

Report to Congress

Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies

*Prepared in response to the Energy
Independence and Security Act of 2007,
Section 633(b)*

November 21, 2008



U.S. DEPARTMENT OF
ENERGY

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Executive Summary

Section 633(b) of the Energy Independence and Security Act of 2007 (EISA) called for a report to be provided to Congress that addresses (1) the potential environmental impacts of marine and hydrokinetic energy technologies; (2) options to prevent adverse environmental impacts; (3) the role of monitoring and adaptive management; and (4) the necessary components of an adaptive management program.

The EISA Report to Congress was prepared based on a review of peer-reviewed literature, project documents, and U.S. and international environmental assessments of these new technologies. The information was supplemented by contacts with technology developers, experts in state resource and regulatory agencies and non-governmental organizations, and input and reviews by Federal agencies (NOAA Fisheries, Minerals Management Service, U.S. Fish and Wildlife Service, National Park Service, Bureau of Indian Affairs, Federal Energy Regulatory Commission).

There are numerous conceptual designs for converting the energy of waves, river and tidal currents, and ocean temperature differences into electricity. Appendix B lists well over 100 ocean energy and hydrokinetic renewable energy technologies. Most of these technologies remain at the conceptual stage – they have not yet been tested in the field or as prototype, full-scale devices. Consequently, there have been few studies of their environmental effects. Most considerations of the environmental impacts have been in the form of predictive studies and environmental assessments that have not yet been verified.

The assessments have identified common elements among these technologies that may pose a risk of adverse environmental effects. These potential impacts include the alteration of currents and waves; alteration of substrates and sediment transport and deposition; alteration of habitats for benthic organisms; noise during construction and operation; emission of electromagnetic fields; toxicity of paints, lubricants, and antifouling coatings; interference with animal movements and migrations; and strike by rotor blades or other moving parts. In the case of ocean thermal energy conversion technologies, additional potential impacts stem from the intake and discharge of large volumes of sea water, temperature and other water quality changes, and entrainment of aquatic organisms into the intake and the discharge plume. Project installation and operation will change the physical environment. Effects on biological resources could include alteration of the behavior of animals, damage and mortality to individual plants and animals, and potentially larger, longer-term changes to plant and animal populations and communities. Table ES-1 summarizes potential direct impacts to aquatic environments from installation and operation of marine and hydrokinetic renewable energy technologies. Some effects are expected to be minor, but the potential significance of many of the environmental issues cannot yet be determined owing to a lack of experience with operating projects.

Although there have been few environmental studies of these new concepts, a preliminary indication of the importance of each of these issues can be gained from

1 published literature related to other technologies, e.g., noises generated by similar marine
2 construction activities, EMF emissions from existing submarine cables, and
3 environmental monitoring of active offshore wind farms. Experience with other, similar
4 activities in freshwater and marine systems will also provide clues to effective impact
5 minimization and mitigation measures that can be applied to these new renewable energy
6 technologies. However, some aspects of the environmental impacts are unique to the
7 technologies, and will require operational monitoring to determine the seriousness of the
8 effects. This is particularly true for the cumulative effects of large numbers of ocean
9 energy or hydrokinetic devices that will comprise fully built-out projects. Impacts to
10 bottom habitats, hydrographic conditions, or animal movements that are inconsequential
11 for a few units may become serious if large, multi-unit projects exploit large areas in a
12 river, estuary, or nearshore ocean. For some environmental issues it will be difficult to
13 extrapolate predicted effects from small to large numbers of units because of
14 complicated, non-linear interactions between the placement of the machines and the
15 distribution and movements of aquatic organisms. Assessment of these cumulative
16 effects will require careful environmental monitoring as the projects are deployed.
17 Evaluation of monitoring results might be usefully conducted in an adaptive management
18 framework.

19
20 There are numerous state and federal agencies and environmental laws and
21 regulations that will influence the development of marine and hydrokinetic technologies.
22 Federal licensing of these renewable energy projects is the responsibility of the Federal
23 Energy Regulatory Commission and the Minerals Management Service. Their licensing
24 decisions will include input from other federal and state agencies, tribes, environmental
25 groups, and other stakeholders. After a licensing decision has been made and operation
26 of the energy project has begun, the identification (and correction) of environmental
27 impacts will depend on appropriate monitoring.

28
29 The ability to modify the project in order to mitigate unacceptable environmental
30 impacts identified by operational monitoring might be based on application of adaptive
31 management principles reflected in the project license conditions. In the context of
32 marine and hydrokinetic energy technologies, adaptive management is a systematic
33 process by which the potential environmental impacts of installation and operation could
34 be evaluated against quantified environmental performance goals during project
35 monitoring. Early information about undesirable outcomes could lead to the
36 implementation of additional minimization or mitigation actions which are subsequently
37 re-evaluated. An adaptive management process is particularly valuable in the early
38 stages of technology development, when many of the potential environmental effects are
39 unknown for individual units, let alone the eventual build out of large numbers of units.
40 Basing the environmental monitoring programs on adaptive management principles, as
41 advocated by many resource and regulatory agencies, will take advantage of ongoing
42 research and monitoring to help refine technology designs and to improve environmental
43 acceptability of future installations.

44

Table ES-1. Summary of potential impacts to the aquatic environment from installation and operation of marine and hydrokinetic renewable energy technologies.

Issue	Effects on the physical and biological environment				
	Physical environment	Animal behavior	Individual injury and mortality	Population-level effects	Community- and ecosystem-level effects
Alteration of currents and waves	Current velocities or wave heights will be reduced in proportion to the size and number of units	Minor effects on animal behavior are expected	No injuries or mortalities are expected	Minor alterations of plant and animal populations from changed hydraulic environment	Minor alterations of plant and animal communities from changed hydraulic environment
Alteration of bottom substrates, sediment transport, and sediment deposition	Slower currents and smaller waves will increase sediment deposition	Minor effects on animal behavior are expected during installation	Few injuries or mortalities are expected from gradual changes in substrate composition and dynamics	Minor, localized changes to plant and animal populations from changes in substrates	Moderate changes to plant and animal communities in vicinity of altered bottom substrates
Alteration of benthic habitats	Altered current velocities and sediment transport and deposition will change habitats for bottom-dwelling plants and animals	Avoidance of unsuitable habitats by some species and attraction by other species	Mortality of sessile organisms during project installation	Population declines in vicinity of the project for some species and population increases for other species	Changes in plant and animal communities in response to altered substrates
Noise	Additional noise in the environment from installation and operation	Avoidance of areas with highest noise levels. Possible masking of animal communications and echolocation	Fish kills near pile-driving activities. Injury and mortality from operational noise probably minor.	Probably minor for fish. Unknown effects for marine mammals and sea turtles	Small or no changes to plant and animal communities from operational noise
Electromagnetic fields (EMF)	New electrical and magnetic fields in the water and sediments near generating devices and electrical cables	EMF may alter feeding behavior or migration of animals near the project	Incidence of injuries and mortalities from the predicted electrical and magnetic field strengths are expected to be small	Minor for feeding behavior changes. Unknown population impacts from effects on long-distance migrations	Minor for feeding behavior changes. Unknown impacts from effects on long-distance migrations

Chemical toxicity	Releases of contaminants from oils and other operating fluids and anti-biofouling coatings	Minor effects on behavior from released contaminants, except for avoidance of oil spills	Toxicity to plants and animals exposed to contaminants. Potential bioaccumulation of metals and other compounds	Potential effects on local plant and animals population from toxicity to individuals	Potential effects on local communities and ecosystems from population-level changes
Interference with animal movements and migrations	Creation of new structures on the bottom and in the water column	Entanglement or avoidance by some organisms. Attraction of some species to new habitat	Injury and mortality associated with entanglement and increased predator activity. Decreased injury and mortality if fishing is reduced.	Potential enhancement because of additional structures and reduced fishing. Potential decline from entanglement and interference with migrations	Unknown overall effect of avoidance and attraction mechanisms and between population enhancement and declines.
Strike	Rigid, moving structure and possible cavitation near rapidly moving blades	Unknown ability of animals to sense and avoid strike will mitigate the potential for damage	Unknown levels of injury and mortality from blade strike, impingement, and exposure to cavitation	Unknown changes to animal populations from strike mortality	Unknown effects on communities and ecosystems from strike mortality
Ocean Thermal Energy Conversion (OTEC) operation	Transfer of large volumes of water between ocean depths. Alteration of water temperatures, dissolved solids, and dissolved gas concentrations. Addition of biocides.	Unknown effects on behavior. Probably avoidance of discharge plume and intakes.	Injury and mortality from entrainment, impingement, and temperature shock. Toxicity of biocides.	Unknown amount of change to plant and animal populations from individual mortalities and avoidance of the project area	Unknown amount of change to communities and ecosystems from mortalities and avoidance of the project area

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Table C-1. Frequencies and intensities of some anthropogenic sounds. Modified from NRC (2000).

Acronyms and Abbreviations

1	
2	
3	A Amperes
4	AAM Active Acoustic Monitoring
5	AC Alternating current
6	ADD Acoustic deterrent device
7	ADM Acoustic daylight monitoring
8	ADS Acoustic Detection Systems
9	AHD – Acoustic harassment device
10	AMD – Acoustic mitigation device
11	B Magnetic field
12	BACI Before-After, Control-Impact experimental design
13	CEQ Council on Environmental Quality
14	dB Decibel
15	DC Direct current
16	DOE U.S. Department of Energy
17	E Electrical field
18	EISA Energy Independence and Security Act of 2007 (Public Law 110-140)
19	EMEC European Marine Energy Centre
20	EMF Electromagnetic field
21	EMS Environmental Management System
22	EPA U.S. Environmental Protection Agency
23	FAD Fish aggregation device
24	FERC Federal Energy Regulatory Commission
25	FRC Foul-release coatings
26	h hour
27	HVDC High voltage, direct current
28	Hz Hertz
29	ISO International Organization for Standardization
30	iE Induced (secondary) electrical field
31	kg Kilogram
32	km kilometer
33	kW Kilowatt
34	nm nautical miles
35	m meter
36	MMS Minerals Management Service
37	MPA Marine Protected Area
38	μPa microPascal
39	m/s meters/second
40	ms milliseconds
41	MW megawatt
42	NEPA National Environmental Policy Act
43	NOAA National Oceanic and Atmospheric Administration
44	OCS Outer Continental Shelf
45	OTEC Ocean Thermal Energy Conversion

- 1 P Pressure
- 2 PAM Passive Acoustic Monitoring
- 3 rms root mean square
- 4 s seconds
- 5 SEL sound exposure level
- 6 SPL sound pressure level
- 7 T Tesla
- 8 V Volt
- 9 WEC Wave Energy Conversion
- 10

Glossary

1
2
3 **Absorption** – conversion of sound to heat.

4
5 **AC** – alternating current

6
7 **Acoustic signature** – the sound pressure levels across the full range of frequencies
8 emitted by a device.

9
10 **Acoustic harassment device** – An underwater noise-generating device used by fish
11 farmers to drive away predatory marine mammals, such as killer whales and seals.

12
13 **Ambient noise** – background noise in the environment without distinguishable sources

14
15 **Acoustic mitigation device** – A device that uses aversive or alarming sounds to move
16 sensitive animals out of high risk areas.

17
18 **Amperage** – The rate of flow of electricity through a wire, measured in amperes, A.

19
20 **Anoxic** – lacking oxygen

21
22 **Attenuation (transmission loss)**– decrease of sound pressure levels or acoustic energy

23
24 **Audiogram** – graph showing the absolute auditory threshold versus frequency

25
26 **Auditory threshold (hearing threshold)** – Minimum sound level that can be perceived
27 by an animal in the absence of background noise

28
29 **B field** – magnetic field, measured in Teslas (T).

30
31 **Bandwidth** – the range of frequencies of a given sound.

32
33 **Benthic macroinvertebrates** – large (i.e., not microscopic) aquatic invertebrates that
34 live in or on the bottom of freshwater and marine systems.

35
36 **Benthos** – the community of aquatic plants and animals that inhabit the bottom of lakes,
37 rivers, and the ocean.

38
39 **Bioaccumulation** – The increase in concentration of a substance, such as a toxic
40 chemical, in various tissues of a living organism.

41
42 **Bioassay** – A method of testing a material's effects on living organisms, for example,
43 tests used to determine the toxicity of specific chemical contaminants.

44

1 **Biofouling** - The undesirable accumulation of microorganisms, plants, algae, and
2 animals on submerged structures
3
4 **Biomass** - The total quantity (weight) of living matter within a given unit of
5 environmental area.
6
7 **Cavitation** – The sudden formation and collapse of low-pressure bubbles in liquids by
8 means of mechanical forces, such as those resulting from rotation of a marine propeller.
9
10 **Cetacean** – a member of an order of aquatic (mostly marine) mammals, including
11 whales, dolphins, and porpoises.
12
13 **DC** – direct current
14
15 **Decibel (dB)** – the logarithmic measure of sound intensity (sound pressure). The decibel
16 value for sound pressure is $20 \log_{10} (P/P_0)$, with P = actual pressure and P_0 = reference
17 pressure.
18
19 **Dipole** - A pair of electric charges or magnetic poles, of equal magnitude but of opposite
20 sign or polarity, separated by a small distance.
21
22 **Dynamic positioning** – A system that generally uses computer-driven propulsion units to
23 maintain a floating offshore drilling rig in position over the well. It might be employed
24 for energy conversion devices to reduce the need for anchors.
25
26 **E field** – electric field, measured in V/m.
27
28 **Echolocation** - A sensory system in certain animals, such as dolphins, in which usually
29 high-pitched sounds are emitted and their echoes interpreted to determine the direction
30 and distance of objects. Also called echo ranging.
31
32 **Embolus** – A mass, such as an air bubble, a detached blood clot, or a foreign body, that
33 travels through the bloodstream and lodges so as to obstruct or occlude a blood vessel.
34
35 **EMF** – electromagnetic field
36
37 **Entrainment** – The incidental trapping of fish and other aquatic organisms in the water
38 that passes through current energy devices or OTEC plants.
39
40 **Electroreception** – the ability of organisms to perceive electrical impulses, often used
41 for detecting objects (electrolocation).
42
43 **Fairing** - a structure whose primary function is to produce a smooth outline and reduce
44 drag
45

1 **Fish Aggregation Device (FAD)** – also called fish attraction device, a structure deployed
2 in open water specifically to congregate fishes.
3
4 **Foraging** – The act of looking or searching for food.
5
6 **Frequency** – the rate of oscillations or vibration.
7
8 **Frequency spectrum** – The range of frequencies representing sounds produced by a
9 given source or audible to an organism.
10
11 **HVDC** – High voltage direct current
12
13 **Hz (Hertz)** – the unit for sound wave frequency, where 1 Hz = 1 cycle per second. One
14 kilohertz (1 kHz) is 1,000 cycles per second.
15
16 **Hydrofoil** - a device consisting of a flat or curved piece (as a metal plate) so that its
17 surface reacts to the water that passes over it
18
19 **Hydrokinetic** – relating to the motions of fluids
20
21 **iE field** – induced electrical field, measured in V/m.
22
23 **Impingement** – the entrapment of fish and shellfish on the outer part of an intake
24 structure or against an intake screening device during water withdrawal.
25
26 **Magnetic flux density** – the density of magnetic lines of force, or magnetic flux lines,
27 passing through a specific area, measured in units of tesla.
28
29 **Magnetoreception** – the ability of some organisms to perceive a magnetic field, often
30 used for orientation and navigation.
31
32 **Marine Protected Area** – any area of the intertidal or subtidal terrain, together with its
33 overlying water and associated flora, fauna, historical and cultural features, which has
34 been reserved by law or other effective means to protect part or all of the enclosed
35 environment.
36
37 **Masking** – obscuring sounds of interest by interfering sounds at similar frequencies.
38
39 **MicroPascal (μPa)** – a unit of pressure. The reference pressure for underwater sound is
40 1 μPa (10⁻⁵ μbar)
41
42 **Mooring** – Equipment, such as anchors or chains, for holding an energy device in place
43
44 **Nekton** – aquatic animals that swim strongly enough to resist the currents.
45

1 **Ocean Thermal Energy Conversion (OTEC)** - The conversion of energy arising from
2 the temperature difference between warm surface water of oceans and cold deep-ocean
3 current into electrical energy or other useful forms of energy.
4 **Odontocetes** – toothed whales, such as belugas, narwhals, dolphins, sperm and killer
5 whales
6
7 **Pascal (Pa)** – unit of pressure equal to one Newton per square meter.
8
9 **Pelagic** – Pertaining to the open sea or water column, away from the sea bottom.
10
11 **Photic zone** – The surface layer of oceans or lakes that is penetrated by enough light to
12 support photosynthesis.
13
14 **Pile/Piling** – Steel tube up to several meters in diameter used as a foundation for offshore
15 structures.
16
17 **Pile driver** – A device used to drive piles into the sediment using impulses or vibrations.
18
19 **Pinger** – A device that emits a short, high-pitched sound burst, sometimes used to deter
20 marine mammals from dangerous areas.
21
22 **Pinniped** – A member of the suborder of carnivorous aquatic mammals that includes the
23 seals, walruses, and similar animals having finlike flippers as organs of locomotion.
24
25 **Plankton** – weakly swimming aquatic plants and animals that drift with the currents.
26
27 **Polychaete** – A mainly marine worm.
28
29 **Prototype** – the first full-scale, functional form of a new type or design.
30
31 **Rise time** – the time needed to go from zero to maximum sound pressure.
32
33 **Rotor** – the rotating part of a current energy conversion device, often propeller-like in
34 form.
35
36 **Sound Exposure Level (SEL)** – Sound level of a single sound event averaged in a way
37 as if the event duration was 1 second.
38
39 **Sound Pressure Level (SPL)** – The intensity of a sound, measured in decibels.
40
41 **Sound transmission** – Propagation of sound from a source through a medium (air, water,
42 or sediments) to a receiver.
43
44 **Species diversity** – The number and frequency of species in a biological assemblage or
45 community.
46

- 1 **Species richness** – The number of species present in an area or sample.
2
- 3 **Strumming** – Vibration of an underwater cable produced by water movements, typically
4 the shedding of von Karman vortex streets from the cable.
5
- 6 **Sweeping** – The movement of unanchored mooring lines or electrical transmission cables
7 in response to water movements.
8
- 9 **Turbidity** – A measure of water cloudiness caused by suspended particles
10
- 11 **Turbine** – a machine that generates rotary mechanical power from the energy of a
12 moving fluid, such as water or air.
13
- 14 **Voltage** – The difference in electrical potential between two points, and thus a measure
15 of the pressure under which electricity flows.
16
- 17 **Wave energy** – the total energy in a wave is the sum of potential energy (due to vertical
18 displacement of the water surface) and kinetic energy (due to water in oscillatory
19 motion).
20
- 21 **Wave Energy Converter (WEC)** – a technical device or system designed to convert
22 wave energy to electrical energy.

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1. Introduction

A new generation of waterpower technologies, broadly categorized as “marine and hydrokinetic” energy systems, offers the possibility of generating electricity from water without the need for dams and diversions. The potential power that could be derived from currents, tides, and waves in rivers and oceans is enormous, and there are numerous plans in the United States and internationally to develop these energy conversion technologies. But because the concepts are new, few devices have been deployed and tested in rivers and oceans and even fewer environmental studies of these technologies have been carried out. Their potential environmental effects remain mostly speculative (Pelc and Fujita 2002; Cada et al. 2007; Michel et al. 2007; Boehlert et al. 2008).

In order to address some of the uncertainties about the environmental effects of ocean and hydrokinetic technologies, Section 633(b) of the Energy Independence and Security Act of 2007 (EISA; Pub. L. 110-140; signed December 19, 2007) called for:

- (b) REPORT.-Not later than 18 months after the date of enactment of this Act, the Secretary, in conjunction with the Secretary of Commerce, acting through the Undersecretary of Commerce for Oceans and Atmosphere, and the Secretary of the Interior, shall provide to the Congress a report that addresses-
- (1) the potential environmental impacts, including impacts to fisheries and marine resources, of marine and hydrokinetic renewable energy technologies;
 - (2) options to prevent adverse environmental impacts;
 - (3) the potential role of monitoring and adaptive management in identifying and addressing any adverse environmental impacts; and
 - (4) the necessary components of such an adaptive management program.

For the purposes of this Act, the term "marine and hydrokinetic renewable energy" means electrical energy from-

- (1) waves, tides, and currents in oceans, estuaries, and tidal areas;
- (2) free flowing water in rivers, lakes, and streams;
- (3) free flowing water in man-made channels; and
- (4) differentials in ocean temperature (ocean thermal energy conversion).

The term “marine and hydrokinetic renewable energy” does not include energy from any source that uses a dam, diversionary structure, or impoundment for electric power purposes.

This report addresses the requirements of EISA Section 633(b) by describing the technologies that are being considered for development (Section 2), their potential environmental impacts and options to minimize or mitigate the impacts (Section 3), and the role of environmental monitoring and adaptive management in guiding their deployment (Section 4). The report is based on (1) a review of existing information obtained from peer-reviewed journals, U.S. and international environmental impact assessments, and websites of technology developers, research organizations, and resource management agencies; (2) contacts with technology developers to ascertain the environmental issues that they have faced and their plans for resolving the issues; and (3) consultations with the technical staff of the Departments of Commerce (National Marine

1 Fisheries Service [NMFS]) and Interior (Minerals Management Service [MMS], U.S.
2 Fish and Wildlife Service [FWS], and National Park Service [NPS]). Input to the report
3 was received from regulatory agencies (e.g., the Federal Energy Regulatory Commission
4 [FERC]), the public, academic institutions, and non-governmental organizations to ensure
5 that their perspectives and concerns are reflected (Appendix A).
6

7 EISA Section 633(b) specifically excludes consideration in this report of energy
8 sources that use dams, diversionary structures, or impoundments, and specifies
9 consideration only of technologies that can be broadly classed as wave energy and
10 current energy devices and Ocean Thermal Energy Conversion (OTEC). This report
11 focuses on potential impacts of these technologies to the environment, particularly
12 aquatic environments (rivers, estuaries, and oceans), fisheries, ecological relationships,
13 and other marine and freshwater aquatic resources. It does not address human use
14 conflicts, other possible impacts to humans (e.g., aesthetics, noise, light, recreation,
15 transportation, navigation, cultural resources), or socioeconomic impacts. The cultural
16 and socioeconomic impacts of these technologies on coastal communities and other users
17 of rivers and oceans are important, and are better addressed more fully in separate,
18 focused reports. For example, Nelson et al. (2008) addressed the potential
19 socioeconomic effects of developing wave energy projects in California. The
20 Programmatic Environmental Impact Statement for Alternative Energy Production and
21 Alternate Uses of Facilities on the Outer Continental Shelf (MMS 2007) considered in
22 detail the effects of alternate energy technologies on other human uses. In this document
23 and the subsequent Record of Decision (73 FR 1894; January 10, 2008), the MMS
24 identified 52 “best management practices” that will be individually considered when
25 authorizing any lease for alternative energy development on the Outer Continental Shelf,
26 along with other project-specific conditions and stipulations. Similarly, the NPS provides
27 comments to the FERC on the potential impacts of proposed hydrokinetic projects to
28 recreation, public access, and aesthetics. Consideration of the full range of impacts to the
29 human environment will occur in the environmental analyses that are done in compliance
30 with the National Environmental Policy Act (NEPA).

31

2. Description of Technologies

Numerous technologies have been proposed to convert the kinetic energy, potential energy, or thermal energy in freshwater and marine systems into electricity. This section provides a brief description of each of these general approaches and the status of technology development. The U.S. Department of Energy's Wind and Hydropower Program recently released the Marine and Hydrokinetic Technologies Database, which provides up-to-date information on marine and hydrokinetic renewable energy, both in the U.S. and around the world. The database includes wave, tidal, current, and ocean thermal energy, and contains information on the various energy conversion technologies, companies active in the field, and development of projects in the water. Depending on the needs of the user, the database can present a snapshot of projects in a given region, assess the progress of a certain technology type, or provide a comprehensive view of the entire marine and hydrokinetic energy industry. The database can be accessed at (<http://aspdev.optimle.com/eere/>). Appendix B provides a printout from the "List All Technologies" function of the database that lists all tidal, wave, and OTEC energy converters and their developmental status.

Current energy technologies (also called tidal or hydrokinetic technologies) convert the kinetic energy associated with moving water into electricity. Current energy technologies depend on the horizontal movements of river currents and ocean currents (tidal and stream) to drive a generator that converts mechanical power into electrical power. Current energy devices are often rotating machines that can be compared to wind turbines – a rotor spins in response to the movements of water currents with the rotational speed being proportional to the velocity of the fluid (Bedard 2005). The rotor may have an open design like a wind turbine (e.g., the Verdant horizontal axis turbine; <http://www.verdantpower.com/>) or may be enclosed in a duct that channels the flow (e.g., the Rotech Tidal Turbine; <http://www.lunarenergy.co.uk/>). Further, the rotor may be characterized by conventional "propeller-type" blades or helical blades (<http://www.gcktechnology.com/GCK/>).

The European Marine Energy Centre (EMEC) further divides current energy converters into four main types: (1) horizontal axis turbines; (2) ducted horizontal axis turbines; (3) vertical axis turbines; and (4) oscillating hydrofoils (Figure 2-1). Horizontal axis turbines may look much like wind turbines, and they extract kinetic energy from the moving water in the same way that wind turbines extract energy from moving air. Enclosing the horizontal rotor inside a duct (often funnel-shaped) has the effect of concentrating the flow past the turbine, which may allow operation over a greater range of current velocities and as a consequence the generation of more electricity per unit of rotor area (Kirke 2006). In vertical axis turbines, the axis of the rotor is oriented perpendicular to the flow; vertical axis turbines may also take different forms, such as being enclosed within a duct. Oscillating hydrofoils pivot in response to tidal currents flowing over a wing or flap-like structure. The movements drive fluid in a hydraulic system to generate electricity.

1 There are no commercial developments of current energy converting technologies
2 in the United States, although several partial- or full-scale prototypes have been tested.
3 For example, Verdant Power is carrying out performance and environmental monitoring
4 of an array of six horizontal axis turbines in the East River in New York City. If
5 operation and environmental impacts are acceptable, this initial project could lead to an
6 arrangement of around 100 turbines.

7
8 *Wave energy technologies* convert wave energy, the sum of potential energy (due
9 to vertical displacement of the water surface) and kinetic energy (due to water in
10 oscillatory motion), into electricity. Thus, these devices operate by means of changes in
11 the height of ocean waves (head or elevation changes). There is a wide variety of wave
12 energy converter designs, and they are categorized in several ways (e.g., Bedard 2005;
13 Michel et al. 2007). The EMEC divides wave energy converters into six main types: (1)
14 point absorbers; (2) attenuators; (3) oscillating wave surge converters; (4) oscillating
15 water column; (5) overtopping devices; and (6) submerged pressure differential devices
16 (Figure 2-2).

17
18 Point absorbers are like buoys, floating at or near the surface and moored to the
19 ocean bottom. These devices are able to capture energy from a wave front greater than
20 the physical dimension of the device. The vertical motions of ocean waves provide the
21 mechanical power to drive an electrical generator. One example of a point absorber is
22 Finavera's AquaBuOY (<http://finavera.com/>), in which wave motions drive a pump that
23 moves fluids over a turbine. Another example of a point absorber is the PowerBuoy
24 (<http://www.oceanpowertechnologies.com/>). Attenuators are floating structures that are
25 orientated parallel to the direction of the incoming wave, rather than perpendicular as
26 with a point absorber. The differences in the relative horizontal and vertical motions of
27 the articulated parts of an attenuator are converted into electricity by an internal
28 generator. An example of an attenuator is the Pelamis, which consists of a series of semi-
29 submerged cylinders linked by hinged joints (<http://www.pelamiswave.com/>). The wave-
30 driven motions of the Pelamis cylinders relative to each other are resisted by hydraulic
31 rams, which move high-pressure oil through hydraulic motors driving electrical
32 generators contained within the cylinders. Oscillating wave surge converters are
33 considered to be a pitching/surging/heaving (PSH) device, which utilizes the relative
34 motion between a flap and a fixed reaction point. These devices are fixed to the bottom
35 (or hang from a floating or shoreline structure) and swing like a gate in response to the
36 surging movement of water in the waves. One example of an oscillating wave surge
37 converter is the Wave Roller (<http://www.aw-energy.com/>), which is being installed and
38 tested in Portugal. An oscillating water column is a partially submerged structure that
39 encloses a column of air above a column of water; a collector funnels waves into the
40 structure below the waterline, causing the water column to rise and fall; this alternately
41 pressurizes and depressurizes the air column, pushing or pulling it through a bidirectional
42 air turbine. Oscillating water column devices can be installed on the shoreline (e.g., the
43 Limpet; www.wavegen.com) or floating and moored to the bottom (e.g., Oceanlinx
44 www.oceanlinx.com). Overtopping devices, such as the Wave Dragon
45 (<http://www.wavedragon.net>), incorporate elements from traditional hydroelectric power
46 plants (vertical axis turbine) in an offshore floating platform. A collector on the partially

1 submerged structure funnels waves over the top of the structure into a reservoir and then
2 the water runs back out to the sea from this reservoir through low-head hydropower
3 turbines. Submerged pressure differential devices, such as CETO
4 (<http://www.carnegicorp.com.au>), are typically located near the shore and attached to
5 the seabed. Wave motions cause the water level to rise and fall above the device, which
6 induces a pressure differential inside the device that can then pump fluid to drive a
7 generator.

8
9 There are no full-scale wave energy projects in operation in the United States,
10 although Finavera experimentally deployed a single prototype AquaBuOY off the coast
11 of Newport, Oregon in September, 2007. On December 21, 2007, Finavera Renewables
12 received a conditioned license from the Federal Energy Regulatory Commission (FERC)
13 to operate and test their AquaBuOY device in Makah Bay, Washington
14 (<http://finavera.com/>). The project will consist of four 250-kW steel wave energy
15 conversion buoys, located 3.7 miles offshore, and associated mooring/anchoring systems
16 and submarine electrical transmission cable. Other wave converter technologies have
17 undergone or are planning pilot scale tests in the U.S., including attenuators (SEADOG in
18 Texas; Waveberg in Florida) and point absorbers (PowerBuoy in New Jersey and
19 Hawaii). Field tests of various wave converter types have been carried out or are planned
20 in other countries: point absorbers (Portugal; United Kingdom; Sweden; Spain; Norway;
21 Denmark; Ireland), attenuators (Portugal; United Kingdom; Israel; Sri Lanka; Canada),
22 oscillating wave surge converters (United Kingdom; Australia; Japan; Denmark),
23 oscillating water column (Portugal; Japan; Ireland; Australia; United Kingdom; Spain),
24 and overtopping devices (Denmark; United Kingdom; Norway). Of these, only the
25 oscillating water column technologies in Portugal, Spain, and the United Kingdom are
26 presently producing electrical power, and commercial operation of three Pelamis
27 attenuators began in Portugal in September 2008.

28
29 *Ocean Thermal Energy Conversion (OTEC)* relies on the temperature difference
30 between cold, deep water and warm, surface waters of the ocean to alternately evaporate
31 and condense a fluid (Figure 2.3). Two distinct types of OTEC technologies have been
32 developed, and a third form is a hybrid of the two; all use thermal energy in seawater to
33 power a steam turbine (TCPA 2008). Closed cycle OTEC uses warm seawater to
34 vaporize a low-boiling point liquid (e.g., ammonia, propane, or freon) that then drives a
35 turbine to generate electricity. The vapor is cooled and condensed back to a liquid by
36 cold seawater at depth, and the cycle repeats. Open cycle OTEC vaporizes warm
37 seawater by lowering the pressure and uses the resulting steam to drive a turbine. Much
38 like closed cycle OTEC, cold seawater condenses the vapor after it leaves the turbine in
39 an open cycle system. Finally, the hybrid design uses steam from boiled seawater to
40 vaporize a low-boiling-point liquid, which then drives a turbine. OTEC plants can be
41 built either onshore or on offshore floating platforms or ships (Pelc and Fujita 2002). If
42 located onshore, the OTEC development could be used not only to generate electricity,
43 but also to provide co-products such as desalinized water, coldwater air conditioning,
44 aquaculture, agriculture, ice, and hydrogen (see Figure 2.4 and
45 <http://www.nrel.gov/otec/applications.html>).

1 Theoretically, OTEC systems can tap an enormous global resource, far higher
2 than that of current and wave energy conversion systems (Buigues 2006). However, the
3 temperature difference between surface and deep waters for OTEC to work efficiently is
4 20° C or higher; the higher the temperature differential, the better the efficiency. These
5 temperature ranges are generally limited to tropical, equatorial oceans with access to deep
6 (e.g., 600 m) water (Heydt 1993). In the U.S., such areas are found mainly near the
7 Hawaiian Islands (http://www.nrel.gov/otec/design_location.html), but potential sites
8 may also occur near Puerto Rico and the continental shelf of the Gulf of Mexico (Pelc
9 and Fujita 2002).
10

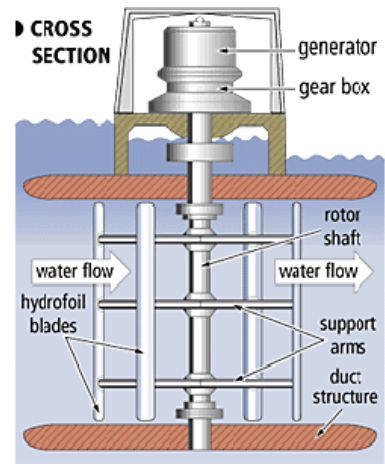
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Horizontal Axis Turbines

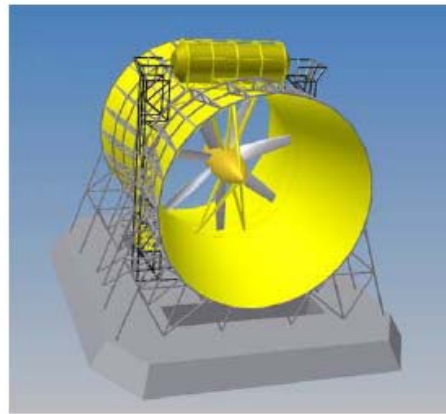


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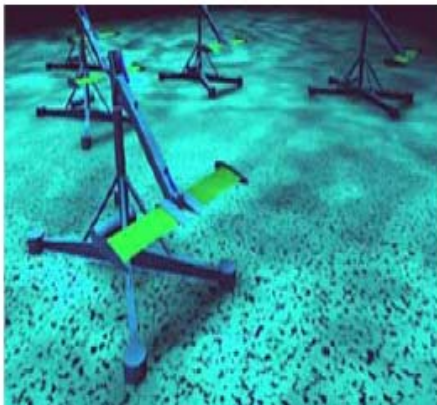
Vertical Axis Turbine



Ducted Horizontal Axis Turbine



Oscillatory

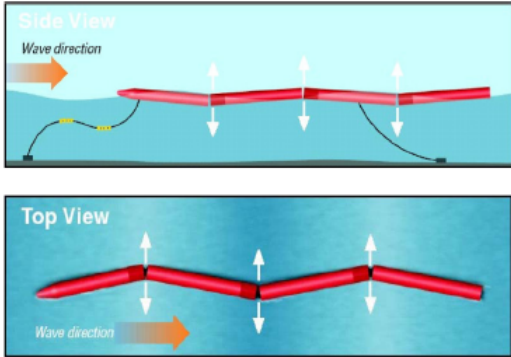


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Figure 2-1. General types of current energy converters. From Bedard (2005).

