Building Capacity for Marine Hydrokinetic Energy: Atlas of Potential Synergistic and Conflicting Environmental, Ecological, and Human Use Considerations

Prepared for the North Carolina Renewable Ocean Energy Program

July 2012 – Final report

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Introduction

Ocean energy extraction has gained attention as a viable component of the energy portfolio of the future. While utility-scale wave and current energy installations have yet to become common, technologies are continuously being developed (U.S. Department of the Interior 2006; EPRI 2011) to take advantage of the vast and renewable ocean energy resources that have the potential to provide the ancillary benefits of reducing carbon emissions and improving energy security. A recent wave resource assessment conducted by the Electric Power Research Institute (EPRI; 2011) estimated a total available wave resource of 2, 640 terawatt-hours (TWh) along the outer continental shelf of the United States (to the 200 m depth contour of the shelf). Additionally, the federal government estimated that capture of just 1/1000th of the current flow of the Gulf Stream would supply over 75 TWh of energy, which is approximately equivalent to 35% of Florida's energy needs (U.S. Department of the Interior 2006). North Carolina (NC) could benefit economically from pursuing the development and utilization of ocean energy resources by taking advantage of access to the ocean along approximately 3,375 miles of coastline (NOAA 2002) and its history of economic success in the research and manufacturing sectors. The area of the relatively shallow continental shelf of NC out to a depth of 50 m exceeds the total shelf area for all other east coast states by a factor of two, so space for shallow-water renewable energy development is abundant off the NC coast. Pursuit of ocean energy by NC also has the potential to reduce its 2008 10% net import of electricity and its ranking as the 13th highest carbon dioxide emitting state in the country (U.S. Energy Information Administration 2010).

While the environmental impacts of marine hydrokinetic (MHK) devices are not generally expected to be extreme, they are under-studied at present because of the lack of utility-scale installations where observations and empirical information can be gathered. Nonetheless, risk assessments of potential environmental impacts of ocean energy devices on marine resources and habitats are necessary for any future ocean installation. In fact, requirements for consideration of several potential impacts are already included in federal and state regulations.

Interference with existing and anticipated human activities is another aspect of the potential environmental impacts of MHK devices that requires careful consideration. The rivers, estuaries, sounds, and nearshore ocean (≤ 15 m depth) shelf constitute locations for several extensive human activities and uses, so judging the level of conflicts and the means of minimizing negative interaction is an additional component of assessing environmental (human, in this case) impacts. Some locations such as ocean inlets, the surf, and other nearshore zones of the ocean are heavily used for multiple recreational and commercial activities, implying a need for spatially explicit planning to minimize conflicts.

Siting of MHK installations off of the NC coast will be based on the availability of wave, ocean current, and tidal current energy and the risk of environmental impacts on organisms and habitats, including aspects that are presently regulated or that may be regulated in the future, and serious conflicts with existing human uses of the coastal ocean. In addition, up-front consideration of potential future uses of the areas where the installations may be located may be necessary to reconcile concerns of various ocean stakeholders who may perceive MHK installations as threats to their interests and be compelled to object to commercial-scale MHK development.

This report addresses the potential environmental and ecological effects posed by commercial installations of ocean wave, ocean current, and tidal current energy generating devices. It does not detail the potential effects of prototype-scale devices, which will need to be considered to obtain permits for their test installations, but the issues that we raise will apply at a smaller scale and can be inferred from our assessment of commercial-scale effects. The report also addresses the temporal and spatial use of the ocean off of the coast of NC by humans and by fish and wildlife. An understanding of the temporal and spatial dynamics of potentially conflicting human uses and of uses by sensitive natural resources could lead to resolution of these conflicts through spatial or temporal segregation before they erupt and become an impediment to development.

Marine hydrokinetic energy devices

Devices to generate electricity from wave and current energy are becoming increasingly diverse in their design. New devices are being developed regularly. In this report, MHK devices were classified by type based upon their physical action, operational depth, and attachment to the seabed (Table 1).

The types of MHK wave devices considered here include wave attenuators, point absorbers, submerged pressure differentials, floating oscillating water columns, overtopping terminators, and surge converters. Wave attenuators are large, floating devices that are oriented parallel to the primary wave direction and are comprised of jointed sections where movement at each joint converts kinetic energy to electrical energy (Appendix A). Attenuators are connected to moorings on the seabed by cables that extend through the water column. They are typically located at depths of greater than or equal to 50 m (CRES 2006). Floating point absorbers are buoy-type wave devices that are situated at the water's surface and absorb energy from all directions as they rise and fall with surface waves relative to their stationary bases (Appendix B). Bases can consist of single block foundations or pier-type structures and the devices can be located in various water depths. Submerged point absorbers devices are similar to point absorbers except that they are situated below the water's surface (Appendix B) and are located at depths of 15 m or more in areas with no breaking waves. Oscillating water column wave devices consist of partially submerged chambers where waves can enter at the base and the rest of the chamber consists of airspace (Appendix C). Electricity is produced when the air is pressurized and depressurized by the wave motion, pushing it through a turbine. Oscillating water columns can be floating units or can be located along steep, rocky shorelines. Because we do not have steep, rocky shorelines in NC, only floating oscillating water column wave energy devices are considered here. They can be located at various water depths ranging from approximately 10 to 80 m. Overtopping terminators consist of large fixed or floating reservoirs with reflective arms that focus surface waves to fall into a reservoir (Appendix D). The falling water powers an internal turbine within the reservoir. The devices can be located at depths of 6 to 30 m, with larger devices located in deeper waters. Surge converting devices are flapping panels that move with wave surges and are attached to a frame that is bolted to the seabed (Appendix E). The devices are located in nearshore waters that are 10 to 15 m deep.

Table 1. Characteristics of different types of wave and current energy devices considered in this report. Mounted devices are those that have frames that are in direct contact with the seabed while those that are anchored are connected to the seabed by cables and moorings.

Notations for Table 2	Device	Description	Operational depth (m)	Physical action	Anchored or mounted to seabed?	Extends above the water's surface?
1	Wave: Attenuators	Floating device that rides waves at the water's surface	≥ 50	Jointed sections move parallel to the wave direction	Anchored	Yes
2	Wave: Point Absorbers (single or multi)	Floating buoy that moves with surface waves	Wide range	Buoy component moves in all directions	Anchored, for single; mounted for multi	Yes
3	Wave: Submerged pressure differential	Floating buoy that moves with waves below the water's surface	Wide range	Buoy component moves in all directions	Anchored	No
4	Oscillating Water column (floating)	A partially submerged chamber of air open to wave forces at the base.	10-80; wide range	Wave forces cause the rise and fall of water in the base, which drives air in and out of the chamber	Anchored	Yes
5	Wave: Overtopping terminator	Fixed structure at sea level; waves push water over the top of the reservoir rotating internal turbines	6 - 30	Internal turbines rotated by falling water	Anchored	Yes
6	Wave: Surge converter	Oscillating arm connected to a stationary base on the seabed	10-15	Pendulum movement of the arm with wave surges	Mounted	Yes
7	Current: Fixed axial and helical turbines	Submerged open- or closed-blade turbines that are mounted to the seafloor and rotate parallel or perpendicular to wave action.	15-30; wide range	Turbines rotate parallel or perpendicular to wave action	Mounted	In some cases, mounting structures extend above the surface
8	Current: Floating axial and helical	Submerged open- or closed-blade turbines mounted on floating structures, which are tethered to the seafloor; the turbine(s) rotate parallel or perpendicular to wave action.	> 25 m	Turbines rotate parallel or perpendicular to wave action.	Anchored	In some cases, buoys extend above the surface
9	Current: Oscillating hydrofoils	Submerged hydrofoils are ; some w/ aerial platform	≥ 9	Pendulum movement of the arm with current flows	Mounted	In some cases, decks attached to mounting structures extend above the surface

The types of current energy devices considered here include fixed and floating axial turbines, fixed and floating helical/cross-flow turbines, and oscillating hydrofoils. Axial turbines are similar to wind turbines, with blades that rotate perpendicular to the movement of currents (Appendix F). The blades can be open or closed (see the Openhydro example in Appendix F). Axial turbines can be attached to various types of fixed structures, ranging from monopiles that extend into decks above the water's surface (that facilitate easier access for device maintenance) to tripods that extend just above the seabed, and include floating structures (see the EvoPod example in Appendix F). One base can support one to several axial turbines (see the Hammerfest Strom and SeaGen examples in Appendix F, respectively). Axial turbine current energy devices can be installed in a wide range of water depths, in part reflecting a wide range in their design elements. Cross-flow or helical turbines are similar in appearance to push reel lawn mowers and can be oriented vertically or horizontally in the water column to rotate parallel to the motion of currents (Appendix G). They too can be attached to fixed bases or be floating structures moored to the seabed and consist of one or several individual turbines. Helical turbines require deeper waters and are typically installed at depths beyond 25 m. Oscillating hydrofoils consist of a hydrofoil attached to an oscillating arm and typically resemble a wing or a tail (Appendix H). A perpendicular lift force is created by the current stream, which induces oscillation of the arm. The arm is typically attached to a fixed structure mounted on the seabed, which in some cases extends above the water's surface as a deck. Depending on their design, oscillating hydrofoil current energy devices can be located in shallower waters (with an approximate minimum depth of 9 m) than the other two types of current energy devices.

Potential environmental and ecological effects

Wave and current energy devices will affect the marine environment and marine organisms as a result of their physical presence and dynamic movement, and potentially by any noise, light, chemicals, and electromagnetic fields that they emit. Rigorous assessment of whether device-mediated disturbances to the environment have negative, positive, or no effects on biota and human activities requires specific information on the magnitude, frequency, and form of the introduced disturbances. Given that the eventual commercial designs of all the wave and current devices under consideration are unknown, at this time most assessments of impacts will be provisional. Some predictions of impacts do not depend on design (e.g., placing device anchors on top of living coral) and can be stated clearly. Some predictions of impacts can lead to alteration of engineering designs to mediate impacts in the final product. The predictions presented here will hopefully enable engineers to avoid designing devices that have inevitable, extensive negative environmental impacts.

