Potential Impacts of Ocean Energy Development on Marine Mammals in Oregon

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Abstract: The demand for clean renewable energy sources is increasing worldwide and the state of Oregon hopes to establish itself as a leader in ocean wave energy research and development. Seven coastal counties have been selected as potential offshore sites for wave energy parks, and Tillamook County has been identified for a potential wind-float park. The state of Oregon works in partnership with several federal, state, and non-profit agencies to oversee the responsible development of ocean energy. The technology used for wave energy development is relatively new and little is known about the environmental impacts it will have on our coastal ecosystems. In an effort to identify potential environmental impacts of wave energy development, a workshop was held at the Hatfield Marine Science Center in Newport, Oregon, to assess uncertainties and identify research projects that could aid in minimizing the impact. Of concern regarding marine mammals was potential collision and entanglement in mooring cables and behavioral reactions to the acoustic output of wave energy buoys during installation and operation. There is available research on the impacts of marine wind energy on marine mammals, however, it is limited and more baseline studies are needed. This review is focused on the development of ocean energy in Oregon, potential impacts to marine mammals, and reviewing current and future research that could aid in mitigating those impacts. Specific interest is placed on the Eastern Gray whale (*Eschrichtius robustus*), Harbor porpoise (*Phocoena phocoena*), and local pinniped populations. While clean renewable energy development in Oregon is beneficial for the economy, it may come with ecological costs, including impacts on Oregon's marine mammals.

Key Words: wave energy, wind energy, marine mammals, environmental impact, gray whale, clean renewable energy.

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1. Introduction

As we move into the 21st century, the demand for clean and sustainable renewable energy is increasing worldwide. The threat of global climate change due to increasing carbon emissions in the atmosphere and reliance on fossil fuels has led to the search for clean renewable energy sources as well as development of technology to harness that energy (Cada et al. 2007; Pelc and Fujita 2002). In 2005, President George W. Bush signed the Energy Policy Act which encouraged the development of renewable energy sources in the United States and provided various tax incentives to those who increased energy efficiency (United States 2005). The act also stated the federal government was required to purchase a minimum of 7.5% of its electricity from renewable energy sources by 2013 (United States 2005). Since then, renewable energy in the United States has skyrocketed and in 2009 over half of newly installed power capacity was from clean renewable energy (REN21 2010).

The demand for clean renewable energy is worldwide. In 2009 renewable energy sources provided a quarter of the global power capacity from all sources, delivering 18% of the electricity supplied globally (REN21 2010). In 2010 more than 100 countries had some type of policy target and/or promotion policy related to renewable energy, compared to 55 countries in 2005 (REN21 2010). Today, more than half of the existing renewable power capacity is in developing countries, providing ample opportunities for job creation and economic stimulus (REN21 2010).

The Pacific Northwest has great potential to develop and deploy ocean energy technology given its wave, wind, and tidal resources. The annual wave energy averages worldwide are shown in Figure 1, identifying the Pacific Northwest as the most viable wave energy source in the U.S. The U.S. also possesses offshore wind energy resources that have the capability of generating four times the amount of the nation's electric capacity, see Figure 2 (Musial and Ram 2010). Tidal energy is also a highly predictable source of clean renewable energy, as it is determined by the moon and sun. Tides along the Pacific Northwest encompass a wide range, ideal conditions for harnessing tidal energy. While tidal energy is a growing industry, this review is focused on ocean energy development in Oregon, specifically wave and wind energy.

2. Ocean Renewable Energy Development

2.1. Wave Energy Background

While the development of wave energy conversion devices (WECs) to harness the power of the ocean is relatively new, the concept dates back to 1799 when the earliest patent known for converting wave energy was filed (Falcão 2010). In the 1940's, Yoshio Masuda, a researcher in Japan, developed the first oscillating water column and has since been regarded as a pioneer in wave energy technology (Falcão 2010). Later on, the oil crisis in 1973 spurred the scientific community to look deeper into the possibility of converting wave energy (Falcão 2010; Patrício et al. 2009). Today, a wide variety of WECs are in development. For more information on specific WEC devices, please see (Lavrakas and Smith 2009).

In the year 2000, the first commercial wave power station in the world was installed on the island of Islay in Scotland. Referred to as the Limpet 500 (Land Installed Marine Powered Energy Transformer), this station designed by Wavegen uses the oscillating water column to generate an output of 500 kW (Pelc and Fujita 2002). On September 23rd , 2008, the first commercial wave farm (Aguçadoura) was opened in northern Portugal near Póvoa de Varzim. The farm had the capacity to generate 22.5 MW utilizing a WEC known as Pelamis, however, due to bearing problems the farm was closed after just two months of operation (Dunnett and Wallace 2009).

2.2. Ocean Wave Energy Development in Oregon

The state of Oregon is committed to the development of clean renewable energy and works with several federal, state, and non-profit agencies to oversee the responsible development of ocean energy technologies. Development of ocean renewable energy in Oregon brings opportunities for economic development in coastal communities, potential workforce generation state wide, as well as meeting the increasing energy demands. For a breakdown of Oregon's energy resources, please see Figure 3 (Boehlert 2009). Oregon hopes to establish itself as the North American leader in ocean renewable energy research and development. To aid in accomplishing this goal the Oregon Innovation Council has created a nonprofit agency, Oregon Wave Energy Trust (OWET), to oversee the responsible development of wave energy in Oregon. Its mission is to aid in the collaboration of stakeholders with research, development, and policy/regulation experts to advance the wave energy industry (OWET 2010).

Being home to the Northwest National Marine Renewable Energy Center (NNMREC) and Hatfield Marine Science Center (HMSC) provides a strong scientific community for potential developers. NNMREC and HMSC attract developers of ocean renewable energy devices to Oregon because they offer testing facilities off of Newport as well as environmental assessment services (Oregon 2010). Currently, a zone of six square miles located directly west of Yaquina Head, Newport, Oregon, is being researched for the best location of NNMREC's 1 square mile mile of test-bed, referred to as the Ocean Test Berth (OTB) for WEC devices. The OTB will consist of both mobile test berths (MOTB) with no connection to the electrical grid, and a grid-connected testing and demonstration facility (GCOTB) (NNMREC 2010). In the summer of 2011 the first WEC device will be tested, using MOTB (NNMREC 2010).

Seven potential offshore sites along the Oregon coast have been identified by the Electric Power Research Institute (EPRI) as viable locations for wave energy parks (Figure 4) (EPRI 2004):

- Clatsop County- Astoria
- Tillamook County- Garibaldi
- Lincoln County- Newport
- Lane County- Florence/Cushman
- Douglas County- Reedsport
- Coos County- Coos Bay
- Curry County- Brookings

Wave park proposals have been submitted to the Federal Energy Regulatory Commission (FERC) for Douglas County and Coos County in Oregon. A settlement agreement was filed by Ocean Power Technologies (OPT) on August 2nd, 2010 for the proposed OPT wave park off of Reedsport, Douglas County, Oregon (FERC 2010). A preliminary permit was issued to OPT on August 10th, 2010 for the Coos Bay OPT wave park in Coos Bay, Coos County, Oregon (FERC 2010).

Reedsport OPT Wave Park LLC (FERC No. 12713) is requesting a license for the proposed deployment and operation of ten OPT PowerBuoys, 2.5 miles off the coast of Gardiner in Douglas County (Reedsport 2010). The wave park will cover a .25 square mile area and have a 1.5MW capacity. Buoys will be in a NE to SW orientation, containing two rows of three buoys and one row of four (Reedsport 2010). OPT proposes to deploy a single 150 kW PowerBuoy (Figure 5) by the end of 2010, followed by the installation of nine additional buoys during the summer of 2011 (Reedsport 2010). Buoys will be anchored to the bottom and attached to mooring lines and sub surface floats. The PowerBuoys will be connected to an underwater substation pod (USP) which will collect the renewable energy and transmit it to shore via cable. The cable will be installed within the existing effluent pipe outfall and then carried to the Gardiner grid connection and shore station by the Douglas Electric Cooperative (DEC) transmission line (Figure 6) (Reedsport 2010). In total, 4,140 MW hours per year will be generated by the project and delivered to the Pacific Northwest transmission grid for use by Oregon customers (Reedsport 2010). For more information regarding project construction, operation and decommissioning plans, please see (Reedsport 2010).

