Review of Recent Literature Relevant to the Environmental Effects of Marine and Hydrokinetic Energy Devices

Task 2.1.3: Effects on Aquatic Organisms – Fiscal Year 2011 Progress Report

Environmental Effects of Marine and Hydrokinetic Energy

RK Kropp

September 2011

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Abstract

A literature search was conducted by using the Web of Science® databases component of the ISI Web of Knowledge[SM] to identify recent articles that would be useful to help assess the potential environmental effects of renewable energy development in the ocean, with emphasis on marine mammals and seabirds. Several relatively recent general review articles that included possible effects on marine mammals, seabirds, and fish (particularly Puget Sound forage fish and salmonids) were examined to begin the search process. From these articles, several general topics of potential environmental effects on marine mammals, seabirds, and fish were derived. These topics were used as the primary search factors. Additional sources were identified by cross-checking the Web of Science databases for articles that cited the review articles. It also became clear that the potential effects frequently were offered as hypotheses that were not supported by the presentation of appropriate documentation. Therefore, the literature search was refined and focused on trying to obtain the necessary information to support or challenge a proposed potential effect.

Project Overview

Energy generated from the world's oceans and rivers offers the potential to make substantial contributions to the domestic and global renewable energy supply. The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Wind and Water Power Program supports the emerging marine and hydrokinetic (MHK) energy industry. As major players in an emerging industry, MHK project developers face challenges with siting, permitting, construction, and operation of pilot- and commercial-scale facilities, as well as the need to develop robust technologies, secure financing, and gain public acceptance.

In many cases, little is known about the potential effects of MHK energy generation on the aquatic environment from a small number of devices or a large-scale commercial array. Nor do we understand potential effects that may occur after years or decades of operation. This lack of knowledge affects the solvency of the industry, the actions of regulatory agencies, the opinions and concerns of stakeholder groups, and the commitment of energy project developers and investors.

To unravel and address the complexity of environmental issues associated with MHK energy, Pacific Northwest National Laboratory (PNNL) is developing a program of research and development that draws on the knowledge of the industry, regulators, and stakeholders and builds on investments made by the EERE Wind and Water Power Program. The PNNL program of research and development—together with complementary efforts of other national laboratories, national marine renewable energy centers, universities, and industry—supports DOE's market acceleration activities through focused research and development on environmental effects and siting issues.

Research areas addressed include

- **Categorizing and evaluating effects of stressors** – Information on the environmental risks from MHK devices, including data obtained from in situ testing and laboratory experiments (see other tasks below) will be compiled in a knowledge management system known as *Tethys* to facilitate the creation, annotation, and exchange of information on environmental effects of MHK technologies. *Tethys* will support the Environmental Risk Evaluation System (ERES) that can be used by developers, regulators, and other stakeholders to assess relative risks associated with MHK technologies, site characteristics, waterbody characteristics, and receptors (i.e., habitat, marine mammals, and fish). Development of *Tethys* and the ERES will require focused input from various stakeholders to ensure accuracy and alignment with other needs.

- **Effects on physical systems** – Computational numerical modeling will be used to understand the effects of energy removal on water bodies from the short- and long-term operation of MHK devices and arrays. Initially, PNNL's three-dimensional coastal circulation and transport model of Puget Sound will be adapted to test and optimize simulated tidal technologies that resemble those currently in proposal, laboratory trial, or pilot study test stages. This task includes assessing changes to the physical environment (currents, waves, sediments, and water quality) and the potential effects of these changes on the aquatic food webs) resulting from operation of MHK devices at both pilot- and commercial-scale in river and ocean settings.

- **Effects on aquatic organisms** – Testing protocols and laboratory exposure experiments will be developed and implemented to evaluate the potential for adverse effects from operation of MHK devices in the aquatic environment. Initial studies will focus on electromagnetic field effects, noise

associated with construction and operation of MHK devices, and assessment of the potential risk of physical interaction of aquatic organisms with devices. A variety of fish species and invertebrates will be used as test animals, chosen due to their proximity to and potential susceptibility to MHK devices.

- **Permitting and planning** – Structured stakeholder communication and outreach activities will provide critical information to the project team to support execution of other project tasks. Input from MHK technology and project developers, regulators and natural resource management agencies, environmental groups, and other stakeholder groups will be used to develop the user interface of *Tethys*, populate the database, define the risk attributes of the ERES, and communicate results of numerical modeling and laboratory studies of exposure of test animals to MHK stressors. This task will also include activities to promote consideration of renewable ocean energy in national and local Coastal and Marine Spatial Planning activities.

The team for the Environmental Effects of Marine and Hydrokinetic Energy Development project is made up of staff, faculty, and students from

- Pacific Northwest National Laboratory
  - Marine Sciences Laboratory (Sequim and Seattle, Washington)
  - Risk and Decision Sciences (Richland, Washington)
  - Knowledge Systems (Richland, Washington)
- Oak Ridge National Laboratory (Oak Ridge, Tennessee)
- Sandia National Laboratories (Albuquerque, New Mexico; Carlsbad, California)
- Oregon State University, Northwest National Marine Renewable Energy Center (Newport, Oregon)
- University of Washington, Northwest National Marine Renewable Energy Center (Seattle, Washington)
- Pacific Energy Ventures (Portland, Oregon).

Acronyms and Abbreviations

ac	acre(s)
DOE	U.S. Department of Energy
EERE	DOE Office of Energy Efficiency and Renewable Energy
ERES	Environmental Risk Evaluation System
FY	fiscal year
ft	foot (feet)
ha	hectare(s)
J	joule(s)
kg	kilogram(s)
kJ	kilojoule(s)
km	kilometer(s)
m	meter(s)
MHK	marine and hydrokinetic
nmi	nautical miles
PNNL	Pacific Northwest National Laboratory

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1.0   Introduction

As part of Task 2.1.3, Effects on Aquatic Organisms, Pacific Northwest National Laboratory (PNNL) project staff performed a literature survey and review to develop information with which to assess risk of adverse outcomes associated with physical interaction with marine hydrokinetic devices (Subtask 2.1.3.6). This report documents those activities.

The methods and approach used to conduct the survey and review are detailed in Section 2. In Section 3, a case study of the potential effects of coastal wave energy parks on gray whale migration is developed. Section 4 provides reviews of articles that were derived from the original general literature search to determine the primary topics of concern regarding the potential effects of marine and hydrokinetic (MHK) devices on seabirds. In Section 5, region-specific literature on potential effects from MHK devices to fish is reviewed. Section 6 is a listing of the full citations for the reviewed articles. Section 7 is a listing of additional relevant sources located during the survey but which have not yet been reviewed.

2.0   Methods and Approach

A literature search was conducted by using the Web of Science® databases component of the ISI Web of Knowledge[SM] to identify recent articles that would be useful to help assess the potential environmental effects of renewable energy development in the ocean, with emphasis on marine mammals and seabirds. Several relatively recent general review articles that included possible effects of marine renewable energy devices on marine mammals, seabirds, and fish (particularly Puget Sound forage fish and salmonids) were examined to begin the search process (e.g., Boehlert et al. 2008; Thompson et al. 2008; Simas et al. 2009). From these articles, several general topics of potential environmental effects on marine mammals (**boldface italics** in Table 2.1) and seabirds (Section 4) were derived. These topics were used as the primary search factors. Searches were conducted with reference to the potential effects of offshore wind farms and MHK devices on marine mammals, seabirds, and fish. Additional sources were identified by cross-checking the Web of Science databases for articles that cited the review articles. It also became clear that the potential effects frequently were offered as hypotheses that often were not supported by the presentation of appropriate documentation. Therefore, the literature search was refined and focused on trying to obtain the necessary information to support or challenge a proposed potential effect to a specific concern.

Table 2.1. Reviewed Literature That Discusses the Potential Effects of Marine Wave Parks on Migrating Marine Mammals

Summary (Key Points in **Boldface Italics**)	Reference
Sound avoidance behavior and any barrier that might be formed by the mooring cables could ***change migration path of cetaceans***, especially ***gray whales***. Whales could be forced to ***swim through a smaller migration corridor***, which could make them ***more susceptible to predators***, such as killer whales (*Orcinus orca*). Gray whale cows and calves could be ***forced further offshore*** where calves might have greater risk for predation. Mooring lines in ***dense arrays could entangle whales***. ***Foraging opportunities might be reduced***.	Boehlert et al. (2008)
Avoiding MHK arrays might cause ***whales to change migration routes***, which may affect an individual whale's fitness. Avoiding arrays could ***increase the distance each whale swims*** during its migration, ***increasing the energetic costs*** of that migration. Avoiding arrays also could ***increase predation risks*** and ***lower feeding opportunities***, which also would directly affect fitness costs.	Simas et al. (2009)
MHK arrays could ***disrupt marine mammal migration patterns***, which may disrupt breeding cycles, exclude whales from key habitat, increase energetic costs, and expose them to different predator threats. Large ocean wave parks may cause whales to ***alter their migration routes between feeding grounds in Alaska and breeding grounds in Mexico***. This could ***delay arrival at either destination***. Mammals that swim into deeper water to avoid wave parks, could experience ***increased threats from predators***, such as great white sharks and killer whales, that they might not encounter in shallow waters. Delay in reaching feeding rounds could ***increase energetic costs*** by ***forcing whales to seek alternative food sources***. Migrating whale cows and calves could be more susceptible to these risks. Migrating marine mammals could become ***entangled by or collide with subsurface components*** and associated supports of arrays.	Thompson et al. (2008)
MHK arrays have ***acoustic signatures that might attract or repel marine mammals.***	Boehlert and Gill (2010)

One of the expressed concerns regarding MHK devices is that placing wave parks in coastal waters could compromise the migration patterns of whales. Disruption of the annual migration of the gray whale (*Eschrichtius robustus*), which swims at least 30,000 km on its round trip from breeding grounds in Baja California to feeding areas in the Bering Sea, is of particular concern. Among the hypothesized effects on the migrating gray whales are increased predation risk by constricting migration corridor to between array and shore or by forcing the whales to swim into deeper waters, increased metabolic energy costs and delays in reaching the destinations, and interrupting feeding by blocking access to benthic areas under arrays. The literature search focused on identifying published studies that could provide information to evaluate these concerns. The results were developed into a technical case study that evaluated the potential effects of the placement of wave parks in coastal waters along the migration route of the gray whale and were rewritten into a more general form that would be suitable for a broader audience. Wave parks and other MHK arrays may have additional effects on gray whales and other marine mammals, including interference with communications, that were not included in this case study.

3.0   Gray Whale Case Study

Among the many concerns raised about the potential effects of coastal MHK devices on marine mammals, one key issue is that the devices could adversely affect migrating gray whales (*Eschrichtius robustus*). Gray whales make one of the longest mammalian migrations known and, because the route follows close to shore along the West Coast of the United States, makes interactions between the migrating whales and MHK installations highly likely. Several review articles have described the possible effects of MHK arrays on migrating mammals in general (Simas et al. 2009) or on gray whales specifically (Boehlert et al. 2008; Thompson et al. 2008). Often the potential risks to mammals are described without reference to supporting literature.

One of the main concerns regarding MHK arrays and migrating gray whales is that the arrays would provide an obstacle in the migration pathway around or through which the gray whales would need to swim. Swimming closer to shore to pass the MHK array barrier could increase the predation risk to gray whales by constricting migration corridor to the distance between the array and shore (Boehlert et al. 2008), which would effectively place more whales in less space, providing killer whales with a greater opportunity to encounter gray whales. Gray whales could swim farther offshore into deeper waters to pass an array, which also could increase their susceptibility to killer whale predation (Boehlert et al. 2008; Thompson et al. 2008). Gray whale cows and their calves would be particularly vulnerable (Boehlert et al. 2008, p. 102).

Gray whales that swim through an MHK array would have to negotiate its gauntlet of subsurface floats and cables. Whales could collide with subsurface parts of the wave buoys or the catenary and tendon lines. Entanglement with the underwater lines is possible, although very unlikely, but more severe threat comes from the derelict fishing gear that could become entangled with the components of the array (FERC 2010).

Avoiding an MHK array would cause the whales to change their usual migration path (Boehlert et al. 2008). Altering the migration path could lengthen the distance traveled during the migration, which would increase the energy requirements of the whales. The increased energy costs could affect the long-term fitness of migrating whales (Simas et al. 2009). Following a different migration route could delay the whales' arrival at the breeding or feeding grounds, which could increase energy costs by requiring whales to find alternative feeding areas (Thompson et al. 2008). Additionally, the placement of MHK arrays in coastal waters could render some primary habitats as unsuitable for whale feeding under arrays, which could affect overall fitness (Simas et al. 2009).

To evaluate the efficacy of the concerns raised about the potential adverse effects of MHK arrays on gray whales, it is necessary to gather information about general and specific migration patterns (distance, timing, route), gray whale predators (main species) and their behavior (hunting tactics), gray whale swimming energetic requirements, gray whale prey (species) and feeding behavior, gray whale sensory perception and response to noise, and the physical aspects of the MHK array (location, dimensions). Much of the information used in the evaluation is derived from studies conducted outside the main area of interest (coastal Oregon) and is used to understand whale biology and how that might be extrapolated to the wave park area. Key points or effects identified by each reviewed paper (***boldface italics***), and their relevance to the evaluation, are captured in Table 3.1, which also includes a citation to the appropriate reference.