The environmental components that may be impacted by particular devices are summarized in Table 2. A summary of general potential impacts on the marine environment, marine organisms, and human uses posed by all devices and the likelihoods of for substantial effects on different groups of actively managed species of value, including forage (prey) fish, fish caught by commercial and recreational fishermen, and protected species is provided here.

Table 2. An overview of effects induced by the presence and/or operation of different types of MHK devices and the natural resource components that may be positively or detrimentally modified. Refer to Table 1 for the notations referring to different types of MHK devices.

Impacts introduced by devices	**Sediment and hydro-dynamics: Nearfield**[1]	**Sediment and hydro-dynamics:Farfield**[2]	**Habitat**	**Invertebrates**	**Fish and invertebrate: eggs and larvae**	**Fishes: juvs and adults**	**Marine mammals**	**Sea turtles**	**Birds**
Collision w/ device; blade/component strike					All	All	All	All	While diving: All except 1 and 5; While flying: All except 3 and 7
Entanglement w/ cables							All	All	While diving: All; While flying: 6,7,9
Operational noise						All	All	All	
Physical presence[3]	All	All	All	All		All	All	All	All

1 Nearfield refers to the physical environment that is within 10 times the diameter of a device or the outer array of structures (Amoundry and others 2009).

2 Far-field refers to the physical environment farther away than nearfield.

3 Physical presence includes attraction to and avoidance of the device by organisms; change/disturb habitat; change flow regime; change energy and sediment transport

Physical presence

The physical presence of submerged structures will attract marine organisms because they provide a habitat alternative to the surrounding soft bottom and open water. The surfaces are often well-colonized by marine epiphytic organisms (Baine 2001; Andersson and Öhman 2010); this phenomenon is called the "reef affect". For example, Langhamer and others (2009) observed epifaunal colonization of point absorbing buoy foundations in Sweden to cover 3.8% of the surface one year following deployment, and the percent cover increased by an order of magnitude during the second year, before it leveled out in the third. The types of organisms that colonize surfaces differ somewhat with different surface materials (Andersson and others 2009; Cangussu and others 2010), orientations, complexities and rugosities (Langhamer and Wilhelmsson 2009), water depths, or a combination of surface characteristics (Glasby and others 2007; Wilhelmsson and Malm 2008). In some cases, non-indigenous species are the primary colonizers, as was the case on wind turbine bases in the North Sea (Kerckhof and others 2011).

Fish also tend to aggregate around various types of marine structures, including ship wrecks, buoys, oil platforms, and piers, which is why they are often termed "fish aggregating devices" (FADs). Fish are expected to aggregate around MHK structures as they do around wind turbine bases (Wilhelmsson and others 2006; Andersson and others 2009; Andersson and Öhman 2010). They utilize structures colonized by epibenthic assemblages for food, shelter from predators, and spawning and nursery habitat. Pelagic species may forage around the structures but benthic and semi-pelagic species use them more as habitat (Andersson 2011).

Reefs and their associated algae, benthic invertebrates, and fish attract higher-order consumers, such as sea turtles, scoters (*Melanitta* sp.), and marine mammals, and larger pelagic predatory fish like sharks, amberjacks (*Seriola dumerili*), king mackerel (*Scomberomorous cavalla*), and cobia (*Rachycentron canadum*). All five species of sea turtles that frequent NC waters may be attracted to structures for foraging, including Kemp's ridley (*Lepidochelys kempii),* loggerhead (*Caretta caretta*), green (*Chelonia* *mydas*), leatherback (*Dermochelys coriacea*), and hawksbill sea turtles (*Eretmachelys imbricata*). Loggerheads and Kemp's Ridleys consume crabs and other benthic invertebrates, while green sea turtles consume the macroalgae on reefs, so these three species might be expected to show this response of enhanced aggregation most strongly. Scoters consume mussels and other attached epifaunal mollusks that colonize reef surfaces. The large pelagic predators consume smaller fish whose abundances are enhanced by the reef presence. A preliminary study of bird behavior near an offshore wind farm showed that the birds seem to be attracted to the devices (Vanermen and others 2010), which the authors posited may have been the result of increased foraging opportunities on the reefs that establish on bases or access to perches upon which they could rest.

Humans are another fish predator that may be attracted to the aggregated assemblages of fish surrounding FADs. Studies of various fisheries in America Samoa (Buckley and others 1989), Japan (Polovina and Sakai 1989), the US. Virgin Islands (Friedlander and others 1994), and South Australia (McGlennon and Branden 2004) have shown that fish catches increase near FADs. However, because an increase in fish recruitment does not necessarily accompany aggregation, increased fishing pressure nearby to FADs may actually lead to overexploitation (Powers and others 2003, Grossman and others 2007).

In some cases, marine organisms may instead avoid introduced structures, especially if repelled by noise. Such avoidance may displace those organisms from an area of foraging, rafting, or breeding habitat or avoidance may cause the organisms to travel further and expend more energy during local or long-distance migrations. Empirical evidence regarding avoidance behavior and the corresponding energetic costs are limited to avoidance of offshore wind installations by birds. Grecian and others (2010) suggest that birds may avoid the portions of MHK devices that extend beyond the surface of the water column similarly to how geese and ducks have been observed to avoid offshore wind turbine installations (Desholm and Kahlert 2005). The Grecian and others review (2010) concluded that avoidance-related impacts will be negligible for most devices, but they point out that more information is needed regarding the impact of larger installations that extend above the water's surface.

The increase in hardened habitat associated with the introduction of wave and current energy device structures is at the expense of the extant benthic habitat, pre-empted by anchoring devices on the bottom, and open water. For this reason, highly biologically diverse and densely colonized areas of benthic habitat, such as coral reefs and hard bottom, should be avoided. Coral reefs and hard bottoms are marine habitats designated as Essential Fish Habitats, which are federally protected by the Magnuson-Stevens Fishery Conservation and Management Act. Obstructions to continuous open water habitat can also introduce the risk of collision for pelagic species. Please reference the '*Collision, Strike, and Shear Stress*' section below for more information.

Introduced structures can also alter the physical environment. Changes in sediment dynamics and hydrodynamics can be localized to the immediate area surrounding a device or array, near-field (as defined by Amoundry and others 2009 as 10 times the diameter of a device or the outer array structures), or far-field (further away than near-field). Empirical evidence of changes in far-field hydrodynamics as a result of MHK installations is limited to hydrodynamic modeling of a 30 turbine, 1 MW tidal turbine project in the East River of New York (Verdant Power New York 2010). Model results depicted the water level of the channel inlet of the East River increasing by 0.012 m and the velocity of water decreasing by 0.07 ms^{-1}, translating to a 2% reduction in the energy flux within the natural channel (Verdant Power New York 2010). For more information, windfarms again serve as a frame of reference for expected effects of MHK devices on near-field sediment and hydro-dynamics. Increases in suspended sediment concentrations during construction of the six windfarms reviewed by Amoundry and others (2009) were small (11% maximum), localized, and temporary. The increases in suspended sediment concentrations are expected to be similar during structure decommissioning. Scour was observed around turbine bases of monopiles (reviewed by Whitehouse and others (2011) and Amoundry and others (2009)). Whitehouse and others (2011) found that only ~5% (n=115) of the windfarm foundations experienced scour depths greater than that recommended in guidance documents published by Det Norske Veritas (2007). Amoudry and others' (2009) assert that scour dynamics are not well understood, nor are long-term changes in bathymetry and hydrodynamics as a consequence of the introduction of stationary structures. However, they concluded that arrays of stationary devices or device components may together act as a singular obstruction, thereby causing a wake that may impact nearby soft sediments.

Near-field changes in sediment dynamics can have a direct effect on marine organisms. Disruption of underlying sediments when devices are secured to the seabed via pilings, anchors, or moorings during construction will increase turbidity temporarily and release any buried contaminants (Cada and others 2007). Sediment disruption may continue during the operation of the device, owing to the movement of rotor components, depending upon the rotor location relative to the seabed. This persistent disturbance could negatively impact larval forms, though the relationship between larval fish and turbidity is complex. For visual plankton feeders, turbidity can impact fish larvae by significantly reducing available distances in which to search and react, resulting in lowered feeding abilities (Boehlert and Morgan 1985). At higher concentrations, short-term exposures to suspended sediment can potentially increase larval fish mortality (Auld and Schubel 1978, Rosenthal 1971, J.J Govoni pers. comm.). Conversely, the larvae of many fish species inhabit estuaries when turbidity is elevated, and some species have been shown to favor more turbid conditions, perhaps because the turbidity provides protection from their own predators (Blaber and Blaber 1980). With regard to the potential far-field effects of MHK devices, changes in hydrodynamics can influence the amount of energy transferred in the form of currents into enclosed water bodies and waves onto shore, which in turn influence shoreline sediment dynamics. Changes in the hydrodynamics surrounding Seagen, a tidal current device, included an increase in turbulent wake extending ~600 m downstream of the device and flow acceleration to ~250 m on either side of the device. Both of these hydrodynamic changes have the potential to influence sediment dynamics, but no measured changes were reported. Meanwhile, McMillan and others (2008) found that tidal amplitude was decreased by

30% in the Bay of Minas and increased by 15% along the coasts of Maine and New Hampshire in a modeling study of a tidal energy installation in the Bay of Fundy. The Limpet, an oscillating water column wave energy converter situated on the coast of Scotland, was observed to act as a breakwater, almost completely dissipating the wave energy and suppressing wave height on the leeward side of the device. Subtle changes in wave climate have been shown to have a first-order (linear) effect on sediment dynamics (Williams and Esteves 2005). Smith and others (2012) found from a modified SWAN model that the wave state affected the size and extent that effect barriers, such as wave energy installations, had on leeward wave height. The effect was larger in size and extent with sea swells as compared to seas driven by local winds.