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2

Attenuator

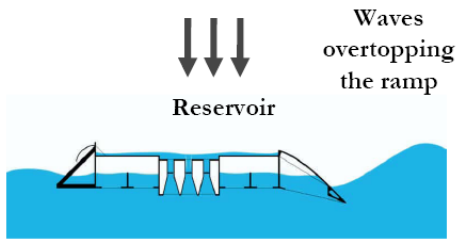


Point Absorber



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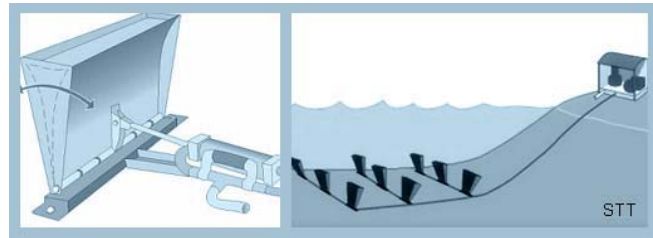
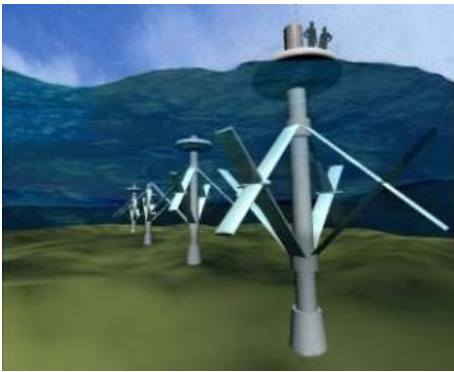
Overtopping



Terminator- Oscillating Water Column



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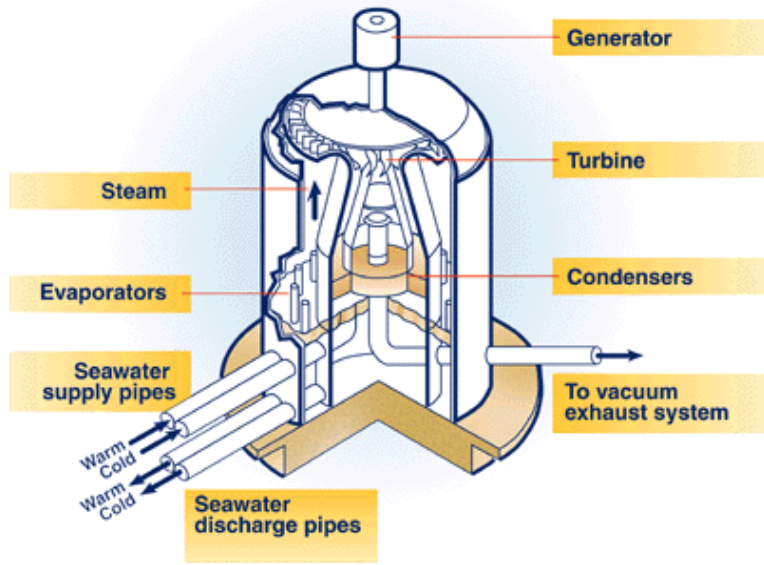


Submerged Pressure Differential

Oscillating Wave Surge Converter

Figure 2-2. General types of wave energy converters. From Bedard (2005).

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Figure 2-3. Schematic of an Ocean Thermal Energy Conversion (OTEC) generation system. Source: National Renewable Energy Laboratory <http://www.nrel.gov/otec/what.html>



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Figure 2-4. Potential co-products of an onshore OTEC electrical energy development. Source: Ocean Engineering & Energy Systems (OCEES) <http://www.ocees.com/mainpages/Coproducts.html>

3. Potential Environmental Impacts and Mitigation Measures

This section summarizes the peer-reviewed literature and technical reports that describe the potential environmental impacts of new ocean energy and hydrokinetic technologies. Environmental issues that apply to all technologies include alteration of river and ocean currents and waves (Section 3.1), alteration of bottom substrates and sediment transport/deposition (Section 3.2), alteration of bottom habitats (Section 3.3), impacts of noise (Section 3.4), effects of electromagnetic fields (Section 3.5), toxicity of chemicals (Section 3.6), and interference with animal movements and migrations (Section 3.7). Designs that incorporate moving rotors or blades also pose the potential for injury to aquatic organisms from strike or impingement (Section 3.8). Finally, ocean thermal energy conversion technologies have unique environmental impacts that are described in Section 3.9.

Measures that could be used to mitigate environmental impacts are also discussed in this section. Some of the possible mitigation measures are structural or operational, but for nearly all of the issues an important consideration for reducing project impacts would be the avoidance of environmentally sensitive areas. These may be areas that are particularly fragile, have high biological productivity or biodiversity, or have some special cultural or environmental values (e.g., critical habitats for endangered species). MMS (2007) described areas of special concern for alternative energy development on the Outer Continental Shelf (OCS), including national marine sanctuaries, national parks, national monuments, national seashores, national wildlife refuges, national estuarine research reserves, and estuaries within the National Estuary Program. Marine reserves are areas where some or all fishing is prohibited (PFMC 2007). Marine protected areas are geographic areas with discrete boundaries that have been designated to enhance the conservation of marine resources; an online inventory of marine protected areas is provided at MPA (2008). NOAA (2008) provides maps of sensitive coastal resources that are at risk from accidents such as oil spills. Examples of at-risk resources include biological resources (birds and shellfish beds), sensitive shorelines (such as marshes and tidal flats), and human-use resources (such as public beaches and parks). Designation of a river under the federal Wild and Scenic Rivers Act may preclude development, and many states have enacted broad river protection programs. In addition to the federal lists, individual states may have their own lists of sensitive areas within which the development of marine and hydrokinetic energy technologies would be constrained or prohibited.

Recent reviews of the potential impacts of these technologies have been conducted (Michel et al. 2007; Boehlert et al. 2008). Many of the reviews and environmental assessments make judgments about significance of potential impacts, but few of these are based on *in situ* monitoring or even predictive modeling. Adding to the uncertainty about the actual impacts of particular technologies are the uncertainties about scaling up from single units to the cumulative impacts of dozens or hundreds of multiple units that will eventually be installed as part of the full build-out of energy projects. For some environmental issues, the cumulative impacts are likely to be approximately proportional

1 to the number of units (habitat alteration; sediment suspension; toxicity of chemicals).
2 On the other hand, for other issues the cumulative impacts may vary with the number of
3 units by a more complicated function (interference with migration; alteration of
4 hydraulics/hydrologic regimes; noise and electromagnetic fields; blade strike;
5 impingement). Phased monitoring would allow for the evaluation of the environmental
6 effects of scaling up from a small number of units to large numbers of units in large
7 projects. In addition to the information gaps identified in this Section, Michel and
8 Burkhard (2007) provide a summary of information needs (their Tables 1-8). Monitoring
9 and research that could reduce the uncertainties about environmental effects of these new
10 technologies are discussed in Section 4.

11
12 Most of the studies summarized in this section relate to the potential direct effects of
13 hydrokinetic and ocean energy technologies. Gill (2005) described a number of indirect
14 ecological effects that would result from extensive installation of offshore renewable
15 energy developments. These possible impacts include changes in food availability,
16 competition, predation, reproduction, and recruitment. The influence of energy
17 developments on these ecological processes is largely speculative at this point, and it is
18 difficult in some cases to predict even the direction of change that could occur.
19 Nonetheless, such indirect effects are real possibilities, and it will be important to
20 consider more subtle environmental changes as basic information on direct effects is
21 developed from the early monitoring efforts.

22 23 24 3.1 Alteration of Currents and Waves

25 3.1.1 Potential Near Field and Far Field Impacts of Hydraulic Alterations

26
27 The extraction of kinetic energy from river and ocean currents or tides will reduce
28 water velocities in the vicinity (near field) of the project (Bryden et al. 2004). Large
29 numbers of devices in a river will reduce water velocities, increase water surface
30 elevations, and decrease flood conveyance capacity; effects would be proportional to the
31 number and size of structures installed in the water. Rotors, foils, mooring and electrical
32 cables, and fixed structures will all act as impediments to water movement. The resulting
33 reduction in water velocities could, in turn, affect the transport and deposition of
34 sediment (Section 3.2), organisms living on or in the bottom sediments (Section 3.3) and
35 plants and animals in the water column (Section 3.7). Conversely, moving rotor and foils
36 might increase mixing in systems where salinity or temperature gradients are well
37 defined. Changes in water velocity and turbulence will vary greatly, depending on
38 distance from the structure. For small numbers of units the changes are expected to
39 dissipate quickly with distance, such that effects are expected to be localized. However,
40 for large arrays the cumulative effects may extend to a greater area.

41
42 The presence of floating wave energy converters will alter wave heights and
43 structures, both in the near and far fields. The above-water structures of wave energy
44 converters will act as a localized barrier to wind, and thus reduce wind-wave interactions.

1 Michel et al. (2007) noted that many of the changes would not directly relate to
2 environmental impacts; for example, impacts on navigational conditions, wave loads on
3 adjacent structures, and recreation on nearby beaches (surfing and swimming) might be
4 expected. Reduced wave action could alter bottom erosion and sediment transport and
5 deposition.
6

7 Although wave measurements at operating wave energy conversion projects have
8 not yet been made, the potential for significant reductions in waves is probably small
9 owing to the low profiles of these devices (especially compared to wind turbines). For
10 example, ASR Ltd. (2007) predicted that operation of wave energy conversion devices at
11 the proposed Wave Hub would reduce wave height at nearby shorelines by 3 to 6 percent.
12 Operation of six Wave Energy Conversion (WEC) buoys in Hawaii was not predicted to
13 impact oceanographic conditions (DON 2003). This conclusion was based on modeling
14 analyses of wave height reduction due to both wave scattering and energy absorption.
15 The proposed large spacing of buoy cylinders (51.5 m apart, compared to a buoy
16 diameter of 4.5 m) resulted in predicted wave height reductions of 0.5 percent for a wave
17 period of 9 s and less than 0.3 percent for a wave period of 15 s. Boehlert et al. (2008)
18 summarized the changes in wave heights that were predicted in various environmental
19 assessments. Recognizing that impacts will be technology- and location-specific,
20 estimated wave height reductions ranged from 3 to 15 percent, with maximum effects
21 closest to the installation and near the shoreline. Millar et al. (2007) used a mathematical
22 model to predict that operation of the Wave Hub, with WECs covering a 1 km X 3 km
23 area, could decrease average wave heights by about 1 to 2 cm at the coastline 20 km
24 distant. This represents an average decrease in wave height of 1%; a maximum decrease
25 in the wave height of 3% was predicted to occur with a 90% energy transmitting wave
26 farm (Smith et al. 2007). Other estimates in other environmental settings predict wave
27 height reductions ranging from 3-13% (Nelson et al. 2008).
28

29 The effects of reduced wave heights on coastal systems will vary from site to site.
30 It is known that the richness and density of benthic organisms is related to such factors as
31 relative tidal range and sediment grain size (e.g., Rodil and Lastra 2004), so changes in
32 wave height can be expected to alter benthic sediments (Section 3.2) and habitat for
33 benthos (Section 3.3). Coral reefs reduce wave heights and dissipate wave and tidal
34 energy, thereby creating valuable ecosystems (Roberts et al. 1992; Lugo-Fernandez et al.
35 1998). In other cases, wave height reductions can have long-term adverse effects. For
36 example, construction of a storm-surge barrier across an estuary in the Netherlands
37 reduced the tidal range and mean high water level permanently by about 12 % from their
38 original values; numerous changes to the affected salt marshes and wetlands soils were
39 observed (de Jong et al. 1994).
40

41 Tidal energy converters can also modify wave heights and structure by extracting
42 energy from the underlying current. The effects of structural drag on currents were not
43 expected to be significant (MMS 2007), but few measurements of the effects of
44 tidal/current energy devices on water velocities have been reported. A few tidal velocity
45 measurements were made near a single, 150 kW Stingray demonstrator in Yell Sound in
46 the Shetland Islands (The Engineering Business Ltd 2005). Acoustic Doppler Current

1 Profilers were installed near the oscillating hydroplane (that travels up and down in the
2 water column in response to lift and drag forces) as well as upstream and downstream of
3 the device. Too few velocity measurements were taken for firm conclusions to be made,
4 but the data suggest that 1.5 to 2.0 m/s tidal currents were slowed by about 0.5 m/s
5 downstream from the Stingray.
6

7 Modeling of the Wave Hub project in the United Kingdom suggested a local
8 reduction in marine current velocities of up to 0.8 m/s, with a simultaneous increase in
9 velocities of 0.6 m/s elsewhere (Michel et al. 2007). Wave energy converters are
10 expected to affect water velocities less than submerged rotors and other, similar designs,
11 because only cables and anchors will interfere with the movements of tides and currents.
12

13 Tidal energy conversion devices will increase turbulence, which in turn will alter
14 mixing properties and sediment transport and, potentially, wave properties. In both the
15 near field and far field, extraction of kinetic energy from tides will decrease tidal
16 amplitude in proportion to the number of units installed, and the hydrologic, sediment
17 transport, and ecological relationships of rivers, estuaries, and oceans could be altered. In
18 the extreme far field, there is an unknown potential for dozens or hundreds of tidal energy
19 extraction devices to alter major ocean currents such as the Gulf Stream (Michel et al.
20 2007). The significance of these potential impacts could be ascertained by predictive
21 modeling and subsequent operational monitoring as projects are installed.
22

23 3.1.2 Mitigation Measures

24
25 Because the extraction of kinetic energy from moving water is a necessary aspect of
26 current/tidal energy converters, effects on water velocities cannot be reduced without
27 reducing the amount of electricity generated. Minimizing the environmental impacts of
28 velocity changes is most easily accomplished by siting the projects away from marine
29 protected areas and sensitive seabed habitats, and avoiding areas where primary
30 production and managed fish species could be disrupted. With regard to non-generating
31 structures (pilings, cables, submerged housing structures), water velocity effects could be
32 reduced by streamlining the shapes, reducing the size and/or overall surface areas,
33 burying electrical cables, and altering the spacing between individual machines. Similar
34 design considerations could also minimize the water velocity effects of wave energy
35 converters. Minimizing the changes in water velocities and wave heights to only those
36 necessary for power production will also serve to minimize the consequent effects on
37 bottom substrates, benthic habitats, and aquatic organisms.
38
39

40 3.2 Alteration of Substrates and Sediment Transport and Deposition

41
42 Operation of hydrokinetic or ocean energy technologies will extract energy from the
43 water, which will reduce the height of waves or the velocity of currents in the local area.

1 This loss of wave/current energy could, in turn, alter sediment transport and the wave
2 climate of nearby shorelines.
3

4 3.2.1 Potential Near Field and Far Field Impacts of the Alteration of 5 Sediment Transport

6
7 Installation of many of the hydrokinetic and ocean energy technologies will entail
8 attaching the devices to the bottom by means of pilings or anchors and cables.
9 Transmission of electricity to the shore will be through cables that are either buried in or
10 attached to the seabed. Thus, project installation will temporarily disturb sediments, the
11 significance of which will be proportional to the amount and type of bottom substrate
12 disturbed. There have been few studies of the effects of burying cables from ocean
13 energy technologies, but experience with other buried cables and trawl fishing give an
14 indication of possible severity of the impacts. For example, Kogan et al. (2006) surveyed
15 the condition of an armored, 6.6-cm diameter coaxial cable that was laid on the surface of
16 the seafloor off Half Moon Bay, California. The cable was not anchored to the seabed.
17 Whereas the impacts of laying the cable on the surface of the seabed were probably
18 small, subsequent movements of the cable had continuing impacts on the bottom
19 substrates. For example, cable strumming by wave action in shallower, nearshore areas
20 had created incisions in rocky siltstone outcrops ranging from surficial scrapes to vertical
21 grooves. This had minor effects on the habitats of aquatic organisms (Section 3.3.2). At
22 greater depths there was little evidence of effects of the cable on the seafloor, regardless
23 of exposure. Limited self-burial of the unanchored cable occurred over an 8-year period,
24 particularly in deeper waters of the continental shelf.
25

26 During operation, changes in current velocities or wave heights (Section 3.1) will
27 alter sediment transport, erosion, and sedimentation. Owing to the complexity of currents
28 and their interaction with structures, operation of the projects will likely increase both
29 scour and deposition, on both localized and far field scales. For example, turbulent
30 vortices that are shed immediately downstream from a velocity-reducing structure (e.g.,
31 rotors, pilings, or concrete anchor blocks) will cause scour, and further downstream this
32 sediment is likely to be deposited. On the average, extraction of kinetic energy from
33 currents and waves is likely to increase sediment deposition in the shadow of the project
34 (Michel et al. 2007), the depth and areal extent of which will depend on local topography,
35 sediment types, and characteristics of the current and the project. Deposition of
36 sediments is likely to cause shoaling and a shift to a finer sediment grain size on the lee
37 side of wave energy arrays (Boehlert et al. 2008).
38

39 In the far field, loss of wave energy may lead to changes in longshore currents,
40 reductions in the width and energy of the surf zone, and changes in beach sand erosion
41 and deposition patterns. Millar et al. (2007) modeled the wave climate near the Wave
42 Hub electrical grid connection point off the north coast of Cornwall. The installation
43 would be located 20 km off the coast, in water depths of 50-60 m. Arrays of wave energy
44 converters (WECs) connected to the Wave Hub would occupy a 1 km X 3 km site. Their
45 mathematical model predicted that an array of WECs would potentially affect the wave

1 climate on the nearby coast, but the reduction of wave height would only be on the order
2 of 1 to 2 cm. It is unknown whether such small changes in the average wave height
3 would measurably alter sediment dynamics along the shore, given the normal variations
4 in waves due to wind and storms.

5
6 Water quality will be temporarily affected by increased suspended sediments
7 (turbidity) during installation and initial operation. Suspension of anoxic sediments may
8 result in a temporary and localized decline in the dissolved oxygen content of the water,
9 but dilution by oxygenated water currents would minimize the impacts. Water quality
10 may also be compromised by the mobilization of buried contaminated sediments during
11 both construction and operation of the projects. Excavation to install the turbines,
12 anchoring structures, and cables could release contaminants adsorbed to sediments,
13 posing a threat to water quality and aquatic organisms. Effects on aquatic biota may
14 range from temporary degradation of water quality (e.g., a decline in dissolved oxygen
15 content) to biotoxicity and bioaccumulation of previously buried contaminants such as
16 metals.

17
18 Changes in scour and deposition will in turn alter the habitats for bottom-dwelling
19 plants and animals (Section 3.3).

21 3.2.2 Mitigation Measures

22
23 Some alteration of sediment transport, erosion and deposition is a necessary
24 consequence of the extraction of energy from currents and waves. As with hydraulic
25 changes, the effects on sediments of non-generating elements (pilings, cables, submerged
26 housing structures) could be reduced by streamlining the shapes, reducing the size and/or
27 overall surface areas, and altering the spacing between individual machines.

28
29 Near and far field effects on the habitats of aquatic organisms could be minimized by
30 proper siting of the project to avoid locations with a particular sensitivity to altered
31 sediment dynamics.

32
33 Regarding the mobilization of buried contaminants, pre-construction surveys of the
34 area subject to excavation during construction and scouring during operation could
35 minimize the risk of water quality degradation and toxicity to aquatic organisms. If
36 contaminants are found, measures to avoid the areas or to isolate and safely contain the
37 contaminants should be investigated. Periodic operational monitoring will help
38 determine whether further minimization or mitigation measures are needed.

41 3.3 Impacts of Habitat Alterations on Benthic Organisms

42
43 Installation and operation of hydrokinetic and marine energy projects can directly
44 displace bottom-dwelling plants and animals, or can alter their habitats by altering water

1 flows, the structure of waves, or substrate composition. Many of the designs will include
2 a large anchoring system made of concrete or metal, mooring cables, and electrical cables
3 that lead from the offshore facility to the shoreline. Electrical cables might simply be laid
4 on the bottom, or more likely will be anchored or buried to prevent movement. Large
5 bottom structures will alter water flow, which may result in localized scour and/or
6 deposition. Because these new structures will impact bottom habitats, consequent
7 changes to the benthic community composition and species interactions in the area
8 defined by the project may be expected.
9

10 3.3.1 Displacement of Benthic Organisms by Installation of the Project

11
12 Bottom disturbances will result from the temporary anchoring of construction
13 vessels, digging and refilling the trenches for power cables, and installation of permanent
14 anchors, pilings, or other mooring devices. Motile organisms will be displaced and
15 sessile organisms destroyed in the limited areas affected by these activities. Temporary
16 increases in suspended sediments and sedimentation down-current from the construction
17 area can be expected. The potential effects of suspended sediments and sedimentation on
18 aquatic organisms are periodically reviewed (e.g., Newcombe and Jensen 1996; Wood
19 and Armitage 1997; Wilber and Clarke 2001; Wilber et al. 2005). When construction is
20 completed, disturbed areas are likely to be recolonized by these same organisms,
21 assuming that the substrate and habitats are restored to a similar state. For example,
22 Lewis et al. (2003) found that numbers of clams and burrowing polychaetes fully
23 recovered one year after construction of an estuarine pipeline, although the numbers of
24 wading birds that forage on these invertebrates were slower to respond.
25

26 3.3.2 Alteration of Habitats for Benthic Organisms During Operation

27
28 Installation of the project will alter benthic habitats over the longer term if the
29 trenches containing electrical cables are backfilled with sediments of different size or
30 composition than the previous substrate. Permanent structures on the bottom (ranging in
31 size from anchoring systems to seabed-mounted generators or turbine rotors) will
32 supplant the existing habitats. These new structures would replace natural hard substrates
33 or, in the case of previously sandy areas, add to the amount of hard bottom habitat
34 available to benthic algae, invertebrates, and fish. This could attract a community of
35 rocky reef fish and invertebrate species (including biofouling organisms) that would not
36 normally exist at that site. Marine fouling communities that developed on monopiles for
37 offshore wind power plants were significantly different from the benthic communities on
38 adjacent hard substrates (Wilhelmsson et al. 2006; Wilhelmsson and Malm, In Press).
39

40 Changes in water velocities (Section 3.1) and sediment transport, erosion and
41 deposition (Section 3.2) caused by the presence of new structures will alter benthic
42 habitats, at least on a local scale. This impact may be more extensive and long-lasting
43 than the effects of installation of anchors and cables. Deposition of sand may impact
44 seagrass beds by increasing the mortality and decreasing the growth rate of plant shoots

1 (Craig et al. 2008). Conversely, deposition of organic matter in the wakes of marine
2 energy devices could encourage the growth of benthic invertebrate communities that are
3 adapted to that substrate. Mussel shell mounds that slough off from oil and gas platforms
4 may create surrounding artificial reefs that attract a large variety of invertebrates (crabs,
5 sea stars, sea cucumbers, anemones) and fish (Love et al. 1999). Accumulation of shells
6 and organic matter in the area would depend on the wave and current energy, activities of
7 biota, and numerous other factors (Widdows and Brinsley 2002). While the new habitats
8 created by energy conversion structures may enhance the abundance and diversity of
9 invertebrates, predation by fish attracted to artificial structures (Section 3.7) can greatly
10 reduce the numbers of benthic organisms (Davis et al. 1982; Langlois et al. 2005).

11
12 Movements of mooring or electrical transmission cables along the bottom
13 (sweeping) could be a continual source of habitat disruption during operation of the
14 project. For example, Kogan et al. (2006) found that shallow water wave action shifted a
15 6.6-cm-diameter, armored coaxial cable that was laid on the surface of the seafloor. The
16 strumming action caused incisions in rocky outcrops, but effects on seafloor organisms
17 were minor. Anemones colonized the cable itself, preferring the hard structure over the
18 nearby sediment-dominated seafloor. Some flatfishes were more abundant near the cable
19 than at control sites, probably because the cable created a more structurally
20 heterogeneous habitat. Sensitive habitats that may be particularly vulnerable to the
21 effects of cable movements include macroalgae and seagrass beds, coral habitats, and
22 other biogenic habitats like worm reefs and mussel mounds.

23
24 Renewable energy projects may also have benefits to some aquatic habitats and
25 populations. The presence of a marine energy conversion project will likely preclude
26 towed-gear fishing activities in the immediate area, serving as a *de facto* Marine
27 Protected Area (MPA). Bottom trawling can disrupt habitats, and benthic communities in
28 areas that are heavily fished tend to be less complex and productive than in areas that are
29 not fished in that way (Kaiser et al. 2000; Jennings et al. 2001). Blyth et al. (2004) found
30 that cessation of towed-gear fishing resulted in significantly greater total species richness
31 and biomass of benthic communities compared to sites that were still fished. The value
32 of these areas in which fishing is precluded (or, at least limited to certain gear types) by
33 the energy project would depend on the species of fish and their mobility. For relatively
34 sedentary animals, reserves less than 1 km across have augmented local fisheries, and
35 reserves in Florida of 16 and 24 km² have sustained more abundant and bigger fish than
36 nearby exploited areas (Gell and Roberts 2003). On the other hand, the protection of
37 long-lived, late-maturing, or migratory marine fish species may require much larger
38 MPAs (> 500 km²) than those envisioned for most energy developments (Kaiser 2005;
39 Blyth-Skyrme et al. 2006).

40 41 42 3.3.3 Mitigation Measures

43
44 The direct effects on habitat from installation of the project structures can be
45 readily estimated based on the surface area disturbed and the densities and composition

1 of the benthic community in that area. Operational effects are more difficult to predict;
2 effects of the facility on velocities and sediment dynamics are highly variable and site-
3 specific, and predicted effects would need to be verified by monitoring.

4
5 The most certain way to minimize impacts on benthic habitats is to site the project
6 in non-sensitive areas. Projects placed further offshore are less likely to impact nearshore
7 currents and communities and more likely to cause disturbance to sandy substrates.
8 Compared to rocky areas, coral reefs, or kelp beds, sandy substrates are easier to restore
9 after construction disturbance and may already support lower benthic diversity and
10 productivity. Habitat areas that are particularly sensitive to disruption (such as coral
11 reefs, seagrass beds, worm reefs, and sponge communities) could be avoided when
12 permanent structures and submarine cables are installed. Divers can be used to direct the
13 placement of cables (Michel et al. 2007). Where it is not practical to route a trench line
14 around sensitive areas, horizontal drilling techniques can be employed. Anchoring
15 systems that use concrete anchors and heavy chains can be designed to reduce the
16 detrimental effects of chain sweep (AquaEnergy, Ltd. 2006).

17
18 Michel et al. (2007) list several possible mitigation measures that were suggested
19 in the assessments they reviewed: (1) route the cable to avoid sensitive substrates such as
20 live coral, seagrass beds, and productive rocky habitats; (2) use horizontal drilling
21 methods for the cable route through sensitive habitats; (3) use dynamic positioning in
22 sensitive areas to reduce the need for anchors; (4) use “soft start-up” of pile driving so
23 that increasing noise levels encourage mobile benthic species to move away from the
24 source of disturbance (Section 3.4.2); and (5) design the mooring systems to minimize
25 the anchor size, footprint on the seafloor, and the chain/cable sweep of the seafloor.

28 3.4 Impacts of Noise

29
30 Freshwater and marine animals rely on sound for many aspects of their lives,
31 including reproduction, feeding, predator and hazard avoidance, communication, and
32 navigation (Popper 2003; Weilgart 2007). Consequently, underwater noise generated
33 during installation and operation of a hydrokinetic or ocean energy conversion device has
34 the potential to impact fish and marine mammals. Noise may interfere with sounds
35 animals make to communicate, drive animals from the area and, if severe enough, could
36 damage their hearing or cause mortalities. For example, it is known from experience
37 with other marine construction activities that the noise created by pile-driving creates
38 sound pressure levels high enough to impact the hearing of harbour porpoises and
39 harbour seals (Thomsen et al. 2006). The effects are less certain for fish (Hasting and
40 Popper 2005), although fish mortalities have been reported for some pile driving
41 activities (Longmuir and Lively 2001; Caltrans 2001). Noise generated during normal
42 operations is expected to be less powerful, but could still disrupt the behavior of marine
43 mammals and fish at great distances from the source. Changes in animal behavior or
44 physiological stresses could lead to decreased foraging efficiency, abandonment of
45 nearby habitats, declines in reproduction, and increases in mortality (NRC 2005), all of

1 which could have adverse effects at the individual and population levels. Construction
2 and operation noise may disturb seabirds using the offshore and intertidal environment.
3 Shorebirds will be disturbed by onshore construction and operations. Alternatively,
4 noises made during construction and operation activity may attract some aquatic animals.
5

6 There are many sources of sound/noise in the aquatic environment (NRC 2003;
7 Simmonds et al. 2003). Natural sources include wind, waves, earthquakes, precipitation,
8 cracking ice, and mammal and fish vocalizations. Human-generated ocean noise comes
9 from such diverse sources as recreational and commercial ship traffic, dredging,
10 construction, oil drilling and production, geophysical surveys, sonar, explosions, and
11 ocean research, many of which will be present in the area of new energy developments.
12 Noises generated by marine and hydrokinetic energy technologies should be considered
13 in the context of these background sounds. The additional noises from these energy
14 technologies could result from installation and maintenance of the units, movements of
15 internal machinery, waves striking the buoys, strum and other noise from water flow
16 moving over mooring and transmission cables, synchronous and additive non-
17 synchronous sound from multiple unit arrays, and environmental monitoring using
18 hydroacoustic techniques.
19

20 3.4.1 Noise in the Aquatic Environment and Its Effects on Animals

21
22 Appendix C provides a description of noise in the aquatic environment, a review
23 of sound levels produced by ocean energy technologies, and their possible effects on
24 aquatic organisms. There is very little information on the sound levels produced by
25 construction and operation of ocean energy conversion devices. If project installation
26 involved pile-driving, nearby noise levels are likely to exceed threshold values for the
27 protection of fish and marine mammals. Operational noise from a small number of units
28 may not exceed threshold levels, but the cumulative noise production from large numbers
29 of units have the potential to mask the communication and echolocation sounds produced
30 by aquatic organisms in the vicinity of the project.
31

32 3.4.2 Mitigation Measures

33
34 The minimization or mitigation of noise from a hydrokinetic or marine energy
35 conversion array could be achieved in a variety of ways, including (1) use of sound
36 insulation within and around the device; (2) employment of bubble screens and other
37 noise barriers during installation; (3) operation of Acoustic Mitigation Devices (AMD) to
38 exclude animals from the area; and (4) location of the project away from sensitive
39 environments. This section considers the information that has been developed about
40 these measures.
41

42 Equipment design will be an important element of any strategy to reduce the
43 source levels of noise. For example, sound insulation might be employed to minimize the
44 noises associated with movements of internal machinery. Noise and pressure changes

1 associated with cavitation of rotor blades could be reduced by optimization of blade
2 shape (Bahaj et al. 2007). Cable strumming occurs when water currents pass over
3 mooring and electrical cables and cause them to vibrate, producing sounds; the
4 characteristics of these sound could change over the life of the project owing to marine
5 fouling. The strumming of thicker cables produces a lower-frequency sound than thinner
6 cables, and looser cables strum at lower levels than tighter cables (but the reduction in
7 noise from a slack cable might be accompanied by an increase in the potential for
8 entanglement of marine mammals and turtles). Anti-strum devices (sheathing or fairing)
9 might be used to reduce the noise levels. The production of synchronous sounds or
10 additive asynchronous sounds from multiple unit arrays could be minimized by proper
11 layout of the array. Modeling of the sound produced by a single unit and small number
12 of units in an array might be used to establish the appropriate spacing of large numbers of
13 units in an energy development (Boehlert et al. 2008).

14
15 Bubble screens or curtains can reduce underwater noise levels by reflecting and
16 absorbing the sound waves. For example, Wursig et al. (2000) used a perforated hose to
17 produce a bubble curtain around pile-driving activities in shallow water. The bubble
18 curtain reduced broadband pulse levels by 3-5 dB, especially in the frequency range of
19 400 to 6400 Hz. While nearby dolphins showed no overt behavioral changes, their
20 speeds of travel increased during pile driving, suggesting that the bubble curtain did not
21 eliminate all responses to the noise. Effective bubble screens have been employed in
22 British Columbia (Longmuir and Lively 2001) and California (Caltrans 2001).