Part of the agreement highlights potential effects on the environment and identifies studies OPT proposes should be conducted (Reedsport 2010). These studies include:

- Marine Geophysical Survey (conducted in September 2007)
- Cetacean Study
- Pinniped Study
- Fish and Invertebrates Study
- Electromagnetic Field Study
- Offshore Avian Use Study
- Wave, Current, and Sediment Transport Study

For the purposes of this review, the focus will be on the proposed cetacean and pinniped studies. The cetacean study will focus on the Eastern gray whale (*Eschrichtius robustus*) and Harbor porpoise (*Phocoena phocoena*) as they are the primary species found in the project area. The Eastern North Pacific stock of gray whales spend their summers feeding in the Bering Sea and migrate south in the winter to calving lagoons in Baja California, Mexico (Ortega-Ortiz and Mate 2008). Consequently, the proposed wave park is located in the migratory path of these whales. There is concern over the potential impacts mooring systems may have on cetaceans, including but not limited to collision, entanglement, and alteration of migration patterns (Boehlert et al. 2008; Ortega-Ortiz and Mate 2008; Ortega-Ortiz and Lagerquist 2008). More detail on potential impact concerns will be given in section three: Potential Impacts on Marine Mammals. The cetacean study seeks to test the hypothesis that whales have the acuity to detect and avoid the system in all seastates (Reedsport 2010). The study has been separated into three phases:

I) Baseline Characterization
II) Acoustic Emissions Characterization
III) Post-Deployment Monitoring

The baseline characterization was conducted by Dr. Joel Ortega-Ortiz and Dr. Bruce Mate from the Oregon State University Marine Mammal Institute on December 10th, 2007 through May 30th, 2008 (Ortega-Ortiz and Mate 2008). Observers surveyed marine mammals from an observation station at Yaquina Head lighthouse in Oregon to gain insight into the distribution and behavior of migrating gray whales. The baseline information gathered will be compared to observations after wave energy facilities are installed and may aid in the identification of potential effects and mitigation measures (Ortega-Ortiz and Mate 2008). Phase II is an acoustic emissions study that will take place after the single PowerBuoy is installed off of Reedsport. The study will look at the acoustic emission vs. seastates representing various ocean conditions (Reedsport 2010). The acoustic outputs will be compared to known acoustic thresholds of cetaceans and used to identify potential impacts (Reedsport 2010). Phase III will consist of observational studies of cetaceans in response to the presence of the wave park after all ten buoys are installed. This study will be shore based and occur December 2011 through April 2012 during peak migration, as well as including other observations throughout the year during other studies (Reedsport 2010).

Regarding pinnipeds there is particular concern they will use the PowerBuoys as haul-out sites. The PowerBuoy has been equipped with an ultra high molecular weight polyethylene coating (UHMWPE) that OPT hopes will prevent pinnipeds from being able to haul-out (Reedsport 2010). The study will assess the presence and abundance of pinnipeds in the proposed wave park area both during operation of the single buoy as well as after all ten buoys are installed. If UHMWPE is not effective at inhibiting pinniped haul-out, OPT will install fencing (Reedsport 2010).

OPT Wave Park LLC was issued a preliminary permit for a wave park off of Coos Bay, Oregon on August 10th, 2010. The permit is to study the feasibility of a Coos Bay OPT Wave Park Project (FERC No. 12749). The proposed project would consist of 200 PowerBuoys with a 100MW capacity, capable of generating an annual average of 276,000 MW hours (FERC 2010).

2.2. Wind Energy Background

Wind power is one of the cleanest renewable energy sources available, emitting no carbon dioxide or pollutants and using no significant water resources as with conventional energy (Pelc and Fujita 2002; Musial and Ram 2010). Development of offshore wind has the ability to aid the United States by meeting rising energy demands, decreasing environmental impacts, stimulating the economy and decreasing our dependency on foreign energy resources (Musial and Ram 2010). Development of offshore wind would also aid in meeting the goals of the Obama administration regarding all renewable energy (White House 2009) by:

- Doubling the nation's supply of renewable energy by 2012.
- Decreasing carbon emissions 80% by 2050.
- Meet the goal of generating 20% or more of our energy from renewable sources by 2030.

Offshore wind energy holds great promise for stimulating the recovering U.S. economy. To achieve the scenario listed above, approximately 54GW of offshore wind energy needs to be generated, which itself could generate $200 billion, the majority of which would remain in local economies (Musial and Ram 2010).

Europe leads the world in offshore wind development. The installed capacity in Europe is around 2,300 MW, mostly in shallow waters (less than 30m) and generated by a total of 830 turbines that send power to nine European countries (Musial and Ram 2010). In 2009 alone, Europe installed 584 MW of offshore wind energy, increasing 56% from 2008 (Musial and Ram 201). Denmark has been a pioneer in the industry, installing the first offshore wind farm in Vindeby, Denmark, in 1991 (Pelc and Fujita 2002). Development in Denmark is on the rise, as the country has set a goal of generating 40% of its power from wind farms by 2030 (Pelc and Fujita 2002). The interest of offshore wind renewable energy is now spreading to countries like Canada, China and the United States. For a summary of the current offshore projects installed, please refer to Table 1.

While the United States leads the world in land-based wind energy, there are no existing offshore wind farms. However, there are around twenty proposed projects in the planning/permitting stage that have the capacity to generate 2,000 MW (Musial and Ram 2010). The total gross United States offshore wind resource is estimated to be around 4,000 GW, potentially four times greater than the current electric capacity (Musial and Ram 2010). The Oregon coast has been identified as an outstanding resource for offshore wind development, due to its strong winds that regularly blow over the Pacific Ocean. While land-based wind power is a good resource, winds across the ocean can be 20% higher, dramatically increasing the potential of renewable energy generation (Pelc and Fujita 2002). Wind speeds tend to increase with increasing distance from shore, which makes offshore deep water wind farms appealing, particularly off the Oregon coast (Musial and Ram 2010).

2.4. Offshore Wind Energy Development in Oregon

Principle Power Inc., a San Francisco and Seattle based company, is committed to developing environmentally sustainable deep water offshore energy using pre-commercial green technologies developed by other companies. They are responsible for lining up the financing and development of renewable energy power plants. Principle Power is looking to build a marine wind farm offshore from the town of Garibaldi in Tillamook County, Oregon. The proposed marine wind farm would consist of 30 wind turbines, each with a capacity of 5MW and a total capacity of 150MW (Barron 2008). The typical land based wind turbine generates around 2.5MW (Woody 2008). Electricity generated by this marine wind farm has the capability of lighting over 50,000 homes, which is almost three times Tillamook County (Hill 2008). The extra electricity can be sold to other states like California, allowing Tillamook County to profit.

The technology that would be used in this marine farm is unlike any other technology in the industry. The WindFloat system has a floating foundation that incorporates technology from designs used by the oil and gas industry (Barron 2008). The floating platform consists of three foundations which are capable of stabilizing the system against the forces of wind and waves (Figure 7). When confronted with rough seas and high winds, the closed-loop active ballast water system is able to mitigate the forces by moving water between the three columns to stabilize the foundation (Principle Power 2010). Heave plates at the base of each column also aid in dampening these effects. Each platform is anchored to the seafloor through six conventional chain and polyester mooring lines (which minimizes the cost) (Principle Power 2010). Electricity that is produced by the wind turbines is transferred to an underwater interconnected grid where it then flows into a single cable back to shore, which costs $1 million per mile (Hill 2008). The Tillamook County Public Utility District has the capacity to support 50MW, so it would be the interconnection point between the wind farm and the regional power grid (Woody 2008).