Summary of physical presence risks by device

In general, the physical presence of a hardened structure is very likely to affect several groups of actively managed species of value (Table 2). Invertebrates, fish, and some diving seabirds may be attracted to the structures for habitat and food. Sea turtles, marine mammals, and large pelagic predatory fishes are also likely to be attracted to the devices, motivated by increases in their own prey. In most cases, the introduction of a hardened structure will positively influence marine organisms by providing habitat and concentrating or augmenting food. However, in some cases, the physical presence has the potential to negatively affect marine organisms. When such at-risk organisms are attracted to devices, it puts them at a greater risk of entanglement with mooring cables and strike by moving components (see '*Entanglement*' and *'Collision, Strike, and Shear Stress*' sections for more information). In addition, if marine organisms exhibit avoidance behavior, the displacement from foraging areas and the increased energetic costs of migration may negatively affect their use of the ocean environment and their fitness. Flying birds are unlikely to be affected by the physical presence of wave and current energy devices that do not extend above the water's surface. However, for wave attenuators, point absorbers, overtopping terminators, oscillating water columns, some types of surge converters, and fixed axial and helical current turbines that do extend above the water's surface, they pose a collision risk (see *'Collision, Strike, and Shear*

Stress' section for more information). Or, if they are perceived and avoided by low-flying birds, the energetic costs associated with habitat displacement and migration along the coast or between pelagic and inland habitats may increase. Seabirds may enjoy a benefit from the presence of devices that provide dry perches above water on which the birds may rest.

Collision, strike, and shear stress

The physical presence of MHK devices in the water column, on the sediment surface, and in some cases, in the overlying atmosphere, also introduces the threat of collision with fixed structures to organisms that use the marine environment and overlying atmosphere. Marine organisms are also subject to direct strike and shear stress generated by moving components of MHKs, such as from the rotation of turbine blades (floating and fixed axial turbines, wave overtopping terminators), pitching motion of buoys and floating components (wave attenuators, point absorbers, and submerged pressure differentials), pendulum-like motion called flapping (wave surge converters), the rising and falling motion of oscillating hydrofoil blades, or from cables and chains. Strike from moving components may pose greater risk of injury than mere presence of fixed structures because moving components may be harder for organisms to perceive and avoid, and introduce an additional force other than that associated with the organism's movement. Organisms are also at risk of strike from boats used during the installation and maintenance of MHKs. Aggregation of marine organisms near MHKs (see *'Physical Presence'* section) could lead to more ship strikes from ships maintaining devices and supporting infrastructure. Fishing activities in the vicinity of MHKs could also increase the risk of fishing boat strike of organisms attracted to devices.

The risk of an impact to any given species of marine organism from collision and strike depends on the organism’s density, habitat use, and the per capita frequency of encounter (see *'Physical Presence'* section and the Biological hotspot map, Fish egg and larvae conflict map, and SPUE maps for marine mammals and sea turtles). In fixed hydroacoustic array, dual identification sonar, and netting studies used by Verdant Power (2011) to monitor fish distribution and behaviors around in-stream tidal turbines in the East River of NC, fish were not present in the vicinity of the tidal turbines when water flow velocities exceeded $0.8ms^{-1}$. Verdant Power (2011) also observed that fish tended to be distributed in the inshore, slower zones of the river, swimming at the surface or bottom of the water column, as opposed to the middle.

Probability of collision or strike

If a device is encountered, mobile organisms will likely prevent collision or strike by avoidance at long-range or evasion at a close-range, as long as the devices are perceived. Perception of the device, is influenced by visual or other sensory acuity as well as environmental conditions such as water turbidity, flow speed, light conditions, and weather. Fog, surface waves, turbidity, or bubbles can obscure devices (Thompson and others 2008).

Fish can be attracted to turbid water as a means of predator avoidance, which would reduce their ability to detect devices, and fish that are nocturnally mobile are more likely to collide with cooling water intakes and vessels at night (Halvey and Dorn 1987). Nocturnally- and crepuscularly-active bird species (e.g., the black-capped petrel) may have difficulty perceiving devices, although nocturnal birds were observed to successfully avoid wind turbines at night (Desholm and Kahlert 2005). Even under conditions of good visibility, organisms may fail to perceive devices if distracted while engaged in foraging or socialization. Pursuit diving seabirds, those that use wing or foot propulsion to pursue prey, and plunge divers, those that dive from flight and enter water at high velocities, may run greater risks of collision or strike because of intense focus on their prey.

Organisms may also rely on senses other than sight to perceive devices. Echolocation may aid mammals in detecting and avoiding devices even in turbid waters, unless their sonar signal is locked onto prey at the exclusion of devices (Wilson and others 2007). The sensing of sound waves may also be used by organisms to avoid collision or strike, yet ship strikes are known to occur despite auditory cues. For instance, David and others (2011) found a high (0.12-2.6 strikes/boat/day) frequency of ship strikes on fin whales in the Mediterranean. A variety of factors is thought to contribute to ship strikes despite auditory cues that could guide avoidance by the mobile organisms, including background noise or sound-blocking structures. Such factors may influence the risk of collision or strike with MHK devices and could motivate the installation and maintenance of collision-avoidance plans (boats are warned to avoid areas where marine mammals are acoustically detected) and devices (sonic alarms that will warn off marine organisms) on ships (Laist and others 2001, Gerstein 2005).

Evasion ability is influenced by travel speed, swimming ability, reaction time, health, and age. Surface-diving birds with slow, controlled dives will have an easier time evading devices than plunge divers that enter the water at high velocities (Wilson and others 2007). Capuska and others (2012) observed collisions between diving gannets (*Morus sp.*) and other birds underwater, suggesting that plunge divers are especially subject to collision risks. Marine mammals are expected to be capable of evading devices because they are highly mobile. Sea turtles will probably perceive devices in time for avoidance due to their slow, deliberate swimming, but evading devices at the last second may be more difficult due to their relatively low agility compared to some fish and mammals. Whales, sea turtles, birds, and many fish also lack reverse propulsion, which may hinder evasion. Evasion ability may also be influenced by age and body-size. For example, Schweizer and others (2012) found that older juvenile fish could evade turbines by swimming against the current, but that younger juveniles could not. In another study, larger adult fish were found to have better avoidance ability than smaller adult fish due to improved swimming strength (EPRI 2011).

Even if devices are perceived, an organism may not recognize the device as a threat, depending on their age and intrinsic recognition of danger. Mammals may approach devices out of curiosity, or in attempt to use a device for hauling out and surfacing. Sea turtles or mammals may be incapable of avoiding devices due to an immediate need for air. Fish schooling behavior may reduce the evasion ability of fish (Isaacman and Lee 2010; Wardle 1986). Seabirds make frequent use of flotsam on the ocean surface for rest stops, and some species make use of flotsam more than others. For example, species lacking highly effective waterproofing on the plumage express high use of perches large enough to allow the birds to remain dry. The magnificent frigatebird (*Fregata magnificens),* sooty tern (*Onychoprion fuscatus)*, and bridled tern (*Onychoprion anaethetus)* fall into this high-use category (C. Haney, Defenders of Wildlife, pers. comm.). Thus, hydrokinetic energy devices that project high enough above the water could provide this synergistic benefit to seabirds, especially important for this set. Nevertheless, if any operation of the hydrokinetic device were to pose a danger to the birds, then the benefit of added resting time could quickly convert to a disadvantage, even leading to injury or mortality, depending on seriousness of the risk. Migrating passerine birds can be blown off course and out to sea to varying distances by spring or fall storms during their seasonal migration. When tired from excess energy demands associated with the extra flight requirements, such songbirds often land on ships for perching and resting. If the MHK device were to pose a risk to a flying or perched bird, then this benefit too could transform into a liability - in essence an attractive nuisance.

While a device may entrain (take up into a stream of water) or impinge (pin against a surface due to water flow) larval fish, these events do not necessarily result in mortality (J.J. Govoni pers. comm. – NMFS Beaufort NC lab). It is certainly possible that larval fish may be able to escape or even avoid potentially harmful encounters with devices, but any generalization regarding the ability of larval fish to do so is not feasible. The swimming abilities of larvae are widely variable among species, and MHK device-specific mortality data are largely unknown.

Risk of collision or strike will also depend on the characteristics of devices. Even if devices are perceived, some current energy devices use engineered features, such as ducts (Hydro Green Energy turbine), which make it impossible to escape once entrained. Risk of collision or strike is expected to increase with the number or density of devices in an array, although the increase may not be proportional to the number of devices, because dodging or deflection from one device may result in running into another device. In addition, a fish killed by one device in an array is not available to be killed by another. The risk of blade strike for rotors will depend on the number of turbine blades, the blade spacing, the rotations per minute, and the blade shape (EPRI 2011).

Few studies have monitored or attempted to measure the likelihood of strike from MHK devices. Video monitoring of fish passage through spherical cross-flow and axial flow hydrokinetic turbines in the laboratory found that 82-94% of fish avoided turbines altogether (EPRI 2011). Verdant Power New York (2011) observed, using dual identification sonar, that fish safely passed through slowly moving blades along hydrodynamic flow lines (the fish were not present in the vicinity of turbines during periods of high, fast flow). Predictive modeling has been used to calculate the likelihood of strike from marine hydrokinetic turbines. For example, a 1/8 chance and a 1/18 chance of strike by a MCT SeaGen turbine were modeled for mammals with a 50 cm girth and a drifting organism with a 20 cm girth, respectively (Fraenkel 2006; Argo Environmental Limited 2006).

Severity of collision or strike

If a collision or strike occurs, organisms may remain unharmed, sustain a sub-lethal injury, or die. Because few MHKs have been deployed, little evidence about risk of injury or mortality exists. However, there are a number of studies that used models or examined collision and strike risks similar to those posed by MHK devices that can be used as proxies.

Studies have examined the rate of injury to or mortality of adult and juvenile fishes due to passage through hydrokinetic current turbines in the laboratory or *in situ*. There have been reports of high adult fish mortality rates as a consequence of pressure, shear, and contact with turbines in high-head hydroelectric dams (Cada and others 2006, Ferguson and others 2008, and Keefer and others 2012) and tidal barrages (Stokesbury and others 1991), which harness the potential energy of tidal range and traditional hydroelectric technology to generate electricity. A study of anadromous and marine fish species passing through a tidal barrage in the Annapolis River, Nova Scotia showed that 98% of clupeids passed through the turbines, despite fishways on either side of the turbines that would allow for safe passage (Stokesbury and others 1991). The mortality of those fish that passed through the tidal barrage turbines was estimated to be 46.3% over the two-year study (Stokesbury and others 1991). The traditional hydropower turbines rotate at speeds much faster than marine hydrokinetic turbines, so the resultant mortality rates do not necessarily apply.