23
24 Nehls et al. (2008) reviewed the costs and possible effectiveness of structural
25 measures to mitigate underwater noise from offshore pile driving. They concluded that
26 bubble curtains would not be feasible at the great water depths and tidal currents where
27 windfarms would be located, nor was modification of the piling hammer to prolong the
28 impact time and lower the noise level. They recommended investigation into the
29 placement of noise barriers around piles in the form of either an inflatable sleeve or a
30 telescoping, foam-filled, double-walled steel tube. The expected pile-driving noise
31 attenuation that could be achieved by these devices is 20 dB and 15 dB broadband,
32 respectively. A fabric barrier system with aerating mechanism effectively reduced the
33 rms impulse sound pressure from pile driving in San Francisco Bay (Caltrans 2001).
34 With no sound attenuation, sound levels of 190 dB re 1 μ Pa (rms) could be detected over
35 200 m from the source. Operation of the fabric barrier system reduced the distance to the
36 190 dB threshold to less than 100 m.

37
38 Acoustic Mitigation Devices (AMD) produce aversive sounds in order to drive
39 animals away from aquaculture facilities and commercial trawling nets. Although
40 constituting another source of noise in the aquatic environment, AMDs might be useful
41 for safely excluding marine mammals, fish, and marine turtles from an ocean energy
42 installation. Gordon et al. (2007) provided a review of the characteristics and
43 effectiveness of AMDs. An effective AMD would broadcast a signal that was
44 sufficiently frightening or aversive to cause animals to move away from the installation
45 without injury. Variations of this concept, such as acoustic deterrent devices (ADD,

1 pingers), seal scarers, and acoustic harassment devices (AHD) are discussed by Nowacek
2 et al. (2007).

3
4 Simmonds et al. (2003) noted that there are few data on the effectiveness of any
5 noise mitigation measures, in part owing to complications associated with the non-
6 uniform way in which sound travels through water and the different sensitivities of
7 different aquatic species, individual members within the group, and the activities being
8 undertaken. Weilgart (2007) concluded that many noise mitigation tools are of
9 questionable effectiveness, and suggested that reducing noise levels and distancing the
10 noise from biologically important areas would offer the most protection.

11
12 NMFS provides an example of a combination of minimization and mitigation
13 measures that can be applied to an underwater noise source. Under the Marine Mammal
14 Protection Act, NMFS is considering the monitoring and mitigation needed to limit the
15 effects of open-water pile driving associated with construction of the San Francisco-
16 Oakland Bay Bridge (73 FR 129:38180-38183; July 3, 2008). These measures include
17 establishment and monitoring of safety/buffer zones where the underwater SPLs are
18 anticipated to equal or exceed 190 dB re 1 μ Pa rms (impulse) for pinnipeds and 180 dB re
19 1 μ Pa rms (impulse) for gray whales and harbor porpoises. The pile driving hammer
20 would be “soft started” (ramped up) prior to operating at full capacity. That is, the initial
21 hammer strikes would be limited to 40-60 percent energy levels with no less than a one-
22 minute interval between strikes in order to allow marine mammals to move from the area.
23 All construction equipment will comply with applicable equipment noise standards of the
24 U.S. Environmental Protection Agency (EPA). In addition to these measures, proposed
25 monitoring would include (1) visual observations beginning at least 30 minutes prior to
26 startup of pile driving and continuing at least 30 minutes after ending and (2)
27 measurements of underwater noise levels near the piles and at reference locations 100 m
28 and 500 m from the construction activities.

29
30 Because of the limitations of visual monitoring of an area for marine mammals,
31 especially at night or under conditions of poor visibility, Acoustic Detection Systems
32 (ADS) are being developed to improve the detection of animals that might be affected by
33 underwater noise (Parvin et al. 2007). The three approaches they described are (1)
34 Passive Acoustic Monitoring (PAM), in which a sonar-type system monitors for the
35 animals’ vocalizations or echolocation signals; (2) Active Acoustic Monitoring (AAM),
36 in which a sonar “ping” is broadcast into the water in search of targets; and (3) Acoustic
37 Daylight Monitoring (ADM; also called Acoustic Daylight Imaging), which detects
38 existing background noise scattered from a target. They concluded that a well-designed
39 PAM system could detect large whales and odontocetes at sufficient range that a noise-
40 producing activity could be suspended until the animal has moved away, but might not
41 suffice for the smaller detection ranges of smaller animals. For example, a PAM system
42 called the T-POD has been used to detect porpoises in the vicinity of wind farms
43 (Tougaard et al. 2005; Carstensen et al. 2006). The T-POD is a small, self-contained data
44 logger that records echolocation clicks from cetaceans; it is programmable and thus can
45 be set to detect the particular frequencies that indicate the presence of particular species.
46 The T-POD can provide data on cetacean echolocations with high temporal resolution but

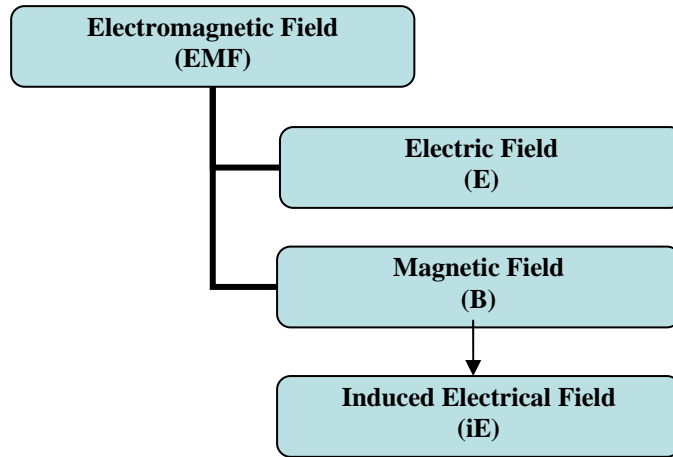
1 low spatial resolution, and was able to demonstrate a decline in harbor porpoise activity
2 during construction of a wind farm. Similarly, Koschinski et al. (2003) used a T-POD to
3 detect a change in echolocation activity among harbour seals and harbour porpoises in
4 response to simulated wind turbine operational noise. The sounds produced by ADS
5 monitoring would constitute yet another source of noise in the aquatic environment which
6 would need to be quantified and minimized.
7
8

9 3.5 Impacts of Electromagnetic Fields

10
11 Underwater cables will be used to transmit electricity between turbines in an array
12 (inter-turbine cables), between the array and a submerged step-up transformer (if part of
13 the design), and from the transformer or array to the shore (CMACS 2003). Ohman et al.
14 (2007) categorize submarine electric cables into the following types: telecommunications
15 cables, high voltage, direct current (HVDC) cables, alternating current three-phase power
16 cables, and low-voltage cables. All these types will emit electromagnetic fields (EMF) in
17 the surrounding water. The electric current traveling through the cables will induce
18 magnetic fields in the immediate vicinity, which can in turn induce a secondary electrical
19 field when animals move through them (CMACS 2003).
20

21 3.5.1 Effects of Electromagnetic Fields on Aquatic Organisms

22
23 Appendix D provides a description of EMF in the aquatic environment, a review
24 of EMF that may be produced by ocean energy technologies, and their possible effects on
25 aquatic organisms. The EMF associated with new marine and hydrokinetic energy
26 designs have not been quantified. The electromagnetic field (EMF) created by electric
27 current passing through a cable is composed of both an electric field (E field) and an
28 induced magnetic field (B field). Although E can be contained within undamaged
29 insulation surrounding the cable, B fields are unavoidable and will in turn induce a
30 secondary electric field (iE field). Thus, it is important to distinguish between the two
31 constituents of the EMF (E and B) and the induced field, iE (Figure 3.5-1; Gill et al.
32 2005).
33
34
35



1
2
3 Figure 3.5-1. Simplified view of the fields associated with submarine power cables.
4 Modified from Gill et al. (2005).

5
6 The EMF associated with new marine and hydrokinetic energy designs have not
7 been quantified. The current state of knowledge about the EMF emitted by submarine
8 power cables is too variable and inconclusive to make an informed assessment of the
9 effects on aquatic organisms (CMACS 2003). Following a thorough review of the
10 literature related to EMF and extensive contacts with the electrical cable and offshore
11 wind industries, Gill et al. (2005) concluded that there are significant gaps in knowledge
12 regarding sources and effects of EMF in the marine environment. They recommended
13 developing information about likely electrical and magnetic field strengths associated
14 with the generating units, offshore sub-stations and transformers, and submarine cables
15 that are a part of offshore renewable energy projects. They cautioned that networks of
16 cables in close proximity to each other, as would be found in large current and tidal
17 energy projects where cables come together at substations, are likely to have overlapping,
18 and potentially additive, EMF fields. These combined EMF fields would be more
19 difficult to evaluate than those emitted from a single electrical cable. The small, time-
20 varying B field emitted by a submarine three-phase, AC cable may be perceived
21 differently by sensitive marine organisms than the persistent, static, geomagnetic field
22 generated by the Earth (CMACS 2003).

23
24 **3.5.2 Mitigation Measures**

25
26 As with many other issues, selecting the proper location for the power project is
27 likely to be the most reliable and cost effective way to minimize the potential effects of
28 EMF. Avoidance of critical migratory paths and ensuring that the electrical transmission
29 cables do not create a physical or electromagnetic barrier to animal movements may
30 obviate the need for additional shielding or cable repairs.

31
32 Damage to the electrical transmission cable could cause an electrical fault or
33 short, during which electrical current would leak to the water. The cable that would be
34 used for the proposed Wave Energy Technology (WET) project in Hawaii would be

1 armored with steel wires and an external jacket to prevent damage (DON 2003). In the
2 event of current leakage from a damaged cable, the WET system includes a computer-
3 controlled electrical fault detection and interruption system which would shunt the
4 electric current to load resistors within 6-20 milliseconds. Studies cited in DON (2003)
5 suggest that electrical fault currents of less than 5 mV and durations less than 20 ms had
6 only minor, transient effects on marine life and nearby divers.

7
8 Industry standard AC cables effectively shield against direct electric field
9 emissions, but cannot completely shield the magnetic field (Gill 2005). CMACS (2003)
10 modeled the strength of the EMF under different conditions of permeability and
11 conductivity of the cable sheath and armor. As either the permeability or the
12 conductivity of the armor increased, the strength of the resultant EMF decreased. The
13 model suggested that using materials with very high permeability and conductivity values
14 to armor submarine power cables could reduce the EMF generated to below the lowest
15 known level that elasmobranchs can detect. Cable burial was predicted to be ineffective
16 in dampening the magnetic (B) field. However, because the B field is strongest at the
17 surface of the cable and declines rapidly with distance, burying the cable in sediment may
18 minimize effects on sensitive fish simply by preventing access to the immediate vicinity
19 of the cable (CMACS 2003).

21 3.6 Toxic Effects of Chemicals

22
23 Chemicals that are accidentally or routinely released from hydrokinetic and ocean
24 energy installations could have toxic effects on aquatic organisms. Accidental releases
25 include leaks of hydraulic fluids from a damaged unit or fuel from a vessel due to a
26 collision with the unit; such events would likely have a low probability of occurrence but
27 potentially a high impact (Boehlert et al. 2008). On the other hand, chronic releases of
28 dissolved metals or organic compounds used to control biofouling in marine applications
29 would result in low, predictable concentrations of contaminants over time. Even at low
30 concentrations that are not directly lethal, some contaminants can cause sublethal effects
31 on sensory systems, growth, and behavior of animals, or may be bioaccumulated.

33 3.6.1 Toxicity of Paints, Anti-Fouling Coatings, and Other Chemicals

34
35 Biofouling (growth on external surfaces by algae, barnacles, mussels, and other
36 marine organisms) will occur rapidly in ocean applications (Langhamer, undated;
37 Wilhelmsson and Malm, In Press). Sundberg et al. (2005) observed that a 3-m-diameter
38 buoy may accumulate as much as 300 kg of biomass on the buoy and mooring cables.
39 The encrustation of biofouling organisms could cause undesirable mechanical wear or
40 changes in the weight, shape, and performance of energy conversion devices that would
41 require increased maintenance or the application of antifouling measures (Figure 3.6.1-1).
42 Encrustation by barnacles and other organisms could increase corrosion and fatigue and
43 decrease electrical generating efficiency.



1
2
3 Figure 3.6.1-1. Growth of biofouling organisms on a floating spherical buoy after 521
4 days at sea. Source: National Oceanic and Atmospheric Administration
5 http://www.aoml.noaa.gov/phod/dac/gdp_drifter.html
6
7

8 Michel et al. (2007) noted that there are three options for removing marine
9 biofouling: use of antifouling coatings, *in situ* cleaning using a high pressure jet spray,
10 and removal of the device from the water for cleaning on a floating platform or onshore.
11 Antifouling coatings hinder the development of marine encrustations by slowly releasing
12 a biocide such as tributyltin (TBT) or copper. As the coatings wear away, they must be
13 reapplied periodically. There are concerns about the immediate toxicity of these biocides
14 to other, non-target organisms, and numerous countries and organizations have called for
15 the ban of TBT as an anti-fouling coating (Antizar-Ladislao 2008). As a result,
16 alternative coatings are being explored. The release of toxic contaminants from a single
17 unit may be relatively minor, but the cumulative impacts of persistent toxic compounds
18 from dozens or hundreds of units may be considerable (Boehlert et al. 2008).
19 Accumulations of biofouling organisms (e.g., barnacles) removed from the project
20 structures may alter nearby bottom substrates and habitats (Section 3.3.2)
21

22 Accidental releases of hydraulic fluids and lubricating oils from inside the energy
23 conversion device or from vessels used to install and service the equipment could have
24 toxic effects. At the least, leaks of inert (non-toxic) oils could cause physical/mechanical
25 effects by coating organisms and blanketing the sediments.
26

27 3.6.2 Mitigation Measures

28

29 Owing to concerns about the toxicity of TBT and copper-containing paints, there
30 has been considerable research into alternative, environmentally friendly antifouling

1 coatings (Yebra et al. 2004; Genzer and Efimenko 2006; Webster et al. 2007). Yebra et
2 al. (2004) reviewed the history of anti-fouling paint development and described
3 promising new alternatives to TBT biocides. They concluded that although biocide-
4 based antifouling coatings will continue to dominate the market in coming years, there is
5 potential in the development of paints with natural biocides or non-biocidal foul-release
6 coatings (FRC) that prevent the adhesion of fouling organisms by providing a low-
7 friction, ultra-smooth surface. FRCs do not prevent fouling, but their surface properties
8 reduce the adhesion of organisms so that they can be easily removed with a brush or
9 water jet. Many of the FRCs are based on silicone oils that are not bound into the resin
10 matrix and thus may leach into the marine environment. Nendza (2007) concluded that
11 the silicone oils in FRCs are very persistent in the environment, but they do not
12 bioaccumulate in marine organisms, and the soluble fractions of the oils have low
13 toxicity. Like any inert oil, at high concentrations silicone oil films or droplets could coat
14 small organisms and cause suffocation. Minimizing the non-toxic coatings may require
15 more mechanical removal of biofouling, which requires more vessel servicing trips that
16 disturb the area and increase the potential for collisions or spills.

17
18 Information about the processes that determine biological activity of anti-fouling
19 paints is being incorporated into mathematical models (Yebra 2006) or screening assays
20 (Watermann et al. 2005; Webster et al. 2007) that predict performance and help speed the
21 testing of alternative paint formulations. As with other issues, it will be important to
22 identify the chemical compounds that may be released into the environment, estimate
23 their concentrations under routine and accident situations, describe the fate of the
24 contaminants in the environment (e.g., taken up by plants and animals, adsorbed to
25 sediments, transported downstream), and, based on this information, judge their toxicity
26 and the need for minimization and mitigation measures.

29 3.7 Interference with Animal Movements and Migrations

30
31 Energy developments will add new structures to the ocean environment that may
32 affect the movements and migrations of aquatic organisms. In addition to structures on
33 the seabed (e.g., anchors, turbines), many of the ocean energy devices would use mooring
34 lines to attach a floating generator to the ocean bottom, and electrical transmission lines
35 to connect multiple devices to each other and to the shoreline. For example, MMS
36 (2007) estimated that wave energy facilities may have as many as 200-300 mooring lines
37 securing the wave energy devices to the ocean floor (based on 2-3 mooring per device
38 and a 100-device facility). Mooring and transmission lines that extend from a floating
39 structure to the ocean floor will create new fish attraction devices in the pelagic zone,
40 pose a threat of collision or entanglement to some organisms, and potentially alter both
41 local movements and long distance migrations of marine animals. The recruitment of
42 species with planktonic (drifting) life stages may be affected to an unknown extent by the
43 reduced water velocities caused by multi-unit projects.

1 3.7.1 Alteration of Local Movement Patterns

2
3 As described in Section 3.3, anchors and other permanent structures on the bottom
4 will create new habitats, and thus may act as artificial reefs (Wilhelmsson et al. 2006).
5 Artificial reefs are often constructed in order to increase fish production, but some studies
6 suggest that they may be less effective than natural reefs (Carr and Hixon 1997), and may
7 even have deleterious effects on reef fish populations by stimulating overfishing and
8 overexploitation (Grossman et al. 1997). Similarly, new structures in the pelagic zone,
9 such as pilings or mooring cables for floating devices, will create habitat that may act as
10 fish aggregation/attraction devices (FADs). FADs are extremely effective in
11 concentrating fishes and making them susceptible to harvest (Dempster and Tacquet
12 2004; Michel et al. 2007; Myers et al. 1986). Sea turtles are also known to be attracted to
13 floating objects (Arenas and Hall 1992). Fish are attracted to the devices as physical
14 structure/shelter, and may feed on organisms attached to the structures (Boehlert et al.
15 2008). Wilhelmsson et al. (2006) found that fish abundance in the vicinity of monopiles
16 that supported wind turbines was greater than in surrounding areas, although species
17 richness and diversity were similar. Most of the fish they observed near the structure
18 were small (juvenile gobies), which may in turn attract commercially important fish
19 looking for prey. Dempster (2005) observed considerable temporal variability in the
20 abundance and diversity of fish associated with FADs moored between 3 and 10 km
21 offshore. The variability was often related to the seasonal appearance of large schools of
22 juvenile fish. Fish assemblages differed between times when predators were present or
23 absent; few small fishes were observed near the FADs when predators were present,
24 regardless of the season. Using FADs as an experimental tool, Nelson (2003) found that
25 fish formed larger, more species-rich assemblages around large FADs compared to small
26 ones, and they formed larger assemblages around FADs with fouling biota. FADs
27 enriched with fish accumulated additional recruits more quickly than those in which fish
28 were removed.

29
30 It is likely that floating wave energy devices will act as FADs, but the effect on
31 fish populations may be difficult to determine. FADs are attractive to fish because they
32 provide food and shelter (Castro et al. 2002), and for that reason they also attract
33 predators (Dempster 2005), which in turn attract commercial and sport fisheries. Without
34 well-designed monitoring, it is arguable whether an energy park will enhance populations
35 of aquatic organisms (by providing more habitat to support more fish), will have no
36 overall effect (because it simply draws fish from other, nearby areas), or will decrease
37 fish populations (by facilitating harvest by predators and fishermen). Kingsford (1999)
38 pointed out that determination of the effects of FADs at a particular location is
39 complicated by the influence of non-independent factors, including the proximity of other
40 FADs (e.g., other wave energy units), the interconnection of multiple FADs to provide
41 routes for the movement of associated fishes, and temporal dependence (the number of
42 fish present at one sampling date influences the number at the next sampling date owing
43 to fish becoming residents). He described statistical approaches that could be applied to
44 experiments on the effects of FADs on fish populations and solutions to the independent
45 factor problems.

1 Because the anchoring systems and mooring lines will exclude some types of
2 fishing (e.g., commercial trawling), energy parks could act as marine protected areas
3 (Section 3.3). PMFC (2008) expressed concerns related to the prohibition of commercial
4 fishing at wave energy test areas. They suggested that there may be either a reduction in
5 total fishing effort and lost productivity or a displacement of fishing effort to areas
6 outside the areas closed to fishing. Displaced fishermen would likely concentrate their
7 efforts in areas immediately outside the wave park boundaries, resulting in increased
8 pressures on fish and habitats in those nearby areas.

9
10 Floating offshore wave energy facilities could create artificial haul-out sites for
11 marine mammals (pinnipeds). Devices with a low profile above the waterline (desirable
12 for aesthetic reasons) may enable seals and sea lions to use them as a haul-out site,
13 particularly if the installations attract the marine mammals by acting as fish concentrating
14 devices. Similarly, the devices may attract seabirds by creating artificial roosting sites or
15 encouraging predation on fish near the FAD (Michel et al. 2007). NOAA considers the
16 creation of such artificial haul outs as undesirable and has recommended the use of
17 deterrents to discourage use by marine mammals.

18 19 3.7.2 Interference with Migratory Animals

20
21 The numerous floating and submerged structures, mooring lines, and transmission
22 cables associated with large ocean energy facilities could interfere with the long-distance
23 migrations of marine animals (e.g., juvenile and adult salmonids, Dungeness crabs, green
24 sturgeon, elasmobranchs, and marine mammals) if they are sited along migration
25 corridors. On the Pacific Coast of the United States, effects on gray whales (*Eschrichtius*
26 *robustus*) may be a particular concern because they migrate within 2.8 km of the
27 shoreline (Hagerman and Bedard 2004). Boehlert et al. (2008) noted that buoys attached
28 to commercial crab pots already comprise a major existing risk to gray whales off the
29 coast of Oregon. Lines associated with lobster pots and other fishing gears are a source
30 of injury and mortality to endangered North Atlantic right whales (*Eubalaena glacialis*)
31 on the East Coast of the U.S. (Caswell et al. 1999; Kraus et al. 2005).

32
33 Entanglement of large, planktonic jellyfish with long tentacles, as well as actively
34 swimming sea turtles and marine mammals, is a potential issue for energy technologies
35 with mooring lines in the pelagic zone. Thin mooring cables are expected to be more
36 dangerous than thick ones because they can cause lacerations and entanglements, and
37 slack cables are more likely to cause entanglements than taut ones (Boehlert et al. 2008).
38 Michel et al. (2007) expect that smaller dolphins and pinnipeds could easily move around
39 mooring cables, but larger whales may have difficulty passing through an energy facility
40 with numerous, closely spaced lines. Marine species with proportionately large pectoral
41 fins or flippers may be relatively more vulnerable to mooring lines, based on information
42 from humpback whale entanglements with pot and gill net lines (Johnson et al. 2005).
43 Boehlert et al. (2008) suggested that whales probably do not sense the presence of
44 mooring cables, and as a result could strike them or become entangled. In addition, they
45 believed that if the cable density is sufficiently great and spacing is close, cables could

1 have a “wall effect” that could force whales around them, potentially changing their
2 migration routes. Whales and dolphins traveling or feeding together may be at a greater
3 risk than solitary individuals because “group responses” may lead some individuals to
4 follow others into danger (Faber Maunsell and Metoc 2007).
5

6 3.7.3 Mitigation Measures

7
8 The most reliable impact mitigation measure is likely to be proper siting of the
9 energy project in order to avoid sensitive fish populations, habitat areas, important fishing
10 grounds, and migration corridors for fish, marine mammals, and sea turtles. Installation
11 could be limited to periods when migratory marine mammals and fish are not present, or,
12 for resident fish, during less sensitive seasons.
13

14 The project design should allow easy escape/exit of animals, including adequate
15 distances between individual units. Cables laid on the surface of the seabed should have
16 enough slack to conform to the contour but enough tension to preclude suspensions or
17 loops. In the water column, taut lines are less likely to cause entanglements than slack
18 lines. Thick mooring lines are less likely to cause abrasions than thin lines, and may be
19 easier for migrating animals to detect. Acoustic pingers, seal-scaring devices, or visual
20 cues (e.g., highly visible paints) have been suggested to reduce entanglements or
21 collisions with turbines or mooring lines.
22

23 As an example of proposed impact minimization measures, the above-water
24 structures of the Makah Bay project would be cone shaped to prevent pinnipeds from
25 using them as haul-out sites (FERC 2006; Preliminary draft EA). Minimizing horizontal
26 surfaces above the waterline would prevent sea turtles and birds from using the devices as
27 resting habitat. Anchor lines would have sufficient tension to minimize entanglement
28 sometimes seen with smaller and lighter tensions.
29
30

31 3.8 Collision and Strike

32
33 Submerged structures present a collision risk to aquatic organisms and diving birds,
34 and the above water components of floating structures may be a risk to flying animals.
35 Wilson et al. (2007) defined collision as physical contact between a device or its pressure
36 field and an organism that may result in an injury to that organism. They noted that
37 collisions can occur between animals and fixed submerged structures, mooring
38 equipment, surface structures, horizontal and vertical axis turbines, and structures that by
39 their individual design or in combination may form traps.
40

41 In an attempt to define the risk of collisions from marine renewable energy devices,
42 Wilson et al. (2007) reviewed information from other industrial and natural activities
43 with similar physical effects: power plant cooling intakes, shipping, fishing gear, fish
44 aggregation devices, wind turbines, and killer whale predatory movements. They

1 concluded that although animals may strike any of the physical structures associated with
2 marine renewable energy devices (vertical or horizontal support piles, ducts, nacelles,
3 anchor blocks, chains, cables, and floating structures), turbine rotors are the most
4 intuitive sources of significant collision risks with marine vertebrates.
5

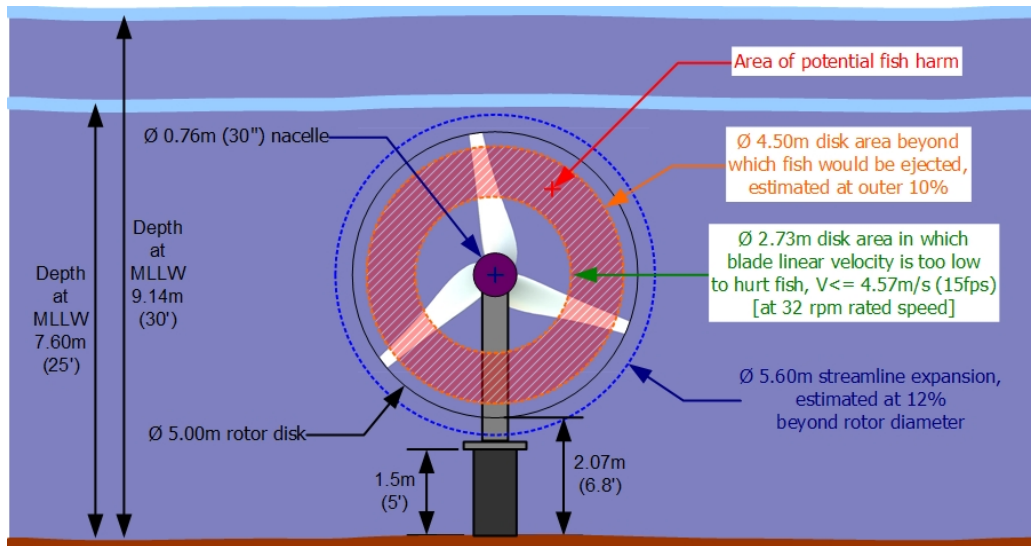
6 3.8.1 Effects of Rotor Blade Strike on Aquatic Animals

7
8 Many of the hydrokinetic and ocean current technologies extract kinetic energy
9 by means of moving/rotating blades. A wide variety of swimming and drifting organisms
10 (fish, sea turtles, diving birds, cetaceans, seals, and otters) may be struck by the blades
11 and suffer injury or mortality (Wilson et al. 2007). The seriousness of strike is related to
12 the animal's swimming ability (i.e., ability to avoid the blade), water velocity, blade
13 design and size, blade movement (rotation) rate, and the part of the rotor that the animal
14 strikes. Horizontal axis turbines might have rotor blades up to 20 m in diameter and spin
15 at a rate of 10 to 20 rpm. The rotor blade tip has a much higher velocity than the hub
16 because of the greater distance that is covered in each revolution. For example, on a rotor
17 spinning at 20 rpm the leading edge of the blade 1 m from the center point will be
18 traveling at a velocity of about 2 m/s, a speed that is likely to be avoidable or undamaging
19 to most organisms. However, a 20-m diameter rotor spinning at 20 rpm would have a tip
20 velocity of nearly 21 m/s. Fraenkel (2006; 2007b) described a horizontal axis turbine
21 (Seagen; Figure 3.8.1-1) with a maximum rotation speed of 12 to 15 rpm, which results in
22 a maximum blade tip velocity of 12 m/s. Wilson et al. (2007) suggested that rotor blades
23 tips will likely move at or below 12 m/s because greater speeds will incur efficiency
24 losses through cavitation.
25
26
27



1
2
3 Figure 3.8.1-1. Artist's impression of the Seagen marine current turbine in Strangford
4 Lough, UK. From Davison and Mallows (2005).
5
6

7 The force of the strike is expected to be proportional to the strike velocity, and
8 consequently, the potential for injury from a strike would be greatest at the outer
9 periphery of the rotor. Unfortunately, little is known about the magnitude of impact
10 forces that cause injuries to most marine and freshwater organisms (Cada et al. 2005;
11 2006). Although the blade tip will be moving at the highest velocity and exhibit the
12 greatest strike force, animals may be able to avoid the tip of an unducted rotor. As shown
13 in Figure 3.8.1-2, relatively safe areas of passage through the rotor would be nearest the
14 hub (because of low velocities) and potentially nearest the tip (because of the opportunity
15 for the animal to move outward to avoid strike). The central zone of relatively high blade
16 velocities and relatively less opportunity to avoid strike may be the most dangerous area
17 (Coutant and Cada 2005). For rotors contained in housings, there would be no
18 opportunity for an organism entrained in the intake flow to escape strike by moving
19 outward from the periphery; safe passage would depend on passing through the rotor
20 between the blades. This suggestion of relatively high and low risk passage zones has not
21 been tested, and remains speculative until the phenomenon is investigated in field
22 applications.
23
24



1
2
3 Figure 3.8.1-2. Predicted zone of potentially damaging strike associated with an
4 unducted horizontal axis turbine. From Coutant and Cada (2005).

5
6 There have been several studies to estimate the potential of fish strike by rotating
7 blades (e.g., Cada 1990; Carlson and Ploskey 2004; Deng et al. 2005), but they all
8 involve conventional hydroelectric turbines that are enclosed in turbine housings and
9 afford little opportunity for flow-entrained organisms to avoid strike. It is likely that both
10 the probability and consequences of organisms striking the rotor blade are greater for a
11 conventional turbine than for an unducted marine current turbine, owing to the greater
12 opportunities for organisms to avoid approaching the marine turbine rotor or moving
13 outward from the periphery. However, passage through a conventional turbine poses
14 only a single exposure to the rotor, whereas passage through a project consisting of large
15 numbers of marine current turbines represents a larger risk of strike that has not been
16 investigated.

17
18 Wilson et al. (2007) described a simple model to estimate the probability of
19 aquatic animals entering the path of a marine turbine. The model is based on the density
20 of the animals and the water volume swept by the rotor. The volume swept by the turbine
21 can be estimated from the radius of the rotor and the velocity of the animals and the
22 turbine blades. They emphasized that their model predicts the probability of an animal
23 entering the region swept by a rotor, not collisions. An encounter may lead to a collision,
24 but only if the animal does not take evasive action or has not already sensed the presence
25 of the turbine and avoided encounter. Applying this simplified model (no avoidance or
26 evasive action) to a hypothetical field of 100 turbines, each with a 2-bladed rotor 16 m in
27 diameter, they predicted that 2% of the herring population and 3.6 to 10.7% of the
28 porpoise population near the Scottish coast would encounter a rotating blade. At this
29 time, there is no information about the degree to which marine animals may sense the
30 presence of turbines, take appropriate evasive maneuvers, or suffer injury in response to a
31 collision. Wilson et al. (2007) suggested that marine vertebrates may see or hear the
32 device at some distance and avoid the area, or, at a closer range, evade the structure by
33 dodging or swerving.

1
2 Fraenkel (2007a) pointed out that compared to ship propellers, the rotors of
3 hydrokinetic and current energy devices are much less energetic. He estimated that a
4 tidal turbine rotor at a good site will absorb about 4 kW/m² of swept area from the
5 current, whereas typical ship propellers release over 100 kW/m² of swept area into the
6 water column. In addition to the greater power density, a ship propeller and ship hull
7 generate suction that can pull objects toward it, increasing the area of influence for strike
8 (Fraenkel 2006). A rotor enclosed within a duct would have a similar effect, whereas an
9 unducted tidal rotor that is driven by water currents does not draw objects toward it.
10

11 3.8.2 Effects of Water Pressure Changes and Cavitation

12
13 In addition to direct strike, there is a potential for adverse effects due to sudden
14 water pressure changes associated with movement of the blade. For example, if the local
15 water pressures immediately behind the turbine blades drop below the vapor pressure of
16 water, cavitation will occur. Cavitation is the process of formation of water vapor
17 bubbles in liquids in areas of extreme low pressure. In association with a turbine,
18 cavitation can occur in areas of low pressure (e.g., downstream surface of blades),
19 increasing local velocities, abrupt changes in the direction of flow, and roughness or
20 surface irregularities (USACE 1995). Once formed, cavitation bubbles stream from the
21 area of formation and travel with the flow to regions of higher pressure, where they
22 collapse. The violent collapse of cavitation bubbles creates shock waves, the intensity of
23 which depends on bubble size, water pressure in the region of collapse, and dissolved gas
24 content. Forces generated by cavitation bubble collapse may reach tens of thousands of
25 kilopascals at the instant and point of collapse within enclosed, conventional
26 hydroelectric turbines (Hamilton 1983; Rodrigue 1986). Cavitation is an undesirable
27 condition that will reduce the efficiency of the turbine and damage blades and nearby
28 organisms (Cada et al. 1997). The pressure drops associated with blades have not been
29 measured in field applications, but experimental evidence suggests that tidal turbines may
30 experience strong and unstable sheet and cloud cavitation, as well as tip vortices at a
31 shallow depth of submergence (Nicholls-Lee and Turnock 2007). If this occurs, aquatic
32 organisms passing near the cavitation zones in the immediate blade area may be injured.
33 The likelihood of cavitation-related injuries would depend on the extent of cavitation and
34 the ability of aquatic organisms to avoid the area; the collapse of cavitation vapor bubbles
35 creates noise which may act as a deterrent.
36

37 3.8.3 Mitigation Measures

38
39 It can be expected that if an organism does not approach the immediate area of the
40 blade leading edge (for strike) or downstream side of the blade tip (for cavitation) the risk
41 of injury will be small. For an organism in the zone of influence of the rotor, the risk of
42 rotor strike from a single unit can be readily estimated from information on such factors
43 as water velocity, blade rotation velocity, and blade length. For example, assuming that
44 the animal is able to sense the presence of the blade and attempt evasive maneuvers, an

1 estimate of its ability to avoid strike might be made by comparing the blade speed with
2 the animal's burst (darting) speed. A fish's maximum burst speed depends on several
3 factors (e.g., species, size, physiological state, water temperature), but it may be roughly
4 estimated as 10 body lengths per second (Videler and Wardle 1991).