The WindFloat platform has the ability to house the largest wind turbine in existence. The turbine hub height is 80-100m and rotator diameter is 120-150m (Principle Power 2010). Due to the large size, fewer turbines can be installed to create the same electrical output. The features of the WindFloat allow it to be placed in water depths greater than 50m, which allows it to exploit superior wind resources than wind farms closer to shore (Principle Power 2010). The proposed wind park would be approximately ten miles offshore, so it won’t be visible from shore. Principle Power says the WindFloats will be assembled onshore and towed to their final location. They have assured the public that the floats will be assembled in a Tillamook County town, so this project provides the opportunity for job creation and stimulation of the economy.

Principle Power is working with Portugal’s EDP (Energias de Portugal) and has plans to deploy a full-scale prototype of the WindFloat’s foundation off the north coast of Portugal sometime in mid 2011 (Kessler 2010). Jon Bonanno, the president of Principle Power LLC, has said that depending on the permit process and financial backing, we could see a wind farm up and running off Oregon’s coast sometime between 2013-2015 (Woody 2008). The earliest cost estimates for the project total $375 million dollars (Woody 2008). Pelc and Fujita (2002) discussed how combined wind and wave energy technology could be more economically efficient as well as less detrimental to the environment. The U.S. National Renewable Energy Center is currently working in conjunction with Portugal’s Wave Energy Center to examine the WindFloat’s hybrid capabilities to generate both wind and wave energy (Balboa 2010).

3. Potential Impacts on Marine Mammals

While marine renewable energy technology holds great potential for decreasing our dependency on fossil fuels, decreasing carbon emissions and providing a clean renewable energy source to meet rising energy demands, it is essential to remember that it may result in adverse impacts to the marine ecosystem. Effects of renewable energy generation may produce an impact on marine life that is greater than expected, when combined with other environmental stressors (Dolman et al. 2007).

Currently, there is little information available on the potential environmental impacts of wave energy development. This is largely due to the lack of WECs deployed in actual seastate conditions (Patrício et al. 2009). While literature indicates wave energy will have a relatively low impact on the environment, these predictions are largely based on literature reviews of offshore wind, of which there are fundamental differences (Dunnet and Wallace 2008; Patrício et al. 2007). With the industry increasing rapidly, the opportunity to study potential environmental impacts is in the near future. On October 11-12, 2007, a workshop was held at the Hatfield Marine Science Center in Newport, Oregon, regarding the ecological effects of wave energy. The goal of this workshop was to assess potential ecological effects of wave energy development, summarize current knowledge, prioritize environmental issues, and recommend studies for the future (McMurray 2007). A workshop on the potential effects of wave buoys on marine mammals of the Oregon coast was held in Portland, Oregon, on October 9-10, 2008. The objective of this workshop was to determine the effects buoys may have on marine mammals (specifically the gray whale) and provide guidance for studies conducted in the future (Ortega-Ortiz and Lagerquist 2008). Concerns identified in these workshops regarding marine mammals and wave energy development include, but are not limited to:

- Alteration of gray whale migratory routes
- Collision
- Entanglement
- Acoustic disturbance
- Increased shipping traffic
- Haul-out sites for pinnipeds

It should also be stated that WECs have the potential for positive environmental effects. While the mooring lines are a concern for collision and entanglement of large marine mammals, they could potentially provide artificial reef habitat, attracting fish and providing foraging sites for pinnipeds and birds (Cada et al. 2007; Patrício et al. 2009). However, colonization by marine organisms may also have negative consequences in terms of maintenance and operation (Cada et al. 2007).

Offshore wind energy development is increasing rapidly and the industry is moving from small-scale farms to large-scale wind farms further offshore (Dolman et al. 2007). The idea of offshore wind energy development is new to the Oregon coast and in its infancy, therefore, there have been no workshops to my knowledge on the subject. Europe is the leader in offshore wind energy development, providing the majority of literature available on potential environmental impacts. Concern for marine mammals includes: acoustic disturbance, vibration, increased vessel traffic, behavioral reactions and masking (Dolman et al. 2007). There are essentially three phases of offshore wind energy development: construction, operation, and decommissioning (this is also true for wave energy) (ICES 2010). Before and during construction there is acoustic disturbance from: seismic exploration, ramming/pile-driving, drilling, dredging, and increased vessel traffic (Dolman et al. 2007; Koschinski et al. 2003). During operation there is low frequency noise and vibration from the generator that is emitted underwater constantly (Tougaard and Henriksen 2009). The decommissioning process often involves underwater explosions, which can be extremely detrimental to the surrounding environment (Tougaard and Henriksen 2009).

Environmental impact assessments on the potential environmental effects of offshore wind energy development will be crucial to implementing mitigation efforts protecting Oregon's marine mammals.

3.1. Gray Whale

The Eastern North Pacific stock of gray whales (*Eschrichtius robustus*) live on the west coast of North America, spending their summers feeding up in the Bering and Chukchi Seas and migrating south to Baja California, Mexico in the winter to breeding and calving lagoons (Ortega-Ortiz and Mate 2008). Some of the population remains in the Pacific Northwest from May-October and are referred to as "resident" gray whales (Ortega-Ortiz and Mate 2008). Gray whales are mysticetes, baleen whales, and spend the majority of their time in coastal waters. They have poor sight and rely heavily on underwater sound for communication, foraging, and navigation purposes (Perrin et. al. 2002). The gray whale emits low frequency broadband signals ranging from around 100 Hz to 4 kHz (Perrin et. al. 2002). Human induced anthropogenic noise often occurs in this low frequency range with high intensity outputs and as a result gray whales have been documented increasing their call types, rates, and frequency in order to overcome the disturbance (Perrin et. al. 2002).

The potential offshore sites identified as good locations for wave park development are located in the migratory path of the Eastern gray whale, as shown in a study conducted by Dr. Ortega-Ortiz and Dr. Mate in 2007/2008 where they tracked the distribution and movement patterns of gray whales off the central Oregon coast. Development of wave energy parks poses great concern over potential collision, entanglement, displacement, and behavioral changes (Boehlert et al. 2008). Little information is known about the acoustic output the wave energy parks will generate. Specifically, there is no information to my knowledge on the acoustic output of the PowerBuoy that will be deployed off of Reedsport. With wave energy development being a new industry, research on the effects of wave energy parks on baleen whales is lacking. The development of wind farms off the Oregon coast also poses similar risks. It is known that wind farms emit low frequency noise during construction and operation, which could ultimately lead to acoustic masking and/or displacement (Cada et al. 2007). The proposed wind farm off of Garibaldi is planning on using a new technology for the biggest marine wind float to date, which is likely to produce louder noise at higher frequencies than the smaller turbines that research has focused on (Tougaard and Henriksen 2009). Additionally, few studies have focused on the hearing threshold of marine mammals at low frequencies and there is no threshold available for the lowest frequency noise emitted from marine wind turbines (Tougaard and Henriksen 2009).

The potential for underwater collision and entanglement is of concern because gray whales have very poor vision, and it is questionable whether their low-frequency calls will be able to detect the wave park(s) and wind farm(s). The possibility of behavioral changes and displacement from their migratory route is something that will need to be taken into consideration (McMurray 2007). The baseline information on distribution and habitat use that Dr. Ortega-Ortiz and Dr. Mate (2008) accrued from their research will be essential in the future to indentify behavioral changes resulting from renewable energy development off the Oregon coast, as well as implementing mitigation measures.