Other studies have examined mortality at lower rotation speeds and have often observed very low mortality rates (Normandeu Associates, Inc. 2009; EPRI 2011). In a river simulation using rainbow trout and largemouth bass, EPRI (2011) showed 98.4% and 99.5% survival of fish at low approach velocities (5-7 ft s^{-1}) for spherical and axial-flow turbines, respectively, and that 83-95% of examined individuals avoided turbines at close range. These authors observed few injuries with most being tail strikes, and that avoidance capacity positively correlated with fish size (EPRI 2011). Normandeau Associates, Inc. (2009) found a 98-99% survival rate in four river fish species at 1 and 48 h post passage through the Hydro Green Energy hydrokinetic system at the Mississippi Lock and Dam No. 2 hydroelectric project (P-4306) Hastings, MN. These studies suggest that for certain current energy devices, collisions will not lead to major injuries for fish, especially if the rotation speed is slow.

The primary risk to fish eggs and larvae is undoubtedly physical stress, or shear stress, associated with the moving components of MHK devices. The diminutive size and fragility of planktonic eggs and larvae leaves them especially susceptible to entrainment, impingement, and physical collision (Marcy and others 1978). The impacts of physical trauma on developing fishes have been recognized for many years (Hayes 1949; Davis 1953; Loitrits 1963). In addition to being a direct source of mortality, physical stress during early larval development can have detrimental effects in later life stages, resulting in a number of deformities (Marcy and others 1978).

Models and wind turbines provide a frame of reference for strike and collision in marine mammals and birds, respectively. Using rubber as a proxy for whale skin, Carlson and others (2012) found that killer whales were unlikely to sustain serious injuries from hydrokinetic turbines. Significant deaths due to collisions between birds and wind power devices suggest that seabirds could suffer serious injuries and mortality from collisions with moving components of MHKs, although wind turbines rotate at much faster speeds (Krigsveld and others 2009).

Impact velocity and mass of an organism are two major factors affecting the likelihood of injury from strike from both current and wave energy devices (Carlson and others 2012; Drewitt and Langston, 2006). Mortality due to blade strike has been suggested to be related to the ratio of an organism's length to the blade thickness and the organism's orientation (Deng and others 2005; EPRI 2008; Tollit and others 2011; EPRI 2011). Tollit and others (2011) suggested that strike mortality is unlikely at impact speeds less than 4.8 ms^{-1}, a speed which some current energy turbines could reach. The maximum tip speed for current energy turbines will likely be 12 ms^{-1} because at higher speeds, devices lose efficiency through cavitation (Wilson and others 2007). Mortality is more likely at the blade tip than the center, because the tip moves faster (Coutant and Cada 2005).

Ship strikes during installation or repair of MHK devices, or from general ship traffic not only pose a direct risk to organisms, but in some cases also serve as a proxy for strike by MHKs. Ship strikes may result in lacerations from propeller strikes or blunt force trauma (fractures, organ damage, hematomas) from the hull. Propeller strikes are a poor proxy for strike from MHK devices, due to rapid rotation speeds, but strike from the hull may be an appropriate proxy (Wilson and others 2007). Ship strikes have killed or injured whales, dolphins, and sea turtles (Wilson and others 2007; Pace and Mussi 2006; Casale and others 2010). Jensen and others (2004) reported that 68% of strikes between ships and large whales caused whale mortality, and 16.4% resulted in injuries. Ship strikes are responsible for 35% of right whale mortality, suggesting that right whales are a major species of concern for strike by MHKs (Knowlton and Kraus 2001). Most major injuries from ship strikes occur at ship travel speeds greater than 7 ms^{-1} (Wilson and others 2007). Therefore, it may be possible to prevent injuries by reducing boating speeds Blunt strikes do not always lead to obvious external damage so injuries and fatalities are under-reported. Even if an organism survives a strike they may die later from infection, disability, or increased vulnerability to predation (Carter 2007). Blunt force trauma is reported to be responsible for more manatee deaths than propeller strikes (Lightsey and others 2006), whereas deaths of right whales are due to blunt trauma only 20% of the time. Other evidence for the severity of collisions with MHKs includes collisions between birds and oil and gas platforms, which were responsible for 50 bird deaths annually per rig in the Northern Gulf of Mexico on average (Russell 2005). Wilson and others (2007) noted that tail slaps from whales occur at velocities similar to current energy device turbines, and these slaps can stun fish (Wilson and others 2007). Collision of organisms with taut cables or chains is also likely to cause injury (Boehlert and others 2008). For instance, Sullivan and others (2006) suggested that seabirds have been killed by striking warp cables on trawlers. There is little evidence of the effects of collisions on jellyfish or squids, but it is likely that these organisms could be torn or dismembered by collisions or strike from MHK cables and rotors.

Summary of collision, strike, and shear strike risk by device

Pelagic fish, sea turtles, and marine mammals that use the entire water column are at risk of impact by collision or strike by several device classes, although they are likely to avoid devices rather than colliding with or being struck by them (Table 2). Most devices do not have rotors or pitching components near the seabed, so demersal fish have a lower risk of collision or strike than pelagic fish. Nonetheless, demersal fish are at potential risk of striking cables and anchoring equipment, and devices with moving components placed near the seabed, such as rotors for some fixed axial turbines and oscillating hydrofoil blades. Wave surge converters may pose a risk to demersal fish, although the flapping motion occurs at a lower speed near the seabed since the tip covers a greater distance. Demersal fish migrating in tidal streams would also be at risk of rotors occurring at mid-depth in shallow waters (Wilson and others 2007). Planktonic fish larvae and eggs will likely follow viscous flow around devices, so collision is unlikely, but they may experience some injury from shear stress (Turnpenny 1998, Turnpenny and others 2000).

Benthic invertebrates are at a low risk of collision or strike because they are primarily stationary or move among or under the sediments. Also, a number of devices occupy a small benthic area (floating point absorbers, wave attenuators, oscillating water columns, and wave overtopping terminators) and are unlikely to be encountered by benthic invertebrates. On the other hand, pelagic invertebrates such as jellyfish and squid are at a potentially high risk of collision or strike, although the population and community scale consequences of such interactions are unknown.

Because most MHKs do not have moving components that extend above the water's surface and stationary components that extend above the surface take up a small area, birds are at low risk of collision or strike while flying. However, diving seabirds as opposed to those solely using the overlying atmosphere are at a higher risk of impact, although the risk will vary based on diving speed and depth. Surface divers have a low likelihood of collision risk due to perception of devices in the portion of the water column that they use, while the risk is high for plunge divers (Wilson and others 2007). Devices submerged at least 1 meter below the surface, including wave surge converters, submerged point absorbers, fixed axial turbines, and oscillating hydrofoils, are unlikely to pose a risk to surface divers such as terns. Deep plunge or pursuit divers are at a higher risk of collision or strike due to the potential to encounter devices at deeper depths that were not perceived at the water's surface.

Floating point absorbers and wave attenuators pose unique strike risks as compared to other MHK devices because they have moving components that float at the water's surface. Marine mammals and sea turtles are at a higher risk of being struck by the pitching components of these devices as they surface for air as compared to when they are fully submerged, and the risk of strike and injury will increase during rough seas. Pinnipeds, such as harbor seals, will likely attempt to use the floating components of these devices as haul-out sites, and may get injured by moving components in the process (Michel and others 2007; Thompson and others 2008). Because the moving components of these devices extend partially above the water's surface, sea birds flying near the water's surface are at a high risk of strike. Diving birds are at risk from the pitching components while entering the water, feeding near the surface, and exiting the water after a dive.

Wave-overtopping terminators and floating oscillating water columns are large devices that will probably be perceived and avoided by marine mammals, sea turtles, and fish. On the other hand, these devices stick out of the water slightly, making them difficult to see for birds that fly close to the water's surface, especially with wave action, so risk for collision is high for flying birds that fly close to the water's surface. The moving components for these devices are also harder to access for most organisms. Entrained marine or diving marine organisms could enter wave over-topping terminators and collide with rotors, but protective grating may exclude large organisms, although juveniles and small animals would still be at risk. Since airspace separates the water from the turbine in an oscillating water column, colliding with the turbine would be impossible for most organisms, although diving birds could enter the device and collide with the rotor while attempting to surface.

Axial flow, floating and cross-flow (helical) turbines as well as the overtopping terminator designs present the most obvious sources of risk associated with physical damage because of the shear stresses and turbulence that would be generated by their rotor components. The amount of risk that any one of these devices poses in terms of physical stress is greatly dependent on their size, rotational speed, and device position within the water column as well as the resilience of the organism effected.

Entanglement

Marine organisms are at risk from entanglement with mooring cables (or lines, chains, etc.), with transmission cables (those that are not buried and used for connecting devices to each other), and with derelict fishing gear entangled in MHK components. Entanglement of marine organisms can cause impaired mobility, impaired foraging ability, wounds, infection, starvation, and drowning (Cassoff and others 2011). For an entanglement to occur, cables must be slack and pliable enough to wrap around an organism, so entanglement is less likely for taut cables (Boehlert and others 2008). For example, the Federal Energy Regulatory Commission (FERC; 2006) suggested that there was a low entanglement risk at the Reedsport Ocean Power Technologies Wavepark in Makah Bay since cables would have a high degree of tension. Entanglement is also more likely with thin cables (Boehlert and others 2008), and cable orientation will also affect the risk of entanglement. For example, horizontal cables will be more dangerous than vertical cables, depending on their location in the water column (Boehlert and others 2008). Additionally, although risk of entanglement may be low for a single device, the risk will be much higher for an array of devices with many cables (MMS 2007; USDOE 2009).

Upon approaching a device, organisms can prevent entanglement by avoiding or evading cables. The likelihood of avoidance or evasion is influenced by many of the same factors affecting risk of collision or strike, including water clarity and lighting, use of the marine environment, and swimming ability (see '*Collision, Strike, and Shear Stress* section). Cables have low profiles and cause little flow disruption and are therefore difficult for organisms to perceive. Organisms with greater mass are more likely to become entangled because sufficient mass relative to the tension of a cable is needed for entanglement. Organisms with long appendages or large pectoral fins and flippers such as sea turtles and large whales are also at a greater risk of entanglement (Johnson 2005, DOE 2009). These organisms are also at a high risk due to low mobility and a lack of reverse propulsion.