5
6 Estimating the probability of strike for a large project with hundreds of closely
7 spaced rotors has not been accomplished. Until information about the ability of aquatic
8 animals to avoid strike is developed, impacts can be reduced by siting projects in areas
9 where blade contact is least likely. Data on animals' migratory paths, preferred depths,
10 diurnal activity, and attraction or repulsion by the project structures might be used to
11 locate projects away from sensitive areas. Unfortunately, the best locations for tidal
12 energy devices are often at "pinch points" where the underwater topography causes
13 currents to accelerate, such as straits between islands and the mainland and shallows
14 around headlands (Fraenkel 2006). If these areas also concentrate aquatic organisms
15 moving with the current, the risk of strike may be increased.

16
17 Structural modifications could be made to reduce the risk of injury from blade
18 strike (Cada et al. 1997). For example, blunt leading edges are less likely to injure an
19 organism than sharp leading edges (Turnpenny et al. 1992). As with conventional
20 hydroelectric turbines, hydrokinetic and ocean current turbine designers have a number of
21 options that can affect the incidence of strike, including altering the number of blades,
22 length of blades, area per blade channel, thickness and bluntness of blade leading edges,
23 and blade tilt. Some turbine designs (especially those with ducted rotors) might support
24 fish screens to prevent contact with the blades, although the possibility of screen
25 impingement of weakly swimming organisms would need to be considered. Also, the
26 growth of biofouling organisms (e.g., marine organisms or zebra mussels) on screens
27 would alter their effectiveness.

28
29 Noise and damaging pressure changes associated with cavitation of rotor blades
30 will be reduced by optimization of blade shape (Bahaj et al. 2007). Batten et al. (2006)
31 applied a computational model to the design of a marine current turbine which suggested
32 that changes in the blade pitch angle or camber can alter stall performance and the
33 possibility of cavitation. They noted that acceptable levels of cavitation for marine
34 turbines are not yet known, but will depend upon the erosion performance of blade
35 materials. Although excessive noise is undesirable, low levels of noise may help animals
36 detect and avoid dangerous areas.

37
38 Wilson et al. (2007) listed a number of techniques that could be considered to
39 minimize collisions, including measures to (1) reduce encounter risk (appropriate
40 locations relative to bathymetry, critical habitat areas, and spacing among individual
41 devices; shut down operation during critical seasons), (2) raise the conspicuousness of the
42 devices (blade colors, lighting, and acoustic deterrents); (3) shield the blades with
43 protective netting or grids; (4) reduce vertical traps in the device design and/or among
44 multiple devices for air-breathing animals; and (5) soften collisions (shock absorbing
45 structures and reduction of sharp edges).

46

3.9 Impacts of Ocean Thermal Energy Conversion (OTEC)

The OTEC technologies operate a low temperature heat engine based on the temperature differences between warm, surface water and cold, deep water (Holdren et al. 1980). OTEC projects will consist of pumps and ducts for transferring large volumes of water (several times more flow than is needed for a once-through cooling system of a comparably-sized steam electric power plant), large heat exchangers, and a working fluid (ammonia, propane, Freon, or water) that can be vaporized and recondensed. Electrical energy could be transported from offshore systems via subsea cables; alternatively, the energy could be converted to chemical energy *in situ* (e.g., hydrogen, ammonia, methanol) and transported to shore in tankers (Pelc and Fujita 2002).

3.9.1 Effects on Ocean Ecosystems

Impacts of construction of an OTEC facility will depend on whether the project is located onshore or offshore. An onshore facility would require the installation of large, long water conduits on the seabed to access deep water. Alternatively, OTEC projects located on offshore platforms would depend on subsea cables to transfer electricity to shore. The installation and maintenance of pipelines and electrical cables would disturb bottom habitats and generate EMF (see Sections 3.3 and 3.5).

The potential environmental effects of OTEC operation have been considered by a number of authors (Holdren et al. 1980; Myers et al. 1986; Harrison 1987; Abbasi and Abbasi 2000; Pelc and Fujita 2002). Meyers et al. (1986) provided the most comprehensive assessment of the possible effects on the marine environment of the types of OTEC facilities that were contemplated in the early 1980s. Most of the likely effects are expected to be physical and chemical changes in the ocean surface waters arising from the transfer of large volumes of cool, deep water. Abbasi and Abbasi (2000) suggested that OTEC plants will displace about 4 m³/s of water per MW of electricity output from both the surface layer and the deep ocean layer, and subsequently discharge the water at some intermediate depth. The warm water intake would be located at about 10-20 m depth, and the cold water intake might extend to a depth of 750-1000 m (Myers et al. 1986). The large transfer of water may disturb the thermal structure of the ocean near the plant, change salinity gradients, and change the amounts of dissolved gases, dissolved minerals, and turbidity. The transfer will result in an artificial upwelling of nutrient-rich deep water, which may increase marine productivity in the area. Moreover, carbon dioxide will also be released when the deep water is warmed and subjected to lower pressures at the surface. The possible amounts of carbon dioxide released have not been rigorously quantified; some estimate that the quantities will be minute (Pelc and Fujita 2002) and others suggest that the contribution will be relatively large (Holdren et al. 1980). The relatively high carbon dioxide and low dissolved oxygen content of the deep water may alter pH and dissolved oxygen concentrations in a surface mixing zone.

The large heat exchangers will need to be treated with biocides (e.g., chlorine or hypochlorite) in order to prevent the growth of bacterial slimes and other biofouling

1 organisms; volumes of biocides would be proportional to the large volume of heating and
2 cooling water. Degradation of the heat exchanger materials will result in chronic releases
3 of metals (e.g., copper, nickel, aluminum). Accidental release of the working fluid that is
4 evaporated and condensed to drive the turbine could have toxic effects. The potential for
5 acute and chronic toxicity and bioaccumulation of metals from deep ocean water will
6 need to be considered (Fast et al. 1990).

7
8 Large marine organisms may be impinged on the screens that protect the OTEC
9 intakes, and smaller organisms (zooplankton and fish eggs and larvae) will pass through
10 the screens and be entrained through the heat exchanger system (Abbasi and Abbasi
11 2000). The numbers of organisms entrained in the water will depend on their
12 concentrations in the intake areas; more aquatic organisms are likely to be impinged and
13 entrained at the surface water intake than from the deep water intake. Because of the
14 large flow rates of water, impingement and entrainment, especially at the warm water
15 intake, will need to be monitored. As with steam electric power plants, the heat
16 exchanger-entrained organisms will be susceptible to mechanical damage in the piping
17 and to rapid changes in temperature, pressure, salinity, and dissolved gases that may
18 cause mortality. For example, the temperature of cold deep water is expected to increase
19 and shallow warm water decrease by about 2-3 °C after passage through the heat
20 exchangers (Myers et al. 1986). Most organisms will probably not be directly impacted
21 by this amount of temperature change. However, secondary entrainment into the
22 discharge plume will also expose marine organisms to chemical, physical, and
23 temperature stresses (Meyers et al. 1986). A mixed discharge of warm and cold water
24 could subject organisms entrained from the warm surface waters to a drop of 10 °C,
25 which would likely cause lethal cold shock for some species. Few organisms are
26 expected to be entrained in the deep, cold water flow, but those that do will be subjected
27 to potentially lethal pressure decreases of 70-100 atmospheres (7100-10,100 kPa; Meyers
28 et al. 1986).

30 3.9.2 Mitigation Measures

31
32 Pelc and Fujita (2002) suggested a number of measures to control the
33 environmental impacts of OTEC, including (1) refraining from siting OTEC plants in
34 sensitive areas such as prime fishing grounds, spawning areas, and sensitive reef habitats
35 (more feasible than for energy technologies located in shallow waters); (2) using the
36 OTEC discharge for ancillary benefits (agriculture, aquaculture, desalinization) to reduce
37 the degree to which the discharges alter local water temperatures and water chemistry; (3)
38 carefully regulating the use of toxic chemicals such as ammonia and chlorine; and (4)
39 relying mainly on relatively small plants, which will reduce the local impacts of
40 entrainment, impingement, and discharges. Abbasi and Abbasi (2000) suggested that the
41 OTEC plant be designed to discharge its water below the photic zone, thereby reducing
42 the amount of carbon dioxide emitted and the negative effects of temperature changes
43 and nutrient over-enrichment. Myers et al. (1986) suggested a variety of measures to
44 reduce the potential effects on fisheries, including (1) locating the cold water intake as
45 deeply as feasible to avoid entrainment of zooplankton and fish eggs and larvae; (2)

1 locating the warm water intake away from concentrations of plankton, possibly in
2 shallow water; (3) minimizing warm water intake velocities to reduce impingement; and
3 (4) optimizing the location of the discharge in order to minimize biocide toxicity, cold
4 shock, and other effects of secondary entrainment, and the possibilities of ciguatera
5 poisoning from toxic algae blooms.

6

1 that adverse ecological effects may occur as a result of exposure to one or more stressors.
2 Combining ecorisk analysis and weight-of-evidence assessment approaches would
3 support sound decision-making even in cases of relatively high uncertainty (e.g., Suter et
4 al. 2002; Forbes and Calow 2002; McDonald et al. 2007). EPA provides guidelines
5 (EPA 1998) and maintains a website for training on the procedures
6 (<http://www.erg.com/portfolio/elearn/ecorisk/html/>). Net Environmental Benefits
7 Analysis (NEBA) is a type of cost-benefit analysis in which the natural resource benefits
8 of alternative mitigation, restoration, enhancement, and preservation actions are
9 rigorously compared. NEBA is commonly used for remediation of chemically
10 contaminated sites (Efroymsen et al. 2004), but Layman et al. (2000) suggested that it
11 may be a useful way to deal with contentious natural resource issues in hydropower
12 licensing. It is especially useful for evaluating impacts over time, where initial changes
13 may be balanced by longer-term recovery of habitats. Adaptive Management (Section
14 4.2) is being applied increasingly as a means of using the results of environmental
15 monitoring to improve to environmental performance of a variety of activities.
16

17 Internationally, the United Nations Environment Programme (UNEP) promotes
18 the use of Environmental Impact Assessment (EIA) and Strategic Environmental
19 Assessment (SEA) as structured approaches for obtaining and evaluating environmental
20 information prior to its use in decision-making (Abaza et al. 2004). EIA makes
21 predictions about changes to the environment from proposed physical developments such
22 as power stations and water resources projects, while SEA focuses on proposed actions at
23 a higher level such as new policies and programs. Like NEPA, the use of EIA/SEA has
24 been formalized in many countries by incorporation into national laws and regulations.
25 UNEP encourages the integration of EIA and SEA in order to ensure that the
26 environmental consequences of both policies and the projects that implement those
27 policies are formally considered by decision makers. The effective application of these
28 processes is encouraged by EIA Principles of Best Practice (Senecal et al. 1999) and SEA
29 Performance Criteria (IAIA 2002).
30

31 Predictive environmental assessments, whether by NEPA, EIA, or SEA, are
32 oriented toward making decisions about policies, programs, or projects before full
33 implementation, when environmentally sound alternatives can still be chosen. After a
34 decision has been made and operation of a marine or hydrokinetic energy project has
35 begun, the identification (and correction) of environmental impacts will depend on
36 monitoring. The ability to modify the project in order to mitigate unacceptable
37 environmental impacts identified by operational monitoring might be based on
38 application of adaptive management principles reflected in the project license conditions.
39

40 4.2 Incorporating Adaptive Management into Development and 41 Environmental Monitoring of Marine and Hydrokinetic Energy 42 Technologies 43

44 Adaptive management is a system of management practices based on clearly
45 identified outcomes and monitoring to determine whether management actions are

1 meeting desired outcomes; and, if not, facilitating management changes that will best
2 ensure that outcomes are met or re-evaluated (Walters 1986; 73 FR 61291-61323,
3 October 15, 2008). In the context of marine and hydrokinetic energy technologies,
4 adaptive management is a systematic process by which the potential environmental
5 impacts of installation and operation could be evaluated against quantified environmental
6 performance goals during project monitoring. Early information about undesirable
7 outcomes can lead to the implementation of minimization or mitigation actions which are
8 subsequently re-evaluated. An adaptive management process is particularly valuable in
9 the early stages of technology development, when many of the potential environmental
10 effects are unknown for individual units, let alone the eventual build out of large numbers
11 of units. There is widespread realization of the possible benefits of incorporating an
12 adaptive management approach in the development and monitoring of these new
13 technologies. For example, PFMC (2008) recommended that license conditions issued
14 by MMS for wave energy test leases incorporate adaptive management to identify and
15 respond to uncertainties in the projects' effects.

16
17 The U.S. Department of the Interior (Williams et al. 2007) adopted the description
18 of adaptive management published by the National Research Council (2004):

19
20 Adaptive management [is a decision process that] promotes flexible decision
21 making that can be adjusted in the face of uncertainties as outcomes from
22 management actions and other events become better understood. Careful
23 monitoring of these outcomes both advances scientific understanding and helps
24 adjust policies or operations as part of an iterative learning process. Adaptive
25 management also recognizes the importance of natural variability in contributing
26 to ecological resilience and productivity. It is not a 'trial and error' process, but
27 rather emphasizes learning while doing. Adaptive management does not
28 represent an end in itself, but rather a means to more effective decisions and
29 enhanced benefits. Its true measure is in how well it helps meet environmental,
30 social, and economic goals, increases scientific knowledge, and reduces
31 tensions among stakeholders.

32
33 Simply stated, it is an iterative process of planning and implementing an action,
34 monitoring, evaluation, and making adjustments as needed.

35
36 Williams et al. (2007) point out that there are two overarching conditions that
37 argue for the application of adaptive management to a decision: (1) there must be a
38 mandate to take action in the face of uncertainty; and (2) there must be an institutional
39 capacity and commitment to undertake and sustain an adaptive program. The mandate
40 might come from laws (e.g., NEPA, Clean Water Act, Endangered Species Act),
41 regulations (e.g., Federal Energy Regulatory Commission license conditions), or policies
42 (e.g., Department of the Interior policy on the use of adaptive management; DOI 2007
43 and 2008 and 73 FR 61291-61323; October 15, 2008).

44
45 Williams et al. (2007) describe other situations in which the use of adaptive
46 management should be considered. Framed in the context of marine and hydrokinetic
47 renewable energy technology developments, these could include:

1
2 (a) *There is a need to make consequential decisions.* That is, there are real, unresolved
3 concerns about the impacts to the environment of the installation and operation of a
4 renewable energy technology whose significance warrant hypothesis testing (e.g., the
5 development of predictive models and collection of monitoring data). Minor issues (e.g.,
6 the decision to implement proven mitigation measures such as environmentally benign
7 chemicals or sound insulation) can be resolved without the commitment of time and
8 resources associated with the adaptive management process.

9
10 (b) *There is an opportunity to apply learning, i.e., the potential issue can be validly*
11 *studied and the initial decision can be revisited and modified over time.* If the methods
12 by which a marine/hydrokinetic facility are installed and operated cannot be satisfactorily
13 evaluated and modified, then adaptive management has no role.

14
15 (c) *Clear and measurable management objectives can be specified by the regulatory and*
16 *resource agencies.* The pre- and post-installation state of water quality, aquatic habitats,
17 and/or aquatic biological communities must be quantified in order detect changes brought
18 about by the energy technology.

19
20 (d) *There is a high value for future decision making,* either related to continued operation
21 of the particular renewable energy facility that is being monitored or to the development
22 of future installations.

23
24 (e) *Testable models can be crafted* to predict the effects of the renewable energy
25 development on the environment, and the output of these models can be compared to
26 monitoring data. The models must reflect appropriate scales for the potential effects –
27 both time scales (seconds vs. days vs. years) and spatial scales (impacts occurring over
28 localized vs. large areas). Expected impacts of a marine/hydrokinetic technology must be
29 clearly stated as one or more testable hypotheses.

30
31 (f) *Effective monitoring can be established that allows statistically based hypothesis*
32 *testing.* Small changes in the environment (e.g., water quality, habitat, biological
33 populations and communities) are difficult to detect, and monitoring that is insufficient to
34 detect real, but small, changes may lead to the erroneous conclusion that the technology
35 has no impacts. The level of field monitoring should be appropriate to adequately test the
36 hypotheses and refine the predictive models and should occur over appropriate time and
37 spatial scales. Monitoring should not be so infrequent that it fails to detect natural or
38 technology-caused changes in the environment. Similarly, monitoring restricted to a
39 local scale (e.g., habitat changes occurring near a single marine turbine) may miss more
40 extensive habitat alterations associated with multiple units.

41
42 When a decision to employ adaptive management has been made, Williams et al.
43 (2007) recommended carrying out the process in a series of nine steps, divided into a set-
44 up phase and an iterative phase:

45
46 Set-up phase

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- (1) stakeholder involvement – ensure that the stakeholders are committed to adaptively manage the enterprise for its duration;
- (2) management objectives – identify clear, measurable, and agreed-upon management objectives to guide decision making and evaluate effectiveness over time;
- (3) management alternatives – identify a set of potential management actions for decision making;
- (4) predictive models – identify models that characterize different ideas/hypotheses about how the system works;
- (5) monitoring plans – design and implement a monitoring plan to track resource status and other key resource attributes;

Iterative phase

- (6) decision making – select management actions based on management objectives, resource conditions, and understanding;
- (7) monitoring responses to management – use monitoring to track system responses to management actions;
- (8) assessment – improve understanding of resource dynamics by comparing predicted and observed changes in resource status;
- (9) adjustment to management actions – go back to step 6 as necessary.

One value of adaptive management is in sharing information, so that future installations can benefit by reducing environmental impacts. The timely availability of monitoring data to all affected agencies and stakeholders is important (CEQ 2003; 40 C.F.R. 1505.3(d)).

Prato (2003) noted that there are two forms of adaptive management – passive and active. In passive adaptive management, simulation models and expert judgment are combined to select a preferred action, and monitoring data are used to revise model parameters. Passive adaptive management is relatively simple and inexpensive to implement, but it is non-experimental and may not provide reliable information for making decisions. On the other hand, active adaptive management uses statistically designed experiments to test assumptions or hypotheses about ecosystem responses to actions. Such experiments could incorporate replication and randomization of management actions (i.e., treatments) and, as a result, may provide more clear-cut, reliable results. Active adaptive management (experiments) may, however, be too difficult and costly to carry out in a large river or marine environment. Prato (2003) suggested that passive adaptive management could be employed to assess actions that have a localized effect or relatively certain outcome, while reserving the resources needed for active adaptive management to the subset of issues with the greatest uncertainty.

The Council on Environmental Quality (CEQ 2003) discussed the value of incorporating adaptive management into the environmental impact analysis model used in

1 the traditional NEPA process. In the traditional process, results from research, modeling,
2 and expert opinions are used to predict potential impacts, mitigation measures are
3 identified, and a document is released for public review. The process does not account
4 for changes in environmental conditions, inaccurate predictions, or subsequent
5 information that might affect the original environmental protections. CEQ considered the
6 “monitor and adapt” elements of adaptive management to be a significant improvement
7 to the traditional NEPA process. Both DOI and the USDA/Forest Service have recently
8 incorporated adaptive management into their NEPA planning process (73 FR
9 61291-61323, October 15, 2008, and 73 FR 43084-43099, July 24, 2008, respectively).

10
11 CEQ (2003) noted that the following key factors must be considered when
12 implementing an adaptive management approach:

- 13 (1) The ability to establish clear monitoring objectives;
- 14 (2) Agreement on the impact thresholds being monitored;
- 15 (3) The existence of a baseline (or the ability to develop a baseline) for the
16 resources being monitored;
- 17 (4) The ability to see the effects within an appropriate time frame after the action
18 is taken;
- 19 (5) The technical capabilities of the procedures and equipment used to identify
20 and measure changes in the affected resources and the ability to analyze the
21 changes; and
- 22 (6) The resources needed to perform the monitoring and respond to the results.

23
24
25 An adaptive management strategy can help determine whether mitigation
26 measures are cost effective and appropriately implemented. The Fish and Wildlife
27 Service (FWS) established a policy “to seek to mitigate losses of fish, wildlife, and their
28 habitats, and uses thereof, from land and water developments” (FWS 1993). The intended
29 effect of the policy is to protect and conserve the most important and valuable fish and
30 wildlife resources while facilitating balanced development of the Nation’s natural
31 resources. FWS developed this mitigation policy with the intention of reducing conflicts
32 between FWS and developers that can result in project delays by allowing developers to
33 anticipate FWS recommendations and plan for mitigation needs early. The policy
34 incorporates CEQ’s definition of “mitigation” in 40 CFR 1508.20(a-e) and states that this
35 is the general order and priority in which mitigation measures should be recommended:

- 36 (a) Avoiding the impact altogether by not taking a certain action or parts of an
37 action.
- 38 (b) Minimizing impacts by limiting the degree or magnitude of the action and its
39 implementation.
- 40 (c) Rectifying the impact by repairing, rehabilitating, or restoring the affected
41 environment.
- 42 (d) Reducing or eliminating the impact over time by preservation and
43 maintenance operations during the life of the action.
- 44 (e) Compensating for the impact by replacing or providing substitute resources or
45 environments.
- 46

1
2 FWS would follow this policy in evaluating proposed marine and hydrokinetic renewable
3 energy projects and preparing recommendations to mitigate any adverse impacts that
4 might be anticipated from them. The FWS policy also encourages and supports post-
5 project evaluations, as could be done under an adaptive management strategy, to
6 determine the effectiveness of recommendations in achieving the mitigation planning
7 goal.

8
9 Adaptive management could also be incorporated into the Environmental
10 Management System (EMS) developed for the marine/hydrokinetic energy technology.
11 An EMS is a structure of procedures and policies used to systematically identify,
12 evaluate, and manage environmental impacts of ongoing activities (CEQ 2007). Like
13 adaptive management, EMS is used by organizations not only to assess environmental
14 issues, but also to actively manage them in a process that includes monitoring and action
15 based on the monitoring results. The International Organization for Standardization
16 (ISO) 14001 Standard (ISO 2004) is a widely used framework for establishing an EMS.
17 ISO 14001 has many elements in common with adaptive management procedures in that
18 it enables organizations to identify and control the environmental impacts of its activities,
19 improve its environmental performance continually, and implement a systematic
20 approach to setting environmental objectives and targets, achieving them, and
21 demonstrating that they have been achieved.

22
23 Because of the similarity of approaches and goals, CEQ (2007) recommended that
24 agencies consider developing complementary NEPA and EMS procedures: “An EMS can
25 support the implementation of a NEPA ‘adaptive management’ approach when there are
26 uncertainties in the prediction of the impacts or outcome of a project implementation, or
27 the effectiveness of proposed mitigation. The checking and corrective action elements of
28 the EMS can add the ‘monitor and adapt’ steps to the traditional NEPA ‘predict-mitigate-
29 implement’ model. The resulting adaptive management approach (the ‘predict-mitigate-
30 implement-monitor-adapt’ model) can provide managers with the flexibility to make
31 necessary corrections or adjustments, possibly without needing new or supplemental
32 NEPA analyses, when the NEPA process has identified and analyzed the range of
33 possible outcomes and the appropriate adjustments to respond to them (see CEQ 2003;
34 FAA 2004). This approach allows continuous improvement in management effectiveness
35 and in reducing environmental impacts within parameters established by the NEPA-
36 informed decision.”

37
38 Marine and hydrokinetic renewable energy projects must comply with a number
39 of environmental laws (e.g., Endangered Species Act [ESA], Marine Mammals
40 Protection Act) that can include adaptive management as part of their implementation.
41 For example, an incidental take permit is required by ESA Section 10(a)(1)(B) when non-
42 Federal entities propose actions that may result in “take” of threatened or endangered
43 wildlife. A Habitat Conservation Plan (HCP) must accompany an application for such a
44 permit. The HCP includes the following (FWS 2005):
45

- 1 (1) an assessment of impacts likely to result from the proposed taking of one or
- 2 more federally listed or unlisted species;
- 3 (2) measures the permit applicant will undertake to monitor, minimize, and
- 4 mitigate such impacts, and the funding that will be made available to implement
- 5 such measures;
- 6 (3) procedures to deal with unforeseen or extraordinary circumstances; and
- 7 (4) alternative actions to the taking that the applicant analyzed, and the reasons
- 8 why the applicant did not adopt such alternatives.

9
10 Adaptive management can often be used as a tool to address uncertainty in the
11 conservation of a species covered by an HCP (FWS/NOAA 2000a). It is an essential
12 component of HCPs that would otherwise pose a significant risk to the species due to
13 significant data or information gaps. These gaps are not limited simply to biological
14 information, but also can include uncertainty in mitigation or management techniques,
15 effects of the action, or any other missing information that poses a significant risk.

16
17 Adaptive management strategies in a HCP can assist applicants who are planning
18 marine and hydrokinetic renewable energy projects to develop an adequate operating
19 conservation program and improve its effectiveness (FWS/NOAA 2000b). An adaptive
20 management strategy contained in a HCP for such projects could (1) identify the
21 uncertainty and the questions that need to be addressed to resolve the uncertainty, (2)
22 develop alternative strategies and determine which ones to implement, (3) include a
23 monitoring program that is able to detect the information necessary to evaluate the
24 strategy, and (4) incorporate feedback loops that link implementation and monitoring to a
25 decision-making process (similar to a dispute-resolution process) that results in
26 appropriate changes in management.

27 28 29 4.3 Federal Licensing of Marine and Hydrokinetic Renewable Energy 30 Technologies

31
32 Lane (2007) outlined the Federal agencies' authorities and Federal legislation that
33 will guide the development of tidal, wave and in-stream generation projects. These will
34 all be considered in the licensing of new projects. Permitting authority for marine and
35 hydrokinetic renewable energy technologies rests with the Federal Energy Regulatory
36 Commission (FERC) and the U.S. Department of Interior's Minerals Management
37 Service (MMS). These Federal agencies have the primary responsibility for ensuring that
38 new renewable energy projects are properly designed, constructed, and monitored to
39 safeguard environmental resources. Some of the uncertainties about the environmental
40 impacts of these technologies will be addressed during the monitoring associated with
41 license conditions issued by the FERC or the MMS.

42
43 The FERC published guidance on licensing procedures (FERC 2008) as part of its
44 ongoing effort to support the advancement and orderly development of innovative
45 hydrokinetic technologies. The guidance noted that the FERC did not propose a new rule

1 for hydrokinetic technologies, but rather proposed adapting existing regulations and, in
2 some cases, providing waivers for specific types of projects. For example, compared to
3 licenses for conventional hydropower projects (which can be issued for a term of up to 50
4 years), pilot projects should not be located in sensitive areas and may have short license
5 terms of 5 years. The pilot project license would emphasize post-license monitoring and
6 would contain conditions that require project modification, shutdown, or removal in the
7 event that monitoring reveals an unacceptable risk to the public or environmental harm
8 (FERC 2008).

9
10 The FERC's primary purpose in providing guidance on expedited licensing
11 procedures is to encourage testing of hydrokinetic pilot projects and reduce the
12 uncertainties surrounding the technologies (FERC 2008). In its draft and final
13 application, the applicant for a hydrokinetic pilot project license will be expected to
14 provide proposed plans that describe monitoring measures, performance standards, and
15 thresholds for modification, shutdown, or removal. Stakeholders (federal, state, and local
16 resource agencies, Indian tribes, non-governmental organizations, and members of the
17 public) will be able to recommend modifications and additional measures or require
18 license conditions.

19
20 The MMS is authorized to grant leases, easements, or rights-of-way on the Outer
21 Continental Shelf (OCS) for activities that produce or support production, transportation,
22 or transmission of energy from sources other than oil or gas (e.g., wind, wave, and ocean
23 current technologies). The OCS comprises submerged lands, subsoil, and sea bed lying
24 between the seaward extent of the states' jurisdictions and the seaward extent of federal
25 jurisdiction, commonly between 3 and 200 nautical miles offshore. The MMS is
26 developing an Alternative Energy and Alternate Use Program and associated regulations.
27 Until the final rulemaking governing new alternative energy projects is issued, MMS will
28 consider activities under an interim policy and guidelines (72 FR 62673; November 6,
29 2007). Under the interim policy, MMS will consider and authorize (1) initial site
30 assessment activities (e.g. collection of resource data); and (2) the installation and
31 operation of facilities to test alternative wave and ocean current generating technologies.
32 The interim policy would not apply to project proposals for the installation of turbines or
33 other energy generating devices associated with the commercial development of
34 alternative energy resources on the OCS.

35
36 The MMS proposed to give priority consideration to issuing limited leases for (1)
37 data collection and technology testing activities related to current resources off the coast
38 of Florida; and (2) data collection and technology testing activities related to wave
39 resources off the coast of Northern California (73 FR 21152; April 18, 2008). Under the
40 interim policy, the installation of resource data collection and technology testing facilities
41 will require MMS review of a plan describing the proposed construction, operation, and
42 removal of the facility. A National Environmental Policy Act (NEPA) review of
43 potential environmental impacts will be conducted for each lease, and appropriate
44 restrictions and mitigation measures may be applied.

45

1 On July 8, 2008, MMS issued a proposed rulemaking and a notice of availability
2 of a draft environmental assessment analyzing the proposal. In the document, MMS states
3 it has conferred with FERC staff to reduce inconsistencies between regulatory
4 requirements applicable to projects licensed by FERC within U.S. territorial seas, and
5 those that would operate under the proposed MMS rules. MMS said such coordination is
6 essential because it is foreseeable that some projects could straddle the boundary between
7 the territorial seas and the OCS. Comments on the proposed rulemaking (MMS-2008-
8 OMM-0012) and draft EA were due on September 8, 2008. Following the 60-day
9 comment period, MMS will release the final rule and final EA for regulating alternative
10 energy production activities and alternate uses of existing facilities on the OCS. MMS
11 expects to complete the final rule by December, 2008.
12
13

14 4.4 Environmental Monitoring

15
16 The monitoring needed to understand and minimize environmental impacts can
17 have either site-specific or general value (Cada et al. 2007). Site-specific research would
18 typically be conducted by the manufacturer/developer and might include impacts of
19 particular design details (e.g., comparison of the toxicity of different paints or lubricating
20 fluids; comparisons of noise measurements to tolerances of local fauna) or the effects on
21 a particular river or estuary that is proposed for development (e.g., collection of sediment
22 cores and modeling of multi-unit placement relative to a specific bottom profile). Site-
23 specific monitoring will focus on specific groups of species of particular interest, e.g.,
24 endangered or threatened species or commercially and recreationally important fish and
25 shellfish. In some cases there is a deficiency of baseline information about the
26 environmental resources of a proposed site, so that pre-installation monitoring will be
27 aimed at determining the occurrence of sensitive habitats and their use by species of
28 concern.
29

30 On the other hand, many environmental questions are of general interest, and the
31 monitoring and research to answer them might best be addressed by collaborative groups
32 with the results made freely available to all stakeholders. Collaborative studies could
33 include experiments to understand the mechanisms of impacts of hydrokinetic and wave
34 conversion devices (e.g., the differences in frequency and severity of strike in ducted vs.
35 unducted rotors or different rotor blade shapes; advanced physical and computational
36 models of alternative multi-unit deployment strategies). Individual developers rarely
37 have the resources to carry out this general research on their own, but the information that
38 comes from such studies is often of interest to a wide audience seeking to refine their
39 designs and operations in order to minimize environmental impacts. An important
40 component of adaptive management (i.e., the continuing process of action, monitoring,
41 evaluation, and adjustment) is the interpretation of site-specific monitoring results in light
42 of the findings of more generalized, explanatory research.
43

44 The site-specific monitoring and general research needs for new ocean energy and
45 hydrokinetic technologies have been considered in various publications. For example,

1 Table 2.1 of EMEC (2005) lists the detailed information that should be provided by a
2 project proponent in order to evaluate the potential environmental effects of installation
3 and operation at their facility off the Orkney coast. Michel and Burkhard (2007)
4 tabulated information needs related to numerous environmental issues, including EMF,
5 noise, movements of aquatic organisms, collision, and habitat changes. Appendix 5 of
6 Boehlert et al. (2008) describes recommended monitoring of a wave farm near Reedsport,
7 Oregon. Although developed for offshore wind farms, the report by Elsam Engineering
8 and Energi E2 (2005) describes a number of techniques for monitoring the status of
9 marine communities.

10
11 The following list of possible monitoring activities associated with each of the
12 environmental issues discussed in this report should not be considered exhaustive. Each
13 site is unique, and may benefit from more or less monitoring for particular environmental
14 issues.

16 4.4.1 Monitoring for Alteration of Currents and Waves

17
18 In order to address the effects of energy extraction on tidal/river currents, current
19 velocities could be measured upstream, downstream, and at the site where the devices
20 will be installed. The monitoring locations should be appropriate for collecting
21 information about water velocity changes associated with both individual units and
22 multiple units, recognizing that for small numbers of units the effects on water velocities
23 are likely to be small and localized. Seasonal variations could be examined by making
24 water velocity measurements over an appropriate time frame (i.e., at different river flows
25 or over several daily and seasonal tidal cycles). For example, to evaluate the influence on
26 tides it would be valuable to obtain at least a 35 day record in two different seasons, both
27 before and after installation of the turbines. After project installation has begun, the
28 velocity measurements could be repeated with one unit in place and again after several
29 units have been installed.

30
31 As with current velocities, wave height measurements could be made at
32 appropriate locations before installation of the ocean energy conversion device, and again
33 after single and multiple units have been installed. Measured changes in current
34 velocities or wave heights could be used to validate predictive models and help explain
35 concomitant changes in sediment transport and aquatic habitats. Monitoring the effects
36 of impact minimization and mitigation measures (Section 3.1.2) would be valuable.