It should also be stated that increasing the development of clean renewable energy beyond the Oregon territorial sea (3 miles offshore) will bring into consideration other cetacean species such as: Blue whale, Fin whale, Humpback whale, Minke whale, killer whale, Sie whale, Sperm whale, Baird's beaked whale, Cuvier's beaked whale, Stejneger's beaked whale, Pygmy sperm whale, Short-finned pilot whale, Dall's porpoise, Bottlenose dolphin, Pacific white-sided dolphin, Risso's dolphin, and Northern right whale dolphin (Ortega-Ortiz and Lagerquist 2008). The proposed WindFloat farm off of Tillamook County is for an offshore distance of ten miles. Therefore, when a workshop is created to address the potential impacts of offshore wind energy development off of Oregon, the marine mammals affected will greatly expand.

3.2. Harbor Porpoise

Harbor porpoise (*Phocoena phocoena*) are odontocetes, toothed whales, generally found in the shallower coastal waters off Oregon. Harbor porpoise use high frequency echolocation for communicating, foraging, and navigation, and are sensitive to acoustic signals. The frequency range their signals occupy is approximately 40Hz to 150 kHz (Richardson et al. 1995). Some of the potential effects of wave and wind energy development are hearing loss, masking of signals, increased stress levels, and habitat abandonment/displacement (Gilles et. al. 2009). While little is known about the effects of wave energy development on harbor porpoise, research is available on the effects of marine wind energy development.

Some researchers speculate that wave and wind energy development will elicit behavioral and physiological effects, particularly during the construction process (pile-driving, drilling, dredging, vibrations, etc.) (Dolman et al. 2007; Gilles et. al. 2009), while others have found a lack of significant behavioral reactions (Tougaard and Henriksen 2009). The noise produced during construction and operation of wind farms is low frequency (Madsen et al. 2006). The harbor porpoise does not produce sound at low frequency and has relatively poor hearing at frequencies below 1 kHz (Madsen et al. 2006). Tougaard and Henriksen (2009) conducted a study on the impact zones for harbor porpoises and harbor seals when exposed to underwater noise from three types of offshore wind turbines. They found that the low intensity, low frequency noise produced by wind turbines had a limited capability of injuring the harbor porpoise or masking their signals, and drew the conclusion that due to the poor hearing capabilities of harbor porpoise in the frequency range of wind turbines, behavioral effects are unlikely. In another study conducted by Koschinski and associates (2003) on behavioral reactions of free-ranging porpoise to noise from marine wind power generators, they found harbor porpoise are able to detect the low frequency sound generated by offshore wind turbines as well as exhibiting avoidance and exploratory behavior.

The research conducted on the effects of marine wind energy development on harbor porpoise is highly contradictory. Therefore, more research is needed in this area before any conclusions can be drawn.

3.3. Pinnipeds

The pinnipeds that may be impacted most by the development of clean renewable ocean energy include the California sea lion (*Zalophus californianus*) and harbor seal (*Phoca vitulina*). California sea lions can be found in Oregon during the months of September – May, and harbor seals are present year round. Sea lions (otarrids) have hearing specialized for above ground because they spend a lot of time hauled out on land as well as mate onshore at breeding rookeries. The frequencies California sea lions use to vocalize are 1-4 kHz and their hearing threshold is in the range of 1-40 kHz (Richardson et al. 1995). Their hearing is more sensitive in air than harbor seals', due to the habitat they occupy. Harbor seals (phocids) are specialized for underwater hearing because that is where they spend a majority of their time foraging and mating. Underwater, harbor seals are capable of hearing frequencies 1–180 kHz as opposed to 1-22.5 kHz in air (Richardson et al. 1995).

The Eastern stock of stellar sea lions (*Eumetopias jubatus*) are also a species present along the coast of Oregon. On April 5, 1990, the stellar sea lion was listed endangered under the Endangered Species Act of 1973 due to the decline of the Western stock (NOAA et al. 2008). However, since the late 1970's the Eastern stock population has more than doubled, increasing 215% with a 3.1% annual rate of increase overall (NOAA et al. 2008; Pitcher et al. 2007). Specifically, in Oregon the stock is increasing 2.5% per year (Pitcher et al. 2007). In 1997 the National Marine Fisheries Service distinguished the two populations, Eastern vs. Western stocks. The Western population remained endangered, while the Eastern population changed to threatened (NOAA et al. 2008). The state of Oregon has eight haul-out sites and two pup rookeries for the Eastern stock (Rogue Reef and Orford Reef) (NOAA et al. 2008). Currently there are no identified threats to the continued recovery of the Eastern stellar sea lion stock and therefore their threatened status is potentially being considered for removal (NOAA et al. 2008). It is speculated that ocean energy development may not have a significant impact on this species because:

1) They migrate through the area, but their haul-out and rookery sights aren't in the areas of the currently-proposed development.

2) They spend a lot of time on land, rather than underwater.

Pinnipeds in general produce low frequency acoustic signals for social communication, foraging, navigation and mating (Southall et al. 2000). One of the concerns regarding pinnipeds and ocean energy development is that the low frequency anthropogenic noise emitted during the construction and maintenance processes may ultimately mask pinniped signals (Koschinski et al. 2003). Specifically, during the mating season male harbor seals have been found to produce low frequency pulsed calls 0.4 – 2 kHz (Koschinski et al. 2003). If mating calls are masked, there could potentially be a negative impact on reproduction. Low frequency, high intensity sound is able to propagate over long distances, and studies indicate harbor seals have the capability of detecting these noises from farther away than species such as harbor porpoise (Tougaard and Henriksen 2009). Koschinski et al. (2003) documented harbor seals showing distinct behavioral responses while surfacing, correlated with increased median distances from the wind turbine source. The installation of wave energy parks and wind farms provides artificial reef to the habitats they are placed in. This has the potential to either attract new fish populations which in turn could attract pinnipeds to the area, or, the electromagnetic fields produced by the transmission cables could cause fish and marine mammals to avoid the area (Cada et al. 2007; McMurray 2007). More research is needed on the effects of electromagnetic fields on fish and marine mammal populations before any conclusions can be drawn. Entanglement and collision is not a significant concern for pinnipeds, given their small size. There is a potential for pinnipeds to use the wave energy buoys as haul-out sites. OPT has addressed this issue by implementing mitigation measures such as the UHMWPE paint that is slippery when wet, and if that fails, OPT plans to install fences (Reedsport 2010).

4. Ongoing Research and Future Assessments

4.1. Development of an acoustic deterrent device for Eastern North Pacific gray whales (Eschrictius robustus)

Oregon State University's Marine Mammal Institute will be deploying a deterrent device in December 2010, 4.0 km directly west of Yaquina Head, Oregon, to test the effectiveness of an acoustic deterrent device in moving Eastern North Pacific gray whales 500m away from the sound source (Lagerquist and Mate 2010). The development of wave and wind energy presents the risk of entanglement in mooring cables, transmission cables, and anchor lines for large cetaceans. At 500m it is believed that gray whales will have little chance of becoming entangled or colliding with objects of concern (Lagerquist and Mate 2010). The proposed acoustic playback study will take place during the southbound and northbound A-phases of migration (from January to mid April 2011) (Lagerquist and Mate 2010). The A-phase of northbound migration begins in mid February when newly pregnant females, adult males, and immature males and females leave Baja California and head north to summer feeding grounds (Ortega-Ortiz and Mate 2008).