Although there are no publications on entanglement with MHKs, fishing gear entanglements can act as a proxy, despite the fact that the pliability of fishing gear relative to that of metal cables and chains should also be considered carefully. Marine mammals, including pinnipeds and cetaceans, sea turtles, and sea birds have become entangled with fishing gear such as gillnets, otter and beam trawls, herring weirs, and pound nets (Wilson and others 2007; Moore and others 2009). Fishing gear often becomes entangled with the mouths of whales, and especially baleen whales, while they are feeding; entanglement at the tail also occurs (Johnson and others 2005). Incidental takes (unintentional harrassment, harm, or collection of threatened or endangered species) threaten many marine mammals, often to the point of extinction (Panigada and others 2006; Zollet and Rosenberg 2005) as even a small rate of entanglement can lead to significant effects on populations of protected marine organisms (Fowler 1987). For example, entanglement was reported to cause 6.7% of North Atlantic right whale mortalities in a 1970-1999 survey (Knowlton and Kraus 2001). For this reason and because the known counts of this species have fallen to only about 350 whales, the North Atlantic right whale is a species of particular concern for entanglement with MHKs.

Although fishing entanglements are comparable to MHK entanglements in many respects, mooring and transmission cables consist of single, visible lines, unlike invisible, and sometimes netted, fishing gear meant to surprise and catch organisms. In addition, mooring and transmission cable materials are far less pliable than lines and ropes used for fishing, making the former less of an entanglement risk than the latter. Also, entanglement may be more likely with fishing gear than MHKs because foraging organisms can be attracted to prey entangled in fishing nets (Wilson and others 2007). However, entanglements and injuries due to single lines have been reported for baleen whales (Hartley 2003), and buoy lines from pot gear are responsible for a large proportion of right and humpback whale entanglements (Johnson and others 2005), suggesting that MHK cables pose a risk to marine organisms.

Summary of entanglement risk by device

When surfacing for air, sea turtles and marine mammals are at a high risk of entanglement from transmission cables connecting arrays of floating point absorbers. The same is true for diving seabirds, although due to their smaller size, they may have an easier time evading transmission cables when crossing the air-sea interface.

Like the risk of collision or strike, the risk of entanglement for diving birds depends on their diving depth. Shallow divers such as terns are at a lesser risk of entanglement in mooring cables well below the surface, like those associated with submerged point absorbers, wave overtopping terminators and oscillating water columns. Floating point absorbers typically extend far below the surface so mooring equipment will not affect shallow divers, although that group will still experience risk from surface connection and transmission cables. Mounted devices , such as surge converting wave energy devices and fixed and oscillated hydrofoil current energy devices, do not have cables associated with them, and thus, will be unlikely to pose the risk of entanglement.

Noise

The marine environment is a noisy place as a result of sounds contributions by various abiotic and biotic processes. Because water is denser than air, it conducts sound pressure waves further and 4.8 times faster than in air. Waves generate noise at levels relative to wave height (reviewed by Chorney and others 2010), and marine mammals, some fish, and some invertebrates generate sounds, as do humans, including noises produced indirectly by boating and port activities.

The sense of sound, and the vibrations and water displacement associated with it, offer important environmental cues for many marine organisms. Sound consists of small fluid motions (vibrations) that have a discernible particle displacement component close to the sound source and a sound pressure component that extends further. Many marine organisms, including marine mammals (Richardson and others 1995; Southall and others 2005; Madsen and others 2006; Tyack 2008), sea turtles (Ridgway and others 1969; Bartol 1999; Southwood and others 2008), some fish (Simpson and others 2005; Southwood and others 2008), and some invertebrates (Ellers 1995; Simpson 2008) use and/or generate sounds for communication (Southwood and others 2008; Tyack 2008), predator and prey location (Southwood and others 2008; Tyack 2008), and/or orientation and navigation (Ellers 1995; Simpson and others 2005, 2008; Southwood and others 2008; Tyack 2008).

Auditory ranges are different among groups and species of marine organisms, although species-specific data are generally lacking. Sea turtles are believed to perceive only low-frequency sounds (~100 to 1000 Hz) with the greatest sensitivity at 200 to 400 Hz (Southwood and others 2008). The ecological role of sound in sea turtles is not well understood (Southwood and others 2008), but there is information about hearing ranges specific to sea turtles found in NC waters. Ridgway and others (1969) observed that the maximum sensitivity to sound for green sea turtles (*Chelonia mydas*) was in the range of 300 to 400 Hz, and 1000 Hz was the maximum frequency perceived. Loggerhead sea turtle's (*Caretta caretta*) sound perception ranged from 250 to 750 Hz, with the greatest sensitivity at the lower end of the range (Bartol 1999). Baleen whales are also believed to be most sensitive to low-frequency sounds (~10 Hz to 10 kHz) based on their morphology and sound production (Southall 2005; Madsen and others 2006). Meanwhile, toothed cetaceans that have been empirically tested are sensitive to mid- to high-range frequencies (~4 Hz to 150 kHz; Southall 2005; Madsen and others 2006). Pinnipeds hear across a wider and lower range of frequencies (50 Hz to 60 kHz) than toothed whales (Richardson and others 1995). Most fish are believed to be hearing generalists, perceiving low-frequency sounds (100 Hz to 1000 Hz) and some have unique anatomical features that allow them to hear a wider range of sounds, ranging up to 4000 Hz and at levels 20 dB or more lower than that perceived by generalists (Hastings and Popper 2005). Reef noise generated by snapping shrimps and fish is generally in the range of 500 to 2000 Hz (Simpson and others 2007, 2008).

Ocean energy generation will add noise and vibrations to the marine environment during the construction, operation, and decommissioning phases. Noise emitted during the construction and decommissioning of most devices that are cabled and moored (surface and submerged point absorbers, wave attenuators, oscillating water columns, overtopping devices, floating current turbines) or mounted via gravity foundation (surge converters) will primarily be caused by boat traffic associated with transporting the devices to and from their deployment locations (Chorney and others 2010). However, if a device requires a monopile foundation (fixed axial and helical current turbines and current energy oscillating hydrofoils), far more noise will be generated by installation and decommissioning than will be produced during operation. For instance, noise from monopile driving for an offshore wind farm was broadband, with peak sound energy at frequencies from 100 Hz to 2kHz, and energy at frequencies up to 10 kHz. Similar sound spectrums and levels can be expected from monopile driving for wave and tidal energy devices (Bailey and others 2010).

MHK installations will also generate and emit noise at lower levels during operation. Noise will be emitted from the movement of turbines, generators, hydraulic components, and other device parts and from structural vibrations, strum on cables, and in some cases, slapping on the water's surface. Noise from a prototype-scale wave energy device, a point absorber called SeaRay, was measured at levels of 116 to 132 dB re 1 μPa (decibels relative to one micropascal) in the integrated bands from 20 Hz to 20 kHz at distances from 10 to 1500 m away (Bassett and others 2011). Bassett and others (2011) noted that the noise levels and spectrum emitted from the wave energy converter (WEC) could be masked by a large cargo vessel 20 km away because the level of noise emitted by such a vessel may be greater than 120 dB. A tidal turbine array modeled by Lloyd and others (2011) found that sounds emitted from tidal turbines will be low frequency (<500 Hz) and that sound transmission losses, and thus the effect that they will have on marine organisms, will be based on the number of turbines, their spacing and diameter, and water depth. The measured operational noise generated by four turbines in an in-stream tidal current demonstration project by Verdant Power in the East River of New York found full-spectrum sound levels to range from 145 dB re 1μPa@ 1m within the array to approximately 125 dB between 700 and 1060 m away from the middle of the array (Verdant Power New York 2010; note that some of the array components were in a state of disrepair at the time, which caused higher noise levels than during full functioning periods).

Sounds generated by the construction, operation, and decommissioning of MHK devices may cause a range of effects on and responses by marine organisms, including temporary or permanent, and even fatal, injuries; masking of sounds generated and used by marine organisms; avoidance of devices; or physiological damage as a result of stress. The severity of the effect of noise on organisms depends upon the level of the sound, which decreases with distance from the source of the sound, as well as the duration of exposure (Kastak and others 2005), and auditory ranges of the receiving organisms.

Acute intense sounds, such as those emitted during the construction and decommissioning of monopile foundations (used for fixed axial and helical current turbines and current energy oscillating hydrofoils), may cause internal trauma to organisms, even rupturing internal organs. André (2011) observed internal lesions in cephalopods exposed to low-frequency sounds and Hastings and Popper (2005) cited several instances where fish mortality could be attributed to internal trauma in their review of grey (not peer-reviewed) literature reporting on the effects of pile-driving on fish. Bailey and others (2010) compared pile driving at an offshore windfarm to the levels and frequencies that would cause permanent or temporary injury or behavioral disturbance to various groups of marine mammals. The researchers predicted that permanent auditory injury would have occurred within 5 m and 20 m of the pile-driving operation for cetaceans and pinnipeds, respectively, and temporary auditory injury would have occurred within 10 m and 40 m for the same groups of marine organisms, respectively. Behavioral disturbance could be expected up to 70 km away for pinnipeds, and organisms with low range frequency hearing could have been disturbed within the 50 m radius surrounding the pile-driving operation.