38 4.4.2 Monitoring for Effects on Sediment Transport

39
40 It is important to characterize the bottom sediments that will be disturbed by
41 installation of the energy conversion devices and their associated cables. Pre-installation
42 monitoring could define the type and size structure of sediments and the presence of
43 contaminants that might degrade water quality. Information on sediment transport

1 dynamics would be useful for predicting the influence of altered hydrography on post-
2 installation sediment transport and deposition.

3
4 Periodic operational monitoring will be valuable for detecting changes in
5 sediment transport and the effects of impact minimization measures. In many cases this
6 will be most easily accomplished by onsite, underwater sampling and visual observations.
7 In other instances, remote monitoring may be used to evaluate the significance of changes
8 brought about by the energy project. For example, Elsam Engineering and Energi E2
9 (2005; p. 61-64) used satellite imagery to determine impacts on shoreline changes as the
10 result of the modified wave climate created by a wind park.
11

12 4.4.3 Monitoring for Effects of Benthic Habitat Alterations

13
14 The amount of benthic habitat that will be altered by installation and operation
15 can be estimated from detailed descriptions of the anchoring system (e.g., number of
16 anchors, size, construction material), the mooring system, the electrical transmission
17 system (length and size of cables, buried or anchored on the surface, construction
18 materials), and the installation procedures (e.g., pile-driving, trenching, boring).
19

20 Pre-installation monitoring could be used to characterize benthic habitat and
21 predict the biological responses. Initial monitoring would include descriptions of the
22 benthic habitats and benthic organisms that will be affected by installation of the project
23 and quantification of the densities and species richness values for benthic organisms.
24 Because plant and animal communities exhibit natural variations both spatially and over
25 time, a Before-After, Control-Impact (BACI) experimental design is often the best way to
26 detect changes that occurred as a result of the project. Monitoring should be frequent
27 during the installation period, and can be less frequent during initial operations if the
28 benthic community recovers.
29

30 As noted in Section 3.3.2, the presence of a marine energy project may reduce
31 fishing pressure in the immediate area, thereby serving as a *de facto* marine reserve. This
32 may be counted as a benefit of the project (by enhancing the marine organisms) or a
33 negative impact (by eliminating areas from commercial or recreational fishing); in either
34 case it may be desirable to evaluate the marine reserve effect with field monitoring.
35 Halpern et al. (2004) describe mathematical models that can be used to predict fisheries
36 benefits of marine reserves, and discuss the difficulties of detecting significant effects
37 given the uncertainties of identifying appropriate control sites and the normal interannual
38 fluctuations in population numbers.
39

40 4.4.4 Monitoring for Effects of Noise

41
42 Monitoring of the potential environmental effects of noise could begin with a
43 complete characterization of the technology, including measurements of the device's
44 acoustic signature: sound pressure levels (SPL) across the full range of frequencies. For

1 example, EMEC (2005) suggested that the amplitude of the noise be quantified for the
2 device as a whole (as dB re 1 μ Pa at 1 m in water or at 20 m in air), or for different parts
3 of the device as appropriate. The relative importance of the new source of noise could be
4 evaluated by making measurements at varying distances from the installation or operation
5 and including background noise levels for comparison. These measurements could be
6 performed under a variety of ocean/river conditions in order to assess how
7 meteorological, current strength, and/or wave height conditions affect sound generation
8 and sound masking. The effects of marine fouling on noise production, noise from any
9 tensioned wires or other components that resonate in water, and the effects of measures to
10 reduce noise could be measured for both individual and multiple units.

11
12 The biological response to the noise generated by installation and operation can
13 be evaluated initially by comparing the device's acoustic signature to information about
14 the hearing sensitivity (e.g., audiograms) of exposed animals. Monitoring of fish, sea
15 turtles, and marine mammal activity might be carried out in parallel with measurements
16 of sound levels (Simmonds et al. 2003). Visual or automated monitoring (e.g. by means
17 of an acoustic detection system) could investigate changes in animal behavior (avoidance,
18 attraction, changes in schooling behavior or migration routes).

20 4.4.5 Monitoring for Electromagnetic Fields

21
22 Because the electromagnetic fields (EMF) associated with submarine electrical
23 transmission cables are poorly understood, it would be useful to characterize and quantify
24 the electric field (E), induced magnetic field (B), and secondary (induced) electric field
25 (iE) (Section 3.5.1; Appendix D). Measurements could be made at various distances
26 from the cable and at the full range of voltages and amperages that the cables will carry
27 as additional generating units are installed. The measurements can be compared to the
28 published electro- and magnetosensitivity of aquatic organisms to evaluate whether the
29 EMF are likely to interfere with local movements or migrations. If the project
30 incorporates networks of cables in close proximity to each other, the complex
31 overlapping and potentially additive effects of the EMF fields could be analyzed.

32
33 Biological responses to the EMF may best be monitored by visual observations of
34 the reactions of organisms known to be sensitive (i.e., elasmobranchs, eels, cod, salmon,
35 and catfish) as they approach the generating device and electrical cables. More
36 generalized research to resolve the EMF issue might be based on the type of mesocosm
37 experiments described in Gill et al. (2005).

39 4.4.6 Monitoring the Toxic Effects of Chemicals

40
41 Monitoring of chemical toxicity could be focused by compiling and assessing
42 information about the toxicity to aquatic organisms of all chemicals associated with the
43 project. The list of chemicals would include hydraulic fluids and lubricating oils that
44 may leak from the generating unit and antifouling coatings that are designed to slowly

1 release toxicants into the environment. As appropriate, the potential for bioaccumulation
2 of toxic compounds (e.g., heavy metals or refractory organic compounds) might be
3 considered and monitored. Screening bioassays for new chemicals could be conducted if
4 information is lacking in the published literature about toxicity to particular species found
5 at the project site.
6

7 4.4.7 Monitoring Interference with Animal Movements and Migrations

8
9 There is insufficient information about the likely effects of numerous mooring
10 and electrical transmission lines associated with large energy conversion projects on the
11 movements and migrations of aquatic animals. With regard to the local movements,
12 these new structures in the pelagic zone may act as fish attraction devices (FADs) and
13 increase the abundance of fish, at least locally. Changes in numbers and relative
14 abundance of fish populations could be monitored before and after project installation,
15 using both control and impacted sites (i.e., a BACI experimental design). Monitoring can
16 be used to determine how economically important species such as albacore, rockfish, and
17 salmon interact with floating wave energy devices, including the time frame for
18 establishment of the fish community, temporal and spatial dimensions of the fish
19 community, and the population structure (Michel et al. 2007). Determination of the
20 effects of FADs at a particular location is complicated by the influence of non-
21 independent factors, including the proximity of other FADs (i.e., other wave energy
22 units), the interconnection of multiple FADs to provide routes for the movement of
23 associated fishes, and temporal dependence (where the number of fish present at one time
24 influences the number at the next time due to fish becoming residents). Kingsford (1999)
25 described statistical approaches that could be applied to experiments on the effects of
26 FADs on fish populations and solutions to the independent factor problems. Suggestions
27 for monitoring the marine reserve effect resulting from a restriction on commercial and
28 recreational fishing are provided in Halpern et al. (2004).
29

30 Effects on long distance movements and migrations are more difficult to assess.
31 They may depend initially on visual observations of the reactions of migrating animals to
32 the energy project. PFMC (2008) concluded that a response protocol for entanglement of
33 organisms in the mooring/electrical lines should be developed. Boehlert et al. (2008)
34 suggested that assessment of behavioral interactions of marine mammals and sea turtles
35 with wave energy conversion devices and cables could include development of a
36 migration corridor model for cetaceans and pinnipeds based on tagging studies.
37

38 4.4.8 Monitoring the Effects of Strike

39
40 Pre-installation predictions about the susceptibility of aquatic organisms to strike
41 could be validated by operational monitoring. Monitoring of strike might be possible by
42 visual observations and/or netting in shallow, clear water environments. In other settings,
43 hydroacoustic monitoring may be needed to assess the incidence of strike. For example,
44 both a mobile hydroacoustic fish survey and a fixed hydroacoustic transducer were

1 employed in an attempt to detect and quantify fish strike at the Roosevelt Island Tidal
2 Energy (RITE) project (Smith 2007). As fish and other aquatic organisms passed through
3 the turbine field, the hydroacoustic monitoring system automatically tracked and
4 documented their location and behavior relative to the zone of risk at each turbine
5 (BioSonics 2008). Strike will not necessarily result in injury or mortality; among other
6 factors, strike injury is related to the velocity of impact (i.e., portion of the blade
7 contacted) and the shape of the leading edge (Section 3.8). Consequently, it would be
8 useful to monitor the consequences of organisms impacting the structures at different
9 velocities and locations.

10
11 The cavitation performance of the rotor could be established, with a view toward
12 reducing blade erosion and injury to animals. Watten et al. (2006) suggested that blade
13 performance predictions include modification to twist/pitch to account for non-uniform
14 inflow from the tidal profile and waves, changes in blade thickness, and performance in
15 yawed flow during tidal changes.

16
17 The risk of rotor strike from a single unit can be readily estimated for an organism
18 in the zone of influence from information on such factors as water velocity, blade rotation
19 rate, and blade length (Section 3.8.1), and these predictions can be verified by operational
20 monitoring. However, estimates of the probability of strike for a large project with
21 hundreds of closely spaced rotors have not been made. Data on animals' migratory paths,
22 preferred depths, diurnal activity, and attraction or repulsion by the project structures
23 might be used to locate projects away from sensitive areas. Monitoring passage of
24 marine organisms through the entire ocean energy project would be needed to resolve
25 uncertainties of cumulative risk of strike from multiple units.

26 27 4.4.9 Monitoring of Ocean Thermal Energy Conversion (OTEC) Projects

28
29 Prior to construction of the OTEC project, data on the vertical distribution of
30 aquatic organisms, especially the eggs and larvae of fish and shellfish, would allow
31 predictions of the susceptibility of aquatic organisms to entrainment in both the cold and
32 warm water intakes (Meyer et al. 1986). In addition, data could be collected to support
33 predictive modeling of the fate of the discharge plume in order to avoid secondary
34 entrainment of marine organisms, maximize dilution and dissipation of biocides, and/or
35 enhance the redistribution of nutrients from deep waters (if desired). As with other ocean
36 energy and hydrokinetic technologies, it will be important to evaluate the toxicity of
37 working fluids, corroded metals, and biocides. Subsequent operational monitoring could
38 be used to validate the predictions about entrainment, discharge plume effects, and
39 chemical toxicity.

40 41 4.4.10 Monitoring for Cumulative Impacts of Multiple Units and Multiple 42 Energy Projects

1 Beyond the environmental evaluations of individual machines, concerns have
2 been expressed about both multiple-unit deployments and the cumulative impacts of
3 energy developments when added to other stresses on aquatic systems (Resolve, Inc.
4 2005). In order for these technologies to make a significant contribution to electricity
5 supply, larger devices or installations of many units will be needed. For example,
6 Williams (2005) suggested that 3,000 to 4,000 open center turbines could be deployed in
7 the Gulf Stream to provide a generation potential of 10,000 MW of electricity. Impacts
8 to bottom habitats, hydrology, or strike that are inconsequential for one or a few units
9 may become significant if energy farms exploit large areas in a river, estuary, or
10 nearshore ocean. By extracting energy from currents, very large installations might
11 conceivably influence large scale ocean circulation patterns. It may not be easy to
12 extrapolate effects from small to large numbers of units because the complicated
13 interactions between water motions and turbines depend on placement of the machines
14 (proximity to each other) as well as local hydraulic conditions. Hydraulic models will
15 likely be needed to predict accurately the effects of multiple units. The deployment of
16 turbines will add to existing environmental stresses and cumulative effects. In rivers, the
17 effects of hydrokinetic turbines would occur in the context of other impacts associated
18 with boat traffic, water withdrawals, and discharges. In the ocean, energy developments
19 must compete with aquaculture, offshore wind, gas and oil platforms, defense-related
20 activities, mining, merchant shipping, recreational and commercial fishing, and
21 recreational boating (Ogden 2005). Perhaps the most sensitive habitats to cumulative
22 impacts are the estuaries, highly complex and productive ecosystems that are already
23 subject to anthropogenic alteration from water diversion, habitat conversion, pollution,
24 dredging, and urbanization (Swanson 2005). As with other cumulative effects, the
25 contribution of new energy developments to overall impacts on aquatic resources could
26 be additive, synergistic, or offsetting. Predictive models and monitoring techniques will
27 need to be developed to understand and resolve the environmental impacts of large
28 energy projects.

29
30 Adequate understanding of environmental effects of ocean energy and
31 hydrokinetic devices is essential to their acceptance by regulators and the public
32 (Resolve, Inc. 2005). In the initial installations of these new technologies, a proportional
33 response from regulators is appropriate – small deployments are likely to have small,
34 localized impacts. Small-scale monitoring programs will help resolve issues of
35 individual installations and, if results are disseminated, will help focus the more extensive
36 monitoring that will be needed for large deployments. At this early stage of technology
37 development, both regulators and developers need to be open to an adaptive management
38 approach, in which environmental monitoring and phased deployment are adjusted to
39 reflect the findings of the previous monitoring (Cada et al. 2007). The process of
40 collecting environmental effects data might be guided by what is needed to achieve the
41 ultimate goal of full-sized, multi-unit projects. It is also important that developers realize
42 that a “disassembly plan” may be required in the event that environmental impacts of a
43 project cross a previously defined threshold for significant environmental impacts.

44

5. Conclusions

Few marine and hydrokinetic renewable energy technologies have been tested at full scale, therefore it is difficult to resolve all of the uncertainties about their specific environmental effects. Relevant information is available in the scientific literature on potential effects, some of which comes from analogous development in marine environments, such as oil and gas wells and undersea cables. Sound assessment methods, such as ecological risk assessment, are available to evaluate and identify adverse impacts, and mitigation practices have been established to address many of these. Quantitative environmental impact assessment techniques, combined with adaptive management as part of project licensing, can be applied to reduce risks and uncertainties of impacts.

There are numerous conceptual designs for converting the energy of waves, river and tidal currents, and ocean temperature differences into electricity. Appendix B lists well over 100 ocean energy and hydrokinetic renewable energy technologies. Most of these technologies remain at the conceptual stage – they have not yet been tested in the field or as prototype, full-scale devices. Consequently, there have been few studies of their environmental effects. Most considerations of the environmental impacts have been in the form of predictive studies and environmental assessments that have not yet been verified.

The assessments have identified common elements among these technologies that may pose a risk of adverse environmental effects. These potential impacts include the alteration of currents and waves; alteration of substrates and sediment transport and deposition; alteration of habitats for benthic organisms; noise during construction and operation; emission of electromagnetic fields; toxicity of paints, lubricants, and antifouling coatings; interference with animal movements and migrations; and strike by rotor blades or other moving parts. In the case of OTEC, additional potential impacts stem from the intake and discharge of large volumes of sea water, temperature and other water quality changes, and entrainment of aquatic organisms into the intake and discharge plume. Some sense of the significance of each of these issues can be gained from published literature related to other technologies, e.g., noises generated by similar marine construction activities, EMF emissions from existing submarine cables, and environmental monitoring of active offshore wind farms. Experience with other, similar activities in freshwater and marine systems will also provide clues to effective impact minimization and mitigation measures that can be applied to these devices. However, some aspects of the environmental impacts are unique to the technologies, and will require operational studies to determine the seriousness of the effects. This is particularly true for the cumulative effects of large numbers of ocean energy or hydrokinetic devices that will comprise fully built-out projects. For example, there is no existing analogous situation that will allow a confident *a priori* evaluation of the risk of strike from passage through a field of hundreds of horizontal axis turbines or of the biological effects of EMF or noise from a network of generating devices with a matrix of electrical cables in the water column and/or along the bottom. Assessment of these effects will require careful environmental monitoring as the projects are deployed.

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Environmentally sound development of ocean and hydrokinetic renewable energy technologies will benefit from the dissemination of not only site-specific monitoring of existing installations, but also generalized research to understand the nature and severity of impacts associated with particular stressors common to many technologies. Basing the environmental monitoring programs on adaptive management principles, as advocated by many resource and regulatory agencies, would allow ongoing research and monitoring to help refine technology designs and to improve environmental acceptability of future installations.

6. Literature Cited

- 1
2
3 Abaza, H., R. Bisset, and B. Sadler. 2004. Environmental Impact Assessment and
4 Strategic Environmental Assessment: Towards and Integrated Approach. United Nations
5 Environment Programme. Geneva, Switzerland. 163 p.
6 <http://www.unep.ch/etb/publications/EnvImpAss/textONUBr.pdf> (accessed November
7 11, 2008).
8
9 Abbasi, S.A. and N. Abbasi. 2000. The likely adverse environmental impacts of
10 renewable energy sources. *Applied Energy* 65:121-144.
11
12 Andrulowicz, E. D. Napierska, and Z. Otremba. 2003. The environmental effects of the
13 installation and functioning of the submarine *SwePol Link* HVDC transmission line: a
14 case study of the Polish Marine Area of the Baltic Sea. *Journal of Sea Research* 49
15 (2003): 337-345.
16
17 Antizar-Ladislao, B. 2008. Environmental levels, toxicity, and human exposure to
18 tributyltin (TBT)-contaminated marine environment. A review. *Environment*
19 *International* 34 (2008):292-308.
20
21 AquaEnergy, Ltd. 2006. Makah Bay Offshore Wave Energy Pilot Project: FERC Docket
22 No. DI02-3-002: Preliminary Draft Environmental Assessment. 179 pp.
23
24 Arenas, P. and M. Hall. 1992. The association of sea turtles and other pelagic fauna with
25 floating objects in the eastern tropical Pacific Ocean. P. 7-10 IN: M. Salmon and J.
26 Wyneken (compilers). Proceedings of the Eleventh Annual Workshop on Sea Turtle
27 Biology and Conservation. U.S. Department of Commerce, NOAA Technical
28 Memorandum NMFS-SEFSC-302.
29 <http://www.nmfs.noaa.gov/pr/pdfs/species/turtlesymposium1991.pdf> (accessed
30 November 6, 2008).
31
32 ASR, Ltd. 2007. Review of Wave Hub Technical Studies: Impacts on Inshore Surfing
33 Beaches. Version 3. Final Report to South West of England Regional Development
34 Agency, Sutton Harbor, Plymouth, United Kingdom.
35 [http://www.sas.org.uk/pr/2007/docs07/Review-of-Wave-Hub-Technical-Studies-Apr-](http://www.sas.org.uk/pr/2007/docs07/Review-of-Wave-Hub-Technical-Studies-Apr-071.pdf)
36 [071.pdf](http://www.sas.org.uk/pr/2007/docs07/Review-of-Wave-Hub-Technical-Studies-Apr-071.pdf) (accessed April 29, 2007).
37
38 Bahaj, A.S., A.F. Molland, J.R. Chaplin, and W.M.J. Batten. 2007. Power and thrust
39 measurement of marine current turbines under various hydrodynamic flow conditions in a
40 cavitation tunnel and a towing tank. *Renewable Energy* 32:407-426.
41
42 Balayev, L.A. and N.N. Fursa. 1980. The behavior of ecologically different fish in
43 electric fields I. Threshold of first reaction in fish. *Journal of Ichthyology* 20(4): 147-
44 152.
45

1 Basov, B.M. 1999. Behavior of sterlet *Acipenser ruthenus* and Russian sturgeon *A.*
2 *gueldenstaedtii* in low-frequency electric fields. *Journal of Ichthyology* 39(9):782-787.
3

4 Basov, B.M. 2007. On electric fields of power lines and on their perception by
5 freshwater fish. *Journal of Ichthyology* 47(8):656-661.
6

7 Bedard, R. 2005. Hydrokinetic energy “lay of the land.” Proceedings of the
8 Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues
9 Workshop. October 26-28, 2005. Washington, DC.
10 http://hydropower.id.doe.gov/hydrokinetic_wave/index.shtml (accessed October 7, 2008).
11

12 Betke, K., M. Schultz-von Glahn, and R. Matuschek. 2004. Underwater noise emissions
13 from offshore wind turbines. Proceedings of the Joint Congress of CFA/DAGA '04.
14 Strasbourg, France. <http://www.itap.de/daga04owea.pdf> (accessed June 18, 2008).
15

16 BioSonics. 2008. BioSonics Pioneers Environmental Monitoring for the Tidal Power
17 Industry. http://www.biosonicsinc.com/resources/monitoring_tidal_power.html
18 (accessed October 7, 2008).
19

20 Blyth, R.E., M.J. Kaiser, G. Edwards-Jones, and P.J.B. Hart. 2004. Implications of a
21 zoned fishery management system for marine benthic communities. *Journal of Applied*
22 *Ecology* 41:951-961.
23

24 Blyth-Skyrme, R.E., M.J. Kaiser, J.G. Hiddink, G. Edwards-Jones, and P.J.B. Hart. 2006.
25 Conservation benefits of temperate marine protected areas: variation among fish species.
26 *Conservation Biology* 20(3):811-820.
27

28 Bochert R. and M.I. Zettler. 2006. Effect of electromagnetic fields on marine organisms.
29 Chapter 14 in: *Offshore Wind Energy*. J. Koller, J. Koppel, and W. Peters (eds.).
30 Springer-Verlag, Berlin.
31

32 Boehlert, G.W., G.R. McMurray, and C.E. Tortorici (eds.). 2008. Ecological Effects of
33 Wave Energy Development in the Pacific Northwest. U.S. Department of Commerce,
34 NOAA Technical Memorandum NMFS-F/SPO-92. 174 p.
35

36 Boles, L.C. and K.J. Lohmann. 2003. True navigation and magnetic maps in spiny
37 lobsters. *Nature* 421:60-63.
38

39 Buigues, G. I. Zamora, A.J. Mazon, V. Valverde, and F.J. Perez. 2006. Sea energy
40 conversion: problems and possibilities. The International Conference on Renewable
41 Energies and Power Quality (ICREPQ '06). 8 p. ([http://www.icrepq.com/icrepq06/242-](http://www.icrepq.com/icrepq06/242-buigues.pdf)
42 [buigues.pdf](http://www.icrepq.com/icrepq06/242-buigues.pdf) (accessed June 4, 2008).
43

44 Bryden, I.G., T. Grinstead, and G.T. Melville. 2004. Assessing the potential of a simple
45 tidal channel to deliver useful energy. *Applied Ocean Research* 26:198-204.
46

1 Cada, G. F. 1990. A review of studies related to the effects of propeller-type turbine
2 passage on fish early life stages. *North American Journal of Fisheries Management*
3 10(4):418-426.
4

5 Cada, G.F., C.C. Coutant, and R.R. Whitney. 1997. Development of Biological Criteria
6 for the Design of Advanced Hydropower Turbines. DOE/ID-10578. U.S. Department of
7 Energy, Idaho Operations Office, Idaho Falls, ID. 85 p.
8

9 Cada, G.F., J. Smith, and J. Busey. 2005. Use of pressure sensitive film to quantify
10 sources of injury to fish. *North American Journal of Fisheries Management* 25(2):57-66.
11

12 Cada, G.F., J.M. Loar, L. Garrison, R.K. Fisher, and D. Neitzel. 2006. Efforts to reduce
13 mortality to hydroelectric turbine-passed fish: Locating and quantifying damaging shear
14 stresses. *Environmental Management* 37(6):898-906.
15

16 Cada, G.F., J. Ahlgrimm, M. Bahleda, T. Bigford, S. Damiani Stavrakas, D. Hall, R.
17 Moursund, and M. Sale. 2007. Potential impacts of hydrokinetic and wave energy
18 conversion technologies on aquatic environments. *Fisheries* 32(4):174-181.
19

20 Caltrans. 2001. Fisheries Impact Assessment. Pile Installation Demonstration Project.
21 San Francisco-Oakland Bay Bridge East Span Seismic Safety Project. PIDP EA 012081.
22 59 p.
23 [http://www.biomitigation.org/reports/files/PIDP_Fisheries_Impact_Assessment_0_1240.](http://www.biomitigation.org/reports/files/PIDP_Fisheries_Impact_Assessment_0_1240.pdf)
24 [pdf](http://www.biomitigation.org/reports/files/PIDP_Fisheries_Impact_Assessment_0_1240.pdf) (accessed November 5, 2008).
25

26 Carr, M.H. and M.A. Hixon. 1997. Artificial reefs: The importance of comparisons with
27 natural reefs. *Fisheries* 22(4):28-33.
28

29 Carstensen, J., O.D. Henriksen, and J. Teilmann. 2006. Impacts of offshore wind farm
30 construction on harbor porpoises: acoustic monitoring of echolocation activity using
31 porpoise detectors (T-PODSs). *Marine Ecology Progress Series* 321:295-308.
32

33 Castro, J.J., J.A. Santiago, and A.T. Santana-Ortega. 2002. A general theory on fish
34 aggregation to floating objects: An alternative to the meeting point hypothesis. *Reviews*
35 *in Fish Biology and Fisheries* 11:255-277.
36

37 Caswell, H., M. Fujiwara, and S. Brault. 1999. Declining survival probability threatens
38 the North American right whale. *Proceedings of the National Academy of Science USA*.
39 96:3308-3313.
40

41 CMACS (Centre for Marine and Coastal Studies). 2003. A Baseline Assessment of
42 Electromagnetic Fields Generated by Offshore Windfarm Cables. COWRIE Report
43 EMF-01-2002 66. Liverpool, UK. <http://www.offshorewind.co.uk/> (accessed August 20,
44 2008).
45

1 CEQ (Council on Environmental Quality). 2003. Modernizing NEPA Implementation.
2 The NEPA Task Force Report to the Council on Environmental Quality. September
3 2003. <http://ceq.eh.doe.gov/ntf/> (accessed April 9, 2008).
4
5 CEQ (Council on Environmental Quality). 2007. Aligning National Environmental
6 Policy Act Processes with Environment Management Systems. A Guide for NEPA and
7 EMS Practitioners. April 2007. <http://ceq.eh.doe.gov/ntf/> (accessed April 9, 2008).
8
9 Collin, S.P. and D. Whitehead. 2004. The functional roles of passive electroreception in
10 non-electric fishes. *Animal Biology* 54(1):1-25.
11
12 Coutant, C.C. and G.F. Cada. 2005. What's the future of instream hydro? *Hydro Review*
13 XXIV(6):42-49.
14
15 Craig, C., S. Wyllie-Escheverria, E. Carrington, and D. Shafer. 2008. Short-term
16 sediment burial effects on the seagrass *Phyllospadix scouleri*. EMRPP Technical Notes
17 Collection (ERDC TN-EMRRP-EI-03). Vicksburg, MS: U.S. Army Engineer Research
18 and Development Center. 10 p.
19
20 Davis, N., G.R. VanBlaricom, and P.K. Dayton. 1982. Man-made structures on marine
21 sediments: effects on adjacent benthic communities. *Marine Biology* 70:295-303.
22
23 Davison, A. and T. Mallows. 2005. Strangford Lough Marine Current Turbine
24 Environmental Statement (Non-Technical Summary). Project No. 9P5161. Royal
25 Haskoning Ltd., Edinburgh, UK.
26
27 de Jong, D.J., Z. de Jong, and J.P.M. Mulder. 1994. Changes in area, geomorphology,
28 and sediment nature of salt marshes in the Oosterschelde estuary (SW Netherlands) due
29 to tidal changes. *Hydrobiologia* 282/283:303-316.
30
31 Dempster, T. 2005. Temporal variability of pelagic fish assemblages around fish
32 aggregation devices: biological and physical influences. *Journal of Fish Biology*
33 66:1237-1260.
34
35 Dempster, T. and M. Taquet. 2004. Fish aggregation device (FAD) research: gaps in
36 current knowledge and future directions for ecological studies. *Reviews in Fish Biology*
37 and Fisheries 14:21-42.
38
39 Deng, D.L., T.J. Carlson, G.R. Ploskey, and M.C. Richmond. 2005. Evaluation of Blade-
40 Strike Models for Estimating the Biological Performance of Large Kaplan Turbines.
41 PNNL-15370. Pacific Northwest National Laboratory, Richland, WA.
42
43 DOI (U.S. Department of the Interior). 2007. Adaptive Management. Order No. 3270.
44 March 9, 2007.
45

1 DOI (U.S. Department of the Interior). 2008. Adaptive Management Implementation
2 Policy. 522 DM 1. February 1, 2008.
3 http://elips.doi.gov/app_DM/act_getfiles.cfm?relnum=3786 (accessed 10/22/08).
4
5 DON (U.S. Department of the Navy). 2003. Environmental Assessment – Proposed
6 Wave Energy Technology Project. Marine Corps Base Hawaii, Kaneohe Bay, Hawaii.
7 Office of Naval Research.
8
9 Efroymsen, R.A., J.P. Nicolette, and G.W. Suter II. 2004. A framework for net
10 environmental benefit analysis for remediation or restoration of contaminated sites.
11 Environmental Management 34(3):315-331.
12
13 Elsam Engineering and Energi E2. 2005. The Danish Offshore Wind Farm
14 Demonstration Project: Horns Rev and Nysted Offshore Wind Farms. Environmental
15 Impact Assessment and Monitoring. Review Report 2004. 135 p.
16 <http://www.hornsrev.dk/Miljoeforhold/miljoerapporter/review%20rapport%202004%20v>
17 [ersion0.pdf](http://www.hornsrev.dk/Miljoeforhold/miljoerapporter/review%20rapport%202004%20v) (accessed August 19, 2008).
18
19 EMEC (European Marine Energy Centre). 2005. Environmental Impact Assessment
20 (EIA) Guidance for Developers at the European Marine Energy Centre. Revision 0,
21 March 2005. http://www.emec.org.uk/emec_documents.asp (accessed October 6, 2008).
22
23 Enger, P.S., L. Kristensen, and O. Sand. 1976. The perception of weak electric d.c.
24 currents by the European eel (*Anguilla anguilla*). Comparative Biochemistry and
25 Physiology 54A:101-103.
26
27 EPA (U.S. Environmental Protection Agency). 1998. Guidelines for Ecological Risk
28 Assessment. EPA/630/R-95/002F. April 1998. Washington, DC.
29 <http://www.epa.gov/portfolio/learn/ecorisk/html/resource/guidelines.pdf> (accessed
30 October 28, 2008).
31
32 FAA (Federal Aviation Administration). 2004. Environmental Management Systems and
33 NEPA Adaptive Management. May 2004.
34 <http://www.faa.gov/regulations%5Fpolicies/policy%5Fguidance/envir%5Fpolicy/>
35 (accessed April 9, 2008).
36
37 Faber Maunsell and Metoc. 2007. Scottish Marine SEA: Environmental Report Section
38 C. Chapter C9: Marine Mammals. Scottish Executive. 42 p. + figures.
39
40 Fast, A.W., F.M. D'Itri, D.K. Barclay, S.A. Katase, and C. Madenjian. 1990. Heavy
41 metal content of coho *Onchorhynchus kisutch* and Chinook salmon *O. tshawytscha*
42 reared in deep upwelled ocean waters in Hawaii. Journal of the World Aquaculture
43 Society 21(4):271-276.
44
45 FERC (Federal Energy Regulatory Commission). 2006. Makah Bay Offshore Energy
46 Pilot Project. FERC Docket No. DI02-3-002. Preliminary Draft Environmental

1 Assessment. FERC Office of Energy Projects, Washington, DC. 179 p.
2 http://www.finavera.com/files/Makah%20Bay%20PDEA_0.pdf (accessed October 3,
3 2008).
4
5 FERC (Federal Energy Regulatory Commission). 2008. Licensing Hydrokinetic Pilot
6 Projects. April 14, 2008. [http://www.ferc.gov/industries/hydropower/indus-
7 act/hydrokinetics.asp](http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics.asp) (accessed November 13, 2008).
8
9 Fernandez, A., J.F. Edwards, F. Rodriguez, A. Espinosa de los Monteros, P. Harraez, P.
10 Castro, J.R. Jaber, V. Martin, and M. Arbelo. 2005. "Gas and fat embolic syndrome"
11 involving a mass stranding of beaked whales (Family Ziphiidae) exposed to
12 anthropogenic sonar signals. *Veterinary Pathology* 42:446-457.
13
14 Forbes, V.E. and P. Calow. 2002. Applying weight-of-evidence on retrospective
15 ecological risk assessment when quantitative data are limited. *Human and Ecological*
16 *Risk Assessment* 8(7):1625-1639.
17
18 Fraenkel, P.L. 2006. Tidal current energy technologies. *Ibis* 148:145-151.
19
20 Fraenkel, P.L. 2007a. Marine current turbines: Pioneering the development of marine
21 kinetic energy converters. *Proceedings of the Institution of Mechanical Engineers, Part*
22 *A: Journal of Power and Energy*. 221(2):159-169.
23
24 Fraenkel, P.L. 2007b. Marine current turbines: Moving from experimental test rigs to a
25 commercial technology. 26th International Conference on Offshore Mechanics & Arctic
26 Engineering. ASME-OMAE07. 10 p.
27
28 FWS (U.S. Fish and Wildlife Service). 1993. Mitigation Policy. 501 FW 2. February 24,
29 1993. <http://www.fws.gov/policy/501fw2.html> (accessed 10/22/08).
30
31 FWS (U.S. Fish and Wildlife Service). 2005. Habitat Conservation Plans, Working
32 Together for Endangered Species. March 2005.
33 [http://www.fws.gov/endangered/pubs/HCPBrochure/HCPsWorkingTogether5-
34 2005web%20.pdf](http://www.fws.gov/endangered/pubs/HCPBrochure/HCPsWorkingTogether5-2005web%20.pdf) (accessed 10/21/08).
35
36 FWS/NOAA (U.S. Fish and Wildlife Service and National Oceanic and Atmospheric
37 Administration). 2000a. Addendum to the HCP Handbook Questions and Answers. May
38 2000. http://www.fws.gov/endangered/pdfs/HCP/Final_Addendum_QandA.pdf (accessed
39 10/21/08).
40
41 FWS/NOAA (U.S. Fish and Wildlife Service and National Oceanic and Atmospheric
42 Administration). 2000b. Availability of a Final Addendum to the Handbook for Habitat
43 Conservation Planning and Incidental Take Permitting Process; Notice. June 1, 2000. 65
44 FR 35241-35257. http://www.fws.gov/endangered/pdfs/HCP/final_notice.pdf
45 (accessed 10/21/08).
46

1 Gell, F.R. and C. M. Roberts. 2003. Benefits beyond boundaries: the fishery effects of
2 marine reserves. *Trends in Ecology and Evolution* 18(9):448-455.
3
4 Genzer, J. and K. Efimenko. 2006. Recent developments in superhydrophobic surfaces
5 and their relevance to marine fouling: a review. *Biofouling* 22(5):339-360.
6
7 Gill, A.B. 2005. Offshore renewable energy: ecological implications of generating
8 electricity in the coastal zone. *Journal of Applied Ecology* 42:605-615.
9
10 Gill, A.B. and H. Taylor. 2002. The potential effects of electromagnetic fields generated
11 by cabling between offshore wind turbines upon elasmobranch fishes. Report to the
12 Countryside Council for Wales (CCW Contract Science Report No. 488). 60 p.
13
14 Gill, A.B., I. Gloyne-Phillips, K.J. Neal, and J.A. Kimber. 2005. The Potential Effects of
15 Electromagnetic Fields Generated by Sub-Sea Power Cables Associated with Offshore
16 Wind Farm Developments on Electrically and Magnetically Sensitive Marine Organisms
17 – A Review. COWRIE Report EM Field 2-06-2004. <http://www.offshorewind.co.uk/>
18 (accessed May 1, 2008).
19
20 Gordon, J., D. Thompson, D. Gillespie, M. Lonergan, S. Calderan, B. Jaffey, and V.
21 Todd. 2007. Assessment of the potential for acoustic deterrents to mitigate the impact on
22 marine mammals of underwater noise arising from the construction of offshore
23 windfarms. COWRIE DETER-01-2007. July 2007. 71 p.
24 <http://www.offshorewindfarms.co.uk/Pages/Publications/> (accessed August 7, 2008).
25
26 Gould, J.L. 1984. Magnetic field sensitivity in animals. *Annual Reviews in Physiology*
27 46:585-598.
28
29 Griffiths, J. 2005. European Marine Energy Centre. Pages 80-84 in *Proceedings of the*
30 *Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues*
31 *Workshop*. U.S. Department of Energy, Washington, DC.
32 http://hydropower.id.doe.gov/hydrokinetic_wave/index.shtml (accessed October 7, 2008).
33
34 Grossman, G.D., G.P. Jones, and W.J. Seaman, Jr. 1997. Do artificial reefs increase
35 regional fish production? A review of existing data. *Fisheries* 22(4):17-23.
36
37 Halpern, B.S., S.D. Gaines, and R.R. Warner. 2004. Confounding effects of the export of
38 production and the displacement of fishing effort from marine reserves. *Ecological*
39 *Applications* 14(4):1248-1256.
40
41 Hamilton, W.S. 1983. Preventing cavitation damage to hydraulic structures. Part one.
42 *Water Power and Dam Construction*. November, 1983. p. 48-53.
43
44 Harrison, J.T. 1987. The 40 MWe OTEC Plant at Kahe Point, Oahu, Hawaii: A Case
45 Study of Potential Biological Impacts. NOAA Technical Memorandum NMFS NOAA-
46 TM-NMFS-SWFC-68. Southwest Fisheries Center, Honolulu, HI. 105 p.