Table 3.1. Summary of Literature Used to Evaluate the Potential Effects of the Placement of Marine Wave Parks on Migrating Gray Whales

Gray Whale	Relevance to Issue	Summary	Reference
Migration	Distance from Shore	*About 66% of the southbound gray whale groups* observed in January 1990 were *more than 10 km (5.4 nmi)* offshore and were *farther off Washington (25 km or 13.5 nmi) than Oregon (12 km or 6.5 nmi)*. *24% of northbound whale groups* observed in March 1990 *were more than 10 km (5.4 nmi)* offshore and were *farther off Washington (12 km or 6.5 nmi) than Oregon (7.5 km or 4.0 nmi)*. 16% of whales were within 5 km of shore in Oregon and 8 whales within 5 km of shore in Washington.	Green et al. (1995)
	Distance from Shore/Swim Speed	Gray whale *pod sizes were larger (1.8 whales) during the day than at night (1.6 whales)*. The average number of whales passing per hour was higher at night than during the day. *Offshore distances were greater during the day (2.3 km) than at night (2.0 km)*. The distance whales swam offshore at night did not differ from that during the day for the second half of the migration. Swimming speed at night did not differ from that during the day in any comparison.	Perryman et al. (1999)
	Route/Timing	Gray whales swimming between winter breeding grounds off Baja California, Mexico, and primary feeding grounds in the Bering and Chukchi Seas, *undertake one of the longest migrations of any mammal*. *Summer feeding aggregations occur off California, Oregon, Washington, and British Columbia*. These whales inhabit an area extending from at least northern California to southeastern Alaska during the spring, summer, and autumn. They move into Oregon waters about August to October.	Calambokidis et al. (2002)
	Swim Speed	The authors tracked a gray whale swimming *at a fairly consistent speed of about 5.6 km/h* from Baja California to the San Francisco, California, area.	Mate and Urban-Ramirez (2003)
	Route/Distance Traveled	Most gray whales belonging to the eastern North Pacific stock *migrate a roundtrip distance of about 15,000 to 20,000 km (about 8100 to 10,800 nmi) between feeding areas in the Arctic to calving and primary breeding areas in Baja California*. Greater calf counts at the northern stations correlated with warmer sea-surface temperature anomalies. Increase in calf sightings related to increased abundance of the population, ocean climate changes, or a combination of both. *About half of the yearly calving now occurs north of Carmel on the southbound migration*, if the median parturition date has not changed.	Shelden et al. (2004)

Table 3.1. (contd)

Gray Whale	Relevance to Issue	Summary	Reference
	Distance from Shore/Swim Speed	Shore-based visual surveys from **Yaquina Head, Oregon**, between December 2007 and May 2008 estimated that **gray whales swam an average of 6.6 km (3.6 nmi) offshore during their southbound migration**. The northbound migration occurs in two phases. Newly pregnant females, anestrous females, adult males, and immature males and females (**Phase A**) **passed Oregon from February to April and swam about 5.1 km (2.8 nmi) offshore**. Gray whale cows with calves (**Phase B**) **passed Oregon from April to May and swam 4.1 km (2.2 nmi) offshore**. Average **water depth at the locations of whale sightings was 46 m (151 ft)**, and most whales follow a path along a constant depth contour rather than following the coastline. Whales tracked at average speeds of 6.74 km/h during the southbound migration, 6.05 km/h during Phase A of the northbound migration, and 5.42 km/h during Phase B.	Ortega-Ortiz and Mate (2008)
Sensory Perception (baleen whales)	Echolocation	Male humpback whales on breeding grounds in Hawaii space themselves and "sing" long "songs." Female humpbacks generally ignore or avoid singing males. The songs are usually described as sexual advertisements. Authors proposed that they could also **serve as "sonar" to help males find non-singing females**, and calculated a detection distance of 4–6 km (2.2–3.2 nmi).	Frazer and Mercado (2000)
	Echolocation	Authors **do not support the "sonar" model of Frazer and Mercado**, which seems to be based on limited observations of whale behavior. Authors contend that using more moderate values in a "noise-limited sonar equation" **would yield calculated detection ranges of 123–235 m** (404–771 ft).	Au et al. (2001)
	Echolocation	Provided rebuttal to Au et al. (2001) by asserting that **noise-limited sonar equation was not adequate to determine whether humpback songs generate detectable echoes from other whales** because it does not consider that much of the noise encountered by singing humpback whales is spectrally and temporally predictable. Called for experiments to test hypothesis.	Mercado and Frazer (2001)
	Vision Color Limitations	Color vision in most terrestrial mammals is based on L-cones (long-to-middle-wave-sensitive; green) and S-cones (short-wave sensitive; blue). Seven species of **toothed whales** and five species of **seals were found to have only L-cones,** which makes them essentially **color-blind**. **S-cones may have been lost in all whales and seals**.	Peichl et al. (2001)

Table 3.1. (contd)

Gray Whale	Relevance to Issue	Summary	Reference
	Vision/ Echolocation	This booklet provides general information on baleen whales, including general sensory perception. The whale *retina contains mostly rods* and is *backed with a reflective layer* (tapetum lucidum) that reflects light back through the lens. *No evidence indicates that baleen whales use echolocation*.	Sea World (2005)
	Sound Production	Humpback whales were found to *produce clicks during underwater lunges*. Relatively low levels occurred at the acoustic tags (between 143 and 154 dB re 1 mPa pp), most energy was less than 2 kHz. Intervals between clicks decreased towards the end of click trains forming a buzz. All clicks were recorded at night and were accompanied by sharp body rolls at the end of click bouts containing buzzes. This acoustic behavior is probably a *humpback night-time feeding tactic and is not a precise echolocation behavior*.	Stimpert et al. (2007)
	Echolocation	Echolocation occurs when an organism projects acoustic signals and obtains uses return echoes from it to sense its surroundings. *Dolphins, bats, and perhaps sperm whales can echolocate*. Some baleen whales produce sounds that can be heard over a thousand miles, and some whales may be able to hear echoes of those sounds that reflect off large objects. *Baleen whale sensitivity different sound frequencies and not well known*, so it is difficult to draw conclusions about the possibility that the whales can echolocate.	Au and Hastings (2008)
Predator Behavior (Killer Whale Feeding)	Prey Type/ Foraging Area	Some *transient killer whales pods* around southern Vancouver Island *foraged almost entirely in open water* and were recorded in the study area throughout the year, whereas others foraged near pinniped haulouts and other nearshore sites. These transient pods used the area primarily during the harbor seal (*Phoca vitulina*) weaning-postweaning period. Occasionally transient and resident killer whale pods were within several kilometers of each other, but there were no mixed groups; *transients appeared to avoid residents*.	Baird and Dill (1995)
	Attacks on Gray Whales/Shelter from Attacks	Migrating *gray whales that cross the deeper waters over Monterey Canyon in California were often attacked by transient killer whales* who tried to separate calves from mothers. Transient killer whales were most common in the area in late spring when gray whale mothers and claves migrated northward and pinnipeds weaned their young. Killer whales appeared to gain an advantage at the boundary of the steep canyon wall and chased crossing gray whales north or east toward the shelf. *When attacked, the gray whales attempted to swim to the safety of shallow water*.	Ternullo and Black (2002)

Table 3.1. (contd)

Gray Whale	Relevance to Issue	Summary	Reference
	Prey Preference– Gray Whales, Seals	During a 3-year survey in the eastern Aleutian Islands, Alaska, the authors observed resident, transient, and offshore killer whale groups. They observed offshore killer whales once and saw residents more often than transients. Most mammal-eating transient killer whales were observed during May and June. ***Transient killer whales fed mainly on gray whales in spring*** and ***northern fur seals*** (*Callorhinus ursinus*) ***in summer***. Steller sea lions (*Eumetopias jubatus*) were not a preferred prey during spring and summer. Most killer whales in the eastern Aleutian Islands were residents that do not eat marine mammals.	Matkin et al. (2007a)
	Prey Preference– Fish, Other Mammals, Seabirds	A 20-year study of killer whale populations in Glacier Bay and Icy Strait, Alaska, showed that West Coast transients and residents were the most commonly observed; Gulf of Alaska transients and offshore killer whales were much less common. ***Resident whales primarily ate silver (or Coho) salmon (Oncorhynchus kisutch) and Pacific halibut (Hippoglossus stenolepis)***, whereas ***transient whales mainly ate harbor seals, harbor porpoise (Phocoena hocoena), Steller sea lions, and seabirds***.	Matkin et al. (2007b)
	Prey Preference– Other Mammals, Seabirds	The authors tracked transient killer whales that occurred throughout the inland waters of southeastern Alaska during all seasons. Most transient killer whales from southeastern Alaska also occurred in British Columbia and Washington waters but only rarely swam off California. Transient killer whales ***ate Dall's porpoise (Phocoenoides dalli), Pacific white-sided dolphins (Lagenorhynchus obliquidens), harbor porpoise, minke whales (Balaenoptera acutorostrata), Steller sea lions, harbor seals, and seabirds***. Transient killer whales did not attack humpback whales (*Megaptera novaeangliae*), elephant seals (*Mirounga angustirostris*), and sea otters (*Enhydra lutris*) although those species were present.	Dahlheim and White (2010)
	Attacks on Gray Whales/Shelter from Attacks	The authors described a 4-year study of foraging and feeding behavior of transient killer whales that aggregate annually at Unimak Island, Alaska, during the northbound migration of gray whales. ***Killer whales attacked gray whale calves or yearlings most frequently*** and abandoned attacks when gray whale cows aggressively defended their calves. Gray whales generally tried to avoid attacks by groups of killer whales by swimming into shallow water along the shoreline. ***Killer whales stopped attacks when gray whales reached waters at depths of 3 m (9.8 ft) or less***. Successful attacks occurred at water depths of 15 to 75 m (49 to 246 ft) deep, or killer whales moved prey into those depths after a kill.	Barrett-Lennard et al. (2011)

Table 3.1. (contd)

3.6

Gray Whale	Relevance to Issue	Summary	Reference
Energetics	Energy Expenditure/Swim Speed	The authors measured swimming speeds and breathing rates for migrating gray whales at Costa Azul, Baja California, and compared the swimming efforts of southbound whales, northbound whales without calves, and northbound mothers and calves. Southbound migrating whales averaged a swimming effort of 7.4 breaths/km with about 0.8 breaths/min. Northbound whales without calves showed the lowest swimming effort of the three migrating groups averaged 4.7 breaths/km with about 0.5 breaths/min. Northbound mothers and calves had swimming efforts of 7.6 breaths/km with 0.5 breaths/min and 10.1 breaths/km with 0.7 breaths/min, respectively. ***The authors calculated the "cost of transport" for northbound calves as about 0.3 and 0.55 J/kg m for 1.5% and 3% tidal volumes, respectively***. ***South migrating gray whales (6.84 km/hr) swim faster than north migrating whales without calves (6.48 km/hr)***. North migrating mother–calf pairs swam at an average speed of about 4.4 km/hr. ***Gray whale calves weigh an average of 4400 kg***.	de la Gala-Hernandez et al. (2008)
Feeding	Benthic Amphipods Important Prey/ Bering Sea	Benthic amphipod populations in the northern Bering Sea had low fecundity and long generation times. ***Most of the amphipod secondary production was comprised of large, long-lived individuals***. These amphipods were ***the major prey of gray whales*** feeding in the Arctic. Amphipod abundance and biomass decreased from 1986 to 1988, which caused a 30% reduction in production. The ***increasing whale population may be approaching the carrying capacity of the benthic amphipod community in the Bering Sea***.	Highsmith and Coyle (1992)
	Hyper-Benthic and Pelagic Prey/ Switch Prey	***Gray whales foraging in Clayoquot Sound during the summer fed on hyper-benthic mysids, pelagic porcelain crab larvae, benthic ampeliscid amphipods, and benthic callianassid ghost shrimps***. During the summer, whales switched from eating mainly mysids to porcelain crab larvae, and then to amphipods corresponding to changes in prey abundance and body size. Selection of amphipod prey was based on high biomass and a high proportion of individuals greater than or equal to 6 mm long. ***Gray whales are "dynamic and selective foragers that switch prey and foraging tactics rapidly to take advantage of short-term availability of energy."***	Dunham and Duffus (2001)

Table 3.1. (contd)

Gray Whale	Relevance to Issue	Summary	Reference
	Benthic Amphipods, Hyper-Benthic, and Pelagic Prey/ Feeding Depth	The study determined that *gray whales* in Clayoquot Sound, British Columbia, *ate pelagic, hyper-benthic, and benthic invertebrates. Prey included mysids* (*Holmesimysis sculpta*)*, porcelain crab zoea larvae* (*Pachycheles rudis*)*, and benthic amphipods* (*Ampelisca agassizi* and *A. careyi*). Whales foraged where most amphipods were greater than 6 mm long. The most consistent *location of the amphipod prey was between the 16- and 20-m depth contours*.	Dunham and Duffus (2002)
	Summer Feeding Aggregation Locations	Photographic surveys documented the range, abundance, and movements of a feeding aggregation of gray whales along the Pacific Northwest coast from southeastern Alaska to northern California. The study focused on the northern Washington coast and Vancouver Island and showed that there were *a few hundred gray whales that ranged from northern California to southeastern Alaska in summer months*. Movements among regions were complex as whales did not always move in the same direction at the same time of year. The *distances moved by individual whales ranged from <1 to 526 nmi* (<2 to 974 km). About 70% to 100% of the whales observed off northern Washington and from southern Vancouver Island to north of Vancouver Island had been seen in previous years. Recruitment into this summer feeding group was not resolved.	Calambokidis et al. (2002)
	Epibenthic or Planktonic Prey/ Feeding Locations in Oregon Waters	"Resident" gray whales annually *spend May through October off the coast of Oregon* and *feed on near-bottom swarms of mysids, with porcelain crab larvae* an occasional minor dietary component. Mysid swarms reach highest biomass in April to May and disappear from nearshore waters by October to November. The authors documented 19 locations along the central Oregon coast between Lincoln City and Seal Rock where gray whales repeatedly forage. The southernmost swarm location in their study, Seal Rock, is about 60 mi (97 km) north of the proposed Reedsport wave park site. *Mysid swarms occurred at depths of about 10 m (33 ft) and, therefore, were close to shore*.	Newell and Cowles (2006)
	Epibenthic or Planktonic Prey/ Use Several Feeding Areas	Gray whales in Clayoquot Sound, British Columbia, *ate mysids throughout the season and ate porcelain crab larvae periodically*. Occasional feeding on crab larvae feeding could lessen pressure on mysid populations, which let mysids reform swarms that could feed gray whales later in the season. *Gray whale populations need several connected habitats to fulfill summer food requirements*.	Nelson et al. (2008)

Table 3.1. (contd)

Gray Whale	Relevance to Issue	Summary	Reference
	Feeding Locations in Oregon Waters/ Prey Type	Gray whales that leave the normal migration to the Bering Sea feed in Oregon waters from about May through October are called summer residents. ***These whales spend at least two days feeding in coastal waters and return to them in successive years***. Resident whales primarily feed on dense swarms of mysids and porcelain crab larvae that typically ***occur in waters that range from 2 to 15 m (6.6 to 49 ft) deep and are within 0.6 km (0.3 nmi) of shore***.	Newell (2009)
	Adaptable Feeding Approach	Several times during the ***Pleistocene, global sea-level changes eliminated or reduced shallow water environments favored by gray whale invertebrate prey***. Fossil evidence showed that gray whales survived these drastic feeding habitat changes, but how they did so is uncertain. The authors used modern estimates of metabolic demand, prey availability, and feeding duration to calculate gray whale feeding habitat carrying capacity for whale populations at current levels. Low sea-level periods eliminated key feeding areas that were not replaced, which affected carrying capacity. ***Gray whales survived the loss of primary feeding areas by switching to a generalist filter-feeding mode***, similar to that documented for summer resident gray whales found off northern Washington State and Vancouver Island.	Pyenson and Lindberg (2011)

The sections that follow summarize the information that was identified to address the concerns (Sections 3.1 through 3.6), synthesize that information into a technically written conclusion about the concerns (Section 3.7), and provide a condensed, simpler version suitable for a broader audience (Section 3.8). Full citations for the reviewed articles are listed in Section 6.

3.1   The Proposed Reedsport, Oregon Wave Park

The first step in evaluating the potential effects of a coastal wave park on gray whale migrations was to identify the location, distance from shore, water depth at the site, and the size of the proposed Oregon wave park. This information was available in the environmental assessment prepared per the National Environmental Policy Act of 1969 and the Federal Energy Regulatory Commission (FERC) regulations, 18 CFR Part 380 (Order No. 486, 52 FR 47897) as part of the licensing procedure for the park (FERC 2010).