Chronic, low-level sounds, unique to each device and the environment in which it is installed (Patricio and others 2009a), will be emitted during the operation of MHK devices (reviewed by Chorney and others 2010) and boat noise will be introduced by all phases of MHK deployment also. Chronic, low-level noise such as boat noise, has been shown to cause avoidance, masking of communication, and stress-induced physiological effects. Boat traffic is already responsible for increasingly high levels of sound in the 20 to 200 Hz frequencies in all of the world's oceans (Tyack 2008) and has been shown to have detrimental effects on several types of fish, invertebrates, and marine mammals. Sea turtles have been observed to be negatively affected boat traffic (reviewed by Samuel and others 2005 and Tyack and others 2008), often showing avoidance. If noise emitted by MHK installations causes avoidance behavior, it will be a particular problem for organisms that show fidelity to specific areas for reproduction, migratory corridors, and foraging. Sea turtles are one group of organisms that exhibit such site fidelity for reproduction (Samuel and others 2005). The low-frequency sounds emitted during operation of MHK devices may mask other low-frequency sounds at frequencies used by invertebrates, fish, sea turtles, and baleen whales or cause marine organisms to alter their communication patterns. Call types, rates, and frequencies of marine mammals have been observed to increase in response to increased anthropogenic noise (reviewed by Davis 2010). Chronic, low-level sounds may also cause stress and other physiological effects. Hastings and Popper (2005) noted predisposition of fish to opportunistic infection and predation in their review of the effects of noise on fish but also highlighted a study by Smith and others (2004) where goldfish exposed to high levels of sound did not show changes in corticosteroid (released as a stress or immune response) levels. Meanwhile, brown shrimp (*Crangon crangon*) exposed to 30 dB noises in the 25 to 400 Hz frequency exhibited signs of stress including decreased growth and reproductive rates and aggression (Lagardère 1982).

Determining the effects and severity of effects of changes in the sound environment on marine organisms due to MHK development is complicated because it depends on so many factors, including the auditory range of the receiving organisms and their proximity to the sound as well as the level and duration of the sound. Attempts have been made to compare the frequencies emitted from various anthropogenic sources to those perceived by marine organisms to determine thresholds for elicitation of permanent and temporary auditory injuries and behavioral responses (Nedwell and others 2007; Noro and others 2011). Patricio and others (2009b) proposed a method of determining the acoustic signature of particular devices installed in particular locations using *in situ* measurements and acoustic numerical models. Similar analyses may be useful to assess auditory risks related to MHK projects on a case by case basis.

Electromagnetics

There are several sources of electromagnetic fields (EMF) in the marine environment, including magnetic elements in the earth’s crust, currents of water passing through these geomagnetic fields and from the internal processes of living organisms. Many marine organisms are sensitive to these electric and/or magnetic fields and use EMF sensing for prey detection and navigation. MHK energy generation will introduce additional anthropogenic EMF to the marine environment on top of that already emitted by nearshore power transmission cables and submarine telecommunications cables. The effect of EMF on marine organism health and behavior is a concern that is still under study.

EMF includes electric fields that are produced by voltage and magnetic fields that are generated by the flow of currents. Electric fields increase in strength as voltage increases and magnetic fields increase in strength as current increases. MHK EMF has several sources, including the hydrokinetic energy devices themselves; aggregation, control, or conversion housing units; and transmission cables. EMF emissions from the devices and housings will likely be shielded by their enclosed metallic structures, but the multiple transmission cables connecting individual devices to one another and housings, and those that transmit power from those housings to onshore substations, will emit EMF. Emission of electric fields from transmission cables can be completely blocked by insulation and armoring (Cada and other 2011). However, emission of magnetic fields from transmission cables is unavoidable, and the flow of water or movement of organisms through the magnetic fields creates a weak electric field, called an induced electric field. If cables are buried, EMF emissions will be reduced because EMF decreases with distance from the source but the sediment does not offer any shielding. EMF emissions can also be reduced by careful design of transmission cables (reviewed by Gill and Taylor 2001). For instance, closely spaced cables with opposite currents will produce magnetic field vectors that will cancel each other out. In addition, medium voltage cables emit a stronger EMF than higher voltage cables. The type of current transmitted through the cables also produces different types of EMF; DC cables produce static EMFs, similar to geomagnetic EMF, and AC cables have cycling polarity that causes alternating magnetic fields. High voltage direct current (DC) cables are typically used for long-distance, high-power applications, whereas, three-phase alternating current (AC) cables are typical for shorter-distance transmission (Öhman and others 2007).

The sensitivity to the electric or magnetic fields or both is specific to species in some cases, but more typically to groups of organisms. For instance, elasmobranchs (cartilaginous fish, including sharks and rays) and some teleosts (bony fish, including tuna and sturgeon) are sensitive to electric fields, but elasmobranchs are orders of magnitude more sensitive than teleosts. Some marine mammals, sea turtles, benthic invertebrates, and teleost fishes, including crabs and eels, are sensitive to magnetic, but not electric, fields. Magnetic perception by several types of fish and sea turtles is believed to help them locate long-distance migratory routes.

The species that are most likely to be affected by the addition of EMF to the marine environment by MHK installations are those that use electroreception for locating prey and those that use magnetic fields for navigation. Organisms that use electroreception for locating prey, such as elasmobranchs and teleosts, may experience increased energetic costs associated with targeting cables rather than food. Organisms that use magnetic fields for orientation may be confused by magnetic fields emitted from transmission cables, but the disorientation may be resolved by their assessment of other environmental cues, as was the case with green turtles (Luschi and others 2007).

Several studies have set out to identify the effects of introduced magnetic fields on marine organisms. Fisher and Slater (2010) reviewed the effects of magnetic fields on invertebrates and found that the survival of several types of invertebrates was not affected by low-level (3.7 μT) magnetic fields but biochemical parameters and the development of two other types of invertebrates were negatively affected by magnetic fields of a greater strength (5.8 to 1000 μT). In addition, static magnetic fields of 10 μT to 0.1 T have been observed to disrupt the mitotic cycle of sea urchin embryos and increase the incidence of a mental abnormality in sea urchins, and EMF was also observed to interfere with the settlement of barnacles (reviewed by Fisher and Slater 2010). The results of experiments on the early life stages of fish show mixed results; chum salmon (*O. keta*) reproduction, larval survival, and deformity was not affected by EMF exposure, whereas 5 to 10 μT of magnetic field exposure caused physiological changes that indicated stress or slowed embryonic development in several freshwater species of fish (reviewed by Fisher and Slater 2010). Different species of eels appear to have variable sensitivities to magnetic fields. Japanese eels (*A. japonica*) were found to be magnetosensitive (at approximately 200 µT levels), while silver eels (*Anguilla anguilla*) crossed high voltage submarine (DC) cables and did not slow their swimming speed near AC cables (reviewed by Fisher and Slater 2010). Fish species (several species of salmon) that contain magnetite crystals believed to sense geomagnetic fields and aid navigation did not appear to rely solely on that magnetically guided means of navigation in a series of experiments (reviewed by Fisher and Slater 2010). Bochert and Zettler (2006) found no differences in survival or distribution in a closed chamber among several benthic species, including fish and invertebrates, subjected to static magnetic fields (3,700 and 2,700 µT, respectively). Numerous studies have also investigated the role of magnetic fields in navigation by juvenile and adult sea turtles (reviewed by Lohmann 2007) and have revealed that sensing of the geomagnetic fields of the Earth are one of a suite of environmental cues that orient these organisms during long-distance migrations and in returning to natal beaches to lay eggs (Luschi and others 2007). Marine mammals also appear to be sensitive to magnetic fields (Kirschvink and others 1985; Walker and others 1992). Kirschvink and others (1985) found that whales use Earth's geomagnetic fields for navigation and seem to strand more frequently in areas with geomagnetic minima.

In a survey of electrical transmission cables used for MHK projects to date, Cada and others (2011) summarized the ranges of reported magnetic field strengths to be 463 to 6660 µT and 20-37 µT at distances of 0 and 1 m from the cable, respectively. Magnetic fields emitted by transmission cables are well within the levels that were observed to cause physiological changes and avoidance in magneto-sensitive species studied to date. Navigation by marine organisms and boats using geomagnetic fields is also likely to be affected by these introduced magnetic fields in the 1-m area surrounding transmission cables because they are of the same magnitude as those of the seabed (20 to 75 µT; Bochert and Zettler 2006). However, many marine organisms appear to use senses in addition to geomagnetic navigation to orient, and thus, may be able to compensate for magnetic anomalies introduced by MHK transmission cables.

Similar studies have been conducted to assess the impact of electric fields on electrically sensitive marine organisms. Teleosts exposed to variable strengths of electric fields showed increased heart rates at 0.007 to 0.07 V/m and electronarcosis or paralysis at strengths of 15 V/m or more (reviewed by Fisher and Slater 2010). Elasmobranchs are generally attracted to electric fields between 5×10^{-7} to 10^{-3} V/m and avoid those at 1 µV/cm or greater (reviewed by Fisher and Slater 2010). Sturgeon, in particular, have been observed to be attracted to levels as low as 200 µV/cm (50 Hz) and deterred by 500 µV/cm (50 Hz) (Basov 1999). The type of current also appears to affect behavioral responses of marine organisms to EMF. Several types of elasmobranchs were observed to respond to alternating electric fields from AC currents as low as 0.1 µV/cm and they were able to locate the source of the field (Kalmijn 1966). In another experiment by Kimber and others (2010), catsharks were more attracted to AC than DC currents.

The Centre for Marine and Coastal Studies (CMACS; 2003) also reported an induced electric field of more than 1 mV/m at a distance of 4 m from a 150 kV cable carrying a 600 A current and extending 100 m from the cable before dissipating. Lower-voltage cables showed similar electric field strengths in the immediate area surrounding the cable, but dissipated more quickly with distance. These electric field strengths are within the range sensed by all elasmobranchs and may interfere with their feeding behavior and navigation.

Light

Lights may be attached to structures that extend above the water's surface or that are situated in shallow water so that MHK devices and installations are visible to mariners during periods of low light availability. Introduction of artificial light can itself affect birds and marine organisms.

Seabirds sometimes circle lighted structures, including oil rigs and wind turbines, during periods of poor visibility (Wiese 2001; Huppop and others 2006; Musial and Ram 2010), which puts them at a greater risk of collision with or strike by a device (see '*Collision, Strike, and Shear Stress'* section). In addition, fledgling petrels (including shearwaters and storm petrels) are attracted to artificial shoreline lights during their first flights from their nests to the ocean, sometimes resulting in their mortality (LeCorre and others 2002; Rodríguez and Rodríguez 2009; Rodríguez and others 2012 and references therein). Therefore, lights installed on MHK devices could attract or disorient seabirds.