The acoustic deterrent device will be anchored to a weighted aluminum framed cage (Lander) directly west of Yaquina Head (Lagerquist and Mate 2010). An Airmar transmitter and five Optima Blue Top D31M batteries will be mounted directly to the Lander (Lagerquist and Mate 2010). A surface buoy will be attached to a single mooring line which will have little to no slack, presenting no entanglement risk to marine mammals in the area (Lagerquist and Mate 2010). The projector will be placed 20m below the surface. The acoustic deterrent device will operate only in daylight hours, and a ramp-up procedure will be implemented prior to every exercise to give any marine life in the area an opportunity to move away from the sound before the full source level is achieved (Lagerquist and Mate 2010). Prior to the playback experiment, Dr. Dave Mellinger and colleagues will measure the acoustic output of the device (Lagerquist and Mate 2010). Observers based on shore at an observation station next to Yaquina Head lighthouse will use binoculars and a theodolite to track the whales' positions and behavior, recording observations into a portable computer (Lagerquist and Mate 2010).

This study is the first of its kind, testing the effectiveness of an acoustic deterrent device to potentially protect gray whales from harm (Lagerquist and Mate 2010). Data collected on the whales' distribution and migration trajectory changes may be used for implementation of mitigation tools to protect the Eastern North Pacific gray whale from injury as well as contribute to the development of effective management strategies (Lagerquist and Mate 2010).

4.2. Sound Propagation Off the Oregon Coast: A Modeling Approach to Evaluate Possible Effects of Man-made Sound on the Marine Environment

In February of 2010, Dr. Elizabeth Küsel presented an abstract on this project at the 2010 Ocean Sciences Meeting held in Portland, Oregon. This research is currently unpublished.

With the potential increase in underwater noise levels caused by wave energy conversion devices, there is concern over the adverse effects this could have on the marine organisms in the surrounding area. Underwater noise is dependent on sound propagation in the ocean, which is itself dependent on the time of year (Küsel et al. 2010). Dr. Küsel, Dr. Klinck, and Dr. Mellinger, from the Cooperative Institute of Marine Resource Studies (CIMRS), plan to use a forward acoustic propagation model and a physical model of the environment to calculate sound transmission loss off the coast of Newport, Oregon (Küsel et al. 2010). They will use sound speed profiles collected from CTD samples during winter (December and January) and Spring (March and April), coinciding with the presence of gray whales off the Oregon coast (Küsel et al. 2010). The data from the sound speed profiles will show varying degrees of water column stratification and will be placed in environmental physical models that include bathymetry and surrounding bottom properties, to estimate the propagation loss and potential received sound levels in the environment (Küsel et al. 2010). Results from this study may be used to assess the impacts of the calculated noise levels on the marine environment and aid in mitigation measures for Eastern North Pacific gray whales.

4.3 Nearshore acoustic baseline measurements off the Central coast of Oregon

The goal of this project is to obtain continuous and adaptive long-term passive acoustic measurements of ambient sound levels in an area designated for the development of wave energy devices in Oregon's nearshore coastal ocean (Haxel and Dziak 2011). An underwater acoustic hydrophone will be moored within the NNMREC study site off of Yaquina Head, Newport, Oregon, sampling continuously in the 1 Hz – 2 kHz range (Haxel and Dziak 2011). This project will provide a sampling of the marine acoustic field before and after the installation of wave energy devices in the NNMREC study area (Haxel and Dziak 2011). The long-term acoustic time series will contribute valuable information regarding the inter-annual and seasonal variability of ambient sounds in the area, as well as the effects of anthropogenic sound (Haxel and Dziak 2011). This project will be conducted over a year, beginning June 2010. The time dependent baseline for acoustic amplitudes versus frequency is an essential component to compare ambient sound levels with post-wave energy development anthropogenic sound levels (Haxel and Dziak 2011). The results from this study will provide information on the harmful acoustic effects of wave energy devices on cetaceans and other marine life in the shallow coastal waters of Oregon (Haxel and Dziak 2011).

4.4 Marine Mammal Seasonality and Ecology on Oregon's Outer Continental Shelf

Dr. Dave Mellinger and colleagues from the Cooperative Institute for Marine Resources Studies at Hatfield Marine Science Center in Newport, Oregon, have proposed to conduct an observational study on the seasonal occurrence and movement of marine mammals on Oregon's outer continental shelf. This project will provide needed baseline information on marine mammal occurrence and behavior, and an understanding of the physical and biological factors that lead to this occurrence (Mellinger et al. 2010). The study area proposed is directly west of the NNMREC wave energy testing site off of Yaquina Head. It is also near two planned Integrated Ocean Observing Systems (IOOS) as well as in the middle of the Navy's Northwest Training Range complex where the number of training operations is planned to increase (Mellinger et al. 2010). The study would be conducted July 1, 2011 through June 30, 2014. Results from this long-term study will answer key regulation and mitigation questions for renewable energy siting and permitting as well as contribute to basic knowledge on marine mammal seasonal occurrence and migration (Mellinger et al. 2010).

In summary, this study will document the occurrence of marine mammals in the vicinity that vocalize at low, mid, and high frequencies. Five autonomous hydrophones will record acoustic noise continuously for a two year span (Mellinger et al. 2010). Four mid-frequency hydrophones will be deployed and record ambient sound up to 16 kHz (Mellinger et al. 2010). One high-frequency hydrophone will be placed in the center of the hydrophone array and record ambient sound up to 100 kHz (Mellinger et al. 2010). To capture summary acoustic information on high-frequency species outside the range of the hydrophones, a C-POD device will be used to record the location of the acoustic event, as opposed to an actual waveform record (Mellinger et al. 2010). A towed hydrophone array, gliders, can be used to assess conditions such as currents, upwelling, hypoxia, turbulence and planktonic blooms, and relate findings to the occurrence of marine mammal species (Mellinger et al. 2010). The recordings will enable researchers to track the direction and movement of marine mammals. In conjunction with these recordings, visual surveys will also take place from boats.

4.5 Pile Driving in Newport Harbor

This research is still in the development stage. Dr. Dave Mellinger and colleagues will conduct research on the pile driving operation at the new NOAA headquarters in Newport, Oregon. The project will be approximately four months long, continuously monitoring the underwater acoustic sound fields produced before, during, and after pile driving activities occur (Mellinger et al. 2010). Their research will evaluate the potential effects of pile driving on nearby marine mammal species, particularly the California sea lion (*Zalophus californianus*) (Mellinger et al. 2010). Two underwater hydrophones will be placed somewhere within Newport Harbor, outside the vessel traffic lane. The Port of Newport and United States Coast Guard will be consulted on the placement. This project will also be accompanied with a visual survey by the Oregon State Marine Mammal Institute.

5. Conclusion

With increasing demand worldwide for sustainable clean renewable energy sources, the responsible development of ocean energy technologies is critical. The state of Oregon is dedicated to the responsible development of ocean energy, overseen by OWET. While the state of Oregon would like to become the North American leader in ocean energy research and development, it is crucial to assess the environmental costs our coastline will endure. The idea of "clean" renewable energy may in fact have significant environmental costs. The workshops held in Oregon on the potential impacts of wave energy have identified current knowledge and areas of research to focus on. In the future, similar workshops should be held regarding the development of offshore wind energy in Oregon. With the state of Oregon, development companies, and scientists working together, the responsible development of ocean energy is achievable.

6. Acknowledgements

Special thanks to Barbara Lagerquist, Kaety Hildenbrand, Sarah Henkel, Dave Mellinger, Holger Klinck, Joe Haxel, Elizabeth Thorp Küsel, Kim Ram-Suryan, Chris Langdon and Chris Eardley for providing valuable information and time to this project.