The wave park proposed for the Oregon coast would be located 4.6 km (2.5 nmi) off Reedsport, Oregon (FERC 2010). The park eventually would contain ten wave buoys spaced 100 m (330 ft) apart encompassing an area of 12.1 ha (30 ac; Figure 3.1). The width of the park presented to the migrating whales probably would be no more than 305 m (1000 ft). Water depths at the proposed park site range from 50 to 69 m (165 to 225 ft). Three 49-m (160-ft) catenary lines would moor each power buoy to 3 of 16 anchors in the array via subsurface floats placed at a water depth of 15 m (50 ft); 32-m (105-ft) tendon lines will run from the float to the anchor on the seabed. Each wave buoy would be connected to an underwater substation pod via a power/fiber optic cable that is connected to a subsurface float and descends to the bottom in a lazy S pattern (FERC 2010). The power/fiber optic cables and mooring lines would be 5–8 cm (2–3 in.) and 13–15 cm (5–6 in.) in diameter, respectively. The power/fiber optic cables would be relatively inflexible, and tension on the mooring lines would be several tons.
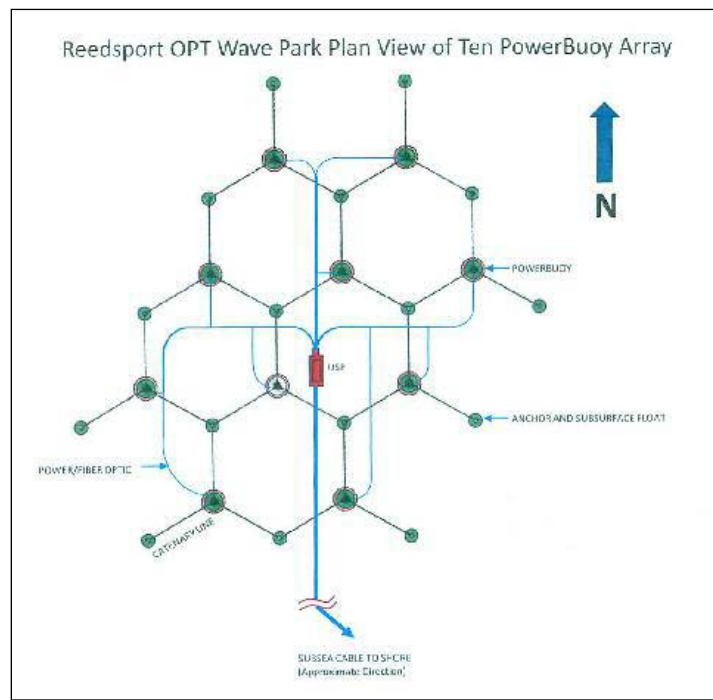

Figure 3.1. Plan View of the Proposed Wave Park at Reedsport, Oregon (from FERC 2010)

During operations, noise would be generated by the array from waves hitting the buoy float, hydraulic cylinder cycling, hydraulic motor spinning, mooring cable vibration (i.e., strumming), and transfer of vibration from the wave buoys' superstructure into the water. These should produce an overall underwater sound level in the range of about 115 to 125 dB (FERC 2010).

3.2   Gray Whale Migration Patterns

The evaluation of the potential effects of a coastal wave park on gray whale migrations required the identification of the distance, timing, and route of the migrations. The literature search found information that provided relatively detailed information about gray whale migration patterns. Studies were available that clearly identified how close the whales swim to the U.S. West Coast during the migrations.

Twice each year, east Pacific gray whales swim between their breeding grounds in Baja California and their main feeding areas in the Bering Sea. This round-trip swim of about 15,000 to 20,000 km (8100 to 10,800 nmi) is one of the longest known migrations by a mammal (Shelden et al. 2004). The whales' migration route is somewhat unusual because it follows very close to the shoreline. This proximity to shore allows scientists to study the migration and permits the general public to observe a large marine mammal. The southbound migration from the Bering Sea to Baja California generally begins in late fall and continues until early winter. The northbound migration occurs in two phases. Adult males, newly pregnant females, and immature whales (called Phase A) begin the northward swim from the central Baja California lagoons back to the feeding grounds in late winter. A few weeks later, mothers and newborn calves (Phase B) begin the journey. The northbound migrations generally are closer to shore than the southbound trip although there is overlap.

Green et al. (1995) found that in 1990 most southbound gray whale groups (66%) swam more than 10 km (5.4 nmi) offshore. Whales that passed Washington were farther offshore (25.2 km; 13.6 nmi) than those that passed Oregon (11.9 km; 6.4 nmi). Most northbound whale groups (76%) swam within 10 km (5.4 nmi) of the shoreline. Again, whales passing Washington were farther offshore (11.8 km; 6.4 nmi) than those passing Oregon (7.5 km; 4.0 nmi). Only 16% of the whales passing Oregon were within 5 km (2.7 nmi) of shore.

Ortega-Ortiz and Mate (2008), via observations at Yaquina Head, Oregon, in late 2007 and early 2008, found that most southbound gray whales passed the Oregon coast in January; the whales appeared along the coast through late February to early March (Figure 3.2). The average distance offshore that whales swam during the southbound trip was 6.6 km (3.6 nmi). The total corridor width extended 2.5 to 12.5 km (1.3 to 6.7 nmi) offshore, and most whales swam at 5.5 to 7 km (3.0 to 3.8 nmi) offshore. Southbound whales swam in waters that averaged 52 m deep (171 ft); with most whales occupied waters 47 to 61 m deep (154 to 200 ft).

During the northbound swim, gray whales in Phase A appeared off Oregon from late February to about mid-April (Ortega-Ortiz and Mate 2008). Whales in this phase swam an average of 5.1 km (2.8 nmi) offshore; the total corridor width extended 1.5 to 10.5 km (0.8 to 5.7 nmi) offshore, and most whales swam 3.5 to 6.5 km (1.9 to 3.5 nmi) offshore. Whales in Phase A swam in waters that averaged 46 m deep (151 ft); most whales occupied waters 39 to 53 m deep (128 to 174 ft). Northbound gray whales in Phase B swam past Oregon from mid-April to late May (Ortega-Ortiz and Mate 2008). Whales in this phase swam an average of 4.1 km (2.2 nmi) offshore. The total corridor width extended 0.25 to

10.25 km (0.1 to 5.5 nmi) offshore, and most whales swam 2.1 to 5.7 km (1.1 to 3.1 nmi) offshore. Whales in Phase A swam in waters that averaged 38 m deep (125 ft), and most whales occupied waters 28 to 48 m deep (92 to 157 ft). Ortega-Ortiz and Mate (2008) reported that migrating whales tend to swim along a path that follows relatively constant water depth rather than swimming a relatively constant distance off the shoreline.
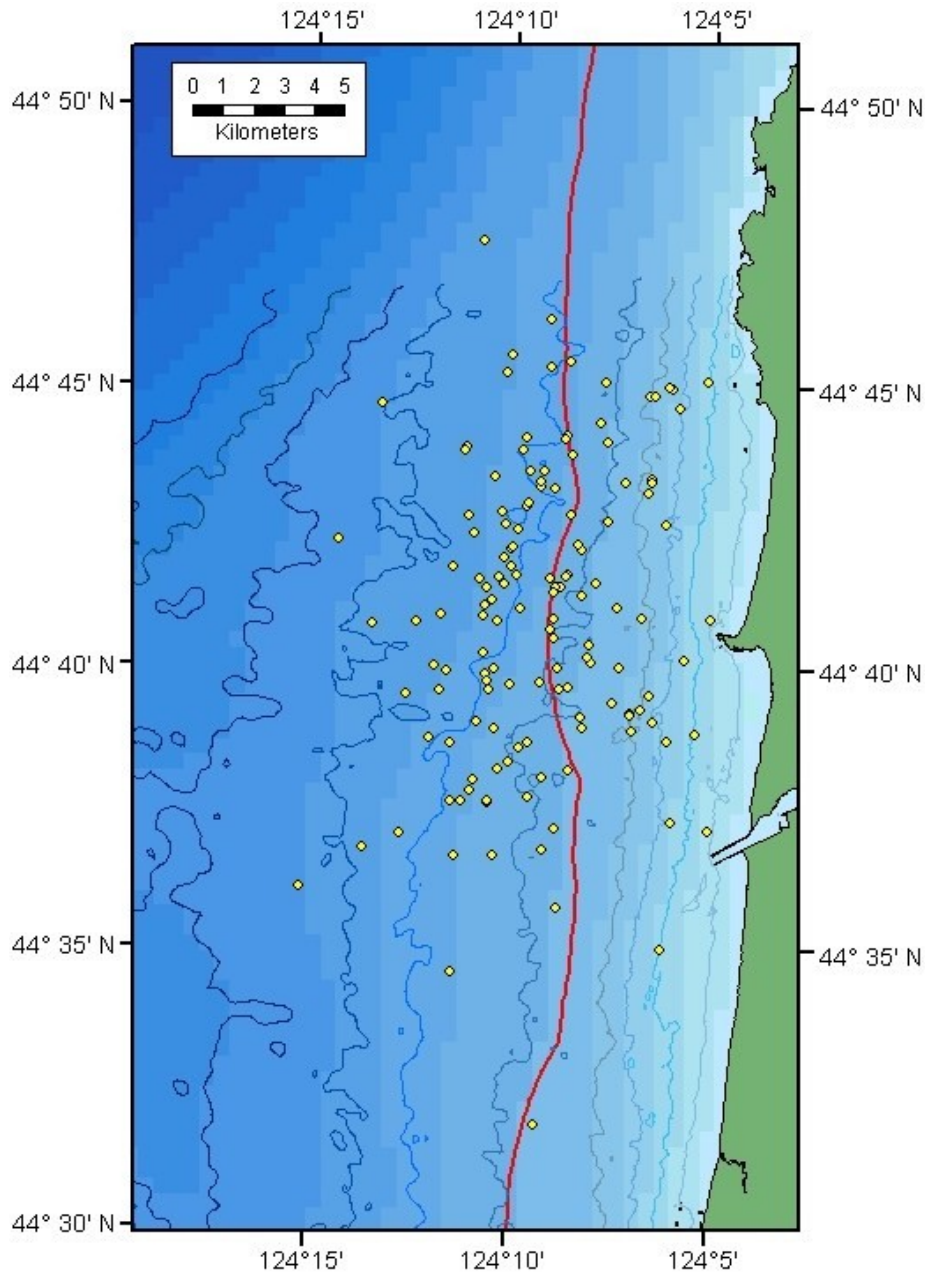

Figure 3.2. Gray Whale Groups (yellow circles) Observed on Scan Surveys Off Yaquina Head During the Northbound Migration of Mothers and Calves (April 7–May 29, 2008). The red line marks the boundary of the State of Oregon territorial sea (from Ortega-Ortiz and Mate 2008)

The information identified in this section and Section 3.1 showed that the placement of a wave park at 4.6 mi off Reedsport, Oregon, would be directly within the normal path of migrating gray whales, and that at least some of the whales very likely would encounter the park. The following sections identify information used to evaluate expressed concerns that such encounters could increase gray whale susceptibility to predation, increase the energetic costs of the migration or delay arrival at the destination, interfere with whale feeding opportunities, or injure whales via collision or entanglement.

3.3 Gray Whale Sensory Perception

The literature search did not identify specific information about gray whale visual acuity but did provide some general features of baleen whale vision. Marine mammal eyes have strong spherical lenses that focus light well underwater, contain mostly rods in the retina, and have a reflective layer (tapetum lucidum) that reflects light through the retina a second time (Sea World 2005). The predominance of rods in the retina is an adaptation to the low underwater light levels. Terrestrial mammal retinas have two types of cones—L-cones, which are sensitive to green to red light, and S-cones, sensitive to blue to ultraviolet light (Peichl et al. 2001). Marine mammals do not have S-cones, which means that they see only one part of the color spectrum. There was no information about the visual discrimination capability of baleen whales.

Toothed whales are known to produce sounds (echolocation) that help them perceive the undersea world around them (Au 2008). Although it is generally acknowledged that baleen whales do not echolocate (Sea World 2005), there has been discussion of the sounds produced by humpback whales (*Megaptera novaeangliae*) and whether those are used for echolocation. Frazer and Mercado (2000) described humpback songs that they concluded were used to locate other humpback whales. The study estimated that whale songs would produce echoes detectable at distances of 4–6 km (2.2–3.2 nmi). Au et al. (2001) challenged the conclusions of Frazer and Mercado, in particular criticizing the use of relatively few observations to construct the echolocation hypothesis. Au et al. (2001) also used a "noise-limited sonar equation" to estimate that the detection distance was 123–235 m (404–771 ft). Mercado and Frazer (2001) rebutted the arguments made by Au et al. (2001), rejected the noise-limited sonar equation as inadequate to evaluate the possibility of humpback songs serving as sonar, and called for experiments to test the echolocation hypothesis. Stimpert et al. (2007) recorded humpback click sequences (calling them 'megapclicks') during two whales' foraging activities, concluding that the clicks were not likely to be true echolocation sounds but might serve to identify large features such as the seafloor or other whales.

There are too many uncertainties regarding baleen whale, especially gray whale, sensory capabilities to determine whether the wave park array structures would be detected by whales passing through an array.

3.4 Gray Whale Predators

Evaluating the potential that a wave park could increase the susceptibility of gray whales to predation requires knowledge of the specific predators and their hunting behavior. The literature search identified the killer whale (*Orcinus orca*) as one of the main gray whale predators (Barrett-Lennard et al. 2011). Killer whales have been fairly well studied, and several sources elucidate their prey and foraging tactics. The general review literature also speculated that predatory attacks by great white sharks (*Carcharodon carcharias*) on gray whales could increase (Thompson et al. 2008). However, searches for information on

white shark predatory behavior and diets did not find documentation that the sharks successfully prey on healthy gray whales.

Killer whale populations in the northeast Pacific are typically separated into three ecotypes that may have some overlap in their geographic ranges but that typically do not interact. Migrating gray whales are most likely to encounter the resident and transient ecotypes. Resident killer whales, which frequent nearshore waters mainly from Alaska to Washington, feed primarily on fish, particularly salmon (Matkin et al. 2007b). Transient killer whales range from Alaska to at least as far south as California and feed primarily on marine mammals, such as Dall's porpoise (*Phocoenoides dalli*), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), harbor porpoise (*Phocoena phocoena*), minke whales (*Balaenoptera acutorostrata*), Steller sea lions (*Eumetopias jubatus*), harbor seals (*Phoca vitulina*), gray whales, and seabirds (Baird and Dill 1995; Matkin et al. 2007a; Dahlheim and White 2010).

Transient killer whales aggregate annually at Unimak Island, Alaska, during the northbound gray whale migration. Barrett-Lennard et al. (2011) found that killer whales most frequently attacked gray whale calves or yearlings and abandoned attacks when gray whale cows aggressively defended their calves. Gray whales generally tried to avoid attacks by groups of killer whales by swimming into shallow water along the shoreline. Killer whales stopped attacks when gray whales reached waters at depths of 3 m (9.8 ft) or less. Successful attacks occurred at water depths of 15 to 75 m (49 to 246 ft) deep. Migrating gray whales that cross the deeper waters over Monterey Canyon in California are often attacked by transient killer whales that frequent the area in late spring when pinnipeds wean their young and northward migrating gray whale cows and calves pass through the area (Ternullo and Black 2002). Small groups of a few killer whales usually attack migrating cow–calf pairs and try to separate calves from their mothers (Ternullo and Black 2002). Killer whales appeared to gain an advantage at the boundary of the steep canyon wall and chased crossing gray whales north or east toward the shelf. Gray whales that are attacked attempt to swim to the safety of shallow water.