Coral and planktonic invertebrates and fish also exhibit behavioral and physiological responses to artificial light. For instance, spawning in at least four orders of fish (Taylor 1984) and 105 species of corals (Babcock and others 1986) is triggered by lunar light levels, and reproduction and foraging behavior was observed to be triggered by darkness thresholds in a bioluminescent invertebrate (*Vargula annecohenae*; Gerrish and others 2009). However, if coral reefs and other known fish breeding grounds are avoided, it is unlikely that the installation of lights on MHK devices will have far-reaching impacts on fish and invertebrate populations.

Antifouling coatings

As was noted in the *'Physical presence'* section, surfaces of introduced structures are typically well colonized by marine epibiota, which is viewed as a synergistic (positive) effect of MHK installations on the surrounding environment and ecology by some. However, this organic colonization along with accumulation of inorganic substances on the surfaces of MHK devices is considered negative and termed "biofouling" by others. Biofouling reduces the efficiency of devices by introducing weight and drag and accelerating surface corrosion. To avoid biofouling, the surfaces of structures introduced to the marine environment are often coated with antifouling paints and treatments that prevent their colonization. Tributyltin (TBT) was an effective and frequently used antifouling coating component until it was found to be toxic to several aquatic organisms, eventually being labeled the most toxic substance to be deliberately introduced to the marine environment by Goldberg (1986). While a ban was placed on the use of TBT as an antifouling coating on vessels less than 25 m long in the USA in 1988 (and many other countries before or soon after; Evans 1999), heavy metals are still among the antifouling treatment components used to prevent or inhibit the biofouling of surfaces in the marine environment.

The heavy metals used in antifouling coatings are leached into the water and end up, in part, in the tissues of marine organisms. For instance, elevated concentrations of heavy metals used in antifouling paints for boat hulls, including copper, tin, and cadmium, were measured in bay mussel (*Mytilus edulis*) tissues in California harbors as compared to non-harbor coastal areas (Young and others 1979). Similarly, Claisse and Alzieu (1993) observed increased copper concentration in oysters (*Crassostrea gigas*) from Archachon Bay after TBT was banned from use on small vessels and copper-based paints replaced it. Copper and other heavy metals leach from the treated surfaces can bioaccumulate in marine organisms and humans, at times reaching concentrations that pose health risks and even death (Eisler 1998).

The use of chemical treatments to prevent biofouling on structures introduced to the marine environment is ubiquitous, and the potential for pollution by and bioaccumulation of heavy metals and is not unique to MHK installations (Boehlert and Gill 2010). However, new, environmentally benign antifouling treatments that deter attachment of organisms or disallow them from staying attached (Callow and Callow 2011), and often involve bioinspired (emulating designs and processes in nature to find solutions to human problems) surfaces (Scardino and Nys 2010; Callow and Callow 2011), have been and continue to be developed. Use of these new antifouling treatments only on device components that would be negatively impacted by epiphytic growth will allow for growth on structures for which it poses no detriment (e.g., foundations) without negating the beneficial aspects of introducing hardened structures to the marine environment. Indeed, it will allow for the establishment of an artificial reef while allowing for the maximum harvest of energy and preventing the introduction of harmful substances to the reef environment.

Impacts on human uses

Because humans are inherently dependent upon terrestrial ecosystems, the density of human use and activity in the oceans generally decreases with distance from the coasts. Despite their terrestrial ties, humans have long used the oceans as a means of transportation for commerce and recreation, and they have exploited marine natural resources. Modern human-use of the waters offshore NC and risks of conflict with MHK devices are discussed by use category below.

Risk of interaction with vessels

Boats and large ships (collectively vessels) are clearly at risk of collision with MHK devices. Such collisions are most likely for devices with components near or above the surface. Collisions could result in damage both to MHK devices and vessels, although damage caused to vessels will most likely occur only with larger MHK structures (oscillating water columns and wave overtopping terminators). Although most vessels will avoid these devices, collisions should be expected, given the significant number of existing collisions between vessels and other even more apparent man-made structures, such as bridges and offshore oil platforms. Recreational boat use is most dense within the estuaries, inlets, the nearshore zone, and the vicinity of known or reputed fishing grounds and dive sites. Another common recreational boat use is cruising and touring. Commercial boat traffic along the NC coast typically consists of commercial fishing and shipping for commerce. Transportation corridors, used for commercial and recreational activities, include the Intracoastal Waterway (inshore waters), navigation corridors, and shipping routes. Recently, the U.S. Coast Guard has tracked vessel use along the U. S. Atlantic coast via Automated Identification Systems (AIS), which are mandated nationally and internationally for certain classes of vessels. Data from AIS indicate that vessels currently utilize vast expanses of the NC coastal ocean, going well beyond identified shipping routes; therefore, knowledge of shipping routes may provide little guidance in minimizing vessel-MHK device interactions offshore. Close to shore (≤ 5 n mi,), vessels tend to be confined to navigation corridors, and these charted, deep-water channels: (1) enable vessels to avoid hazardous shoals and obstacles, and (2) organize flow of vessel traffic. The shipping industry has a well-established historic use of offshore waters; thus any new uses of the marine environment that cause ships to divert their course, such as to avoid MHK devices, would result in an increase in monetary costs and would likely be thwarted by the industry.

Fishing and diving

The locations and depths of commercial and recreational fishing activities are dependent upon the life histories of target species and the types of gear used. While gill nets are employed in nearshore waters (≤ 15 m depth), long-lines tend to be used further offshore. Hook-and-line gear and trawl nets are used throughout NC coastal waters. Black-bass pots sit on the sea floor and are fished between 10 to 40 m depths. Scuba diving is practiced in both nearshore and offshore waters; however, divers should be accompanied by a boat, except when diving off the immediate shoreline. Habitats important to the various life stages of fishes (such as hard bottom habitat, wrecks and artificial reefs) are often targeted by fishermen because these features tend to support higher abundances of fishes. Because these three-dimensional habitats support a variety of organisms at various trophic levels, other predators (e.g., larger fishes, sea turtles, marine mammals and birds) use these habitats as foraging grounds as well. Hence, human exploitation of these areas for fishing and diving is common. The NC coastal waters are famous for recreational fishing on the diversity of organisms found here (in part supported by convergence of Labrador Current and Gulf Stream) and for diving on the numerous shipwrecks, for which the Cape Hatteras shoals region has been deemed the Graveyard of the Atlantic. Meetings of regional stakeholder groups (commercial and recreational fishermen, diving and ecotourism communities) have successfully served to provide offshore energy developers with key information about site specific resources, resource characteristics and how these resources are used by stakeholders, thereby helping developers and government reduce potential conflicts.

Nearshore recreational activities

Numerous recreational activities occur at high densities within approximately two miles of the coast. Such activities include: swimming, surfing, stand-up paddle-boarding, kite surfing, sail-boarding, kayaking, hang gliding, tubing in tow, surf fishing, snorkeling, jet skiing, wave-runner riding, and small recreational boating. These activities generally occur at highest densities in the summer, fall and spring, as compared to the winter. NC's mild climate enables year-round water activities with new water sports constantly emerging.

Military uses

North Carolina has a reputation as a military-friendly state and this is reflected in the numbers of bases for the U.S. Marine Corps, Army, Air Force and Coast Guard. The largest coastal NC military installations are the Marine Corps Base at Camp Lejeune in Onslow County and the Marine Corps Air Station at Cherry Point in Craven County; each of these units has priority access to extensive coastal lands and waters, which excludes many non-military activities. Even though UNC faculty worked closely with all NC military installations to learn where military activities would restrict offshore wind energy development, the Pentagon expanded the areas in state waters that are to be excluded for wind energy development because of conflicts with planned Department of Defense (DoD) activities (Voss and others 2012). We used the water-based components of the Pentagon-approved DoD exclusion areas for wind energy development to map where military activity would probably also exclude MHK energy development. These areas include the Camp Lejeune training and live-range firing areas off of Onslow Beach and the military exclusion zones in Onslow and Hatteras Bays. To the best of our knowledge, the Pentagon has not yet considered whether new or different military exclusion zones would be required in NC for MHK energy development. It is expected that BOEM will make available for MHK energy development only lease blocks that have passed Pentagon review.

Beach nourishment projects

Sea-level rise and coastal erosion have prompted most coastal communities in NC to initiate programs that repeatedly mine offshore sand deposits for beach renourishment projects. Offshore sand resources are limited along the NC coast, especially for the region south of Cape Lookout. Because long-term plans exist for renourishing many ocean beaches, especially in heavily developed coastal counties, one can expect intense competition for areas of the NC Continental Shelf comprised of sandy unconsolidated sediments. Given the extent of protected areas on the State's sea floor (e.g., hard bottom habitat, wrecks, artificial reefs), MHK energy development will likely compete with beach renourishment projects for offshore areas containing sand resources.

Offshore wind energy development

Locations that may be optimal for MHK energy development may also be optimal for offshore wind energy development. Offshore wind energy development is proceeding in advance of MHK energy development along the U.S. Atlantic coast. BOEM is expected to complete its designation of the NC Wind Energy Areas (WEAs) by summer of 2012, and two or three of these WEAs are slated to be included in a Call for Information and Nominations by BOEM, expected to be published in the Federal Register by fall of 2012. It may be that wind turbines and MHK devices can be sited at common locations, if deemed compatible; however, BOEM has yet to specify whether lease blocks can be used for multiple energy generating purposes or leased by more than one entity for different purposes. In summary, MHK energy development can learn from the experiences of offshore wind energy development along the U.S. Atlantic coast; however, wind energy developers will likely have first choice of available BOEM lease blocks throughout the this region.

Mapped uses of the marine environment off of the North Carolina coast

Base map

The base map was composed of the following layers: bathymetry (NOAA Coastal Services Center 2005), NC shoreline (NOAA National Ocean Service 2002), and the Gulf Stream location ± 90% confidence intervals (UNC 2009). The map coordinate system was GCS_WGS_1984. The bathymetric layer (NOAA Coastal Services Center 2005) is a vector coverage resulting from the composite of several datasets with isobath intervals of 2 m in coastal areas to 200 m in deep offshore areas. The NC shoreline layer (NOAA National Ocean Service 2002) is a vector coverage representing NOAA National Ocean Service shoreline maps and CAD-based Standard Digital Data Exchange Format data. The Gulf Stream ± 90% confidence intervals layer (UNC 2009) was constructed by Harvey Seim (UNC-Chapel Hill) and Jesse Cleary (Duke University) using Gulf Steam mean frontal position information south of Cape Hatteras extracted from Miller (1994), and east and north of Cape Hatteras from a sea surface temperature analysis conducted by Shay (unpublished) using methods described by Cayula and Cornillon (1992). This base map was used as the template for all other map products (Figure 1).