1
2 Hastings, M.C. and A.N. Popper. 2005. Effects of Sound on Fish. Report to California
3 Department of Transportation. January 28, 2005. 82 p.
4 http://www.dot.ca.gov/hq/env/bio/files/Effects_of_Sound_on_Fish23Aug05.pdf
5 (accessed August 7, 2008).
6
7 Heydt, G.T. 1993. An assessment of ocean thermal energy conversion as an advanced
8 electric generation methodology. Proceedings of the Institute of Electrical and
9 Electronics Engineers 81(3):409-418.
10
11 Holdren, J.P., G. Morris, and I. Mintzer. 1980. Environmental aspects of renewable
12 energy sources. Annual Review of Energy 5:241-291.
13
14 IAIA (International Association for Impact Assessment). 2002. Strategic Environmental
15 Assessment Performance Criteria. Special Publication Series No. 1. 1 p.
16 <http://www.iaia.org/modx/assets/files/sp1.pdf> (accessed November 11, 2008).
17
18 Irwin, W.P. and K.J. Lohmann. 1996. Disruption of magnetic orientation in hatchling
19 loggerhead sea turtles by pulsed magnetic fields. Journal of Comparative Physiology A
20 191:475-480.
21
22 ISO (International Organization for Standardization). 2004. ISO 14001:2004.
23 Environmental Management Systems – Requirements with Guidance for Use.
24 http://www.iso.org/iso/iso_14000_essentials (accessed April 9, 2008).
25
26 Jennings, S., J.K. Pinnegar, N.V.C. Polunin, and K.J. Warr. Impacts of trawling
27 disturbance on the trophic structure of benthic invertebrate communities. Marine
28 Ecology Progress Series 213:127-142.
29
30 Johnsen, S. and K.J. Lohmann. 2005. The physics and neurobiology of
31 magnetoreception. Neuroscience 6:703-712.
32
33 Johnsen, S. and K.J. Lohmann. 2008. Magnetoreception in animals. Physics Today.
34 61(3):29-35.
35
36 Johnson, A., G. Salvador, J. Kenney, J. Robbins, S. Kraus, S. Landry, and P. Clapham.
37 2005. Fishing gear involved in entanglements of right and humpback whales. Marine
38 Mammal Science 21(4):635-645.
39
40 Kaiser, M.J., F.E. Spence, and P.J.B. Hart. 2000. Fishing-gear restrictions and
41 conservation of benthic habitat complexity. Conservation Biology 14(5):1512-1525.
42
43 Kaiser, M.J. 2005. Are marine protected areas a red herring or fisheries panacea.
44 Canadian Journal of Fisheries and Aquatic Sciences 62:1194-1199.
45

1 Kalmijn, A.T. 1982. Electric and magnetic field detection in elasmobranch fishes.
2 Science 218(4575):916-918.
3
4 Kalmijn, A.T. 2000. Detection and processing of electromagnetic and near-field acoustic
5 signals in elasmobranch fishes. Philosophical Transactions of the Royal Society of
6 London B. 355:1135-1141.
7
8 Kingsford, M.J. 1999. Fish attraction devices (FADs) and experimental designs.
9 Scientia Marina 63(3-4):181-190.
10
11 Kirke, B.K. 2006. Developments in Ducted Water Turbines. Cyberiad. Adelaide,
12 Australia. 12 p. <http://www.cyberiad.net/tide.htm> (accessed June 5, 2008).
13
14 Kogan, I., C.K. Paull, L.A. Kuhnz, E.J. Burton, S. Von Thun, H.G. Greene, and J.P.
15 Barry. 2006. ATOC/Pioneer Seamount cable after 8 years on the seafloor: Observations,
16 environmental impact. Continental Shelf Research 26 (2006):771-787.
17
18 Koschinski, S., B.M. Kulik, O.D. Henriksen, N. Tregenza, G. Ellis, C. Jansen, and G.
19 Kathe. 2003. Behavioural reactions of free-swimming porpoises and seals to the noise of
20 a simulated 2 MW windpower generator. Marine Ecology Progress Series 265:263-273.
21
22 Kraus, S.D., M.W. Brown, H. Caswell, C.W. Clark, M. Fujiwara, P.K. Hamilton, R.D.
23 Kenney, A. R. Knowlton, S. Landry, C.A. Mayo, W.A. McLellan, M.J. Moore, D.P.
24 Nowacek, D.A. Pabst, A.J. Read, and R.M. Rolland. 2005. North Atlantic right whales in
25 crisis. Science 309:561-562.
26
27 Lane, N. 2007. Issues Affecting Tidal, Wave, and In-Stream Generation Projects.
28 Congressional Research Service Report to Congress, Order code RL33883, Updated
29 September 20, 2007.
30
31 Langhamer, O. Undated. Man-made offshore installations: Are marine colonizers a
32 problem or an advantage? Introductory Research Essay, Uppsala University. 21 p.
33 [http://www.el.angstrom.uu.se/forskningsprojekt/Islandsberg_pek/Man-](http://www.el.angstrom.uu.se/forskningsprojekt/Islandsberg_pek/Man-made%20offshore%20installations.pdf)
34 [made%20offshore%20installations.pdf](http://www.el.angstrom.uu.se/forskningsprojekt/Islandsberg_pek/Man-made%20offshore%20installations.pdf) (accessed August 11, 2008).
35
36 Langlois, T.J., M.J. Anderson, and R.C. Babcock. 2005. Reef-associated predators
37 influence adjacent soft-sediment communities. Ecology 86(6):1508-1519.
38
39 Layman, S.R., M.J. Kealy, and J.P. Nicolette. 2000. Use of a net environmental benefits
40 analysis approach in the alternative hydropower licensing process. Proceedings of
41 HydroVision 2000, HCI Publications, Inc., Kansas City, MO.
42
43 Lewis, L.J., J. Davenport, and T.C. Kelly. A study of the impact of a pipeline
44 construction on estuarine benthic invertebrate communities. Part 2. Recolonization by
45 benthic invertebrates after 1 year and response of estuarine birds. Estuarine, Coastal and
46 Shelf Sciences 57 (2003):201-208.

1
2 Lohmann, K.J. and C.M.F. Lohmann 1996. Detection of magnetic field intensity by sea
3 turtles. *Nature* 380:59-61.
4
5 Longmuir, C. and T. Lively. 2001. Bubble curtain systems help protect the marine
6 environment. *Pile Driver Magazine*. Summer 2001. p. 11-16.
7
8 Love, M.S., J. Caselle, and L. Snook. 1999. Fish assemblages on mussel mounds
9 surrounding seven oil platforms in the Santa Barbara Channel and Santa Maria Basin.
10 *Bulletin of Marine Science* 65(2):497-513.
11
12 Lugo-Fernandez, A. H.H. Roberts, and W.J. Wiseman, Jr. 1998. Tide effects on wave
13 attenuation and wave set-up on a Caribbean coral reef. *Estuarine, Coastal and Shelf*
14 *Science* 47:385-393.
15
16 Madsen, P.T. 2005. Marine mammals and noise: Problems with root mean square sound
17 pressure levels for transients. *Journal of the Acoustic Society of America* 117(6):3952-
18 3957.
19
20 Marra, L.J. 1989. Sharkbite on the SL submarine lightwave cable system: History,
21 causes, and resolution. *IEEE Journal of Oceanic Engineering* 14(3):230-237.
22
23 McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M-N. Jenner, J.D. Penrose, R.I.T.
24 Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine Seismic Surveys:
25 Analysis and Propagation of Air-Gun Signals; and Effects of Air-Gun Exposure on
26 Humpback Whales, Sea Turtles, Fishes and Squid. Report R99-15. Centre for Marine
27 Science and Technology, Curtin University of Technology, Western Australia.
28
29 McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M-N. Jenner, J.D. Penrose, R.I.T.
30 Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000b. Marine seismic surveys: a study
31 of environmental implications. *Australian Petroleum Production Exploration Association*
32 *Journal* 2000:692-708.
33
34 McDonald, B.G., A.M.H. deBruyn, B.G. Wernick, L. Paterson, N. Pallerin, and P.M.
35 Chapman. 2007. Design and application of a transparent and scalable weight-of-evidence
36 framework: an example from Wabamun Lake, Alberta, Canada. *Integrated*
37 *Environmental Assessment and Management* 3(4):476-483.
38
39 Meyer, C.G., K.N. Holland, and Y.P. Papastamatiou. 2004. Sharks can detect changes in
40 the geomagnetic field. *Journal of the Royal Society Interface* 2(2):129-130.
41
42 Michel, J., H. Dunagan, C. Boring, E. Healy, W. Evans, J. Dean, A. McGillis, and J.Hain.
43 2007. Worldwide Synthesis and Analysis of Existing Information Regarding
44 Environmental Effects of Alternative Energy Uses on the Outer Continental Shelf. OCS
45 Report MMS 2007-038. Minerals Management Service, U.S. Department of the Interior,

1 Washington, DC. <http://www.mms.gov/offshore/AlternativeEnergy/Studies.htm>
2 (accessed April 25, 2008).
3
4 Michel, J. and E. Burkhard. 2007. Workshop to Identify Alternative Energy
5 Environmental Information Needs – Workshop Summary. OCS Report MMS 2007-057.
6 Minerals Management Service, U.S. Department of the Interior, Washington, DC.
7 <http://www.mms.gov/offshore/AlternativeEnergy/Studies.htm> (accessed April 25, 2008).
8
9 Millar, D.L., H.C.M. Smith, and D.E. Reeve. 2007. Modelling analysis of the sensitivity
10 of shoreline change to a wave farm. *Ocean Engineering* 34(2007):884-901.
11
12 MMS (Minerals Management Service). 2007. Programmatic Environmental Impact
13 Statement for Alternative Energy Development and Production and Alternate Uses of
14 Facilities on the Outer Continental Shelf. Final EIS. MMS 2007-046. October 2007.
15 <http://ocsenergy.anl.gov/> (accessed August 13, 2008).
16
17 Moore, S.E. and J.T. Clarke. 2002. Potential impact of offshore human activities on gray
18 whale (*Eschrichtius robustus*). *Journal of Cetacean Research and Management* 4(1):19-
19 25.
20
21 MPA (U.S. Marine Protected Areas). 2008. The Marine Protected Areas Inventory.
22 <http://www.mpa.gov/> (accessed November 13, 2008).
23
24 Myers, E.P., D.E. Hoss, D.S. Peters, W.M. Matsumoto, M.P. Seki, R.N. Uchida, J.D.
25 Ditmars, and R.A. Paddock. 1986. The potential impact of ocean thermal energy
26 conversion (OTEC) on fisheries. NOAA Technical Report NMFS 40. U.S. Department of
27 Commerce, Seattle, WA. 33 pp.
28
29 Nedwell, J.R., B. Edwards, A.W.H. Turnpenny, and J. Gordon. 2004. Fish and Marine
30 Mammals Audiograms: A Summary of Available Information. Subacoustech Report ref:
31 534R0214 to Chevron Texaco Ltd., TotalFinaElf Exploration UK Plc, DSTL, DTI and
32 Shell U.K. Exploration and Production Ltd. 281 p.
33 <http://www.subacoustech.com/information/publications.shtml> (accessed May 30, 2008).
34
35 Nehls, G., K. Betke, S. Eckelmann, and M. Ros. 2007. Assessment and costs of potential
36 engineering solutions for the mitigation of the impacts of underwater noise arising from
37 the construction of offshore windfarms. COWRIE ENG-01-2007. October 2007. 47 p.
38 <http://www.offshorewindfarms.co.uk/Pages/Publications/> (accessed August 7, 2008).
39
40 Nelson, P.A. 2003. Marine fish assemblages associated with fish aggregating devices:
41 Effects of fish removal, FAD size, fouling communities, and prior recruits. *Fishery*
42 *Bulletin* 101(4):835-850.
43
44 Nelson, P.A., D. Behrens, J. Castle, G. Crawford, R.N. Gaddam, S.C. Hackett, J. Largier,
45 D.P. Lohse, K.L. Mills, P.T. Raimondi, M. Robart, W.J. Sydeman, S.A. Thompson, and
46 S. Woo. 2008. Developing Wave Energy in Coastal California: Potential Socio-

1 Economic and Environmental Effects. California Energy Commission, PIER Energy-
2 Related Environmental Research Program & California Ocean Protection Council CEC-
3 500-2008-083. http://www.resources.ca.gov/copc/docs/ca_wec_effects.pdf (accessed
4 November 19, 2008).
5
6 Nendza, M. 2007. Hazard assessment of silicone oils (polydimethylsiloxanes, PDMS)
7 used in antifouling-/foul-release-products in the marine environment. *Marine Pollution*
8 *Bulletin* 54:1190-1196.
9
10 Newcombe, C.P. and J.O.T. Jensen. 1996. Channel suspended sediment and fisheries: A
11 synthesis for quantitative assessment of risk and impact. *North American Journal of*
12 *Fisheries Management* 16(4): 693-727.
13
14 Nicholls-Lee, R.F. and S.R. Turnock. 2007. The use of computational fluid dynamics in
15 the optimisation of marine current turbines. *Proceedings of NuTTS 2007: 10th Numerical*
16 *Towing Tank Symposium, September 23-25, 2007, Hamburg, Germany.* 6 p.
17
18 NMFS (National Marine Fisheries Service). 2003. Taking Marine Mammals Incidental
19 to Conducting Oil and Gas Exploration Activities in the Gulf of Mexico. March 3, 2003.
20 *Federal Register* 68(41):9991-9996.
21
22 NOAA (National Oceanic and Atmospheric Administration). 2008. Environmental
23 Sensitivity Index Mapping. NOAA's National Ocean Service, Office of Response and
24 Restoration. http://response.restoration.noaa.gov/book_shelf/827_ERD_ESI.pdf
25 (accessed November 13, 2008).
26
27 Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of
28 cetaceans to anthropogenic noise. *Mammal Review* 37(2):81-115.
29
30 NRC (National Research Council). 2000. *Marine Mammals and Low-Frequency Sound.*
31 *Progress Since 1994.* National Academy Press, Washington, DC.
32
33 NRC (National Research Council). 2003. *Ocean Noise and Marine Mammals.* National
34 *Academies Press, Washington, DC.*
35
36 NRC (National Research Council). 2004. *Adaptive Management for Water Resources*
37 *Planning.* The National Academies Press. Washington, DC.
38
39 NRC (National Research Council). 2005. *Marine Mammal Populations and Ocean*
40 *Noise: Determining when Noise Causes Biologically Significant Effects.* National
41 *Academy Press, Washington, DC.*
42
43 Ogden, J. 2005. Resource concerns associated with the off-shore environment. Pages
44 51-53 in *Proceedings of the Hydrokinetic and Wave Energy Technologies Technical and*
45 *Environmental Issues Workshop.* U.S. Department of Energy, Washington, DC.
46 http://hydropower.id.doe.gov/hydrokinetic_wave/index.shtml (accessed October 7, 2008).

1
2 Ohman, M.C., P. Sigray, and H. Westerberg. 2007. Offshore windmills and the effects of
3 electromagnetic fields on fish. *Ambio* 36(8):630-633.

4
5 PFMC (Pacific Fisheries Management Council). 2008. June 17, 2008 letter from D.O.
6 McIsaac, Executive Director of PFMC to Director Randall Luthi, Minerals Management
7 Service, regarding Docket ID MMS-2008-OMM-0020.

8
9 Parvin, S.J., J.R. Nedwell, and E. Harland. 2007. [Lethal and Physical Injury of Marine](#)
10 [Mammals, and Requirements for Passive Acoustic Monitoring](#). Subacoustech Report
11 Reference: 565R0212, February 2007 to DTI, 1 Victoria Street, London, SW1H 0ET.
12 <http://www.subacoustech.com/information/publications.shtml> (accessed May 30, 2008).

13
14 Pelc, R. and R.M. Fujita. 2002. Renewable energy from the ocean. *Marine Policy*
15 26:471-479.

16
17 PFMC (Pacific Fisheries Management Council). 2007. Marine Reserves.
18 <http://www.pcouncil.org/reserves/reservesback.html> (accessed November 13, 2008).

19
20 Ploskey, G.R. and T.J. Carlson. 2004. Comparison of Blade-Strike Modeling Results
21 with Empirical Data. PNNL-14603. Pacific Northwest National Laboratory, Richland,
22 WA.

23
24 Popper, A.N. 2003. Effects of anthropogenic sound on fishes. *Fisheries* 28:24-31.

25
26 Prato, T. 2003. Adaptive management of large rivers with special reference to the
27 Missouri River. *Journal of the American Water Resources Association (JAWRA)*
28 39(4):935-946.

29
30 Resolve, Inc. 2005. Proceedings of the Hydrokinetic and Wave Energy Technologies
31 Technical and Environmental Issues Workshop. U.S. Department of Energy,
32 Washington, DC. http://hydropower.id.doe.gov/hydrokinetic_wave/index.shtml (accessed
33 October 7, 2008).

34
35 Roberts, H.H., P.A. Wilson, and A. Lugo-Fernandez. 1992. Biologic and geologic
36 responses to physical processes: examples from modern reef systems of the Caribbean-
37 Atlantic region. *Continental Shelf Research* 12(7/8):809-834.

38
39 Rodil, I.F. and M. Lastra. 2004. Environmental factors affecting benthic macrofauna
40 along a gradient of intermediate sandy beaches in northern Spain. *Estuarine, Coastal and*
41 *Shelf Science* 61:37-44.

42
43 Rodrigue, P.R. 1986. Cavitation pitting mitigation in hydraulic turbines. Volume 2:
44 cavitation review and assessment. EPRI AP-4719, Electric Power Research Institute,
45 Palo Alto, CA.

46

1 Rommel, S.A. Jr. and J.D. McCleave. 1972. Oceanic electric fields: perception by
2 American eels? *Science* 176:1233-1235.
3

4 Senecal, P., B. Goldsmith, S. Conover, B. Sadler, and K. Brown. 1999. Principles of
5 Environmental Impact Assessment Best Practice. 4 p.
6 http://www.iaia.org/modx/assets/files/Principles%20of%20IA_web.pdf (accessed
7 November 11, 2008).
8

9 Simmonds, M.P., S.J. Dolman, and L. Weilgart (eds.). 2003. Oceans of Noise. A Whale
10 and Dolphin Conservation Society Science Report. 164 p. www.wdcs.org (accessed
11 May 30, 2008).
12

13 Smith, H.C.M., D.L. Millar, and D.E. Reeve. 2007. Generalization of wave farm impact
14 assessment on inshore wave climate. Proceedings of the 7th European Wave and Tidal
15 Energy Conference, September 11-13, 2007, Porto, Portugal. 7 p.
16 [http://www.see.ed.ac.uk/comp/pcsoft/apps/shire/.n/Research-](http://www.see.ed.ac.uk/comp/pcsoft/apps/shire/.n/Research-Institutes/ies/Conf_proceedings/EWTEC_2007/papers/1060.pdf)
17 [Institutes/ies/Conf_proceedings/EWTEC_2007/papers/1060.pdf](http://www.see.ed.ac.uk/comp/pcsoft/apps/shire/.n/Research-Institutes/ies/Conf_proceedings/EWTEC_2007/papers/1060.pdf) (accessed October 6,
18 2008).
19

20 Smith, R. 2007. The Roosevelt Island Tidal Energy (RITE) Project Environmental
21 Assessment. Environmental Monitoring, Evaluation and Protection in New York:
22 Linking Science and Policy. Presentation at the New York State Energy Research and
23 Development Authority Conference, November 15-16, 2007.
24 http://www.nyserda.org/Programs/Environment/EMEP/conference_2007/Smith_Ron.pdf
25 (accessed October 7, 2008).
26

27 Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr.,
28 D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and
29 P.L. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific
30 recommendations. *Aquatic Mammals* 33(4):411-521.
31

32 Sundberg J. and O. Langhamer. 2005. Environmental questions related to point-absorbing
33 linear wave-generators: impact, effects and fouling. In: Proceeding of the 6th European
34 Wave and Tidal Energy Conference. 30th August–2nd September 2005. Glasgow,
35 Scotland.
36

37 Suter, G.W. II, S.B. Norton, and S.M. Cormier. 2002. A methodology for inferring the
38 causes of observed impairments in aquatic ecosystems. *Environmental Toxicology and*
39 *Chemistry* 21(6):1101-1111.
40

41 Swanson, T. 2005. Resource concerns associated with estuaries. Pages 45-49 in
42 Proceedings of the Hydrokinetic and Wave Energy Technologies Technical and
43 Environmental Issues Workshop. U.S. Department of Energy, Washington, DC.
44 http://hydropower.id.doe.gov/hydrokinetic_wave/index.shtml (accessed October 7, 2008).
45

1 TCPA (Texas Comptroller of Public Accounts). 2008. Ocean Power. Chapter 20 in The
2 Energy Report. May, 2008. <http://www.window.state.tx.us/specialrpt/energy/> (accessed
3 June 4, 2008).
4
5 The Engineering Business Ltd. 2005. Stingray Tidal Stream Energy Device – Phase 3.
6 T/06/00230/00/REP URN 05/864. 110 p. + appendices.
7 <http://www.engb.com/downloads/Stingray%20Phase%203r.pdf> (accessed August 18,
8 2008).
9
10 Thomsen, F., K. Ludeman, R. Kafemann, and W. Piper. 2006. Effects of offshore wind
11 farm noise on marine mammals and fish. biola, Hamburg, Germany on behalf of
12 COWRIE, Ltd. www.offshorewind.uk (accessed May 12, 2008).
13
14 Tougaard, J., J. Carstensen, J. Teilmann, and N.I. Bech. 2005. Effects of the Nysted
15 Offshore Wind Farm on harbour porpoises. Annual status report for the T-POD
16 monitoring program. NERI Technical Report. 49 p.
17 http://uk.nystedhavmoellepark.dk/upload/pdf/marsvin_2004.pdf (accessed August 7,
18 2008).
19
20 Turnpenny, A.W.H., M.H. Davis, J.M. Fleming, and J.K. Davies. 1992. Experimental
21 studies relating to the passage of fish and shrimps through tidal power turbines. Marine
22 and Freshwater Biology Unit, National Power, Fawley, Southampton, Hampshire,
23 England.
24
25 USACE (U.S. Army Corps of Engineers). 1995. Proceedings: 1995 Turbine Passage
26 Survival Workshop. U.S. Army Corps of Engineers, Portland District, Portland, OR.
27 212 p. + appendices.
28
29 Viada, S.T., R.M. Hammer, R. Racca, D. Hannay, M.J. Thompson, B.J. Balcom, and
30 N.W. Phillips. 2008. Review of potential impacts to sea turtles from underwater
31 explosive removal of offshore structures. Environmental Impact Assessment Review
32 28(2008): 267-285.
33
34 Videler, J.J. and C.S. Wardle. 1991. Fish swimming stride by stride: speed limits and
35 endurance. Reviews in Fish Biology and Fisheries 1:23-40.
36
37 Wahlberg, M. and H. Westerberg. 2005. Hearing in fish and their reactions to sounds
38 from offshore wind farms. Marine Ecology Progress Series 288:295-309.
39
40 Walker, M.M., C.E. Diebel, C.V. Haugh, P.M. Pankhurst, J.C. Montgomery, and C.R.
41 Green. 1997. Structure and function of the vertebrate magnetic sense. Nature 390:371-
42 376.
43
44 Walker, M.M., T.P. Quinn, J.L. Kirschvink, and C. Groot. Production of single-domain
45 magnetite throughout life by sockeye salmon, *Oncorhynchus nerka*. Journal of
46 Experimental Biology 140:51-63.

1
2 Walters, C. 1986. Adaptive Management of Renewable Resources. Macmillan
3 Publishing Company, New York. 374 p.
4
5 Watermann, B.T., B. Daehne, S. Seivers, R. Dannenberg, J.C. Overbeke, J.W. Klijnstra,
6 and O. Heemken. 2005. Bioassays and selected chemical analysis of biocide-free
7 antifouling coatings. *Chemosphere* 60(2005):1530-1541.
8
9 Watten, W.M.J., A.S. Bahaj, A.F. Molland, and J.R. Chaplin. 2006. Hydrodynamics of
10 marine current turbines. *Renewable Energy* 31:249-256.
11
12 Wave Dragon Wales Ltd. 2007. Wave Dragon Pre-Commerical Wave Energy Device.
13 Volume 2, Environmental Statement. April, 2007. <http://www.wavedragon.co.uk/>
14 (accessed August 4, 2008).
15
16 Webster, D.C., B.J. Chisholm, and S.J. Stafslie. 2007. Mini-review: combinatorial
17 approaches for the design of novel coating systems. *Biofouling* 23(3/4):179-192.
18
19 Weilgart, L.S. 2007. The impacts of anthropogenic ocean noise on cetaceans and
20 implications for management. *Canadian Journal of Zoology* 85:1091-1116.
21
22 Widdows, J. and M. Brinsley. 2002. Impact of biotic and abiotic processes on sediment
23 dynamics and the consequences to the structure and functioning of the intertidal zone.
24 *Journal of Sea Research* 48:143-156.
25
26 Wilber, D.H. and D.G. Clarke. 2001. Biological effects of suspended sediments: A
27 review of suspended sediment impacts on fish and shellfish with relation to dredging
28 activities in estuaries. *North American Journal of Fisheries Management* 21(4):855-875.
29
30 Wilber, D. H., W. Brostoff, D.G. Clarke, and G.L. Ray. 2005. Sedimentation: Potential
31 biological effects from dredging operations in estuarine and marine environments. DOER
32 Technical Notes Collection ERDC TN-DOER-E20. U.S. Army Engineer Research and
33 Development Center, Vicksburg, MS. [http://stinet.dtic.mil/cgi-](http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA434926&Location=U2&doc=GetTRDoc.pdf)
34 [bin/GetTRDoc?AD=ADA434926&Location=U2&doc=GetTRDoc.pdf](http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA434926&Location=U2&doc=GetTRDoc.pdf)
35
36 Wilhelmsson, D., T. Malm, and M.C. Ohman. 2006. The influence of offshore
37 windpower on demersal fish. *ICES Journal of Marine Science* 63:775-784.
38
39 Wilhelmsson, D. and T. Malm. In Press. Fouling assemblages on offshore wind power
40 plants and adjacent substrata. *Estuarine, Coastal and Shelf Science* (2008).
41
42 Wilkens, L.A. and M.H. Hoffman. 2005. Behavior of animals with passive, low-
43 frequency electrosensory systems. Pages 229-263 In: *Electroreception*. T.H. Bullock,
44 C.D. Hopkins, A.N. Popper, and R.R. Fay (eds.). Springer Handbook of Auditory
45 Research Volume 21, Springer, New York.
46

1 Williams, H. 2005. Open center turbine. Pages 12-13 In: Proceedings of the
2 Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues
3 Workshop. U.S. Department of Energy, Washington, DC.
4 http://hydropower.id.doe.gov/hydrokinetic_wave/index.shtml (accessed October 7, 2008).
5
6 Williams, B.K., R.C. Szaro, and C.D. Shapiro. 2007. Adaptive Management: The U.S.
7 Department of the Interior Technical Guide. Adaptive Management Working Group,
8 U.S. Department of the Interior, Washington, DC.
9
10 Wilson, B., R.S. Batty, F. Daunt, and C. Carter. 2007. Collision Risks Between Marine
11 Renewable Energy Devices and Mammals, Fish and Diving Birds. Report to the Scottish
12 Executive. Scottish Association for Marine Science, Oban, Scotland. PA25 1QA. 110 p.
13
14 Wood, P.J. and P.D. Armitage. 1997. Biological effects of fine sediment in the lotic
15 environment. *Environmental Management* 21(2): 203-217.
16
17 Woytenek, W., X. Pei, and L.A. Wilkens. 2001. Paddlefish strike at artificial dipoles
18 simulating the weak electric fields of planktonic prey. *The Journal of Experimental*
19 *Biology* 204:1391-1399.
20
21 Wursig, B. C.R. Greene, Jr., and T.A. Jefferson. 2000. Development of an air bubble
22 curtain to reduce underwater noise of percussive piling. *Marine Environmental Research*
23 49:79-93.
24
25 Yebra, D.M., S. Kiil, and K. Dam-Johansen. 2004. Antifouling technology – past,
26 present and future steps towards efficient and environmentally friendly antifouling
27 coatings. *Progress in Organic Coatings* 50:75-104.
28
29 Yebra, D.M., S. Kiil, K. Dam-Johansen, and C.E. Weinell. 2006. Mathematical modeling
30 of tin-free chemically-active antifouling paint behavior. *AIChE Journal* 52(5):1926-
31 1940.
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Appendix A

List of Individuals, Agencies, and Organizations Contacted

(to be provided)

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Appendix B

Technology Concepts and Developers

Table B-1. List of marine tidal energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting kinetic energy of river or tidal currents. Modified from the European Marine Energy Centre website: http://www.emec.org.uk/tidal_developers.asp

Company	Technology Name	Device Class	Prototype (Field) Installations	Country	Published Environmental Studies
Aquantis http://aquantistech.com/	Aquantis C-Plane	Horizontal axis turbine – tethered to seabed	None	USA	N
Atlantis Resources Corp http://www.atlantisresourcescorporation.com/	Aquanator	Oscillating hydrofoil - Pile mounted	None	Australia	N
BioPower Systems Pty Ltd http://www.biopowersystems.com/	bioStream and bioWave	Oscillating hydrofoil – Seabed mounted	None	Australia	N
Blue Energy http://www.bluenergy.com/	Blue Energy Ocean Turbine (Davis Hydro Turbine)	Vertical axis turbine – Ducted and pile mounted	Prototypes tested in Ontario, Nova Scotia, and Florida Gulf Stream	Canada	N
Clean Current Power Systems http://www.cleancurrent.com/	Clean Current Tidal Turbine	Horizontal axis (enclosed tips) - Pile mounted	Race Rocks Ecological Reserve, British Columbia	Canada	N
Edinburgh Designs http://www.edesign.co.uk/	Vertical-axis, variable pitch tidal turbine	Vertical axis turbine - Floating	None	UK	N
Edinburgh University	Polo	Vertical axis turbine -	None	UK	N
FreeFlow69 http://www.freeflow69.com/	OHEG and Osprey	Horizontal axis turbine – floating platform	None	UK	N
GCK Technology http://www.gcktechnology.com/GCK/	Gorlov Turbine	Vertical or horizontal axis turbine - Floating	Small prototypes tested in Maine, Massachusetts, Cape Cod Canal,	USA	N

Table B-1. List of marine tidal energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting kinetic energy of river or tidal currents. Modified from the European Marine Energy Centre website: http://www.emec.org.uk/tidal_developers.asp