3.5 Gray Whale Energetics and Swimming Speed

Forcing whales to detour around wave parks could increase energy expended during migrations, which could increase the whales' stress because they do not feed much while migrating (Thompson et al. 2008); the detour could delay the whales' arrival at the feeding or breeding destinations. To evaluate these concerns, it is necessary to know the average amount of energy that gray whales require during normal migratory swimming, the total distance of the migration (Section 3.2), and the average swimming speed during migration. Few studies provide such information, probably because of the difficulty in studying a large marine mammal in the wild. The literature search identified only one study that measured the energetic cost of swimming in a gray whale. That study estimated the energetic cost of swimming for a gray whale calf at 0.5 to 0.6 joules (J) per kg per m (de la Gala-Hernández et al. 2008). The search did not find documentation of the swimming costs for adult gray whales.

Several studies have measured the swimming speeds of migrating gray whales. Two of the studies estimated swim speeds over relatively short distances. These indicated that gray whales without calves swim at 6.7 to 6.8 km/h (3.6 to 3.7 nmi/h) during the southbound migration but are somewhat slower during the northbound migration, ranging from 6.1 to 6.5 km/h (3.3 to 3.5 nmi/h) (de la Gala-Hernández et al. 2008; Ortega-Ortiz and Mate 2009). Mate and Urban-Ramirez (2003) tracked a single whale at a relatively consistent speed of 5.6 km/h (3.9 nmi/h) during its trip from Baja California to the San

Francisco area. Northbound whales probably swim slower than southbound whales because they have to swim against the California Current. Gray whale cows and their calves swim at slower speeds. Ortega-Ortiz and Mate (2009) measured the speed of Phase B migrating whales at an average of 5.4 km/h (2.9 nmi/h) while passing Oregon. De la Gala-Hernández et al. (2008) measured the average swimming speed of cow–calf pairs at 4.4 km/h (2.4 nmi/h).

3.6 Gray Whale Feeding

The literature search identified several studies that provide the information about gray whale prey and feeding behavior that are needed to evaluate the potential for wave parks to interfere with gray whale feeding opportunities. Some of these studies are based on observations of whale feeding in areas distant from the proposed wave park site (e.g., Bering Sea and Clayoquot Sound, British Columbia) but provide useful information about key prey species and specific feeding behaviors that may also be used by whales traveling off Oregon. These studies also document the diverse feeding behavior that enables gray whales to adapt to changing feeding opportunities.

It is well established that gray whales migrate northward to the Bering Sea where they feed on the very productive community of benthic amphipods, primarily on relatively large individuals (Highsmith and Coyle 1992). However, migrating gray whales typically feed somewhat sporadically, although some whales leave migratory routes to feed in shallow, coastal waters (Dunham and Duffus 2001; Newell and Cowles 2006). Whales that leave the migration route, often called summer residents in the areas where they feed, use two basic sources of food, one pelagic and one benthic. Whales in Clayoquot Sound fed on pelagic hyper-benthic mysids and porcelain crab larvae, switching from mysids to crab larvae and then switching to benthic amphipods as the latter became more abundant and achieved high biomass (Dunham and Duffus 2001, 2002; Nelson et al. 2008). Prime amphipod habitat was located in waters less than 20 m (66 ft) deep. Whales that leave the migration route off Oregon from about May through October spend at least 2 days feeding in coastal waters and return to them in successive years. These summer resident whales, similar to those in Clayoquot Sound, feed primarily on dense swarms of mysids, small planktonic shrimp-like crustaceans, and porcelain crab larvae that typically occur in waters that range from 2 to 15 m (6.6 to 49 ft) deep and are within 0.6 km (0.3 nmi) of shore (Newell and Cowles; Newell 2009). The ability to switch from one prey type to another led Dunham and Duffus (2001, p. 299) to characterize gray whales as "dynamic and selective foragers that switch prey and foraging tactics rapidly to take advantage of short-term availability of energy." The adaptability of switching from a benthic feeding to generalized filter feeding probably has enabled gray whales to adapt to the changes in sea level that have occurred in the northeast Pacific since the Pleistocene, allowing them to survive major loss of prime feeding habitat (Pyenson and Lindberg 2011).

3.7 Putting It All Together

The wave park proposed for the Oregon coast would be located about 4.6 km (2.5 nmi) offshore, which is within the path of migrating gray whales, particularly those swimming northward to feeding grounds in the Bering Sea. A primary concern associated with locating wave parks within gray migration routes is that the parks could act as a barrier that would cause whales to alter their normal migration route by swimming closer to or farther from shore. The general review articles suggest that such a deviation could

adversely affect gray whales by increasing their susceptibility to predation, increasing the energetic costs of the migration, delaying arrival at the feeding or breeding destinations, and blocking access to feeding areas.

Gray whales encountering a wave park of the size proposed off Reedsport, Oregon, would face a potential barrier that is about 305 m (1000 ft) wide. Some whales likely would swim around the array toward deeper waters, others likely would swim closer to shore, and some may try to swim through the array. It is difficult to predict whether a whale would swim through or around an array and whether a whale swimming through an array would be able to successfully negotiate the buoys and associated mooring cables within the array. The spacing between buoys in the array would be about 101 m (330 ft), so that a whale might have enough room to navigate through the array. Considering the uncertainty that a gray whale could use sonar to detect the relatively thin mooring cables, and the possibility that vision would not provide much warning, a whale could hit a cable. However, the cables are relatively taut and, it is not likely that a whale would become entangled within them. A more significant possible danger to a whale swimming through the array is the possibility of becoming entangled in derelict fishing gear that gets caught on array structures. Monitoring is planned for the Reedsport project that would determine whether whales safely avoid the array.

A whale approaching the center of the array would have to swim at least 150 m (492 ft) to swim away from the park to avoid the array and would swim about 150 m back to get online with its previous path (if it even did so). Because some northbound whales often range farther offshore than the proposed park location and some range closer to shore, it is not possible to predict the direction in which a whale encountering the array would swim.

An expressed concern is that wave parks could increase gray whale susceptibility to predation, either by making them swim into deeper waters or by concentrating them in the more restricted waters between the array and the shore. Considering the projected size of the Oregon wave park and the whales' normal path through the area, any whale detouring around the wave park would still be within the boundaries of the normal migration route, regardless of whether it passed seaward or shoreward of the park, and those whales should be no more susceptible to predation than other whales traveling along the migration corridor. Gray whales swimming along the Oregon coast use a migration corridor that is about 9 to 10 km (4.9 to 5.4 nmi) wide. Therefore, avoiding the wave park likely would not significantly reduce the width of the migration corridor such that a high density of whales would be forced into a small area.

The detour around a wave park would make the whales swim farther than they normally would, which could increase the energetic costs of the migration. Using the information provided in de la Gala-Hernández et al. (2008), it is possible to estimate the total energetic cost of the migration and the cost of any additional swimming required to avoid a wave park. For an average gray whale calf that weighs about 4400 kg (9700 lb), the energy required to swim about 1 km is about 2,200,000 to 2,640,000 J, which extrapolates to a total expenditure of about 33,000,000 to 52,800,000 kJ for the entire swim north (15,000 to 20,000 km). Presuming that a detour could cause the whale to swim an extra 1 km (0.5 nmi), which probably is an overestimate given the size of the planned park at Reedsport, the energy expended for that swim would be about 2,200 to 2,640 kJ per calf, which is a trivial addition to the total energy required for the migration.

To estimate the potential delay in arriving at the feeding area destination in the Bering Sea, one has to presume that the swimming speeds estimated in the literature could be or would be maintained for the

entire migration. Using a swim speed of 5.6 km/h that was measured for a whale swimming a relatively long distance (Mate and Urban-Ramirez 2003) and a migration distance of 15,000 km, the estimated minimum time for a whale to complete the northbound part of the migration would be at least 112 days. Based on the same swim speed, the estimated additional time to swim about 1 km to avoid a wave park is about 11 minutes. Gray whale cow–calf pairs swim at a speed of 4.4 km/h (de la Gala-Hernández et al. 2008), which would increase the migration time to at least 142 days. Avoiding the park would add about 14 minutes to the total migration time for a cow–calf pair.

Wave parks could interrupt gray whale feeding opportunities. Most migrating gray whales feed sporadically. Those that do feed in coastal waters along the migration route typically are summer residents that feed primarily on swarms of hyper-benthic mysid crustaceans, supplemented by planktonic porcelain crab larvae and benthic amphipods. All of these prey are typically located in relatively shallow waters that are much closer to shore than the proposed location of the Reedsport wave park. Gray whales are very adaptable feeders and have the ability to switch from a prey declining in availability to one more abundant. It is not likely that a wave park would seriously compromise gray whale feeding.

In summary, it is clear migrating gray whales most likely would encounter a wave park such as that proposed for Reedsport, Oregon, but it is not reasonable to presume that such an encounter has the potential to significantly interrupt the annual gray whale migration.

3.8 Coastal Wave Parks Should Not Interfere with Gray Whale Migrations

Twice each year, east Pacific gray whales (*Eschrichtius robustus*) swim between their breeding grounds in Baja California and their main feeding areas in the Bering Sea. This round-trip swim of about 15,000 to 20,000 km (8100 to 10,800 nmi) is one of the longest known migrations by a mammal **{Shelden et al. 2004}**. The whales' migration route is somewhat unusual because it follows very close to the shoreline. This proximity to shore allows scientists to study the migration and permits the general public to observe a large critter. However, the placement of wave parks, such as those proposed for along the Oregon coast, for energy generation in coastal areas along the migration route has raised concern that the parks could interfere with the migration. The primary concerns are that the whales would change course to avoid the wave parks, which could increase susceptibility to predation, increase the energy expended during the migration, or decrease feeding opportunities **{Thompson et al. 2008}**.
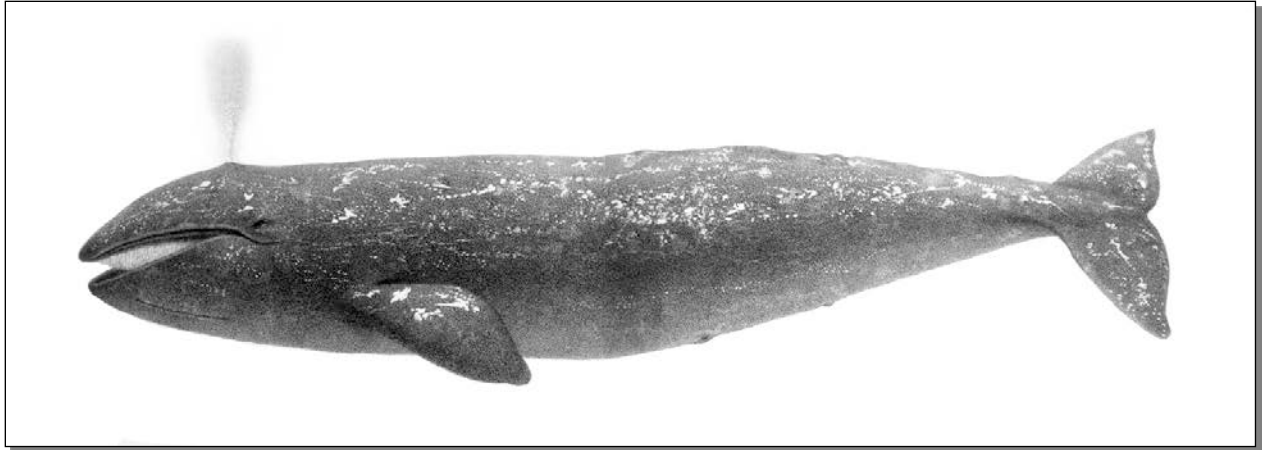
*The gray whale (*Eschrichtius robustus*). Illustration by Charles Melville Scammon (1872; Natural History of the Cetaceans and Other Marine Mammals of the Western Coast of North America, with an Account of the American Whale Fishery. J. H. Carmany & Company, San Francisco)*

Gray whales feeding in the Bering Sea begin the southerly trip in late fall, with most passing by the Oregon coast in December and January **{Ortega-Ortiz and Mate 2008}**, arriving at their Baja breeding grounds in early winter. Adult males, newly pregnant females, and immature whales begin the northward swim back to the feeding grounds in late winter. A few weeks later, mothers and newborn calves begin the journey. Northbound whales pass the Oregon coast from late February to late May, with the peak occurrence from late March to early May **{Ortega-Ortiz and Mate 2008}**. The northbound migrations generally are closer to shore than the southern trip although there is overlap. A study in 2007 and 2008 along the Oregon coast **{Ortega-Ortiz and Mate 2008}** found that the average distance offshore during the southbound trip was about 6.6 km (3.6 nmi) offshore although the width of the migration corridor used by most whales ranged from about 5.5 to 7 km (3.0 to 3.8 nmi). During the northbound swim, most whales are from about 2 to 6.5 km (1.1 to 3.5 nmi) offshore and individual whales tend to swim along a relatively constant water depth rather than follow the coastline.
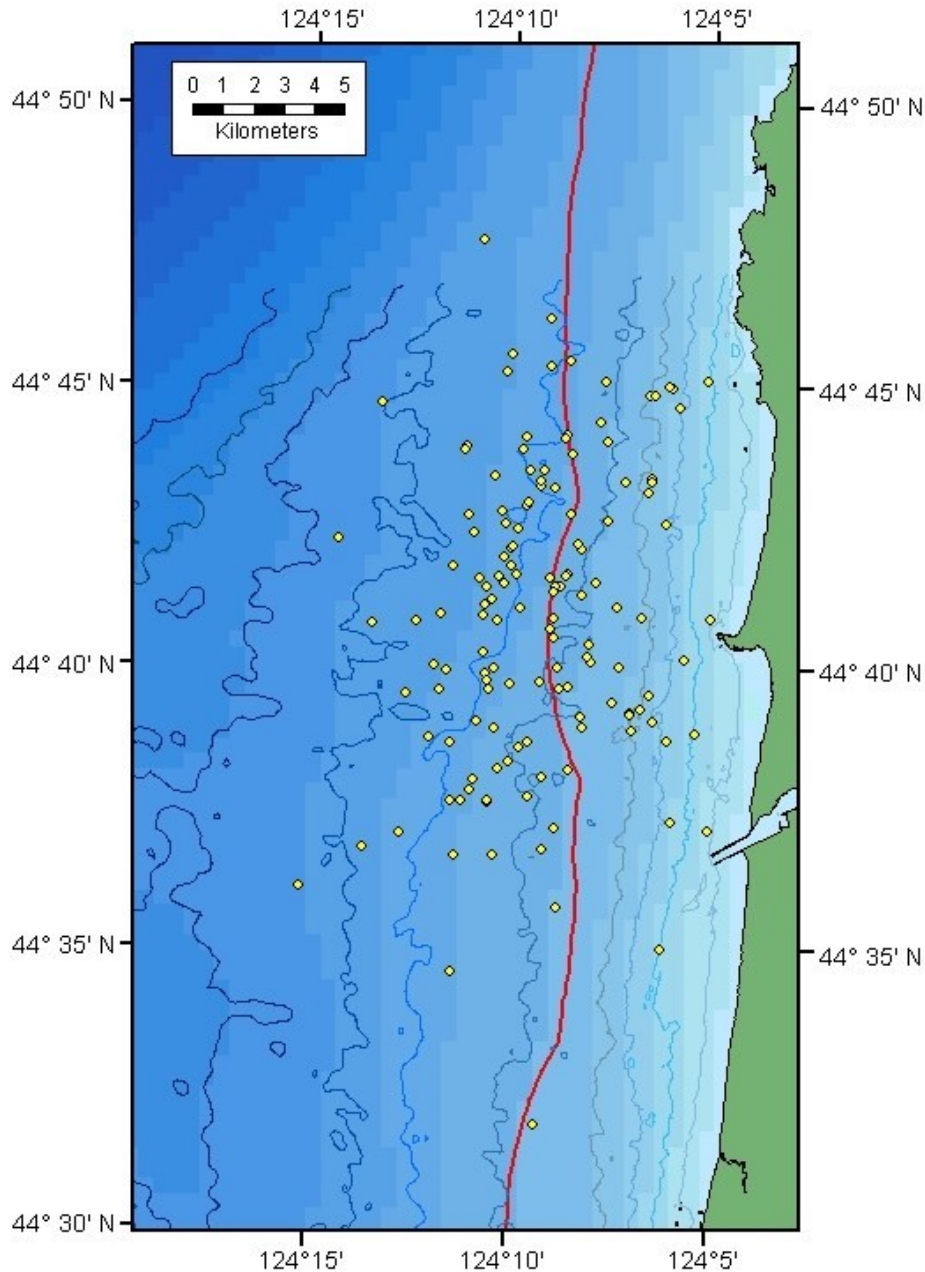
Gray whale groups (yellow circles) observed on scan surveys off Yaquina Head during the northbound migration of mothers and calves (April 7-May 29, 2008). The red line marks the boundary of the State of Oregon territorial sea. {From Ortega-Ortiz and Mate 2008}