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8. Figures and Tables

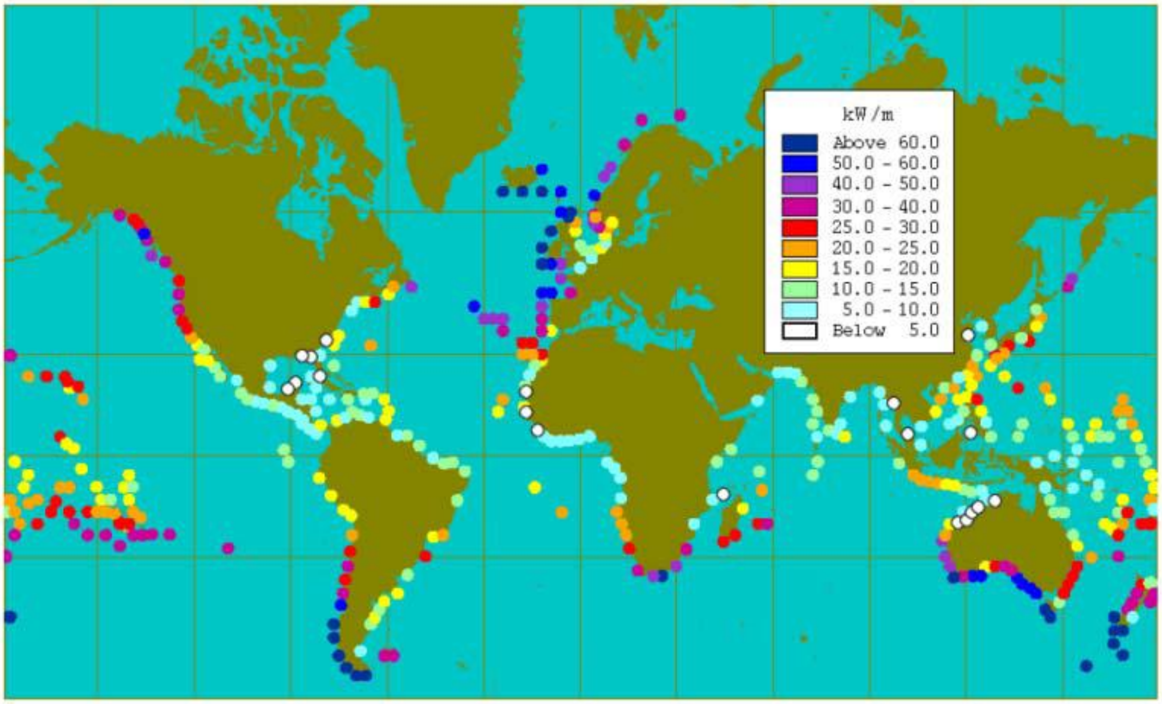
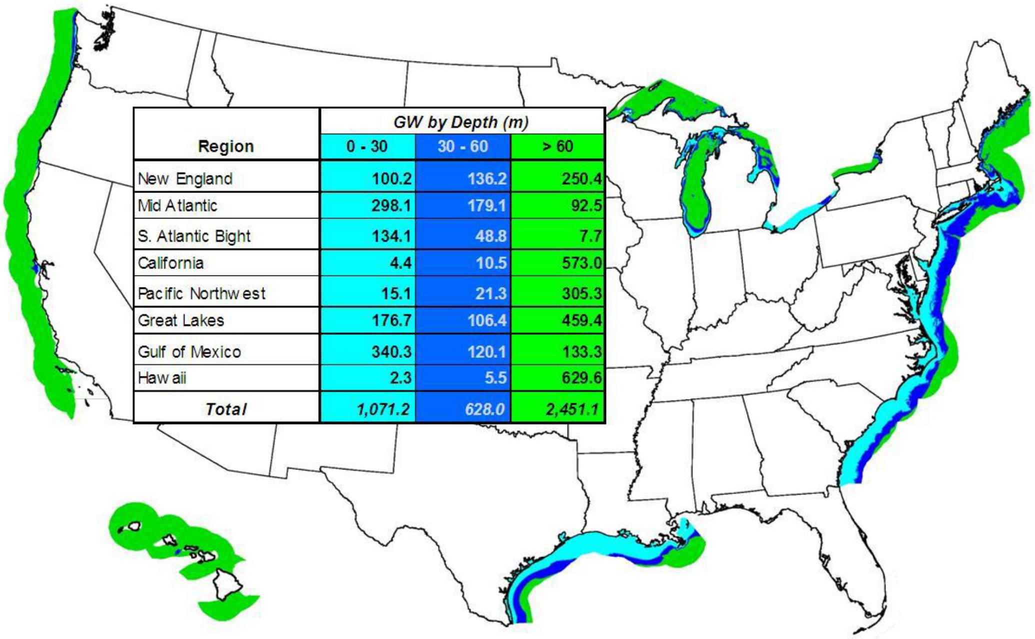


Figure 1. Annual wave energy averages worldwide in kW/m wave front (Bedard 2005).



Region	GW by Depth (m)		
	0 - 30	30 - 60	> 60
New England	100.2	136.2	250.4
Mid Atlantic	298.1	179.1	92.5
S. Atlantic Bight	134.1	48.8	7.7
California	4.4	10.5	573.0
Pacific Northwest	15.1	21.3	305.3
Great Lakes	176.7	106.4	459.4
Gulf of Mexico	340.3	120.1	133.3
Hawaii	2.3	5.5	629.6
Total	*1,071.2*	*628.0*	*2,451.1*

Figure 2. United States offshore wind resource by region and depth for annual average wind speed sites above 7.0 m/s (Musial and Ram 2010).

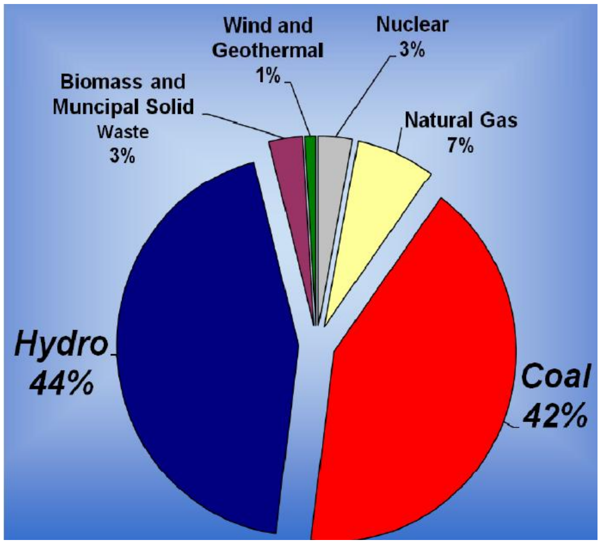


Figure 3. Electricity supplies in Oregon (Boehlert 2009).

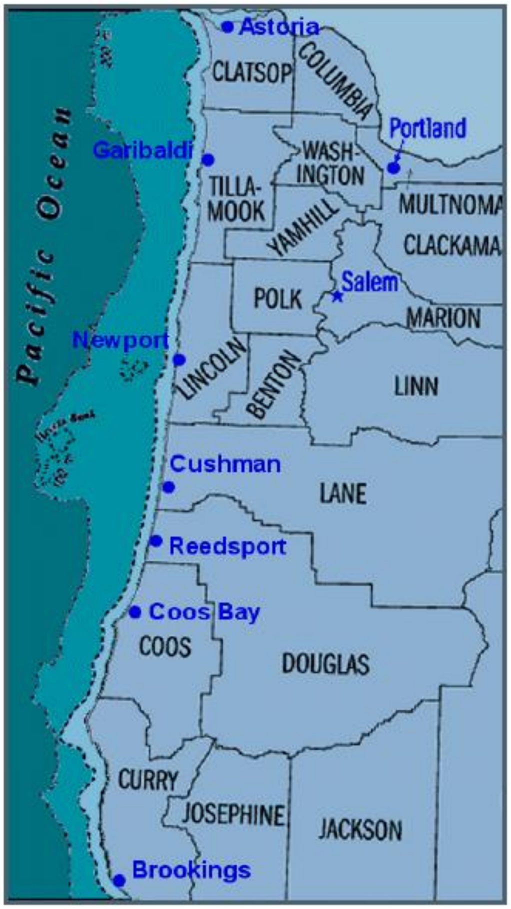


Figure 4. The seven potential offshore sites along the Oregon coast identified as viable locations for wave energy (EPRI 2004).