Company	Technology Name	Device Class	Prototype (Field) Installations	Country	Published Environmental Studies
			Brazil and Korea		
Greenheat Systems Ltd http://www.greenheating.com/	Gentec Venturi	Horizontal axis turbine (enclosed tips)	None	UK	N
Hammerfest Strom http://www.e-tidevannsenergi.com/	Tidal Stream Turbine	Horizontal axis turbine- Seabed mounted gravity base	Kvalsundet, Norway	Norway	N
Hydro-Gen http://www.hydro-gen.fr/	Hydro-gen	Horizontal axis turbine – Floating paddle wheel	None	France	N
Hydro Green Energy, LLC http://www.hgenenergy.com/index.html	Hydro kinetic turbine (HTA arrays)	Ducted horizontal axis turbine – Floating or seabed mounted	None	USA	N
Hydrohelix Energies http://www.hydrohelix.fr/	hydro-helix – Sabella	Horizontal axis turbine (enclosed tips) – Seabed mounted	None	France	N
Ing Arvid Nesheim http://www.anwsite.com/	Waterturbine	Vertical axis turbine (enclosed) - Floating	None	Norway	N
Kinetic Energy Systems http://www.kineticenergysystems.com/	Hydrokinetic Generator, KESC Bowsprit Generator, KESC Tidal Generator	Horizontal axis turbine – Seabed mounted	None	USA	N
Lunar Energy http://www.lunarenergy.co.uk/	Rotech Tidal Turbine	Horizontal axis turbine (enclosed) – seabed mounted	None, although installations in South Wales and Korea announced	UK	N

Table B-1. List of marine tidal energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting kinetic energy of river or tidal currents. Modified from the European Marine Energy Centre website: http://www.emec.org.uk/tidal_developers.asp

Company	Technology Name	Device Class	Prototype (Field) Installations	Country	Published Environmental Studies
Marine Current Turbines http://www.marineturbines.com http://www.seageneration.co.uk/	Seagen, Seaflow	Horizontal axis turbine – pile mounted	Bristol Channel, UK Strangford Lough, Northern Ireland	UK	Y
Neptune Systems http://www.neptunesystems.net/	Tide Current Converter	Superconducting magnet – seabed mounted	None	Netherlands	N
Neptune Renewable Energy Ltd http://www.neptunerenewableenergy.com	Proteus	Vertical axis turbine (enclosed) - Floating	None	UK	N
New Energy Corporation http://www.newenergycorp.ca/	EnCurrent Vertical Axis Hydro Turbine	Vertical axis (cross flow) turbine	Prototypes tested in Nova Scotia	Canada	N
Ocean Renewable Power Company http://www.oceanrenewablepower.com	OCGen	Horizontal axis (cross flow) turbine (ducted) - Floating	1/3-sized prototype tested off Eastport, Maine from 12/07 to 4/08	USA	Y
OpenHydro http://www.openhydro.com/	Open-Centre Turbine	Horizontal axis turbine (ducted) - seabed mounted or gravity base	Prototype testing in Orkney, Scotland	Ireland	N
Overberg Limited http://www.oceanflowenergy.com/	Evopod	Horizontal axis turbine - Floating	None	UK	N
Ponte di Archimede http://www.pontediarchimede.it/language_us/	Kobold Turbine	Vertical axis (crossflow) turbine – seabed mounted, floating	Strait of Messina, Sicily	Italy	N

Table B-1. List of marine tidal energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting kinetic energy of river or tidal currents. Modified from the European Marine Energy Centre website: http://www.emec.org.uk/tidal_developers.asp

Company	Technology Name	Device Class	Prototype (Field) Installations	Country	Published Environmental Studies
Pulse Generation http://www.pulsegeneration.co.uk/	Pulse Generators	Oscillating hydrofoil - Seabed mounted or gravity base	None	UK	N
Robert Gordon University http://www.rgu.ac.uk/cree/general/page.cfm?page=10769	Sea Snail	Hydrofoil that induces downward force - Seabed mounted or gravity base	Orkney, Scotland	UK	N
Rugged Renewables http://www.emat.co.uk/	Savonius turbine	Horizontal axis turbine (ducted) - Seabed mounted or gravity base	None	UK	N
Scotrenewables http://www.scotrenewables.com/	SRTT (Scotrenewables Tidal Turbine)	Horizontal axis turbine - Floating	Testing planned at EMEC, Orkney, Scotland	UK	N
SMD Hydrovision http://www.smd.co.uk/	TIDEL	Horizontal axis turbine – moored to seabed	None	UK	N
Statkraft http://www.statkraft.com/	Tidevannskraft	Horizontal axis turbine - Floating	None	Norway	N
Swanturbines Ltd. http://www.swanturbines.co.uk/	Swan Turbine	Horizontal axis turbine - Seabed mounted or gravity base	None	UK	N
Tocado BV Tidal Energy http://tocado.com/?Tocado	Tocado	Horizontal axis turbine - Pile mounted	Barrage discharge in the Netherlands	Netherlands	Y
The Engineering Business http://www.engb.com/	Stingray EB Frond	Oscillating hydrofoil - Seabed mounted	Shetland Islands	UK	Y

Table B-1. List of marine tidal energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting kinetic energy of river or tidal currents. Modified from the European Marine Energy Centre website: http://www.emec.org.uk/tidal_developers.asp

Company	Technology Name	Device Class	Prototype (Field) Installations	Country	Published Environmental Studies
		or gravity base			
Tidal Electric http://www.tidalelectric.com/	Tidal Lagoons (impoundments)	Horizontal Bulb turbine - Seabed mounted or gravity base	None	UK/USA	N
Tidal Generation Limited http://www.tidalgeneration.co.uk/	Deep-gen	Horizontal axis turbine - Seabed mounted or gravity base	Tests planned at EMEC, Orkney, Scotland	UK	N
Tidal Energy Ltd http://tidalenergy.net.au/?D=1	Davidson-Hill Venturi turbine	Vertical axis (crossflow) turbine (ducted) – Pile mounted	None	Australia	N
Tidal Sails http://www.tidalsails.com/	Tidal Sails AS	Oscillating hydrofoil - Floating	None	Norway	N
TidalStream http://www.teleos.co.uk/Home.htm	TidalStream	Horizontal axis turbine (ducted) – Floating, but tethered to seabed	None	UK	N
UEK Corporation http://www.uekus.com/	UEK (Underwater Electric Kite)	Horizontal axis turbine – Anchored to seabed or structures	Chesapeake Bay Ontario, other proposed sites	USA	N
University of Strathclyde	Contra-rotating (coaxial) marine current turbine	Horizontal axis turbine	None	UK	N
Verdant Power http://www.verdantpower.com/	Free Flow Turbine	Horizontal axis turbine- Pile mounted	East River, New York	USA	Y

Table B-1. List of marine tidal energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting kinetic energy of river or tidal currents. Modified from the European Marine Energy Centre website: http://www.emec.org.uk/tidal_developers.asp

Company	Technology Name	Device Class	Prototype (Field) Installations	Country	Published Environmental Studies
Vortex Hydro Energy http://www.vortexhydroenergy.com/	VIVACE	Horizontal bar moves in response to vortex-induced vibrations	None	USA	N
Woodshed Technologies - CleanTechCom Ltd http://www.woodshedtechnologies.com.au/	Tidal Delay	Standard impulse turbine installed in siphon pipe over/under natural barrier	Tests planned at EMEC, Orkney, Scotland	Australia / UK	N

Table B-2. List of marine wave energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting the potential energy of waves. Modified from the European Marine Energy Centre website:
http://www.emec.org.uk/wave_energy_devices.asp

Company	Technology Name	Device class	Prototype (Field) Installations	Country	Published Environmental Studies
Able Technologies L.L.C. http://www.abletechnologiesllc.com/	Electricity Generating Wave Pipe	Point absorber – Fixed pipe is secured to the ocean floor	None	USA	N
Applied Technologies Company Ltd http://www.atecom.ru/we/	Float Wave Electric Power Station	Attenuator	None	Russia	N
Aqua Energy / Finevara Renewables http://finavera.com/	Aqua Buoy	Point absorber – Moored to the seabed	Makah Bay, Washington Figueira da Foz, Portugal	USA	N
Aquamarine Power http://www.aquamarinepower.com/	Oyster	Oscillating wave surge converter – Secured to bottom in shallow water	EMEC tests at Orkney (?)	Scotland	N
Arlas Invest	MAUI Wave Energy Converter	Point absorber	None	Spain	N
AW Energy http://www.aw-energy.com/	WaveRoller	Oscillating wave surge converter – Secured to bottom in shallow water	EMEC/Orkney Portugal	Finland	Y
AWS Ocean Energy http://www.awsocan.com/	Archimedes Wave Swing	Point absorber – Moored to the seabed	EMEC/Orkney	Scotland	N
BioPower Systems Pty Ltd http://www.biopowersystems.com/	bioWave	Oscillating wave surge converter – Secured to bottom in shallow water	Australia (early 2009)	Australia	N
Brandl Motor http://brandlmotor.de/index_eng.htm	Brandl Generator	Attenuator – Moored to seabed	None	Germany	N
Caley Ocean Systems http://www.caley.co.uk/os/index.htm	Wave Plane	Overtopping device	No longer involved?	UK/Denmark	N
College of the North Atlantic	Wave Powered Pump – small	Attenuator	None	Canada	N

Table B-2. List of marine wave energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting the potential energy of waves. Modified from the European Marine Energy Centre website: http://www.emec.org.uk/wave_energy_devices.asp

Company	Technology Name	Device class	Prototype (Field) Installations	Country	Published Environmental Studies
http://www.cna.nl.ca/oar/research.asp	and designed for aquaculture but could be scaled up				
Columbia Power Technologies/Oregon State U. http://www.columbiapwr.com/	Direct drive, permanent magnet linear generator buoy	Point absorber – moored to the seabed	Newport, Oregon	USA	N
C-Wave http://www.cwavepower.com/	C-wave	Attenuator / Oscillating wave surge converter	None	UK	N
Daedalus Informatics Ltd http://www.daedalus.gr/	Wave Energy Conversion Activator	Oscillating water column - Shoreline	None	Greece	N
Delbuoy	Wave Powered Desalination	Point absorber	No longer under development	USA	N
Ecofys http://www.ecofys.com/	Wave Rotor	Submerged pressure differential – Secured to the seabed	None	Netherlands	N
Ecole Centrale de Nantes http://www.ec-nantes.fr/	SEAREV	Attenuator – Moored to seabed	None	France	N
Edinburgh University http://www.mech.ed.ac.uk/research/wavepower/	Sloped IBS Buoy	Attenuator	None	UK	N
Embley Energy http://www.sperboy.com/	Sperboy	Attenuator / Oscillating water column – Moored to the seabed	None	UK	N
Energias de Portugal	Foz do Douro breakwater	Oscillating water column – Breakwater at a river mouth	Foz do Douro, Portugal	Portugal	N
Float Inc. http://www.floatinc.com/	Pneumatically Stabilized Platform	Attenuator	None	USA	N
Floating Power Plant AS http://www.poseidonorgan.com/	Poseidon's organ	Oscillating wave surge converter - floating	Reduced-scale prototype at Lolland,	Denmark	N

Table B-2. List of marine wave energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting the potential energy of waves. Modified from the European Marine Energy Centre website: http://www.emec.org.uk/wave_energy_devices.asp

Company	Technology Name	Device class	Prototype (Field) Installations	Country	Published Environmental Studies
			Denmark		
Floating Wave Powered Generator http://www.gedwardcook.com/wave.html	Patent Pending Number US60/662/582	Attenuator	None – patent is for sale	USA	N
Fred Olsen & Co./Ghent University http://www.seewec.org/	SEEWEC	Attenuator	None – Planned for Wave Hub, Cornwall	Norway / EU	N
Green Ocean Energy http://www.greenoceanenergy.com/	Ocean Treader	Point absorber – Moored to the seabed	None	UK	N
Greenheat Systems Limited http://www.greenheating.com/	GENTECH venturi	Overtopping device	None	UK	N
Hydam Technology	McCabe Wave Pump	Attenuator – Floating barges	None	Ireland	N
Independent Natural Resources http://www.inri.us/	SEADOG	Attenuator	Pilot-scale tests near Freeport and Galveston, Texas	USA	N
Ing Arvid Nesheim http://www.anwsite.com/	Oscillating Device	Point absorber – Moored to the seabed	None	Norway	N
Instituto Superior Tecnico http://www.pico-owc.net/	Pico OWC	Oscillating water column – shoreline installation	Pico Island, Azores, Portugal	Portugal	N
JAMSTEC http://www.jamstec.go.jp/jamstec/MTD/Whale/	Mighty Whale	Oscillating water column – Floating, and moored to the bottom	Gokasho Bay, Japan	Japan	N
Joules Energy Efficiency Services Ltd	TETRON	Other	None	Ireland	N
Lancaster University http://www.engineering.lancs.ac.uk/lureg/research/	PS Frog	Attenuator	None	England	N
Langlee Wave Power AS http://www.langlee.no/	Langlee Water Wings	Oscillating Wave Surge Converter – Secured to	None	Norway	N

Table B-2. List of marine wave energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting the potential energy of waves. Modified from the European Marine Energy Centre website: http://www.emec.org.uk/wave_energy_devices.asp

Company	Technology Name	Device class	Prototype (Field) Installations	Country	Published Environmental Studies
		the bottom			
Manchester Bobber http://www.manchesterbobber.com/	Manchester Bobber	Attenuator	None	UK	N
Martifer Energia http://www.martifer.com/Group/EN/home.html	ONDA 1	Attenuator – Floating and moored to the seabed	None	Portugal	N
Maritime Energy Developments http://pagesperso-orange.fr/bulgewave/	Anaconda Wave Energy Bulging Snake	Attenuator – Moored to the bottom	None	UK	N
Muroran Institute of Technology http://www.muroran-it.ac.jp/index-e.html	Pendulor	Oscillating wave surge converter	Matshike Harbor, Muroran, Japan	Japan	N
Neptune Renewable Energy Ltd http://www.neptunerenewableenergy.com/	Triton	Oscillating wave surge converter	None	UK	N
Neptune Systems http://www.neptunesystems.net/	MHD Neptune/Superconducting magnet solenoid	Point absorber – secured to the seabed	None	Netherlands	N
Norwegian University of Science and Technology http://www.sffe.no/index_e.htm	CONWEC	Point absorber	None	Norway	N
Ocean Energy Ltd http://www.oceanenergy.ie/	OE Buoy	Oscillating water column – Floating and moored to the bottom	Galway, Ireland	Ireland	N
Ocean Motion International http://www.oceanmotion.ws/	OMI Combined Energy System	Point absorber – Secured to the seabed with rigid piling	None	USA	N
Ocean Navitas http://www.oceannavitas.com/	Aegir Dynamo	Attenuator	None	UK	N
Ocean Power Technologies http://www.oceanpowertechnologies.com/	PowerBuoy	Point absorber – moored to the seabed	New Jersey Oahu, Hawaii Santona, Spain Planned for Wave	UK / USA	Y

Table B-2. List of marine wave energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting the potential energy of waves. Modified from the European Marine Energy Centre website: http://www.emec.org.uk/wave_energy_devices.asp

Company	Technology Name	Device class	Prototype (Field) Installations	Country	Published Environmental Studies
			Hub, Cornwall		
Ocean Wave Energy Company http://www.owec.com/	OWEC	Point absorber	None	USA	N
Ocean Wavemaster Ltd http://www.oceanwavemaster.com/	Wave Master	Point absorber – Moored to the seabed	None	UK	N
Oceanlinx (formerly Energetech) http://www.oceanlinx.com/	Denniss-Auld Turbine	Oscillating water column – Floating and moored to the seabed	Port Kembla, Australia Planned for Wave Hub, Cornwall	Australia	N
Offshore Wave Energy Ltd http://www.owel.co.uk/print/overview.htm	OWEL Energy Converter / Grampus	Oscillating water column	None	UK	N
ORECon http://www.orecon.com/	MRC 1000	Oscillating water column – Floating and moored to the bottom	None	UK	N
Pelagic Power http://www.pelagicpower.com/	Pelagic Power wave pump	Point absorber – Moored to the seabed	None	Norway	N
Pelamis Wave Power http://www.pelamiswave.com/	Pelamis	Attenuator	Agucadoura, Portugal Orkney, Scotland	UK	N
Renewable Energy Holdings http://www.reh-plc.com/	CETO	Oscillating wave surge converter	Fremantle, Western Australia	AUS / UK	N
Scientific Applications & Research Associates, Inc. (SARA) http://www.sara.com/RAE/ocean_wave.html	MHD Wave Energy Converter (MWEC)	Point absorber – moored to the seabed	None	USA	N
SDE http://www.sde.co.il/	S.D.E	Attenuator - Shoreline	Israel	Israel	N

Table B-2. List of marine wave energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting the potential energy of waves. Modified from the European Marine Energy Centre website: http://www.emec.org.uk/wave_energy_devices.asp

Company	Technology Name	Device class	Prototype (Field) Installations	Country	Published Environmental Studies
Sea Power International AB http://www.seapower.se/english.htm	Stream turbine	Attenuator (might be Savonius vertical axis turbine?)	?	Sweden	?
Seabased AB http://www.seabased.com/engelsk/	Direct drive, permanent magnet linear generator buoy	Point absorber – fixed to the seabed	None	Sweden	N
SeaVolt Technologies http://www.seavolt.com/	Wave Rider	Attenuator – moored to seabed	None	USA	N
SEEWEC Consortium http://www.seewec.org/index.html	FO3 device (Buldra)	Point absorber – floating and moored to the seabed	Norway	UK	N
SeWave Ltd http://www.sewave.fo/	OWC	Oscillating water column	None	Faroe Islands	N
SurfPower http://www.surfpower.ca/	SurfPower	Point absorber – fixed to the seabed	None	USA	N
Swedish Centre for Renewable Electric Energy Conversion http://www.el.angstrom.uu.se/meny/eng/index_E.html	Wave Power Project, Islandsberg	Point absorber – generator mounted on the seabed	Lysekil, Sweden	Sweden	Y
SyncWave Energy Inc. http://www.syncwaveenergy.com	SyncWave Power Resonator	Point absorber	None	Canada	N
Trident Energy Ltd, Direct Thrust Designs Ltd http://www.tridentenergy.co.uk/index.php	Direct Energy Conversion Method	Point absorber	Suffolk Coast, England in summer 2008	UK	N
Trotman Unit (Private Researcher) http://www.trotmanunitwavepower.com/	Inshore Wave Power	Attenuator / Point absorber	None	Scotland	N
Union Electrica Fenosa of Spain http://www.unionfenosa.es/	OWC	Oscillating water column	None	Spain	N
Vortex Oscillation Technology Ltd	Vortex oscillation	Attenuator	None	Russia	N

Table B-2. List of marine wave energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting the potential energy of waves. Modified from the European Marine Energy Centre website:

http://www.emec.org.uk/wave_energy_devices.asp

Company	Technology Name	Device class	Prototype (Field) Installations	Country	Published Environmental Studies
http://www.vortexosc.com/					
Wave Dragon http://www.wavedragon.net/	Wave Dragon	Overtopping device – Floating, moored to the seabed	Denmark/Wales	Wales / Denmark	Y
Wave Energy http://www.waveenergy.no/index.htm	Seawave Slot-Cone Generator	Overtopping device – Shoreline, floating or fixed to the seabed	None	Norway	N
Wave Energy Technologies, Inc. http://waveenergytechnologies.com/	WET EnGen	Point absorber – moored to the bottom	Small-scale model off Sandy Cove, Nova Scotia	Canada	N
Wave Energy Technology http://www.wavenergy.co.nz/	(WET-NZ)	Attenuator	Small experimental device on Canterbury coast	New Zealand	N
Wave Power Group http://www.mech.ed.ac.uk/research/wavepower/	Salter Duck, Sloped IPS	Attenuator	None	UK	N
Wave Star Energy ApS http://www.wavestarenergy.com/	Wave Star	Point absorber	Small scale model since 2006 at Nissum Bredning, Denmark	Denmark	N
Waveberg Development http://www.waveberg.com/	Waveberg	Attenuator – moored to the seabed	Small scale models in Nova Scotia and Florida	Canada	N
WaveBob Limited http://www.wavebob.com/	Wave Bob	Point absorber – moored to the seabed	Galway, Ireland	Ireland	N
Wavegen http://www.wavegen.com/	Limpet	Oscillating water column	Island of Islay, Scotland Mutriku, Spain	UK	N
Wavemill Energy	Wavemill	Oscillating water column	None	Canada	N

Table B-2. List of marine wave energy concepts and developers, and the status of installation and environmental studies in 2008. These devices generate electricity by converting the potential energy of waves. Modified from the European Marine Energy Centre website: http://www.emec.org.uk/wave_energy_devices.asp

Company	Technology Name	Device class	Prototype (Field) Installations	Country	Published Environmental Studies
WavePlane A/S http://www.waveplane.com/	Wave Plane	Overtopping device	None	Denmark	N
West Wave (consortium of E.ON and Ocean Prospect) http://www.eon-uk.com/generation/westwave.aspx	Pelamis	Attenuator	Planned for Wave Hub, Cornwall	UK	N
WindWavesAndSun http://www.windwavesandsun.com/	WaveBlanket	Attenuator	None	USA	N

Appendix C

Noise in the Aquatic Environment and Its Effects on Aquatic Animals

Expressing Underwater Sounds

There are many ways to express the intensity and frequency of underwater sound waves (see discussions by Wahlberg and Westerberg 2005 and Thomsen et al. 2006). An underwater acoustic wave is generated by displacement of water particles. Consequently, the passage of an acoustic wave creates local pressure oscillations that travel through water with a given sound velocity. These two parameters, pressure and velocity, are used to define the intensity of an acoustic field, and therefore are useful for considering the effects of noise on aquatic animals.

The intensity of the acoustic field is defined as the vector product of the local pressure fluctuations and the velocity of the particle displacement. A basic unit for measuring the intensity of underwater noise is the sound pressure level (SPL). The SPL of a sound, given in decibels (dB), is calculated by:

$$\text{SPL (dB)} = 20 \log_{10} (P/P_0)$$

where P is a pressure fluctuation caused by a sound source, and P_0 is the reference pressure, defined in underwater acoustics as $1 \mu\text{Pa}$ at 1 m from the source (Thomsen et al. 2006). Using the above formula, doubling the pressure of a sound (P) results in a 6 dB increase in SPL.

The sound pressure of a continuous signal is often expressed by a root mean square (rms) measure, which is the square root of the mean value of squared instantaneous sound pressures, integrated over time (Madsen 2005). Like SPL, the resulting integration of instantaneous sound pressure levels is also expressed in dB re $1 \mu\text{Pa}$ (rms). An rms level of safe exposure to received noise has been established for marine mammals; the lower limits for concern about temporary or permanent hearing impairments in cetaceans and pinnipeds are currently 180 and 190 dB re $1 \mu\text{Pa}$ (rms) respectively (NMFS 2003; Southall et al. 2007). However, Madsen (2005) argues that rms safety measures are insufficient, and should be supplemented by other estimates of the magnitude of noise (e.g., maximum peak-to-peak SPL in concert with a maximum received energy flux level).

Sound intensity is greatest near the sound source and, in the far field, decreases smoothly with distance. As the acoustic wave propagates through the water, intensity is reduced by geometric spreading (dilution of the energy of the sound wave as it spreads out from the source over a larger and larger area), and, to a lesser extent, absorption, refraction, and reflection (Wahlberg and Westerberg 2005). Attenuation of sound due to spherical spreading in deep water is estimated by $20 \log_{10} r$, where r is the distance in m

from the source (NRC 2000). Assuming simple spherical spreading (no reflection from the sea surface or bottom) and the consequent transmission loss of SPL, a 190 dB source level would be reduced to 150 dB at 100 m. Close to the source, changes in sound intensity vary in a more complicated fashion, particularly in shallow water, as a result of acoustic interference from natural or man-made sounds or where there are reflective surfaces (seabed and water surface).

Sound Exposure Level (SEL) is a measure of the cumulative physical energy of the sound event which takes into account both intensity and duration. SELs are computed by summing the cumulative sound pressure squared (p^2) over time and normalizing the time to 1 second. Because calculation of the SEL for a given underwater sound source is a way to normalize to one second the energy of noise that may be much briefer (such as the powerful, but short impulses caused by pile driving), SEL is typically used to compare noise events of varying durations and intensities.

In addition to intensity, underwater noise will have a range of frequencies (Hz or cycles per s). For convenience, measurements of the potentially wide range of individual frequencies associated with noise are integrated into “critical bands” or filters; the width of a band is often given in 1/3-octave levels (Thomsen et al. 2006). Thus, sounds can be expressed in terms of the intensities (dB) at particular frequency (Hz) bands (Figure C-1; Table C-1).

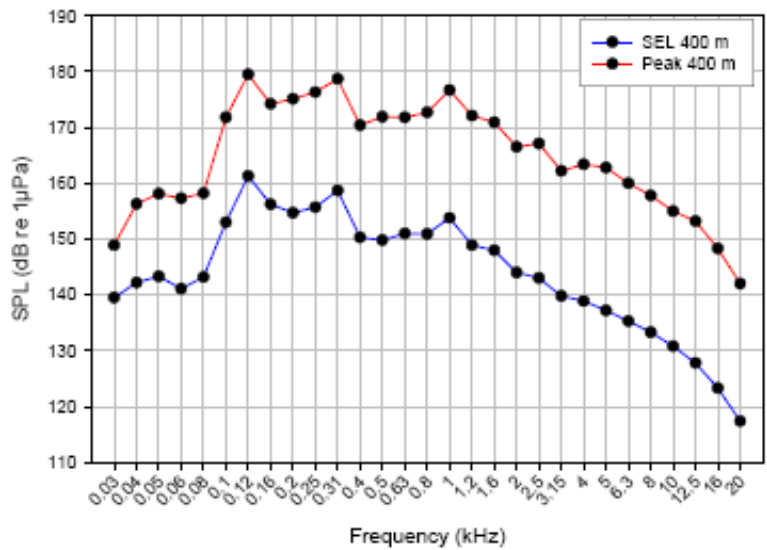


Figure C-1. Frequency spectrum (at 1/3-octave band levels) of pile-driving pulses at 400 m from the source. From Thomsen et al. (2006).

Table C-1. Frequencies and intensities of some anthropogenic sounds. Modified from NRC (2000).		
Source	Frequency at the highest level 1/3-octave band (Hz)	Source level at the highest level 1/3-octave band (dB re 1

		$\mu\text{Pa at 1 m}$
5-m Zodiac inflatable boat	6,300	152
Bell 212 helicopter	16	159
Large tanker	100 + 125	177
Icebreaker	100	183
Medium-sized support/supply ships ^b	10-20	130-160
Acoustic Thermometry of Ocean Climate (ATOC) ^a	75	195
Air gun array	50	210
Heard Island Feasibility Test (HIST; research device)	50 + 63	221
Military search sonar	2,000-5,000	230+
Pile-driving (Sweden; 30 m from source) ^b	250	140->180
Pile-driving (UK; 1 m from source) ^b	200 + 800 + 1,600	262
Pile-driving (Germany; 400 m from source) ^b See Figure C-1 for frequency spectrum	125 + 315 + 1,100	180

^a scientific research device.

^b from Thomsen et al. (2006).

NRC (2000) pointed out that there are four fundamental properties of sound transmission in water relevant to the consideration of the effects of noise on aquatic animals:

(1) The transmission distance of sound in seawater is determined by a combination of geometric spreading loss and an absorptive loss that is proportional to the sound frequency. Thus, attenuation (weakening) of sound increases as its frequency increases.

(2) The speed of a sound wave in water is proportional to the temperature.

(3) The sound intensity decreases with distance from the sound source.

Transmission loss of energy (intensity) due to spherical spreading in deep water is estimated by $20 \log_{10} r$, where r is the distance in m from the source.

(4) The strength of sound is measured on a logarithmic scale.

From these properties, it can be seen that high frequency sounds will dissipate faster than low frequency sounds, and a sound level may decrease by as much as 60dB at 1 km from the source. Acoustic wave intensity of 180 dB is 10 times less intense than 190 dB, and 170 dB is 100 times less than 190 dB (NRC 2000).

Noise Produced by Ocean Energy Technologies

There is very little information available on sound levels produced by construction and operation of ocean energy conversion structures (Michel et al. 2007). However, reviews of the construction and operation of European offshore wind farms provide useful information on the sensitivity of aquatic organisms to underwater noise.

For example, Thomsen et al. (2006) reported that pile-driving activities generate brief, but very high sound pressure levels over a broad band of frequencies (20->20,000 Hz). Single pulses are about 50-100 ms in duration and occur approximately 30-60 times per minute. The SEL at 400 m from the driving of a 1.5-m-diameter pile exceeded 140 dB re 1 μ Pa over a frequency range of 40-3,000 Hz (Betke et al. 2004). It usually takes 1-2 h to drive one pile into the bottom. Sounds produced by the pile-driving impacts above the water's surface enter the water from the air and from the submerged portion of the pile, propagate through the water column, and into the sediments, from which they pass successively back into the water column. Larger-diameter, longer piles require relatively more energy to drive into the sediments, which results in higher noise levels. For example, the SPL associated with driving 3.5-m-diameter piles is expected to be roughly 10 dB greater than for a 1.5-m-diameter pile (Thomsen et al. 2006).

Some ocean energy technologies will be secured to the bottom by means of moorings and anchors drilled into rock. Like pile-driving, hydraulic drilling will occur during a limited time period, and noise generation will be intermittent. DON (2003) summarized underwater SPL measurements of three hydraulic rock drills; frequencies ranged from about 15 Hz to over 39 kHz, and SPLs ranged from about 120 to 170 dB re 1 μ Pa. SPLs were relatively consistent across the entire frequency range.

During operation, vibration of the device's gearbox, generator, and other moving components are radiated as sound into the surrounding water. Noise during operation of wind farms is of much lower intensity than noise during construction (Thomsen et al. 2006; Betke et al. 2004), and the same may be true for hydrokinetic and ocean energy farms. However, this source of noise will be continuous. Measurements of sound levels associated with the operation of hydrokinetic and ocean energy farms have not yet been published. One example of a wave energy technology, the WEC buoy that has been tested in Hawaii, has many of the mechanical parts contained within an equipment canister or mounted to a structure through mounting pads. Thus, the acoustic energy produced by the equipment is not well coupled to the seawater, which is expected to reduce the amount of radiated noise (DON 2003). Although no measurements had been made, it was predicted that the acoustic output from the WEC buoy system would probably be in the range of 75-80 dB re 1 μ Pa. This SPL is equivalent to light to normal density shipping noise, although the frequency spectrum of the WEC buoy is expected to be shifted to higher frequencies than typical shipping noise.

By comparison, Thomsen et al. (2006) reported the ambient noise measured at 5 different locations in the North Sea (Figure C-2). Depending on frequency, SPL ranged from 85 to 115 dB, with most energy occurring at frequencies less than 100 Hz.

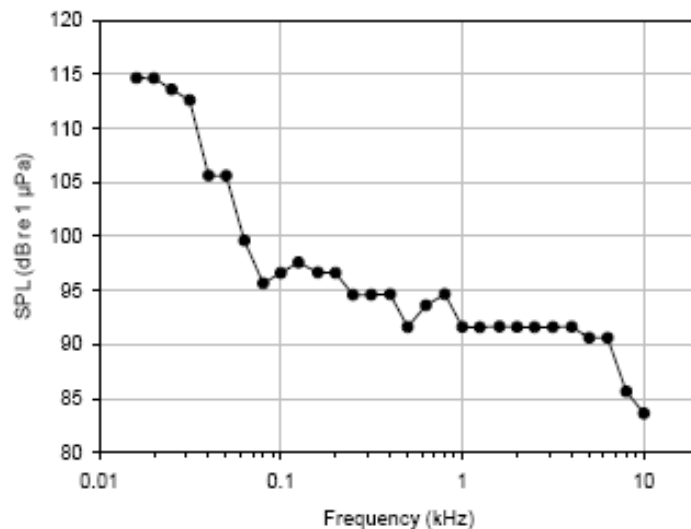


Figure C-2. Frequency spectrum (at 1/3-octave band levels) of ambient noise measured at 5 different locations on the North Sea at wind speeds of 3-8 m/s. From Thomsen et al. (2006).

The Environmental Statement for the proposed installation of the Wave Dragon wave energy demonstrator off the coast of Pembrokeshire predicted noise levels associated with installation of concrete caisson (gravity) blocks and steel cable mooring arrangement, installation of subsea cable, and support activity (Wave Dragon Wales Ltd. 2007). Installation of gravity blocks is not expected to generate additional noise over and above that of the vessel conducting the operation. Vessel noise will depend on size and design of the ship, but is expected to be up to 180 dB re 1 μPa at 1 m. Other predicted installation noise sources and levels stem from operation of the ship’s echosounder (220 dB re 1 μPa at 1 m peak-to-peak), cable laying and fixing (159-181 dB re 1 μPa at 1 m), and directional drilling (129 dB re 1 μPa rms at 40 m above the drill). There are no measurements available for the noise associated with operation of an overtopping device such as the Wave Dragon. Wave Dragon Wales Ltd. (2007) predicted that operational noise would result from the Kaplan-style hydro turbines (an estimated 143 dB re 1 μPa at 1 m), as well as unknown levels and frequencies of sound from wave interactions with the body of the device, hydraulic pumps, and the mooring system.