The wave park proposed for the Oregon coast would be located 4.6 km (2.5 nmi) off Reedsport **{FERC 2010}**, well within the gray whale migration path, particularly for northbound whales. The park eventually would contain ten wave buoys spaced 101 m (330 ft) apart encompassing an area of 12.1 ha (30 ac). The width of the park presented to the migrating whales probably would be no more than 305 m (1000 ft). Water depths at the park range from 50 to 69 m (165 to 225 ft). Although the ability of the whales to detect the array at a distance, it seems likely that many whales encountering the park likely would swim around it. Whales swimming through the array would risk collisions with the buoys or

cables in the array, but the possibility of injury could be relatively small {**FERC 2010**}. Some of the whales that swim around the array would alter course to shallower waters closer to shore, whereas others would head for deeper waters farther offshore. A whale heading for the center of the park would have to detour the farthest, 150 m (492 ft) to swim away from the park and 150 m back to get online (if it even did so). The more distant that the park was detected as a "barrier," the less detour would be needed to get around it. No doubt some whales would attempt to swim through the park.

Wave parks could increase gray whale susceptibility to predation by making them swim into deeper waters. The killer whale is one of the main gray whale predators {**Barrett-Lennard et al. 2011**}. Migrating gray whales that cross the deeper waters over Monterey Canyon in California are often attacked by killer whales who try to separate calves from mothers {**Ternullo and Black 2002**}. Killer whales appear to gain an advantage at the boundary of the steep canyon wall. Gray whales respond to attacks by moving into shallower water, if possible, where the killer whales will often stop the attack {**Barrett-Lennard et al. 2011**}. Given the projected size of the Oregon wave park and the whales' normal path through the area, any whale detouring around the wave park would still be within the boundaries of the normal migration route and would be no more susceptible to predation than other whales traveling along that path.

Forcing whales to detour around wave parks could increase energy expended during migrations, which could increase the whales' stress because they do not feed much while migrating {**Thompson et al. 2008**}. The energetic cost of swimming has been estimated for a gray whale calf at about 0.5 to 0.6 joules per kg per meter {**de la Gala-Hernández et al. 2008**}. For an average calf (4400 kg), the energy required to swim 1 km would be about 2,200 to 2,640 kJ per km, which extrapolates to about 33,000,000 to 52,800,000 kJ for the northbound migration. Presume that a detour would cause the whale to swim an extra 1 km (0.5 nmi), which probably is an overestimate given the size of the planned park at Reedsport, the energy expended for that swim would be about 2,200 to 2,640 kJ per calf, which is trivial versus the total required.

Based on an average swimming speed of 5.6 km/hr, which measured for a whale swimming a relatively long distance {**Mate and Urban-Ramirez 2003**}, the estimated minimum time for a whale to complete the northbound part of the migration would be about 112 days. Based on the same swim speed, detouring around a wave park would add about 11 minutes to the migration. Gray whale cow-calf pairs swim at a speed of 4.4 km/hr {**de la Gala-Hernández et al. 2008**}, so that avoiding the wave park would add about 14 minutes to the total migration time of at least 142 days.

Wave parks could interrupt gray whale feeding opportunities. Migrating gray whales feed somewhat sporadically, but some whales leave migratory routes to feed in shallow, coastal waters {**Dunham and Duffus 2001, Newell and Cowles 2006**}. Whales that leave the migration feed in Oregon waters from about May through October and have been called summer residents. Summer residents spend at least two days feeding in coastal waters and return to them in successive years. Resident whales primarily feed on dense swarms of mysids, small planktonic shrimp-like crustaceans, and porcelain crab larvae that typically occur in waters that range from 2 to 15 m (6.6 to 49 ft) deep and are within 0.6 km (0.3 nmi) of shore {**Newell 2009**}. The proposed Reedsport wave park is farther offshore and in deeper waters than where mysid swarms form.

Evidence gathered to date indicates that the proposed wave parks should not adversely affect migrating, or summer-resident, whales by increasing their susceptibility to predation, increasing energy requirements, or interrupting feeding behavior.

4.0   Seabirds

The review articles summarized in this section were derived from the original general literature search to determine the primary topics of concern regarding the potential effects of MHK devices on seabirds. Key points or effects identified by each reviewed paper (**boldface italics**), and their relevance to the evaluation, are captured in Table 4.1, which also includes a citation to the appropriate source as listed in Section 6 (References).

Table 4.1. Reviewed Literature Relevant to the Potential Effects of the Placement of Marine Hydrokinetic Devices and Wind Farms on Seabirds

Effects on Seabirds	Summary (Key Points in **Boldface Italics**)	Reference
Review	The authors explored the possible consequences of increased use of marine renewable energy installations (MREIs) for seabirds. ***Direct negative effects include risk of collision, disturbance, displacement and redirection during construction, operation and decommissioning***. Above-water collision with wind-powered devices is a concern but is not as significant for low-profile wave-powered devices. Wave devices introduce the ***possibility of underwater collisions***; could affect marine birds by altering oceanographic processes that determine food availability. Conversely, wave-powered MREIs could enhance seabird habitats by providing bird roosting sites and underwater substrates that aggregate prey. The net result ***could improve and protect foraging opportunities for marine birds***, albeit with the ***possible risk of underwater collisions with structures***.	Grecian et al. (2010)
Review	The authors summarized the possible effects of tidal stream and wave (TSW) power generation activity in Scottish Waters on seabirds. The authors evaluated potential ***increased rates of energy acquisition*** (e.g., greater prey abundance) or ***expenditure*** (e.g., increased foraging distance if birds avoid developments placed in normal feeding areas). Energy budget changes could affect reproduction and survival. The authors stated that ***susceptibility to the affects of TSW development probably depends on each species' foraging method, flight behavior, and ability to withstand environmental fluctuations***.	Langton et al. (2011)
Collisions with Structures	The authors evaluated the potential effects of offshore wind farms on birds, which can be at risk from collisions, barrier effects, and habitat loss during 2003–2004 study of year-round bird migration over the North Sea with regard to offshore wind farms. Data from radar, thermal imaging, and visual and acoustic observations confirmed that ***many diurnal and nocturnal migrants cross the German Bight***. The authors documented that ***migration occurred year round*** but showed ***much seasonal and weather-related variation*** in intensity, time, altitude, and species. The study found that about ***half of the birds fly at "dangerous" altitudes*** that could lead to interaction with future wind farms. Also, reverse migrations could increase the risk of collision for many birds. The authors found that ***terrestrial birds, mostly passerines, are attracted by illuminated offshore obstacles***, especially under low visibility conditions, and that many birds collide with the structures. The study showed that on a few nights per year many interactions between birds and offshore wind arrays can be expected. The authors ***recommended that wind turbines be shut down on nights predicted to have adverse weather and high migration intensity***. They also suggested that ***wind turbines should be made more recognizable to birds*** and that ***platform lighting should be changed from continuous to intermittent***.	Huppop et al. (2006)

Table 4.1. (contd)

Effects on Seabirds	Summary (Key Points in ***Boldface Italics***)	Reference
Wind Park Avoidance	Two main issues regarding offshore wind farms and birds are disturbance and collision risk. ***Wintering common eiders (*** Somateria mollissima***) avoided the Tuno Knob offshore wind park in the Kattegat, Denmark***. Fewer flying birds were in corridors within 200 m of or within the park than in corridors 200 to 600 m outside the park. ***Rotor movement and noise during turbine operation did not affect flying behavior***. Observations for ***landing birds were similar to those for flying birds***. ***Physical presence of the structures caused avoidance behavior*** and might decrease use of otherwise suitable habitat. Results may not be representative of conditions at night or during periods of poor visibility, such as fog and snow.	Larsen and Guillemette (2007)
Night Collisions with Turbines	Bird collision fatality data from 30 wind farms across North America used to estimate that ***night migrant fatality rates ranged from less than 1 bird /turbine/year to 7 birds/turbine/year at turbines from 54 to 125 m tall***. Rates higher in eastern North America and lowest in the west. ***Events involving more than 3 birds killed in 1 night at 1 turbine were rare***, occurring at 4 of 25,000 turbine searches; may have been caused by lighting and weather conditions at the sites, but the ***L-864 flashing red lights recommended by the Federal Aviation Administration were not involved***.	Kerlinger et al. (2010)

5.0   Fish

The 2010 MHK literature review (Kropp 2010) discussed the general effects of MHK devices on fish, including the habitat effects and construction impacts. Principal habitat effects discussed were the function of MHK structures as fish attraction devices and artificial reefs. The effect of pile-driving noise on fish was the main construction-related topic discussed.

The focus of the limited 2011 literature review of the effects of MHK devices on fish was directed toward identifying potential effects within a specific geographic area—Puget Sound. To accomplish this, the initial literature search was to identify the fish species, or species groups, most likely to be of concern. Then the search focused on literature that identified the abundance and distribution of the fish within Puget Sound and other features of fish biology that could be important in determining the potential effects of MHK devices installed in the Sound.

Key points or effects identified by each reviewed paper (***boldface italics***), and their relevance to the evaluation, are captured in Table 5.1, which also includes a citation to the appropriate reference as listed in Section 6.

5.1   Review Articles

Forage Fish—Several fish species are important forage for higher trophic levels in Puget Sound. Forage species that reproduce in nearshore habitats within the Sound are Pacific herring (*Clupea pallasi*), sand lance (*Ammodytes hexapterus*), and surf smelt (*Hypomesus pretiosus*). Some of the areas are relatively close to proposed MHK tidal power sites. Herring and surf smelt spawning habitat includes areas just north of Tacoma Narrows and next to Admiralty Inlet. Sand lance spawning beaches include an area in southwestern Tacoma Narrows and next to Admiralty Inlet. The sites near Admiralty Inlet are not along the inlet per se but are located to the west (Port Townsend, Kilisut Harbor) and south (Port Gamble). Eulachon (*Thaleichthys pacificus*) and longfin smelt (*Spirinchus thaleichthys*) spawn in freshwater, and Northern anchovy (*Engraulis mordax*) spawn in open saltwater. All use marine nearshore zone habitats during non-spawning stages.

Salmon—Several salmon species—Chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), pink (*O. gorbuscha*), and sockeye (*O. nerka*)—regularly use Puget Sound nearshore waters as temporary habitiat during their migration from freshwater spawning areas. Most of the literature identified in the search concerned chum, Chinook, and coho salmon. The information in the various studies that were reviewed suggest that there is a potential for MHK devices to interact with migrating young salmon in Puget Sound and along the coast of Oregon.

Nearshore environments may be particularly important rearing areas for juvenile Chinook in the north Sound and chum in the south Sound (near Tacoma Narrows). Small Chinook fry (<50 mm fork length) enter estuaries from December through April. Some of these, called migrant fry, swim quickly through the delta, spending a few days there before entering Puget Sound. Others, called delta fry, use small dendritic tidal channels and sloughs in tidal wetlands and remain in the deltas as long as 120 days. Parr migrant and yearling salmon leave freshwater rearing habitats and migrate downstream to the estuary in late spring. Juvenile Chinook occur widely throughout the Sound's nearshore ecosystems after leaving delta habitats. Chinook abundance nearshore typically peaks in June and July, although some fish may

linger through October. The Strait of Georgia is an important area for juvenile Chinook. Young Chinook that leave the Strait before September tend to do so to the north. However, those leaving during October and November travel south through the Strait of Juan de Fuca. The specific southern route out of the Strait of Georgia has not been identified. On a larger scale, most juvenile Chinook, except those from the Columbia River, remained within 100 to 200 km of their birth rivers until their second year at sea. Chinook stocks from the Strait of Georgia and Puget Sound stocks entered continental shelf waters after their first year at sea. Columbia River spring Chinook were recovered as far north as Prince William Sound, Alaska, during their first summer at sea, whereas most Columbia River fall Chinook salmon were recovered from Vancouver Island south. Some Columbia River spring and fall Chinook salmon actively migrated south of the Columbia River to waters along the Oregon coast. Sub-yearling Chinook salmon use the surf zone off southern Oregon dissipative sandy beaches during about two months of the summer. Smaller fish feed mainly on amphipods in early summer, and larger fish eat mostly larval and juvenile fish later in summer.

Chum salmon fry swim through natal estuaries into Puget Sound or remain in estuarine habitats for weeks before entering shoreline areas in the Sound. Small chum fry (<50–60 mm) migrate mainly along shallow shoreline waters that are less than 2 m deep. At about 60 mm in length, chum fry start using nearshore surface waters. Chum abundance in nearshore areas peaks in May and June, declining as fish move farther offshore and migrate out of Puget Sound. Some chum still occur in nearshore areas through October. Coho salmon smolt migration patterns have suggested distinct population groupings that range from Kodiak Island to the Queen Charlotte Islands, the Queen Charlotte Islands south to the Columbia River; and from the Columbia River southward.