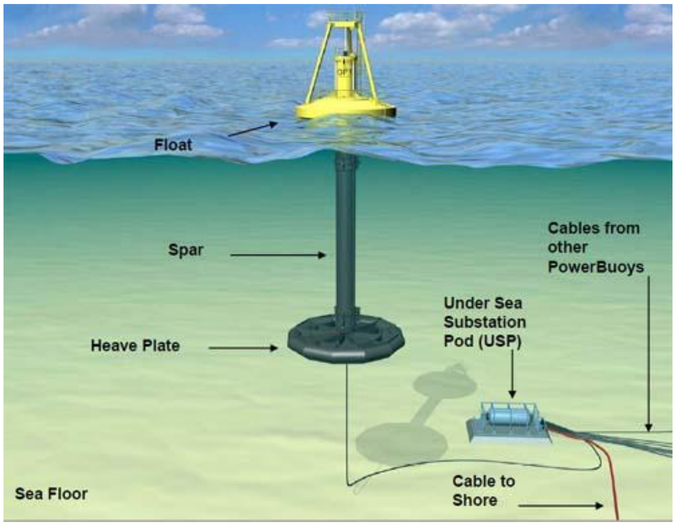


Figure 5. Ocean Power Technology's PowerBuoy (OPT 2010).

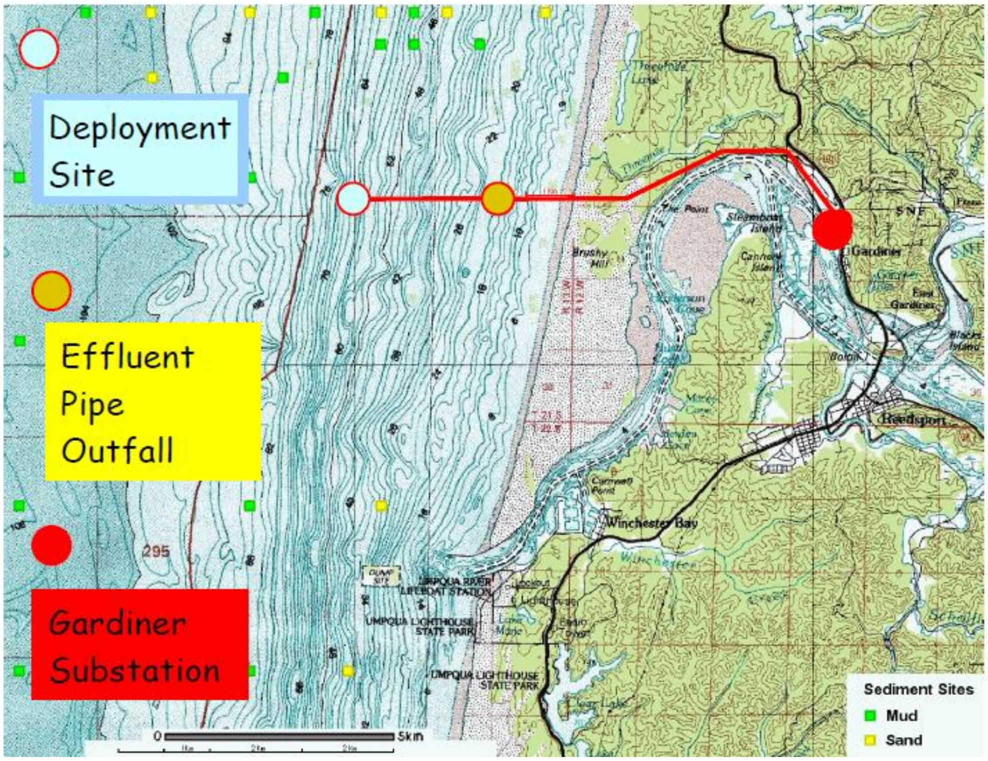


Figure 6. Reedsport OPT Wave Park Project (Reedsport 2010).