In April, 2008 the Ocean Renewable Power Company (ORPC) made limited measurements of underwater noise associated with operation of their 1/3-scale working prototype in-stream tidal energy conversion device, its Turbine Generator Unit (TGU). The TGU is a single horizontal axis device with two advanced design cross-flow turbines that drive a permanent magnet generator. An omnidirectional hydrophone, calibrated for a frequency range of 20 Hz - 250 kHz, was used to make near field measurements adjacent to the barge from which the turbine was suspended and at approximately 15 m from the turbine. Multiple far field measurements were also made at distances out to 2.0 km from the barge. Noise measurements were made over one full tidal cycle, with supplemental measurements taken later (Ernest Hauser, Ocean Renewable Power

Company Maine, LLC; personal communication, June 25, 2008). Sound pressure levels (SPL) at 1/3-octave frequency bands were used to calculate root mean squared (rms) levels and sound exposure levels (SEL). During times when the turbine generator unit was not operating, background noise ranged from 112 to 138 dB re 1 μ Pa rms and SELs ranged from 120 to 140 dB re 1 μ Pa. A single measurement made when the turbine blades were rotating (at 52 rpm) resulted in an estimate of 132 dB re 1 μ Pa (rms) and an SEL of 126 dB re 1 μ Pa at a horizontal distance of 15 m and a water depth of 10 m. These very limited readings suggest that the single 1/3-scale turbine generator unit did not increase noise above ambient levels.

In addition to the sound intensity and frequency spectrum produced by the operation of individual machines, impacts of noise will depend on the geographic location of the project (water depth, type of substrate), the number of units, and the arrangement of multiple-unit arrays. For example, owing to noise from surf and surface waves, noise levels in shallow, nearshore areas (≤ 100 m deep and within 5 km of the shore) are typically somewhat higher for low frequencies (≤ 1 kHz) and much higher at frequencies above 1 kHz (DON 2003; Appendix F).

Potential Effects of Noise on Aquatic Animals

Owing to the complexity of describing underwater sounds, investigators have often used different units to express the effects of sound on aquatic animals, and have not always reported precisely the experimental conditions. For example, acoustic signal characteristics that might be relevant to biological effects include frequency content, rise time, pressure and particle velocity time series, zero-to-peak and peak-to-peak amplitude, mean squared amplitude, duration, integral of mean squared amplitude over duration, sound exposure level, and repetition rate (NRC 2003; Thomsen et al. 2006). Each of these sound characteristics may differentially impact different species of aquatic animals, but the relationships are not sufficiently understood to specify which are the most important. Many studies of the effects of noise report the frequency spectrum and some measure of sound intensity (SPL, rms, and/or SEL).

Underwater noise can be detected by fish and marine mammals if the frequency and intensity falls within the range of hearing for the particular species. An organism's hearing ability can be displayed as an audiogram, which plots sound pressure level (dB) against frequency (Hz). Nedwell et al. (2004) compiled audiograms for a number of aquatic organisms, examples of which are shown in Figure C-3. If the pressure level of a generated sound is transmitted at these frequencies and exceeds the sound pressure level (i.e., above the line) on a given species' audiogram, the organism will be able to detect the sound. There is a wide range of sensitivity to sound among marine fish. The herrings (Clupeoidea) are highly sensitive to sound owing to the structure of their swim bladder and auditory apparatus, whereas flatfish such as plaice and dab (Pleuronectidae) that have no swim bladder are relatively insensitive to sound (Nedwell et al. 2004). Possible responses to the received sound may include altered behavior (attraction, avoidance, interference with normal activities) or, if the intensity is great enough, hearing damage or

mortality. For example, fishkills have been reported in the vicinity of pile-driving activities (Longmuir and Lively 2001; Caltrans 2001).

NRC (2000) reviewed studies that demonstrated a wide range of susceptibilities to exposure-induced hearing damage among different marine species. The implications are that critical sound levels will not be able to be extrapolated from studies of a few species (although a set of representative species might be identified), and it will not be possible to identify a single sound level value at which damage to the auditory system will begin at all, or even most, marine mammals. Participants in a recent National Oceanic and Atmospheric Administration (NOAA) workshop (Boehlert et al. 2008) suggested that sounds that are within the range of hearing and “sweep” in frequency are more likely to disturb marine mammals than constant-frequency sounds. Thus, devices that emit a constant frequency may be preferable to ones that vary. They believed that the same may be true, although perhaps to a lesser extent, for sounds that change in amplitude.

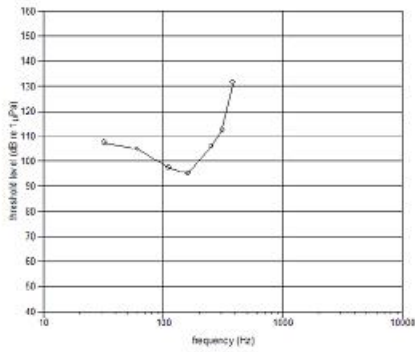
Moore and Clarke (2002) compiled information on the reactions of gray whales (*Eschrichtius robustus*) to noise associated with offshore oil and gas development and vessel traffic. Gray whale responses included changes in swim speed and direction to avoid the sound source, abrupt but temporary cessation of feeding, changes in calling rates and call structure, and changes in surface behavior. They reported a 0.5 probability of avoidance when continuous noise levels exceeded about 120 dB re 1 μ Pa and when intermittent noise levels exceeded about 170 dB re 1 μ Pa. They found little evidence that gray whales travel far or remain disturbed for long as a result of noises of this nature.

Weilgart (2007) reviewed the literature on the effects of ocean noise on cetaceans, focusing on underwater explosions, shipping, seismic exploration by the oil and gas industries, and naval sonar operations. She noted that strandings and mortalities of cetaceans have been observed even when estimated received sound levels were not high enough to cause hearing damage. This suggests that a change in diving patterns may have resulted in injuries due to gas and fat emboli. That is, aversive noise may prompt cetaceans to rise to the surface too rapidly, and the rapid decompression causes nitrogen gas supersaturation and the subsequent formation of bubbles (emboli) in their tissues (Fernandez et al. 2005). Other adverse (but not directly lethal) impacts could include increased stress levels, abandonment of important habitats, masking of important sounds, and changes in vocal behavior that may lead to reduced foraging efficiency or mating opportunities. Weilgart (2007) pointed out that responses of cetaceans to ocean noise are highly variable between species, age classes, and behavioral states, and many examples of apparent tolerance of noise have been documented.

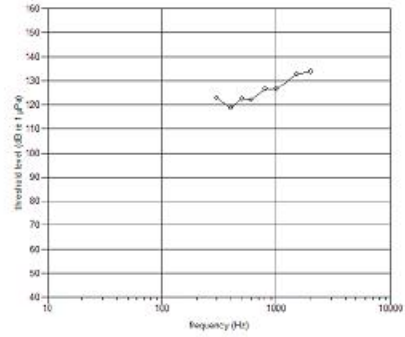
Nowacek et al. (2007) reviewed the literature on the behavioral, acoustic, and physiological effects of anthropogenic noise on cetaceans. They concluded that the noise sources of primary concern are ships, seismic exploration, sonars, and some acoustic harassment devices (AHDs) that are employed to reduce the by-catch of small cetaceans and seals by commercial fishing gear.

Two marine mammals whose hearing and susceptibility to noise have been studied are the harbor porpoise (*Phocoena phocoena*) and the harbor seal (*Phoca vitulina*). Both species inhabit shallow coastal waters in the North Atlantic and North Pacific. Harbor porpoises are found as far south as Central California on the West Coast. The hearing of the harbor porpoise ranges from below 1 kHz to around 140 kHz. In the United States, harbor seals range from Alaska to Southern California on the West Coast, and as far south as South Carolina on the East Coast. Harbor seal hearing ranges from less than 0.1 kHz to around 100 kHz (Thomsen et al. 2006).

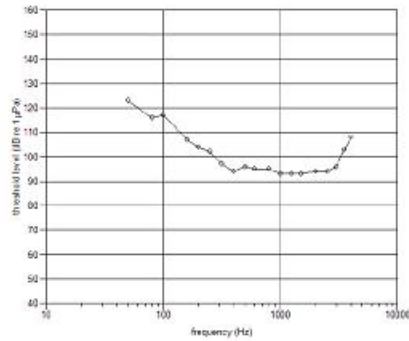
The responses of green turtles (*Chelonia mydas*) and loggerhead turtles (*Caretta caretta*) to the sounds of air guns used for marine seismic surveys were studied by McCauley et al. (2000a,b). They found that above a noise level of 166 dB re 1 μ Pa rms the turtles noticeably increased their swimming activity, and above 175 dB re 1 μ Pa rms their behavior became more erratic, possibly indicating that the turtles were in an agitated state. Caged squid (*Sepioteuthis australis*) showed a strong startle response to an airgun at a received level of 174 dB re 1 μ Pa rms. When sound levels were ramped up (rather than a sudden nearby startup), the squid showed behavioral responses (e.g., rapid swimming) at sound levels as low as approximately 156 dB re 1 μ Pa rms, but did not display the startle response seen in the other tests.



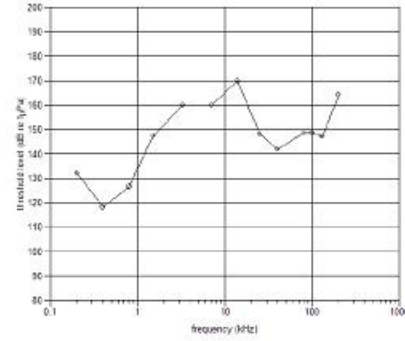
Atlantic salmon, *Salmo salar*



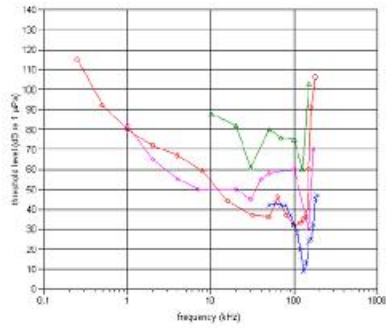
Bluegill sunfish, *Lepomis macrochirus*



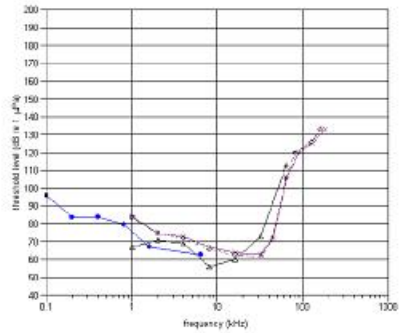
Channel catfish, *Ictalurus punctatus*



American shad, *Alosa sapidissima*



Harbor porpoise, *Phocoena phocoena*



Harbor seal, *Phoca vitulina*

Figure C-3. Examples of audiograms of fish and marine mammals. From Nedwell et al. (2004).

Thomsen et al. (2006) compared the underwater noise associated with pile driving to the audiograms of harbor porpoises and harbor seals. They concluded that pile-driving noise would likely be detectable at least 80 km away from the source. The zone of masking (the area within which the noise is strong enough to interfere with the detection of other sounds) may differ between the two species. Because the echolocation (sonar) used by harbor porpoises is in a frequency range (120-150 kHz) where pile-driving noises have little or no energy (Figure C-1), they considered masking of echolocation to be unlikely. On the other hand, harbor seals communicate at frequencies ranging from 0.2 to 3.5 kHz, which is within the range of highest pile-driving sound pressure levels; thus, harbor seals may have their communications masked at considerable distances by pile-driving activities.

Hastings and Popper (2005) reviewed the literature on the effects of underwater sounds on fish, particularly noises associated with pile driving. The limited number of quantitative studies found evidence of changes in the hearing capabilities of some fish, damage to the sensory structure of the inner ear, or, for fish close to the source, mortality. They concluded that the body of scientific and commercial data is inadequate to develop more than the most preliminary criteria to protect fish from pile driving sounds, and suggested the types of studies that could be conducted to address the information gaps. Similarly, Viada et al. (2008) found very little information on the potential impacts to sea turtles of underwater explosives. Although explosives produce greater sound pressures than pile driving and are unlikely to be used in most ocean energy installations, studies of their effects provide general information about the peak pressures and distances that have been used to establish safety zones for turtles.

Wahlberg and Westerberg (2005) compared source level, underwater measurements of sounds from offshore windmills to information about the hearing capabilities of three species of fish (goldfish, Atlantic salmon, and cod). They predicted that these fish could detect offshore windmills at a maximum distance of about 0.4 to 25 km, depending on wind speed, type and number of windmills, water depth, and substrate. They could find no evidence that the underwater sounds emitted by windmill operation would cause temporary or permanent hearing loss in these species, even at a distance of a few meters, although sound intensities might cause permanent avoidance within ranges of about 4 m. They noted that shipping causes considerably higher sound intensities than operating windmills (although the noise from shipping is transient), and noises from installation may have much more significant impacts on fish than those from operation.

In the Environmental Assessment of the proposed Wave Energy Technology (WET) Project, DON (2003) considered the sounds made by hydraulic rock drilling to be detectable by humpback whales, bottlenose dolphins, Hawaiian spinner dolphins, and green sea turtles. Assuming a transmission loss due to spherical spreading, drilling sound pressure levels of 160 dB re 1 μ Pa would decrease by about 40 dB at 100 m from the source. They regarded a SPL of 120 dB re 1 μ Pa to be below the level that would affect these four species. In fact, they reported that other construction activities involving similar drilling attracted marine life, fish and sea turtles in particular, perhaps because bottom organisms were stirred up by the drilling (DON 2003; Appendix F).

There are considerable information gaps regarding the effects of noise generated by marine and hydrokinetic energy technologies on cetaceans, pinnipeds, turtles, and fish. Sound levels from these devices have not been measured, but it is likely that installation will create more noise than operation, at least for those technologies that require pile-driving. Operational noise from generators, rotating equipment, and other moving parts may have comparable frequencies and magnitudes to those measured at offshore wind farms. However, the underwater noise created by a wind turbine is transmitted down through the pilings, whereas noises from marine and hydrokinetic devices are likely to be greater because they are at least partially submerged. It is probable that noise from marine energy projects may be less than the intermittent noises associated with shipping and many other anthropogenic sound sources (seismic exploration, explosions, commercial and naval sonar).

The resolution of noise impacts will require information about the device's acoustic signature (e.g., sound pressure levels across the full range of frequencies) for both individual units and multiple-unit arrays, similar characterization of ambient (background) noise in the vicinity of the project, the hearing sensitivity (e.g., audiograms) of fish and marine mammals that inhabit the area, and information about the behavioral responses to anthropogenic noise (e.g., avoidance, attraction, changes in schooling behavior or migration routes). Simmonds et al. (2003) describe the types of *in situ* monitoring that could be carried out to develop information on the effects of underwater noise arising from a variety of activities. The studies include monitoring marine mammal activity in parallel with sound level monitoring during construction and operation. Baseline sound surveys would be needed against which to measure the added effects of energy generation. It will be important to measure the acoustic characteristics produced by both single units and multiple units in an array, owing to the possibility of synchronous or asynchronous, additive noise produced by the array (Boehlert et al. 2008). Minimally, the operational monitoring would quantify the sound pressure levels across the entire range of sound frequencies for a variety of ocean/river conditions in order to assess how meteorological, current strength, and/or wave height conditions affect sound generation and sound masking. The monitoring effort should consider the effects of marine fouling on noise production, particularly as it relates to mooring cables.

Appendix D

Electromagnetic Fields in the Aquatic Environment and their Effects on Aquatic Animals

Nature of the Underwater Electromagnetic Field

The electromagnetic field (EMF) created by electric current passing through a cable is composed of both an electric field (E field) and an induced magnetic field (B field). Although E can be contained within undamaged insulation surrounding the cable, B fields are unavoidable and will in turn induce a secondary electric field (iE field). Thus, it is important to distinguish between the two constituents of the EMF (E and B) and the induced field, iE (Figure D-1; Gill et al. 2005). Because the electric field is a measure of how the voltage changes when a measurement point is moved in a given direction, E and iE are expressed in volts/m (V/m).

The intensity of a magnetic field can be expressed as magnetic field strength or magnetic flux density (CMACS 2003). The magnetic field can be visualized as field lines, and the field strength (measured in amperes/m, A/m) corresponds to the density of the field lines. Magnetic flux density is a measure of the density of magnetic lines of force, or magnetic flux lines, passing through an area. Magnetic flux density (measured in teslas, T) diminishes with increasing distance from a straight current-carrying wire. At a given location in the vicinity of a current-carrying wire, the magnetic flux density is directly proportional to the current in amperes. Thus, the magnetic field B is directly linked to the magnetic flux density that is flowing in a given direction.

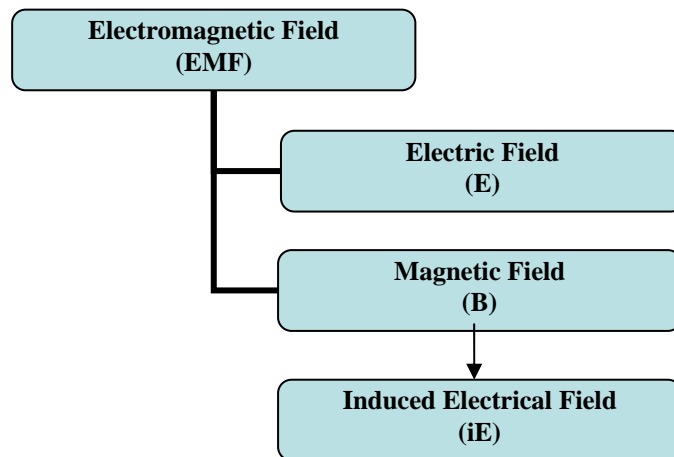
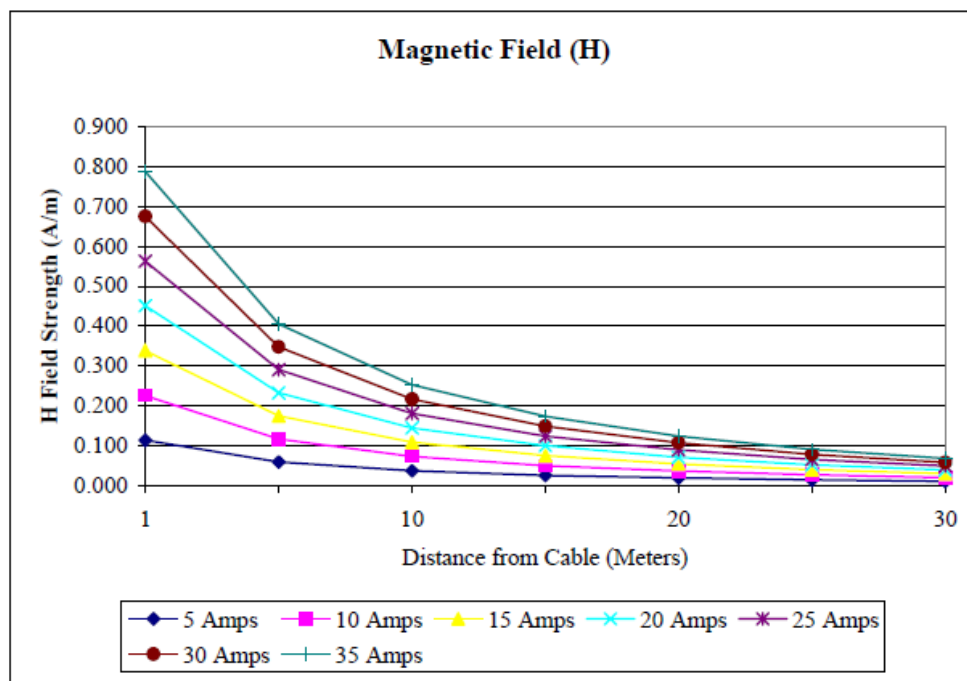
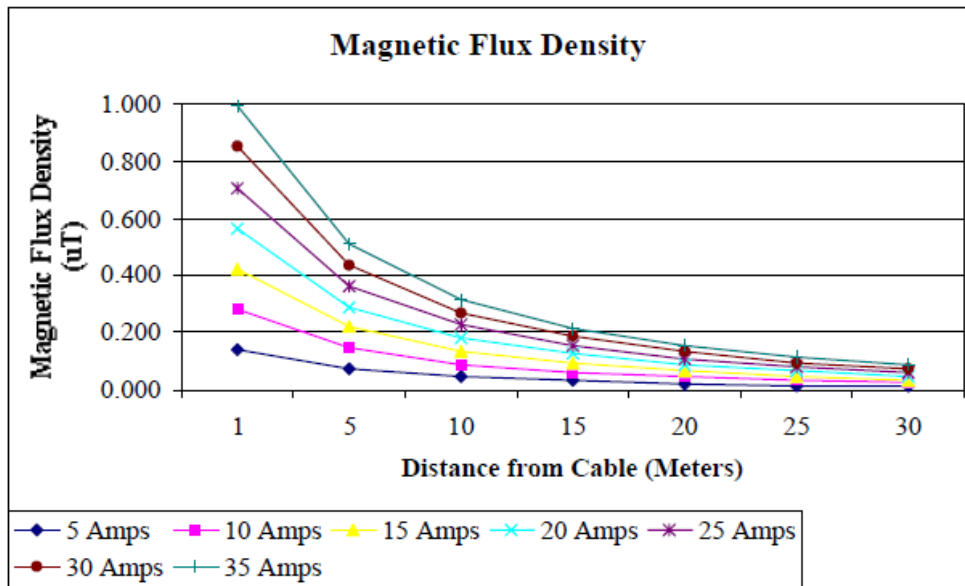


Figure D-1. Simplified view of the fields associated with submarine power cables. Modified from Gill et al. (2005).

The EMF associated with new marine and hydrokinetic energy designs have not been quantified. However, there is considerable experience with submarine electrical transmission cables, and some predications and measurements of their associated electrical and magnetic fields. For example, the Wave Energy Technology (WET) generator will be housed in a canister buoy and connected to shore by a 1190-m-long, 6.5-cm-diameter electrical cable (Appendix F of DON 2003). The cable is designed for three-phase AC (alternating current) transmission, can carry up to 250 kW, and has multiple layers of insulation and armoring to contain the electrical current. Depending on current flow (amperage), at 1 m from the cable the magnetic field strength was predicted to range from 0.1 to 0.8 A/m, and the magnetic flux density would range from 0.16 to 1.0 μ T (Figure D-2). The estimated strength of the electric field at the surface of the cable (apparently the *iE*) would range from 1.5 to 10.5 mV/m. The electric field strength, magnetic field strength, and magnetic flux density would all decrease exponentially with distance from the cable.

CMACS (2003) surveyed cable manufacturers and independent investigators to compile estimates of the magnitudes of E, B, and *iE* fields. Most agreed that the E field can be completely contained within the cable by insulation. Estimates of the B field strength ranged from zero (by one manufacturer) to 1.7 and 0.61 μ T at distances of 0 and 2.5 m from the cable respectively. By comparison, the Earth's geomagnetic field strength ranges from approximately 20 to 75 μ T (Bochert and Zettler 2006). In another study cited by CMACS (2003), a 150 kV cable carrying a current of 600 A generated an induced electric field (*iE*) of more than 1 mV/m at a distance of 4 m from the cable; the field extended for approximately 100 m before dissipating. Lower voltage/amperage cables generated similarly large *iE* fields near the cable, but the fields dissipated much more rapidly with distance.





D-2. Calculated magnetic field (A/m) and magnetic flux density (μT) near the WEC submarine power cable. From DON (2003).

For short distance undersea transmission of electricity, three-phase AC power cables are most common; HVDC are used for longer distance, high power applications (Ohman et al. 2007). In AC cables the voltage and current alternate sinusoidally at a given frequency (50 or 60 Hz), and therefore the E and B fields are also time varying. That is, like AC current, the magnetic field induced by a three-phase AC current has a cycling polarity, which is not like the natural geomagnetic fields. On the other hand, the E and B fields produced by a direct current (DC) cable (e.g., HVDC) are static. Because the magnetic fields induced by static (DC) and alternating current cables are different, they are likely to be perceived differently by aquatic organisms.

Because neither sand nor seawater has magnetic properties, burying a cable will not affect the magnitude of the magnetic (B) field; that is, the B fields at the same distance from the cable are identical, whether in water or sediment (CMACS 2003). On the other hand, owing to the higher conductivity of seawater compared to sand, the iE field associated with a buried cable is discontinuous across the sand/water boundary, and the iE field strength is greater in water than in sand at a given distance from the cable. For example, for the three-phase AC cable modeled by CMACS (2003), the estimated iE field strengths at 8 m from the cable were $10 \mu\text{V/m}$ and $1\text{-}2 \mu\text{V/m}$ in water and sand, respectively.

The EMF generated by a multi-unit array of marine or hydrokinetic devices will differ from EMF associated with a single unit or from the single cable sources that have been surveyed. Depending on the power generation device, a project may have electrical cables running vertically through the water column, as well as multiple cables running

along the seabed or converging on a subsea pod. The EMF created by a matrix of cables has not been quantified.

Effects of Electromagnetic Fields on Aquatic Organisms

Electrical Fields

Natural electric fields can occur in the aquatic environment as a result of biochemical, physiological, and neurological processes within an organism, or as a result of an organism swimming through a magnetic field (Gill et al. 2005). Some of the elasmobranchs (sharks, skates, and rays) have specialized tissues that enable them to detect electric fields (electroreception), an ability which allows them to detect prey and potential predators and competitors. Two species of Asian sturgeon have been reported to alter their behavior in changing electric fields (Basov 1999; 2007). Other fish species (e.g., eels, cod, Atlantic salmon, catfish, paddlefish) will respond to induced voltage gradients associated with water movement and geomagnetic emissions (Collin and Whitehead 2004; Wilkens and Hofmann 2005), but their electrosensitivity does not appear to be based on the same mechanism as sharks (Gill et al. 2005).

Balayev and Fursa (1980) observed the reactions of 23 species of marine fish to electric currents in the laboratory. Visible reactions occurred following exposure to electric fields ranging from 0.6 to 7.2 V/m, and varied depending on the species and orientation to the field. They noted that changes in the fishes' electrocardiograms occurred at field strengths 20 times lower than those that elicited observable behavioral responses. Enger et al. (1975) found that European eels (*Anguilla anguilla*) exhibited a decelerated heart rate when exposed to a direct current electrical field with a voltage gradient of about 400 to 600 $\mu\text{V}/\text{cm}$. In contrast, Rommel and McCleave (1972) observed much lower voltage thresholds of response (0.07 to 0.67 $\mu\text{V}/\text{cm}$) in American eels (*Anguilla rostrata*). The eels' electrosensitivity measured by Rommel and McCleave is well within the range of naturally occurring oceanic electric fields, which by their estimates are at least 0.10 $\mu\text{V}/\text{cm}$ in many currents in the Atlantic Ocean and may have values up to 0.46 $\mu\text{V}/\text{cm}$ in the Gulf Stream.

Kalmijn (1982) described the extreme sensitivity of some elasmobranchs to electric fields. For example, the skate (*Raja clavata*) exhibited cardiac responses to uniform square-wave fields of 5 Hz at voltage gradients as low as 0.01 $\mu\text{V}/\text{cm}$. Dogfish (*Mustelus canis*) initiated attacks on electrodes from distances in excess of 38 cm and voltage gradients as small as 0.005 $\mu\text{V}/\text{cm}$.

Marra (1989) described the interactions of elasmobranchs with submarine optical communications cables. The cable created an iE field (1 $\mu\text{V}/\text{m}$ at 0.1 m) when sharks crossed the magnetic field induced by the cable. The sharks responded by attacking and biting the cable. Marra (1989) was unable to identify the specific stimuli that elicited the attacks, but he suggested that at close range the shark interpreted the electrical stimulus of the iE field as prey, which it then attacked.

The weak electric fields produced by swimming movements of zooplankton can be detected by juvenile freshwater paddlefish (*Polyodon spathula*). Wojtenek et al. (2001) used dipole electrodes to create electric fields that simulated those created by water flea (*Daphnia* sp.) swimming. They tested the effects of alternating current oscillations at frequencies ranging from 0.1 to 50 Hz and stimulus intensities ranging from 0.125 to 1.25 μA peak-to-peak amplitude. Paddlefish made significantly more feeding strikes at the electrodes at sinusoidal frequencies of 5-15 Hz, compared to lower and higher frequencies. Similarly, the highest strike rate occurred at the intermediate electric field strength (stimulus intensity of 0.25 μA peak-to-peak amplitude). Strike rate was reduced at higher water conductivity, and their fish habituated (ceased to react) to repetitive dipole stimuli that were not reinforced by prey capture.

Gill and Taylor (2002; cited in CMAC 2003) carried out a pilot study of the effects on dogfish of electric fields generated by a DC electrode in a laboratory tank. They reported that the dogfish avoided constant electric fields as small as 1,000 $\mu\text{V}/\text{m}$, which would be produced by 150 kV cables with a current of 600 A. Conversely, the dogfish were attracted to a field of 10 $\mu\text{V}/\text{m}$ at 0.1 m from the source, which is similar to the bioelectric fields emitted by dogfish prey. The electrical field created by the three-phase, AC cable modeled by CMACS (2003) would likely be detectable by a dogfish (or other similarly sensitive elasmobranchs) at a radial distance of 20 m. It is possible that the ability of fish to discriminate an electrical field is a function of not only the size/intensity but also the frequency (Hz) of the emitted field.

Magnetic Fields

Many terrestrial and aquatic animals can sense the Earth's magnetic field and appear to use this magnetosensitivity for long distance migrations. Aquatic species whose long-distance migrations or spatial orientation appear to involve magnetoreception include eels (Westerberg and Begout-Aranas 1999; cited in CMACS 2003), spiny lobsters (Boles and Lohmann 2003), elasmobranchs (Kalmijn 2000), sea turtles (Lohmann and Lohmann 1996), rainbow trout (Walker et al. 1997) and possibly Pacific salmon (Walker et al. 1988). Because some aquatic species use the Earth's magnetic field to navigate or orient themselves in space, there is a potential for the magnetic fields created by the numerous electrical cables associated with offshore power projects to disrupt these movements.

Gill et al. (2005) placed magnetosensitive organisms into two categories: (1) those able to detect the iE field caused by movement through a natural or anthropogenic magnetic field, and (2) those with detection systems based on ferromagnetic minerals (magnetite or greigite). Johnsen and Lohmann (2005; 2008) add a third possible mechanism for magnetosensitivity – chemical reactions involving proteins known as cryptochromes. Those species using the iE mode may either do it passively (the animal estimates its drift from the electric fields produced by the interaction between tidal/wind-driven currents and the vertical component of the Earth's magnetic field) or actively (the animal derives its magnetic compass heading from its own interaction with the horizontal

component of the Earth's magnetic field). For example, Kalmijn (1982) suggested that the electric fields that elasmobranchs induce by swimming through the Earth's magnetic field may allow them to detect their magnetic compass headings; the resulting voltage gradients may range from 0.05 to 0.5 $\mu\text{V}/\text{cm}$. Detection of a magnetic field based on internal deposits of magnetite occurs in a wide range of animals, including birds, insects, fish, sea turtles, and cetaceans (Gould 1984; Bochert and Zettler 2006). There is no evidence to suggest that seals are sensitive to magnetic fields (Gill et al. 2005).

Westerberg and Begout-Aranas (1999; cited in CMACS 2003) studied the effects of a B field generated by a HVDC power cable on eels (*Anguilla anguilla*). The B field was on the same order of magnitude as the Earth's geomagnetic field and, coming from a DC cable, was also a static field. Approximately 60% of the 25 eels tracked crossed the cable, and the authors concluded that the cable did not appear to act as a barrier to the eel migration. In another behavioral study, Meyer et al. (2004) showed that conditioned sandbar and scalloped hammerhead sharks readily responded to localized magnetic fields of 25 to 100 μT , a range of values that encompasses the strength of the Earth's magnetic field.

Some sea turtles undergo transoceanic migrations before returning to nest on or near the same beaches where they were hatched. Boles and Lohmann (1996) showed that sea turtles have the sensory abilities necessary to approximate their global position on a magnetic map. This would allow them to exploit unique combinations of magnetic field intensity and field line inclination in the ocean environment to determine direction and/or position during their long-distance migrations. Irwin and Lohmann (2005) found that magnetic orientation in loggerhead sea turtles (*Caretta caretta*) can be disrupted at least temporarily by strong magnetic pulses (five brief pulses of 40,000 μT with a 4 ms rise time).

The emphasis of most of these studies has on the value of magnetoreception for navigation; marine and hydrokinetic energy technologies are unlikely to create magnetic fields strong enough to cause physical damage. For example, Bochert and Zettler (2006) summarized several studies of the potential injurious effects of magnetic fields on marine organisms. They subjected several marine benthic species (flounder, blue mussel, prawn, isopods and crabs) to static (DC-induced) magnetic fields of 3,700 μT for several weeks and detected no differences in survival compared to controls. In addition, they exposed shrimp, isopods, echinoderms, polychaetes, and young flounder to a static, 2,700 μT magnetic field in laboratory aquaria where the animals could move away from or toward the source of the field. At the end of the 24-h test period, most of the test species showed a uniform distribution relative to the source, not significantly different from controls. Only one of the species, the benthic isopod *Saduria entomon*, showed a tendency to leave the area of the magnetic field. The oxygen consumption of two North Sea prawn species exposed to both static (DC) and cycling (AC) magnetic fields were not significantly different from controls. Based on these limited studies, Bochert and Zettler (2006) could not detect changes in survival, behavior, or a physiological response parameter (oxygen consumption) of a variety of marine benthic organisms resulting from magnetic flux densities that may be encountered near an undersea electrical cable.

The current state of knowledge about the EMF emitted by submarine power cables is too variable and inconclusive to make an informed assessment of the effects on aquatic organisms (CMACS 2003). Following a thorough review of the literature related to EMF and extensive contacts with the electrical cable and offshore wind industries, Gill et al. (2005) concluded that there are significant gaps in knowledge regarding sources and effects of electrical and magnetic fields in the marine environment. They recommended developing information about likely electrical and magnetic field strengths associated with existing sources (e.g., telecommunications cables, power cables, electrical heating cables for oil and gas pipelines), as well as the generating units, offshore sub-stations and transformers, and submarine cables that are a part of offshore renewable energy projects. They cautioned that networks of cables in close proximity to each other, as would be found in large current and tidal energy projects where cables come together at substations, are likely to have overlapping, and potentially additive, EMF fields. These combined EMF fields would be more difficult to evaluate than those emitted from a single electrical cable. The small, time-varying B field emitted by a submarine three-phase, AC cable may be perceived differently by sensitive marine organisms than the persistent, static, geomagnetic field generated by the Earth (CMACS 2003).