Rockfish—Rockfish in Puget Sound form mixed species assemblages that use species-specific habitats during their different life stages. Most adult rockfish use high-relief, rocky habitats. Some rockfish larvae and juveniles use open-water and nearshore habitats. Nearshore vegetated habitats are used as nursery areas for juveniles and connect those nurseries to adult habitats. There is concern over the status of several rockfish species in parts of the Sound. Copper rockfish are listed as Vulnerable in the South Sound, and quillback rockfish are Vulnerable in the North and Depleted in the South. Yelloweye and canary rockfish are Depleted in North and South Sound.

Table 5.1. Reviewed Literature Relevant to the Potential Effects of the Placement of Marine Hydrokinetic Devices on Fish in Puget Sound

Fish Group	Relevance to Issue	Summary	Reference
Forage Fish	Species/spawning sites	Forage fish species in Puget Sound occupy all nearshore marine and estuarine habitats, many of which are used for spawning. Critical spawning habitats for Pacific herring, surf smelt, and Pacific sand lance commonly occur in Pacific Northwest beach nearshore zones. **Herring and surf smelt spawning habitat includes areas just north of Tacoma Narrows and next to Admiralty Inlet. Sand lance spawning beaches include an area in southwestern Tacoma Narrows and next to Admiralty Inlet**. All three species use nearshore habitats near spawning areas as nursery grounds. Northern anchovies spawn and incubate their eggs in open water. Eulachon and longfin smelt spawn in freshwater streams. All use marine nearshore zone habitats during non-spawning stages. Herring are resident or migratory but generally do not form large nearshore schools after spawning. Herring spawning biomasses have stayed moderately stable for 20 years.	Penttila (2007)
	Pacific herring	***Pacific herring are abundant, important prey for seabirds in the Salish Sea***. Herring abundance in the Strait of Georgia increased from the 1980s to 2003 but subsequently declined. Most spawning activity now occurs in the northwestern part of the Salish Sea. ***Mean spawning time is mid-March***, which is as it has been historically, but there are now fewer spawns in January/February and April/May than before. The 2005 and 2007 cohorts of juvenile herrings were negligible.	Therriault et al. (2009)
Salmonids	Chinook, chum nearshore use	Juvenile chum, pink, coho, and Chinook salmon were sampled at southeastern Whidbey basin (north Sound) and **south of the Tacoma Narrows sill and north of the Nisqually River (south Sound)**. Densities in the nearshore were highest April to June; pink and chum generally preceding Chinook and coho into nearshore habitats. Chinook occurred during July in the north Sound. South Sound juvenile Chinook salmon were predominantly hatchery fish (98%); 44% of north Sound Chinook were marked hatchery fish. The Chinook and chum salmon in nearshore regions grew steadily through time, whereas pink and coho salmon varied inconsistently. The seasonal extent of occurrence in catches and the documented growth suggested that **nearshore environments may be particularly important rearing areas for juvenile Chinook in the north Sound and chum in the south Sound**.	Duffy et al. (2005)

Table 5.1. (contd)

Fish Group	Relevance to Issue	Summary	Reference
	Chinook salmon habitat use	Juvenile Chinook salmon in nearshore habitat are referred to as migrant fry, delta fry migrants, parr migrants, and yearlings, depending on their emigration from freshwater and their size at that time. **Small fry (<50 mm fork length) are the first juvenile Chinook to arrive in estuaries**, entering their natal deltas from December through April. **Some pass through the natal delta quickly, spending a few days there before entering Puget Sound (migrant fry)**. Others **remain in natal deltas as long as 120 days and use small dendritic tidal channels and sloughs in tidal wetlands (delta fry)**. **Parr migrant and yearling salmon leave freshwater rearing habitats and migrate downstream to the estuary in late spring**. Fish size upon arrival in the delta and fish residence time there tend to be inversely related (except for migrant fry). Increasing water temperatures and other environmental factors, may affect the timing of juvenile Chinook salmon departure from delta habitats. Juvenile Chinook occur widely throughout the Sound's nearshore ecosystems after leaving delta habitats. Abundance nearshore typically peaks in June and July; some may linger through October. Smaller juvenile Chinook salmon (<70 mm) use low gradient, shallow waters that have fine-grained sediments, low salinity, and low wave energy. Larger juvenile Chinook salmon use more Puget Sound habitats including deeper, farther offshore habitats; eventually most fish leave for North Pacific Ocean feeding grounds.	Fresh (2006)
	Chum salmon habitat use	**Most chum salmon fry leave freshwater within 1-2 days of emergence, sometimes as early as December**. Fish emerging early are likely summer run chum salmon, with those emerging later belonging to other races. **Chum salmon fry either pass through natal estuaries into Puget Sound or remain in estuarine habitats for weeks before entering shoreline areas**. Juvenile chum often occur in non-natal estuaries. Chum nearshore migration rates in areas depend fish size, foraging success, and environmental factors (e.g., currents). Small chum fry (<50-60 mm) migrate mainly along the shoreline in water less than 2 m deep. Chum fry larger than 60 mm start to use nearshore surface waters. Chum abundance in nearshore areas peaks in May and June, declining as chum move farther offshore and migrate out of Puget Sound; some still occur in nearshore areas through October.	(Fresh 2006)
	Summer migration from Strait of Georgia	Coded-wire tagged coho salmon moved out of the Strait of Georgia in July and September; most migrating fish eventually died. **Coho salmon moved northward out of the Strait of Georgia between July and September**. The hatchery coho salmon proportion declined as hatchery fish abundance and marine survival declined; wild coho salmon abundance was more stable.	Beamish et al. (2008)

Table 5.1. (contd)

Fish Group	Relevance to Issue	Summary	Reference
	Fall migration from Strait of Georgia	About 19% of the juvenile coho salmon tagged in the northern Strait of Georgia in July 2006 and 52% of those tagged in September 2006 left the Strait; **most left in October and November through the Strait of Juan de Fuca, not to the north**. The path from the tagging site through the Strait of Juan de Fuca was not identified.	Chittenden et al. (2009)
	Juvenile Chinook beach use	Beach seine *samples collected in water 1 m deep in the surf-zone of a southern Oregon dissipative sandy beach* during the summer of 2006 *caught 48 sub-yearling Chinook salmon*. Mean standard length of fish caught in the surf-zone increased from 9.1 cm in July to 12 cm in September. Smaller fish fed mostly on amphipods in early summer; larger fish ate mostly larval and juvenile fish later in summer. All prey items were common in the surf zone. *Juveniles appear to spend up to two months in summer in the surf-zone before migrating offshore*.	Jarrin et al. (2009)
	Juvenile Chinook coastal migrations	From 1995 to 2006, coded-wire-tagged juvenile Chinook salmon originating from Oregon to Southeast Alaska were recovered along the coasts of Oregon, Washington, British Columbia, and Alaska from March to November. *Most juveniles, except those from the Columbia River, remained within 100–200 km of their natal rivers* until their second year at sea, irrespective of their freshwater history and adult run timing. Most coastal stocks began the northward migration during their second or possibly third year at sea; the Strait of Georgia and Puget Sound stocks primarily swam into continental shelf waters after their first year at sea. Columbia River spring Chinook were recovered as far north as Prince William Sound, Alaska, during their first summer at sea; most Columbia River fall Chinook salmon were recovered from Vancouver Island south. *Some Columbia River spring and fall Chinook salmon actively migrated south of the Columbia River to waters along the Oregon coast*. Distance offshore not clearly specified.	Trudel et al. (2009)
	Coho salmon smolt migrations	Coho salmon smolt migration patterns showed *a trend toward later, shorter, and more predictable migrations with increasing latitude*. Migration patterns identified distinct coho population groupings: Kodiak Island to the Queen Charlotte Islands, British Columbia; Queen Charlotte Islands south to the Columbia River; and from the Columbia River southward. The regional patterns suggested that coho populations have *adapted to differences in timing and relative predictability of marine environmental conditions that are beneficial to smolts*.	Spence and Hall (2010)

Table 5.1. (contd)

Fish Group	Relevance to Issue	Summary	Reference
Rockfish	Key rockfish stocks/status	Rockfish in Puget Sound form mixed species assemblages that use species-specific habitats during their different life-stages. **Copper, quillback, and brown rockfish populations that live south of Port Townsend are distinct from those in northern waters**. Rockfish eat many prey types and are prey for marine fishes, marine mammals, and seabirds. Most adult rockfish use high-relief, rocky habitats; some rockfish larvae and juveniles use open-water and nearshore habitats. **Nearshore vegetated habitats are nursery areas for juveniles and connect nurseries to adult habitats**. Rockfish status is called Healthy, Precautionary, Vulnerable, or Depleted based on the magnitudes of population trends. Most rockfish species have Precautionary status; copper rockfish are Vulnerable in the South Sound; quillback rockfishes are Vulnerable in the North and Depleted in the South; yelloweye and canary rockfish are in Depleted in the North and South Sound. Greenstriped rockfish, redstripe rockfish, and shortspine thornyheads, which inhabit relatively deepwater, are Healthy.	Palsson et al. (2009)

6.0   References

18 CFR Part 380. 2007. "Regulations Implementing the National Environmental Policy Act." *Code of Federal Regulations*, Federal Energy Regulatory Commission.

Au WWL. 2008. "Echolocation in Marine Mammals." In WWL Au and MC Hastings, *Principles of Marine Bioacoustics*. Springer Science + Business Media, LLC, New York, New York.

Au WWL, A Frankel, DA Helweg, and DH Cato. 2001. "Against the Humpback Whale Sonar Hypothesis." *IEEE Journal of Oceanic Engineering* 26:295–300.

Baird RW and LM Dill. 1995. "Occurrence and Behaviour of Transient Killer Whales: Seasonal and Pod-Specific Variability, Foraging Behaviour, and Prey Handling." *Canadian Journal of Zoology – Revue Canadienne de Zoologie* 73:1300–1311.

Barrett-Lennard LG, CO Matkin, JW Durban, EL Saulitis, and D Ellifrit. 2011. "Predation on Gray Whales and Prolonged Feeding on Submerged Carcasses by Transient Killer Whales at Unimak Island, Alaska." *Marine Ecology-Progress Series* 421:229–241.

Beamish RJ, RM Sweeting, KL Lange, and CM Neville. 2008. "Changes in the Population Ecology of Hatchery and Wild Coho Salmon in the Strait of Georgia." *Transactions of American Fisheries Society* 37:503–520.

Boehlert GW and AB Gill. 2010. "Environmental and Ecological Effects of Ocean Renewable Energy Development a Current Synthesis." *Oceanography* 23:68–81.

Boehlert GW, GR McMurray, and CE Tortorici (eds). 2008. *Ecological Effects of Wave Energy Development in the Pacific Northwest: A Scientific Workshop, October 11–12, 2007.* NOAA Technical Memorandum NMFS-F/SPO-92, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington. Available at http://spo.nmfs.noaa.gov/tm/ (October 2010).

Calambokidis J, JD Darling, V Deecke, P Gearin, M Gosho, W Megill, CM. Tombach, D Goley, C Toropova, and B Gisborne. 2002. "Abundance, Range and Movements of a Feeding Aggregation of Gray Whales (*Eschrichtius robustus*) from California to Southeastern Alaska in 1998." *Journal of Cetacean Research and Management* 4:267–276.

Chittenden CM, RJ Beamish, CM Neville, RM Sweeting, and RS McKinley. 2009. "The Use of Acoustic Tags to Determine the Timing and Location of the Juvenile Coho Salmon Migration Out of the Strait of Georgia, Canada." *Transactions of the American Fisheries Society* 138:1220–1225.

Dahlheim ME and PA White. 2010. "Ecological Aspects of Transient Killer Whales *Orcinus orca* as Predators in Southeastern Alaska." *Wildlife Biology* 16:308–322.

de La Gala-Hernandez SR, G Heckel, and JL Sumich. 2008. "Comparative Swimming Effort of Migrating Gray Whales (*Eschrichtius robustus*) and Calf Cost of Transport Along Costa Azul, Baja California, Mexico." *Canadian Journal of Zoology – Revue Canadienne De Zoologie* 86:307–313.

Duffy EJ, DA Beauchamp, and RM Buckley. 2005. "Early Marine Life History of Juvenile Pacific Salmon in Two Regions of Puget Sound." *Estuarine Coastal and Shelf Science* 64:94–107.

Dunham JS and DA Duffus. 2001. "Foraging Patterns of Gray Whales in Central Clayoquot Sound, British Columbia, Canada." *Marine Ecology-Progress Series* 223:299–310.

Dunham JS and DA Duffus. 2002. "Diet of Gray Whales (*Eschrichtius robustus*) in Clayoquot Sound, British Columbia, Canada." *Marine Mammal Science* 18:419–437.

FERC – Federal Energy Regulatory Commission. 2010. *Environmental Assessment for Hydropower License: Reedsport OPT Wave Park Project FERC Project No. 12713-002; Oregon*. Federal Energy Regulatory Commission, Office of Energy Projects, Division of Hydropower Licensing, Washington, D.C.

Frazer L N and E Mercado. 2000. "A Sonar Model for Humpback Whale Song." *IEEE Journal of Oceanic Engineering* 25:160–182.

Fresh KL. 2006. *Juvenile Pacific Salmon in Puget Sound*. Puget Sound Nearshore Partnership Report No. 2006-06, Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Grecian WJ, R Inger, MJ Attrill, S Bearhop, BJ Godley, MJ Witt, and SC Votier. 2010. "Potential Impacts of Wave-Powered Marine Renewable Energy Installations on Marine Birds." *Ibis* 152:683–697.

Green GA, JJ Brueggeman, RA Grotefendt, and CE Bowlby. 1995. "Offshore Distances of Gray Whales Migrating Along the Oregon and Washington Coasts, 1990." *Northwest Science* 69:223–227.

Highsmith R C and KO Coyle. 1992. "Productivity of Arctic Amphipods Relative to Gray Whale Energy-Requirements." *Marine Ecology-Progress Series* 83:141–150.

Huppop O, J Dierschke, KM Exo, E Fredrich, and R Hill. 2006. "Bird Migration Studies and Potential Collision Risk with Offshore Wind Turbines." *Ibis* 148:90–109.

Jarrin JRM, AL Shanks, MA Banks. 2009. "Confirmation of the Presence and Use of Sandy Beach Surf-Zones by Juvenile Chinook Salmon." *Environmental Biology of Fishes* 85:119–125.

Kerlinger P, JL Gehring, WP Erickson, R Curry, A Jain, and J Guarnaccia. 2010. "Night Migrant Fatalities and Obstruction Lighting at Wind Turbines in North America." *Wilson Journal of Ornithology* 122:744–754.

Kropp RK. 2010. *Review of Recent Literature Relevant to the Environmental Effects of Marine and Hydrokinetic Energy Devices. Task 2.1.3: Effects on Aquatic Organisms – Fiscal Year 2010 Progress Report*. PNNL-19903, Pacific Northwest National Laboratory, Richland, Washington.

Langton R, IM Davies, and BE Scott. 2011. "Seabird Conservation and Tidal Stream and Wave Power Generation: Information Needs for Predicting and Managing Potential Impacts." *Marine Policy* 35:623–630.

Larsen JK and M Guillemette. 2007. "Effects of Wind Turbines on Flight Behaviour of Wintering Common Eiders: Implications for Habitat Use and Collision Risk." *Journal of Applied Ecology* 44:516–522.