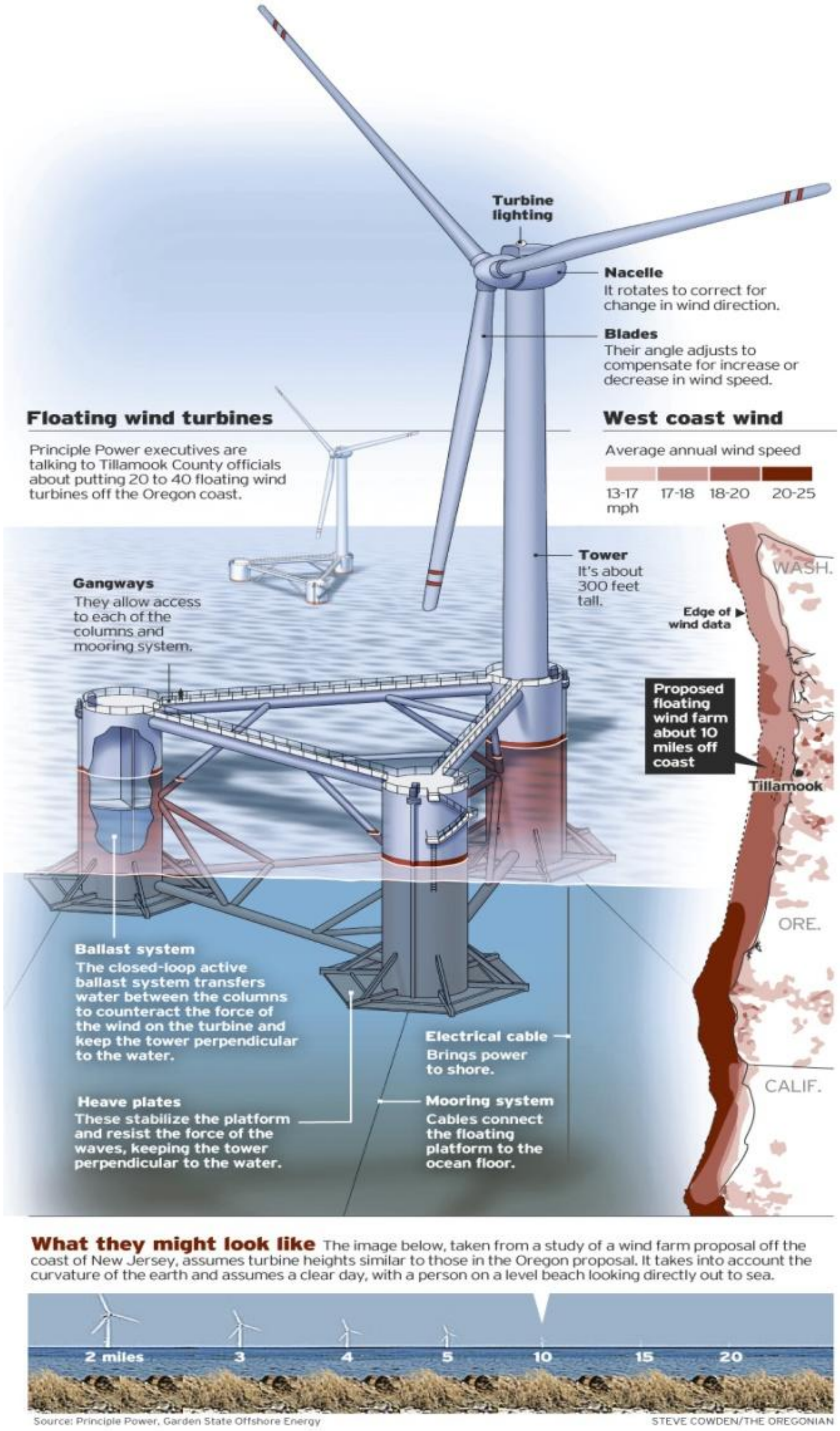
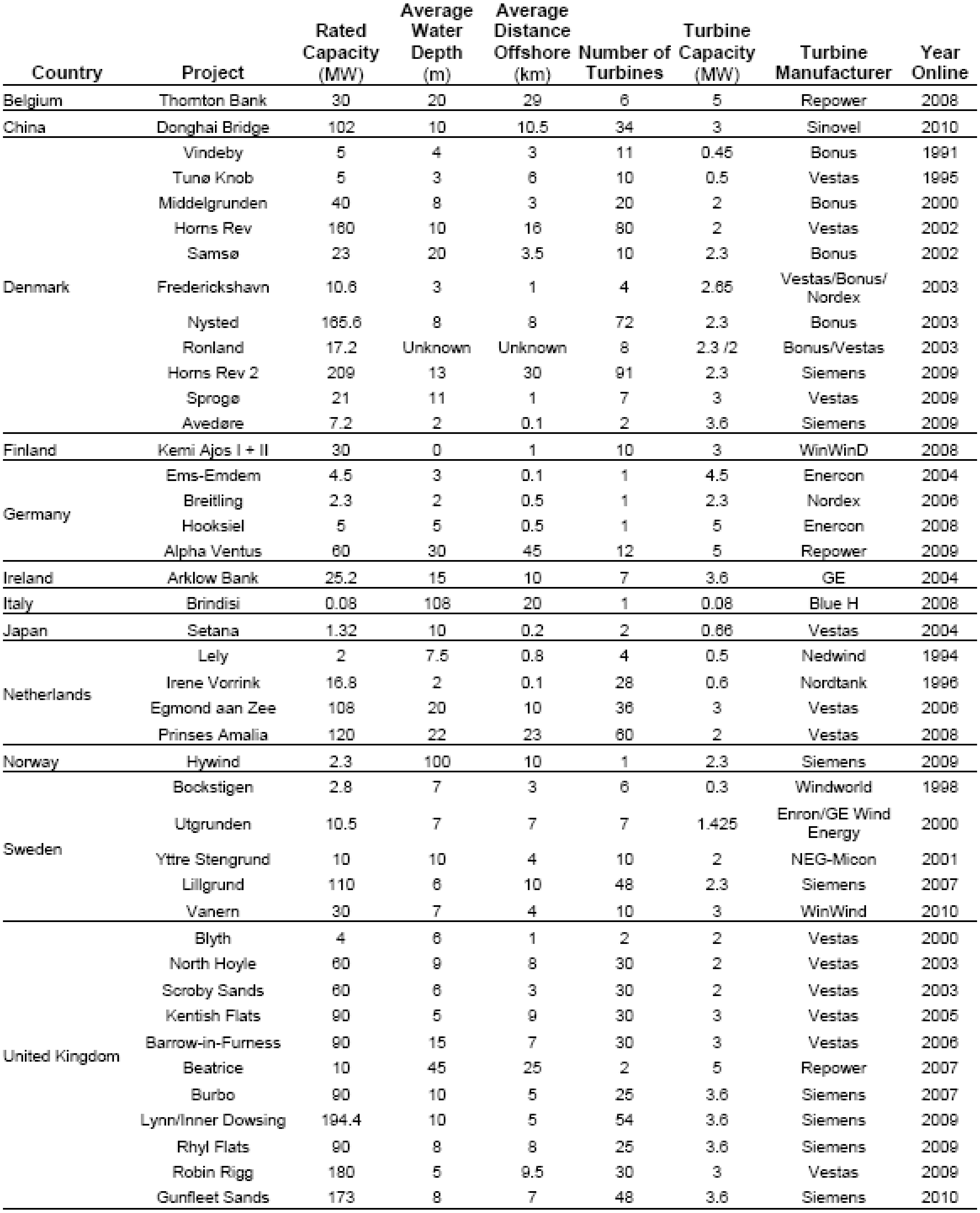


Figure 7. Principle Power's WindFloat (Principle Power 2010).

Table 1. Summary of Current Offshore Projects Installed Worldwide as of the Second Quarter of 2010 (Musial and Ram 2010).



Country	Project	Rated Capacity (MW)	Average Water Depth (m)	Average Distance Offshore (km)	Number of Turbines	Turbine Capacity (MW)	Turbine Manufacturer	Year Online
Belgium	Thornton Bank	30	20	29	6	5	Repower	2008
China	Donghai Bridge	102	10	10.5	34	3	Sinovel	2010
Denmark	Vindeby	5	4	3	11	0.45	Bonus	1991
	Tunø Knob	5	3	6	10	0.5	Vestas	1995
	Middelgrunden	40	8	3	20	2	Bonus	2000
	Horns Rev	160	10	16	80	2	Vestas	2002
	Samsø	23	20	3.5	10	2.3	Bonus	2002
	Frederickshavn	10.6	3	1	4	2.65	Vestas/Bonus/ Nordex	2003
	Nysted	165.6	8	8	72	2.3	Bonus	2003
	Ronland	17.2	Unknown	Unknown	8	2.3 /2	Bonus/Vestas	2003
	Horns Rev 2	209	13	30	91	2.3	Siemens	2009
	Sprogø	21	11	1	7	3	Vestas	2009
	Avedøre	7.2	2	0.1	2	3.6	Siemens	2009
Finland	Kemi Ajos I + II	30	0	1	10	3	WinWinD	2008
Germany	Ems-Emdem	4.5	3	0.1	1	4.5	Enercon	2004
	Breitling	2.3	2	0.5	1	2.3	Nordex	2006
	Hooksiel	5	5	0.5	1	5	Enercon	2008
	Alpha Ventus	60	30	45	12	5	Repower	2009
Ireland	Arklow Bank	25.2	15	10	7	3.6	GE	2004
Italy	Brindisi	0.08	108	20	1	0.08	Blue H	2008
Japan	Setana	1.32	10	0.2	2	0.66	Vestas	2004
Netherlands	Lely	2	7.5	0.8	4	0.5	Nedwind	1994
	Irene Vorrink	16.8	2	0.1	28	0.6	Nordtank	1996
	Egmond aan Zee	108	20	10	36	3	Vestas	2006
	Prinses Amalia	120	22	23	60	2	Vestas	2008
Norway	Hywind	2.3	100	10	1	2.3	Siemens	2009
Sweden	Bockstigen	2.8	7	3	6	0.3	Windworld	1998
	Utgrunden	10.5	7	7	7	1.425	Enron/GE Wind Energy	2000
	Yttre Stengrund	10	10	4	10	2	NEG-Micon	2001
	Lillgrund	110	6	10	48	2.3	Siemens	2007
	Vanern	30	7	4	10	3	WinWind	2010
United Kingdom	Blyth	4	6	1	2	2	Vestas	2000
	North Hoyle	60	9	8	30	2	Vestas	2003
	Scroby Sands	60	6	3	30	2	Vestas	2003
	Kentish Flats	90	5	9	30	3	Vestas	2005
	Barrow-in-Furness	90	15	7	30	3	Vestas	2006
	Beatrice	10	45	25	2	5	Repower	2007
	Burbo	90	10	5	25	3.6	Siemens	2007
	Lynn/Inner Dowsing	194.4	10	5	54	3.6	Siemens	2009
	Rhyl Flats	90	8	8	25	3.6	Siemens	2009
	Robin Rigg	180	5	9.5	30	3	Vestas	2009
	Gunfleet Sands	173	8	7	48	3.6	Siemens	2010