. Taylor, *Estimates of sperm whale abundance in the Northeastern temperate Pacific from a combined acoustic and visual survey*. Marine Mammal Science, 2006. **21**(3): p. 429-445.
72. Buckland, S.T., et al., *Introduction to Distance Sampling: Estimating Abundance of Biological Populations*2001: Oxford University Press.
73. Kyhn, L.A., et al., *From echolocation clicks to animal density--acoustic sampling of harbor porpoises with static dataloggers*. J Acoust Soc Am, 2012. **131**(1): p. 550-60.

74. Petersen, J. and T. Malm, *Offshore wind farms: Threats to or Possibilities for the Marine Environment*. *Ambio*, 2006. **35**(2): p. 75-80.
75. Maar, M., et al., *Local effects of blue mussels around turbine foundations in an ecosystem model of Nysted off-shore wind farm, Denmark*. *Journal of Sea Research*, 2009. **62**(2-3): p. 159-174.
76. Wilhelmsson, D., T. Malm, and M. Ohman, *The influence of offshore windpower on demersal fish*. *ICES Journal of Marine Science*, 2006. **63**(5): p. 775-784.
77. Silverstein, K. *Offshore Wind Projects Could Provide Refreshing Energy Source*. *Forbes*, 2013.
78. *Energy Department Announces \$180 Million for Ambitious New Initiative to Deploy U.S. Offshore Wind Projects*. 2012.
79. *Interior Announces First-Ever Renewable Energy Lease Sales on the Outer Continental Shelf*. 2012.
82. *DOE provides detailed offshore wind resource maps*. 2012 December 2 2012]; Available from: <http://www.eia.gov/todayinenergy/detail.cfm?id=4770>.
83. Musial, W., *Large-Scale Offshore Wind Power in the United States: Assessment of Opportunities and Barriers*, 2010, National Renewable Energy Laboratory: nrel.gov.
84. *Alternative Energy Programmatic EIS*, 2007, Department of Interior.
85. Vann, A., *Wind Energy: Offshore Permitting*, C.R. Service, Editor 2012, Congressional Research Service.
86. Luczkovich, J.J., D.A. Mann, and R.A. Rountree, *Passive Acoustics as a Tool in Fisheries Science*. *Transactions of the American Fisheries Society*, 2008. **137**(2): p. 533-541.
87. *ESA Basics*. 2011; Available from: http://www.fws.gov/endangered/esa-library/pdf/ESA_basics.pdf.
88. *Secretary of Interior v. California - 464 U.S. 312* 1984 [cited 2012 December 4 2012]; Available from: <http://supreme.justia.com/cases/federal/us/464/312/>.
89. *Proposed Mitigation Measures to Protect North Atlantic Right Whales from Site Assessment and Characterization Activities of Offshore Wind Energy Development in the Mid-Atlantic Wind Energy Areas*, 2012, BOEM.
90. *Deepwater Wind Adjusts Offshore Wind Farm Development Plan In Order To Minimize Wildlife Impacts* North American Wind Power, 2013.
91. Jedele, T., Conservation Law Foundation, personal communication March 23, 2013.