Mate BR and J Urban-Ramirez. 2003. "A Note on the Route and Speed of a Gray Whale on its Northern Migration from Mexico to Central California, Tracked by Satellite-Monitored Radio Tag." *Journal of Cetacean Research and Management* 5:155–157.

Matkin CO, LG Barrett-Lennard, H Yurk, D Ellifrit, and AW Trites. 2007a. "Ecotypic Variation and Predatory Behavior Among Killer Whales (*Orcinus orca*) off the Eastern Aleutian Islands, Alaska." *Fishery Bulletin* 105:74–87.

Matkin D R, JM Straley, and CM Gabriele. 2007b. *Killer Whale Feeding Ecology and Non-Predatory Interactions with Other Marine Mammals in the Glacier Bay Region of Alaska.* In JF Piatt and SM Gende (eds.), *Proceedings of the Fourth Glacier Bay Science Symposium*, October 26–28, 2004. U.S. Geological Survey Scientific Investigations Report 2007-5047. Pp. 155-158.

Mercado E and LN Frazer. 2001. "Humpback Whale Song or Humpback Whale Sonar? A Reply to Au et al." *IEEE Journal of Oceanic Engineering* 26:406–415.

National Environmental Policy Act. 1969. Public Law 91-190, as amended, 42 USC 4321 et seq.

Nelson T A, DA Duffus, C Robertson, and LJ Feyrer. 2008. "Spatial-Temporal Patterns in Intra-Annual Gray Whale Foraging: Characterizing Interactions Between Predators and Prey in Clayquot Sound, British Columbia, Canada." *Marine Mammal Science* 24:356–370.

Newell C. 2009. "Ecological Interrelationships Between Summer Resident Gray Whales (*Eschrichtius robustus*) and Their Prey, Mysid Shrimp (*Holmesimysis sculpta* and *Neomysis rayi*) along the Central Oregon Coast." MS Thesis, Oregon State University, Corvallis, Oregon. 95 pp.

Newell CL and TJ Cowles. 2006. "Unusual Gray Whale *Eschrichtius robustus* Feeding in the Summer of 2005 Off the Central Oregon Coast." *Geophysical Research Letters* 33(L22S11):1–5. doi:10.1029/2006GL027189.

Ortega-Ortiz J G and BR Mate. 2008. *Distribution and Movement Patterns of Gray Whales Migrating by Oregon: Shore-Based Observations off Yaquina Head, Oregon, December 2007-May 2008.* Report submitted to the Oregon Wave Energy Trust. Oregon State University Marine Mammal Institute, Newport, Oregon.

Palsson WA, T-S Tsou, GG Bargmann, RM Buckley, JE West, ML Mills, YW Cheng, and RE Pacunski. 2009. *The Biology and Assessment of Rockfishes in Puget Sound.* Fish Management Division, Fish Program, Washington Department of Fish and Wildlife, Olympia, Washington.

Peichl L, G Behrmann, and RHH Kröger. 2001. "For Whales and Seals the Ocean is not Blue: A Visual Pigment Loss in Marine Mammals." *European Journal of Neuroscience* 13:1520–1528.

Penttila D. 2007. *Marine Forage Fishes in Puget Sound.* Puget Sound Nearshore Partnership Report No. 2007-03, Seattle District, U.S. Army Corps of Engineers, Seattle District, Seattle, Washington.

Perryman WL, MA Donahue, JL Laake, and TE Martin. 1999. "Diel Variation in Migration Rates of Eastern Pacific Gray Whales Measured with Thermal Imaging Sensors." *Marine Mammal Science* 15:426–445.

Pyenson ND and DR Lindberg. 2011. "What Happened to Gray Whales during the Pleistocene? The Ecological Impact of Sea-Level Change on Benthic Feeding Areas in the North Pacific Ocean." *PLoS ONE* 6(7):e21295. doi:10.1371/journal.pone.0021295.

Sea World, Inc. 2005. *Baleen Whales*. A Sea World Education Department Publication. Available at http://www.seaworld.org/animal-info/info-books/baleen/pdf/ib-baleen.pdf (September 2011).

Shelden KEW, DJ Rugh, and A Schulman-Janiger. 2004. "Gray Whales Born North of Mexico: Indicator of Recovery or Consequence of Regime Shift?" *Ecological Applications* 14:1789–1805.

Simas T, A Moura, R Batty, D Thompson, and J Norris. 2009. *Deliverable D6.3.1. Uncertainties Regarding Environmental Impacts. A Draft*. Report prepared for Equitable Testing and Evaluation of Marine Energy (EquiMar) Extraction Devices in terms of Performance, Cost and Environmental Impact under Grant agreement number: 213380. Available at http://www.equimar.org/equimar-project-deliverables.html (September 2011).

Spence BC and J D Hall. 2010. "Spatiotemporal Patterns in Migration Timing of Coho Salmon (*Oncorhynchus kisutch*) Smolts in North America." *Canadian Journal of Fisheries and Aquatic Sciences* 67:1316–1334.

Stimpert AK, DN Wiley, WWL Au, MP Johnson, and R Arsenaul. 2007. "'Megapclicks': Acoustic Click Trains and Buzzes Produced during Night-Time Foraging of Humpback Whales (*Megaptera novaeangliae*)." Biology Letters 3(5):467–470.

Ternullo R and N Black. 2002. "Predation Behavior of Transient Killer Whales in Monterey Bay, California." Presented to the Fourth International Orca Symposium, Chize, France, September 2002. Monterey Bay Whale Watch, Pacific Grove, California.

Therriault TW, DE Hay, and JF Schweigert. 2009. "Biological Overview and Trends in Pelagic Forage Fish Abundance in the Salish Sea (Strait of Georgia, British Columbia)." *Marine Ornithology* 37:3–8.

Thompson SA, J Castle, KL Mills, and WJ Sydeman. 2008. "Wave Energy Conversion Technology Development in Coastal California: Potential Impacts on Marine Birds and Mammals." In *Developing Wave Energy in Coastal California: Potential Socio-Economic and Environmental Effects*, PA Nelson, D Behrens, J Castle, G Crawford, RN Gaddam, SC Hackett, J Largier, DP Lohse, KL Mills, PT Raimondi, M Robart, WJ Sydeman, SA Thompson, and S Woo, CEC-500-2008-083, pp. 137–163. California Energy Commission, PIER Energy-Related Environmental Research Program & California Ocean Protection Council, Sacramento, California.

Trudel M, J Fisher, JA Orsi, JFT Morris, ME Thiess, RM Sweeting, S Hinton, EA Fergusson, and DW Welch. 2009. "Distribution and Migration of Juvenile Chinook Salmon Derived From Coded Wire Tag Recoveries Along the Continental Shelf of Western North America." *Transactions of the American Fisheries Society* 138:1369–1391.

7.0 Unreviewed Sources

The articles listed in this section were derived from the original general literature search on the potential effects of MHK devices on marine mammals, fish, and seabirds but were not fully reviewed. The articles are listed alphabetically by first author.

Au WWL, PE Nachtigal, and JL Pawloski. 1997. "Acoustic Effects of the ATOC Signal (15 Hz, 195 Db) on Dolphins and Whales." *Journal of the Acoustical Society of America* 101:2973–2977.

Bailey H, B Senior, D Simmons, J Rusin, G Picken, and PM Thompson. 2010. "Assessing Underwater Noise Levels During Pile-Driving at an Offshore Windfarm and Its Potential Effects on Marine Mammals." *Marine Pollution Bulletin* 60:888–897.

Baird RW, MB Hanson, and LM Dill. 2005. "Factors Influencing the Diving Behaviour of Fish-Eating Killer Whales: Sex Differences and Diel and Interannual Variation in Diving Rates." *Canadian Journal of Zoology-Revue Canadienne De Zoologie* 83:257–267.

Bateson M. 2007. "Environmental Noise and Decision Making Possible Implications of Increases in Anthropogenic Noise for Information Processing in Marine Mammals." *International Journal of Comparative Psychology* 20:169–178.

Bauer S, Z Barta, BJ Ens, GC Hays, JM McNamara, and M Klaassen. 2009. "Animal migration: linking models and data beyond taxonomic limits." *Biology Letters* 5:433–435.

Beamish RJ and M Folkes. 1998. "Recent changes in the marine distribution of juvenile chum salmon off Canada." *North Pacific Anadromous Fish Commission Bulletin* 1:443–453.

Blake RW. 2009. "Biological implications of the hydrodynamics of swimming at or near the surface and in shallow water." *Bioinspiration & Biomimetics* 4:1–9. Published online at http://stacks.iop.org/BB/4/015004: doi:10.1088/1748-3182/4/1/015004.

Blew J, M Hoffmann, G Nehls, and V Hennig. 2008. *Investigations of the Bird Collision Risk and the Responses of Harbour Porpoises in the Offshore Wind Farms Horns Rev, North Sea, and Nysted, Baltic Sea, in Denmark. Part I: Birds*. Final Report to German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (FKZ 0329963 + FKZ 0329963A).

Brandt MJ, A Diederichs, K Betke, and G Nehls. 2011. "Responses of Harbour Porpoises to Pile Driving at the Horns Rev II Offshore Wind Farm in the Danish North Sea." *Marine Ecology-Progress Series* 421:205–216.

Burger J, C Gordon, J Lawrence, J Newman, G Forcey, and L Vlietstra. 2011. "Risk Evaluation for Federally Listed (Roseate Tern, Piping Plover) or Candidate (Red Knot) Bird Species in Offshore Waters: A First Step for Managing the Potential Impacts of Wind Facility Development on the Atlantic Outer Continental Shelf." *Renewable Energy* 36:338–351.

Calambokidis J, GS Schorr, GH Steiger, J Francis, M Bakhtiari, G Marshal, EM Oleson, D Gendron, and K Robertson. 2007. "Insights into the Underwater Diving, Feeding, and Calling Behavior of Blue Whales from a Suction-Cup-Attached Video-Imaging Tag (Crittercam)." *Marine Technology Society Journal* 41:19–29.

Calambokidis J, GH Steiger, DK Ellifrit, BL Troutman, and CE Bowlby. 2004. "Distribution and Abundance of Humpback Whales (*Megaptera novaeangliae*) and Other Marine Mammals Off the Northern Washington Coast." *Fishery Bulletin* 102:563–580.

Calambokidis J, GH Steiger, K Rasmussen, J Urban, KC Balcomb, PL de Guevara, M Salinas, JK Jacobsen, CS Baker, LM Herman, S Cerchio, and JD Darling. 2000. "Migratory destinations of humpback whales that feed off California, Oregon and Washington." *Marine Ecology-Progress Series* 192:295–304.

Calambokidis J, GH Steiger, JM Straley, LM Herman, S Cerchio, DR Salden, J Urban, JK Jacobsen, O von Ziegesar, KC Balcomb, CM Gabriele, ME Dahlheim, S Uchida, G Ellis, Y Miyamura, PL de Guevara, M Yamaguchi, F Sato, SA Mizroch, L Schlender, K Rasmussen, J Barlow, and TJ Quinn. 2001. "Movements and Population Structure of Humpback Whales in the North Pacific." *Marine Mammal Science* 17:769–794.

Cheneval O, RW Blake, AW Trites, and KHS Chan. 2007. "Turning Maneuvers in Steller Sea Lions (*Eumetopias jubatus*)." *Marine Mammal Science* 23:94–109.

Corkeron PJ and RC Connor. 1999. "Why do baleen whales migrate?" *Marine Mammal Science* 15:1228–1245.

Dahlheim ME, A Schulman-Janiger, N Black, R Ternullo, D Ellifrit, and KC Balcomb. 2008. "Eastern Temperate North Pacific Offshore Killer Whales (*Orcinus orca*): Occurrence, Movements, and Insights into Feeding Ecology." *Marine Mammal Science* 24:719–729.

Darling JD, KE Keogh, and TE Steeves. 1998. "Gray whale (*Eschrichtius robustus*) habitat utilization and prey species off Vancouver Island, BC." *Marine Mammal Science* 14:692–720.

Deecke VB. 2006. "Studying marine mammal cognition in the wild - a review of four decades of playback experiments." *Aquatic Mammals* 32:461–482.

Deecke VB, JKB Ford, and PJB Slater. 2005. "The Vocal Behaviour of Mammal-Eating Killer Whales: Communicating With Costly Calls." *Animal Behaviour* 69:395–405.

Desholm M and J Kahlert. 2005. "Avian Collision Risk at an Offshore Wind Farm." Biology Letters 1:296–298.

Drewitt AL and RHW Langston. 2006. "Assessing the Impacts of Wind Farms on Birds." *Ibis* 148:29–42.

Drewitt AL and RHW Langston. 2008. "Collision Effects of Wind-Power Generators and Other Obstacles on Birds." *Annals of the New York Academy of Sciences* 1134:233–266.

Fahlman A, GD Hastie, DAS Rosen, Y Naito, and AW Trites. 2008. "Buoyancy Does Not Affect Diving Metabolism During Shallow Dives in Steller Sea Lions *Eumetopias jubatus*." *Aquatic Biology* 3:147–154.

Fahlman A, C Svard, DAS Rosen, DR Jones, and AW Trites. 2008. "Metabolic Costs of Foraging and the Management of O_2 and CO_2 Stores in Steller Sea Lions." *Journal of Experimental Biology* 211:3573–3580.

Fahlman A, R Wilson, C Svard, DAS Rosen, and AW Trites. 2008. "Activity and Diving Metabolism Correlate in Steller Sea Lion *Eumetopias jubatus*." *Aquatic Biology* 2:75–84.

Fiedler PC, SB Reilly, RP Hewitt, D Demer, VA Philbrick, S Smith, W Armstrong, DA Croll, BR Tershy, and BR Mate. 1998. "Blue whale habitat and prey in the California Channel Islands." *Deep Sea Research Part II Topical Studies in Oceanography* 45:1781–1801.

Garthe S and O Huppop. 2004. "Scaling Possible Adverse Effects of Marine Wind Farms on Seabirds: Developing and Applying a Vulnerability Index." *Journal of Applied Ecology* 41:724–734.

Gayeski N, B McMillan, and P Trotter. 2011. "Historical Abundance of Puget Sound Steelhead, *Oncorhynchus mykiss*, Estimated from Catch Record Data." *Canadian Journal of Fisheries and Aquatic Sciences* 68:498–510.

Gilles A, M Scheidat, and U Siebert. 2009. "Seasonal Distribution of Harbour Porpoises and Possible Interference of Offshore Wind Farms in the German North Sea." *Marine Ecology-Progress Series* 383:295–307.

Giuggioli L and F Bartumeus. 2010. "Animal Movement, Search Strategies and Behavioural Ecology: A Cross-Disciplinary Way Forward." *Journal of Animal Ecology* 79:906–909.

Götz T and VM Janik. 2010. "Aversiveness of Sounds in Phocid Seals: Psycho-Physiological Factors, Learning Processes and Motivation." *Journal of Experimental Biology* 213:1536–1548.

Goldbogen JA, J Calambokidis, DA Croll, JT Harvey, KM Newton, EM Oleson, G Schorr, and RE Shadwick. 2008. "Foraging Behavior of Humpback Whales: Kinematic and Respiratory Patterns Suggest a High Cost for a Lunge." *Journal of Experimental Biology* 211:3712–3719.

Goldbogen JA, J Calambokidis, E Oleson, J Potvin, ND Pyenson, G Schorr, and RE Shadwick. 2011. "Mechanics, Hydrodynamics and Energetics of Blue Whale Lunge Feeding: Efficiency Dependence on Krill Density." *Journal of Experimental Biology* 214:131–146.

Goldbogen JA, ND Pyenson, and RE Shadwick. 2007. "Big gulps require high drag for fin whale lunge feeding." *Marine Ecology-Progress Series* 349:289–301.

Hanke FD, W Hanke, C Scholtyssek, and G Dehnhardt. 2009. "Basic Mechanisms in Pinniped Vision." *Experimental Brain Research* 199:299–311.

Hanke FD, C Scholtyssek, W Hanke, and G Dehnhardt. 2011. "Contrast Sensitivity in a Harbor Seal (*Phoca vitulina*)." *Journal of Comparative Physiology A-Neuroethology Sensory Neural and Behavioral Physiology* 197:203–210.

Hastie GD, DAS Rosen, and AW Trites. 2006. "The Influence of Depth on a Breath-Hold Diver: Predicting the Diving Metabolism of Steller Sea Lions (*Eumetopias jubatus*)." *Journal of Experimental Marine Biology and Ecology* 336:163–170.

Hastie GD, DAS Rosen, and AW Trites. 2007. "Reductions in Oxygen Consumption During Dives and Estimated Submergence Limitations of Steller Sea Lions (*Eumetopias jubatus*)." *Marine Mammal Science* 23:272–286.

Hazen EL, AS Friedlaender, MA Thompson, CR Ware, MT Weinrich, PN Halpin, and DN Wiley. 2009. "Fine-Scale Prey Aggregations and Foraging Ecology of Humpback Whales *Megaptera novaeangliae*." *Marine Ecology-Progress Series* 395:75–89.

Hildebrand JA. 2005. *Impacts of Anthropogenic Sound. Marine Mammal Research: Conservation beyond Crisis.* The Johns Hopkins University Press, Baltimore, Maryland, pp. 101–124.

Hildebrand JA. 2009. "Anthropogenic and Natural Sources of Ambient Noise in the Ocean." *Marine Ecology-Progress Series* 395:5–20.

Hindle AG, DAS Rosen, and AW Trites. 2010. "Swimming Depth and Ocean Currents Affect Transit Costs in Steller Sea Lions *Eumetopias jubatus*." *Aquatic Biology* 10:139–148.

Hindle AG, BL Young, DAS Rosen, M Haulena, and AW Trites. 2010. "Dive Response Differs Between Shallow- and Deep-Diving Steller Sea Lions (*Eumetopias jubatus*)." *Journal of Experimental Marine Biology and Ecology* 394:141–148.

Jensen FH, L Bejder, M Wahlberg, NA Soto, M Johnson, and PT Madsen. 2009. "Vessel Noise Effects on Delphinid Communication." *Marine Ecology-Progress Series* 395:161–175.

Kerlinger P, JL Gehring, WP Erickson, R Curry, A Jain, and J Guarnaccia. 2010. "Night Migrant Fatalities and Obstruction Lighting at Wind Turbines in North America." *Wilson Journal of Ornithology* 122:744–754.

Kyhn LA, FH Jensen, K Beedholm, J Tougaard, M Hansen, and PT Madsen. 2010. "Echolocation in Sympatric Peale's Dolphins (*Lagenorhynchus australis*) and Commerson's Dolphins (*Cephalorhynchus commersonii*) Producing Narrow-Band High-Frequency Clicks." *Journal of Experimental Biology* 213:1940–1949.

Laake J, A Punt, R Hobbs, M Ferguson, D Rugh, and J Breiwick. 2009. *Re-analysis of Gray Whale Southbound Migration Surveys 1967-2006.* NOAA Technical Memorandum NMFS-AFSC-203.

LeBoeuf BJ, DE Crocker, DP Costa, SB Blackwell, PM Webb, and DS Houser. 2000. "Foraging ecology of northern elephant seals." *Ecological Monographs* 70:353–382.

Lindstrøm U, T Haug, and I Rottingen. 2002. "Predation on Herring, *Clupea harengus*, by Minke Whales, *Balaenoptera acutorostrata*, in the Barents Sea." *ICES Journal of Marine Science* 59:58–70.

Madsen PT, M Wahlberg, J Tougaard, K Lucke, and P Tyack. 2006. "Wind Turbine Underwater Noise and Marine Mammals: Implications of Current Knowledge and Data Needs." *Marine Ecology-Progress Series* 309:279–295.

Manktelow S. 2000. *The Effect of Local Weather Conditions on Bird-Aircraft Collisions at British Airports*. International Bird Strike Committee Report IBSC25/WP-BB4.

Martin GR. 2011. "Understanding Bird Collisions with Man-Made Objects: a Sensory Ecology Approach." *Ibis* 153:239–254.

Masden EA, DT Haydon, AD Fox, RW Furness, R Bullman, and M Desholm. 2009. "Barriers to Movement: Impacts of Wind Farms on Migrating Birds." *ICES Journal of Marine Science* 66:746–753.

Mate BR, BA Lagerquist, and J Calambokidis. 1999. "Movements of North Pacific blue whales during the feeding season off southern California and their southern fall migration." *Marine Mammal Science* 15:1246–1257.

Melnychuk MC, DW Welch, CJ Walters, and V Christensen. 2007. "Riverine and Early Ocean Migration and Mortality Patterns of Juvenile Steelhead Trout (*Oncorhynchus mykiss*) from the Cheakamus River, British Columbia." *Hydrobiologia* 582:55–65.

Merkel FR. 2010. *Light-induced bird strikes on vessels in Southwest Greenland*. Technical Report No. 84, Pinngortitaleriffik, Greenland Institute of Natural Resources. Available only at http://www.natur.gl.

Miksis-Olds JL and T Wagner. 2011. "Behavioral Response of Manatees to Variations in Environmental Sound Levels." *Marine Mammal Science* 27:130–148.

Mitani Y, RD Andrews, K Sato, A Kato, Y Naito, and DP Costa. 2010. "Three-Dimensional Resting Behaviour of Northern Elephant Seals: Drifting Like a Falling Leaf." *Biology Letters* 6:163–166.

Moore ME, BA Berejikian, and EP Tezak. 2010. "Early Marine Survival and Behavior of Steelhead Smolts Through Hood Canal and the Strait of Juan De Fuca." *Transactions of the American Fisheries Society* 139:49–61.

Moore ME, FA Goetz, DM Van Doornik, EP Tezak, TP Quinn, JJ Reyes-Tomassini, and BA Berejikian. 2010. "Early Marine Migration Patterns of Wild Coastal Cutthroat Trout (*Oncorhynchus clarki clarki*), Steelhead Trout (*Oncorhynchus mykiss*), and Their Hybrids." *PloS ONE* 5(9):e12881. doi:10.1371/journal.pone.0012881.

Moore SE, JM Grebmeier, and JR Davies. 2003. "Gray Whale Distribution Relative to Forage Habitat in the Northern Bering Sea: Current Conditions and Retrospective Summary." *Canadian Journal of Zoology-Revue Canadienne De Zoologie* 81:734–742.

Morton AB and HK Symonds. 2002. "Displacement of *Orcinus orca* (L.) By High Amplitude Sound in British Columbia, Canada." *ICES Journal of Marine Science* 59:71–80.

Nachtigall PE and AY Supin. 2008. "A False Killer Whale Adjusts Its Hearing When It Echolocates." *Journal of Experimental Biology* 211:1714–1718.

Nevitt GA. 2008. "Sensory Ecology on the High Seas: the Odor World of the Procellariiform Seabirds." *Journal of Experimental Biology* 211:1706–1713.

Noren DP. 2011. "Estimated Field Metabolic Rates and Prey Requirements of Resident Killer Whales." *Marine Mammal Science* 27:60–77.

Parsons ECM, SJ Dolman, M Jasny, NA Rose, MP Simmonds, and AJ Wright. 2009. "A Critique of the UK's JNCC Seismic Survey Guidelines for Minimising Acoustic Disturbance to Marine Mammals: Best Practise?" *Marine Pollution Bulletin* 58:643–651.

Parsons ECM, SJ Dolman, AJ Wright, NA Rose, and WCG Burns. 2008. "Navy Sonar and Cetaceans: Just How Much Does the Gun Need to Smoke Before We Act?" *Marine Pollution Bulletin* 56:1248–1257.

Pontius KE and MD Kirchhoff. 2009. "Prey-Capture by Marbled Murrelets in Southeast Alaska." *Northwestern Naturalist* 90:151–155.

Potvin J, JA Goldbogen, and RE Shadwick. 2009. "Passive Versus Active Engulfment: Verdict From Trajectory Simulations of Lunge-Feeding Fin Whales *Balaenoptera physalus*." *Journal of the Royal Society Interface* 6:1005–1025.

Quinn TP, BR. Dickerson, and LA Vøllestad. 2005. "Marine Survival and Distribution Patterns of Two Puget Sound Hatchery Populations of Coho (*Oncorhynchus kisutch*) and Chinook (*Oncorhynchus tshawytscha*) Salmon." *Fisheries Research* 76:209–220.

Regular PM, GK Davoren, A Hedd, and WA Montevecchi. 2010. "Crepuscular Foraging by a Pursuit-Diving Seabird: Tactics of Common Murres in Response to the Diel Vertical Migration of Capelin." *Marine Ecology-Progress Series* 415:295–304.

Riesch R and VB Deecke. 2011. "Whistle communication in mammal-eating killer whales (Orcinus orca): further evidence for acoustic divergence between ecotypes." *Behavioral Ecology and Sociobiology* 65:1377–1387.

Rosen DAS and AW Trites. 2002. "Cost of Transport in Steller Sea Lions, *Eumetopias jubatus*." *Marine Mammal Science* 18:513–524.

Ruggerone GT and FA Goetz. 2004. "Survival of Puget Sound Chinook Salmon (*Oncorhynchus tshawytscha*) in Response to Climate-Induced Competition With Pink Salmon (*Oncorhynchus gorbuscha*)." *Canadian Journal of Fisheries and Aquatic Sciences* 61:1756–1770.

Scholtyssek C, A Kelber, and G Dehnhardt. 2008. "Brightness Discrimination in the Harbor Seal (*Phoca vitulina*)." *Vision Research* 48:96–103.

Shamoun-Baranes J, E van Loon, H van Gasteren, J van Belle, W Bouten, and L Buurma. 2006. "A Comparative Analysis of the Influence of Weather on the Flight Altitudes of Birds." *Bulletin of the American Meteorological Society* 87:47–61.

Simon M, PK Mcgregor, and F Ugarte. 2007. "The Relationship Between the Acoustic Behaviour and Surface Activity of Killer Whales (*Orcinus orca*) That Feed on Herring (*Clupea harengus*)." *Acta Ethologica* 10:47–53.

Simon M, M Wahlberg, and LA Miller. 2007. "Echolocation Clicks From Killer Whales (Orcinus Orca) Feeding on Herring (*Clupea harengus*) (L)." *Journal of the Acoustical Society of America* 121:749–752.

Stelle LL, WM Megill, and MR Kinzel. 2008. "Activity Budget and Diving Behavior of Gray Whales (*Eschrichtius robustus*) in Feeding Grounds Off Coastal British Columbia." *Marine Mammal Science* 24:462–478.

Thompson PM, D Lusseau, T Barton, D Simmons, J Rusin, and H Bailey. 2010. "Assessing the Responses of Coastal Cetaceans to the Construction of Offshore Wind Turbines." *Marine Pollution Bulletin* 60:1200–1208.

Todd VLG, WD Pearse, NC Tregenza, PA Lepper, and IB Todd. 2009. "Diel Echolocation Activity of Harbour Porpoises (*Phocoena phocoena*) Around North Sea Offshore Gas Installations." *ICES Journal of Marine Science* 66:734–745.

Tyack PL. 2008. "Implications for Marine Mammals of Large-Scale Changes in the Marine Acoustic Environment." *Journal of Mammalogy* 89:549–558.

Tynan CT, DG Ainley, JA Barth, TJ Cowles, SD Pierce, and LB Spear. 2005. "Cetacean Distributions Relative to Ocean Processes in the Northern California Current System." *Deep-Sea Research Part Ii-Topical Studies in Oceanography* 52:145–167.

Unger S. 1997. "Identification of *Orcinus orca* by Underwater Acoustics in Dabob Bay." *Oceans '97 Mts/Ieee Conference Proceedings* 1 and 2:333–338.

Verfuss UK, LA Miller, PKD Pilz, and HU Schnitzler. 2009. "Echolocation by Two Foraging Harbour Porpoises (*Phocoena phocoena*)." *Journal of Experimental Biology* 212:823–834.

Weber JM. 2009. "The Physiology of Long-Distance Migration: Extending the Limits of Endurance Metabolism." *Journal of Experimental Biology* 212:593–597.

Williams R, D Lusseau, and PS Hammond. 2006. "Estimating Relative Energetic Costs of Human Disturbance to Killer Whales (*Orcinus orca*)." *Biological Conservation* 133:301–311.

Williams R and DP Noren. 2009. "Swimming Speed, Respiration Rate, and Estimated Cost of Transport in Adult Killer Whales." *Marine Mammal Science* 25:327–350.

Williams R, AW Trites, and DE. Bain. 2002. "Behavioural Responses of Killer Whales (*Orcinus orca*) to Whale-Watching Boats: Opportunistic Observations and Experimental Approaches." *Journal of Zoology* 256:255–270.

Williams TM. 1999. "The Evolution of Cost Efficient Swimming in Marine Mammals: Limits to Energetic Optimization." *Philosophical Transactions of the Royal Society of London Series B Biological Sciences* 354:193–201.

Witteveen BH, GAJ Worthy, KM Wynne, AC Hirons, AG Andrews, and RW Markel. 2011. "Trophic Levels of North Pacific Humpback Whales (*Megaptera novaeangliae*) Through Analysis of Stable Isotopes: Implications on Prey and Resource Quality." *Aquatic Mammals* 37:101–110.

Womble JN, MF Sigler, and MF Willson. 2009. "Linking Seasonal Distribution Patterns With Prey Availability in a Central-Place Forager, the Steller Sea Lion." *Journal of Biogeography* 36:439–451.

Wright AJ, NA Soto, AL Baldwin, M Bateson, CM Beale, C Clark, T Deak, EF Edwards, A Fernández, A Godinho, L Hatch, A Kakuschke, D Lusseau, D Martineau, LM Romero, L Weilgart, B Wintle, G Notarbartolo-di-Sciara, and V Martin. 2007. "Do Marine Mammals Experience Stress Related to Anthropogenic Noise?" *International Journal of Comparative Psychology* 20:274–316.

Young BL, DAS Rosen, M Haulena, AG Hindle, and AW Trites. 2011. "Environment and Feeding Change the Ability of Heart Rate to Predict Metabolism in Resting Steller Sea Lions (*Eumetopias jubatus*)." *Journal of Comparative Physiology B-Biochemical Systemic and Environmental Physiology* 181:105–116.