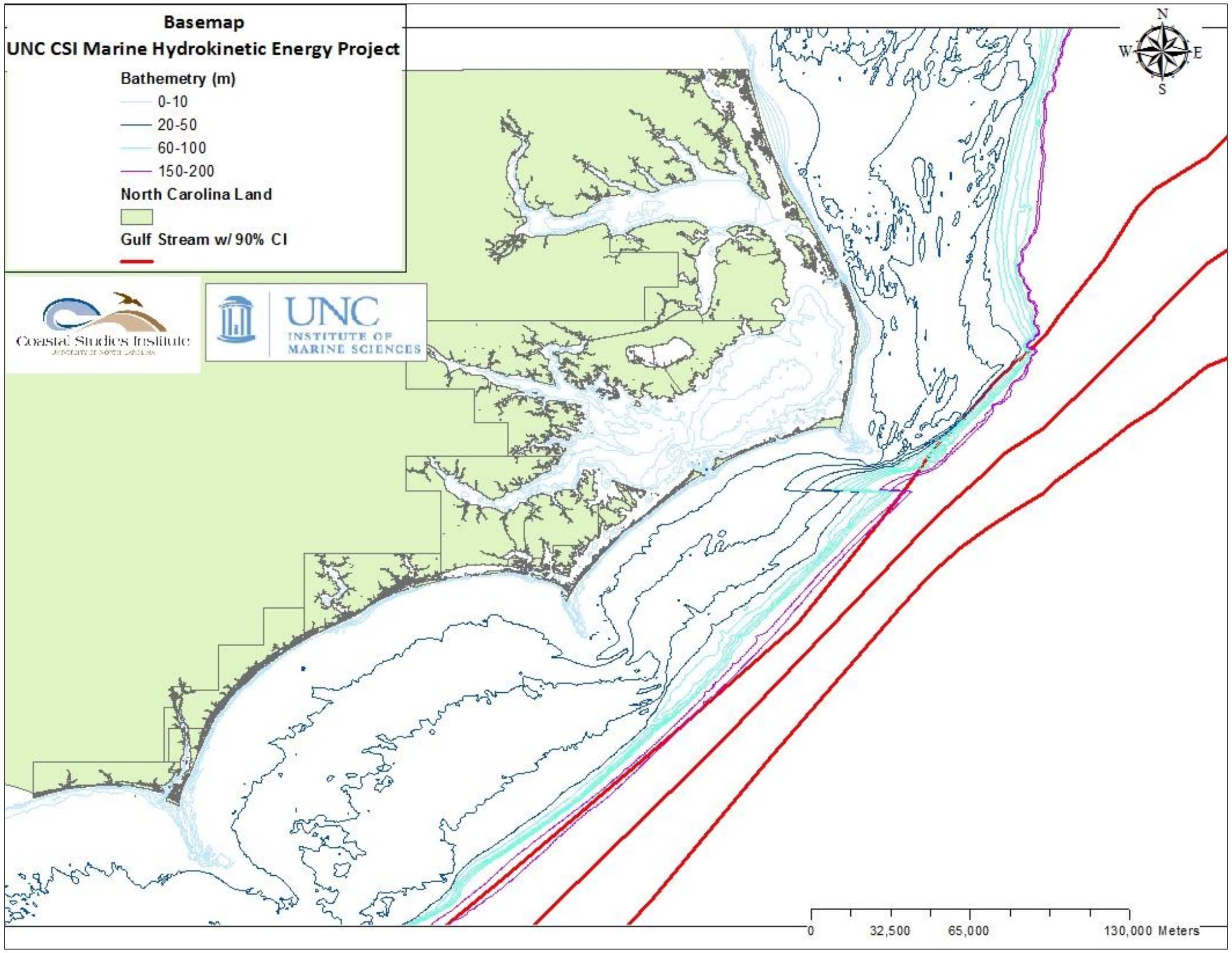

Figure 1. Base map created for the UNC Coastal Studies Institute marine hydrokinetic energy study (see text for more detail).

Important habitats map

This map illustrates areas so important to the life histories of fishes, coastal birds and seabirds, sea turtles, and marine mammals that they represent biological “hot spots” along the NC coast and offshore waters. These are areas where risks of faunal interaction with MHK devices are greatest and where injuries to organisms are likely to be most detrimental (Figure 2). Marine hydrokinetic installations planned in or near these areas will require special consideration and will be subjected to extensive environmental assessment and permitting requirements. Some MHK devices pose distinct risks to the diverse organisms and habitats that occur within these important waters. Mapped areas include federally-protected Essential Fish Habitat (EFH) such as hard bottom reefs, artificial reefs, and shipwrecks, as well as other biologically active, designated areas such as an Audubon Important Bird Area (The Point), the Gulf Stream, the nearshore zone, cape shoals, inlets, and shallow estuarine areas.

Habitat Areas of Particular Concern (HAPC) are a subset of EFH that are particularly important to the long-term survival and productivity of designated species and are extremely vulnerable to degradation, specifically as a result of fishing or other human disturbances. Hard bottom is an EFH-HAPC for which only some locations offshore NC are known, including the mapped 10 Fathom Ledge and Big Rock. Additional areas where hard bottom exists or is likely exists are shown in the map of generalized geology of the sea floor offshore NC (Figure 3); however, identification of hard bottom habitat is incomplete along the southern U.S. Atlantic coast.

The essential fish habitats shown in Figure 2 are intended to protect: temperate coral communities, the snapper and grouper complex, shrimp, tilefish, coastal migratory pelagic fish, and dolphin/wahoo as designated by the South Atlantic Fishery Management Council (SAFMC). Hard bottom habitats and the Charleston Bump are essential habitat for dolphin and wahoo and the snapper and grouper complex. Small spawning aggregation areas for the snapper and grouper complex are scattered between The Point and the Charleston Bump. All of the abovementioned regions (with the exception of the spawning aggregation areas for the snapper and grouper complex), along with the sandy shoals of Capes Lookout, Fear, and Hatteras from the shore to the Gulf Stream are EFH for coastal migratory pelagic fish. The Charleston Bump Complex is generally a biologically important area of upwelling that is a NOAA National Marine Fisheries Service Closed Area. Shrimp nursery areas are found within 30 m of shore, south of the point of Hatteras Island, whereas tilefish habitat extends north of the point of Hatteras Island at 150-200 m. Crab spawning sanctuaries designated by the NC Department of Natural Resources, Division of Marine Fisheries are incorporated in the nearshore, inlet, and capes layer. The nearshore, inlet, and cape areas are also important habitat for the eggs and larvae of fishes and invertebrates that are transported along the coast and through inlets, into estuaries, via longshore currents. Artificial reefs and wrecks and 30 nm surrounding them are also protected as EFH. The Florida Fish and Wildlife Conservation Commission-Fish and Wildlife Research Institute's Habitat and Ecosystem Internet Map Server GIS data was the data source for the essential fish habitat, crab spawning sanctuaries, and habitat areas of particular concern GIS data layers that were used to construct this map (Habitat and Ecosystem Internet Map Server GIS data). The NCDMF was the originator of the crab spawning sanctuary data layers (for 2004) provided by FWR-FWRI.

Sargassum (*Sargassum muticum*) habitat is free-floating seaweed propelled by oceanic currents and found chiefly within the Gulf Stream; hence, it varies spatially in its occurrence in U.S. south Atlantic offshore waters, including those of NC. This mobile habitat occurs in higher densities along the western wall of the Gulf Stream; however, *Sargassum* is also carried nearshore in eddies as both warm- and cold-core rings that cleave off of the Gulf Stream. *Sargassum* supports a great diversity of marine organisms including pelagic seabirds, marine mammals, sea turtles and many types of fish including billfishes and sailfishes (SAMFC 2002). The Comprehensive Ecosystem-Based Amendment 2 (CE-BA 2) (SAFMC 2011) has proposed to alter the *Sargassum* Fisheries Management Plan (SAFMC 2002) so that the EFH designation would apply to the upper 10 m of the surface as bounded by the Gulf Stream. This designation, if approved, "would limit the EFH to include only those surface waters where *Sargassum* most commonly occurs and where densities are often the highest" (NMFS 2002). A map showing the proposal *Sargassum* EFH zone is shown as Figure 4-8 in the CE-BA 2. A GIS layer depicting the proposed location of this EFH is not yet available (R. Pugliese, SAFMC, pers. comm.); therefore, *Sargassum* is not represented in our Important Habitats map, even though it is designated as both EFH and EFH-HAPC in the Fishery Management Plans of several SAFMC–managed and federally-protected (e.g., sea turtles) species.

The Audubon Society has designated an Important Bird Area (IBA) on the outer continental shelf offshore from Cape Hatteras, also known as The Point (Audubon 2011). This area, which envelopes the convergence of the cool waters of Labrador Current and the warm waters Gulf Stream, forms one of the richest, most productive and most important areas for pelagic birds in the western Atlantic. This IBA encompasses approximately 245,621 ha, includes water depths of 90-915 m, and lies on the western boundary of the Gulf Stream. Large mats of *Sargassum* form surface reefs and concentrate rare and endangered seabirds, marine mammals, sea turtles and fishes. Although this IBA probably has the greatest density of seabirds in the southeastern US, it currently is afforded no formal protection (Audubon 2011). Most other designated IBAs within the North Carolina coastal region are confined to the mainland, barrier islands or NC-managed waters. Both the Audubon Society and the SAFMC have recognized the importance of the convergence zone of the Labrador Current and Gulf Stream to fish and wildlife by each designating biological hotspots known as The Point; however, these areas only partially overlap. Each designated area reflects the objectives of the respective organization, with the Audubon IBA extending landward near seabird nesting grounds, and the SAFMC area extending seaward into the Gulf Stream.

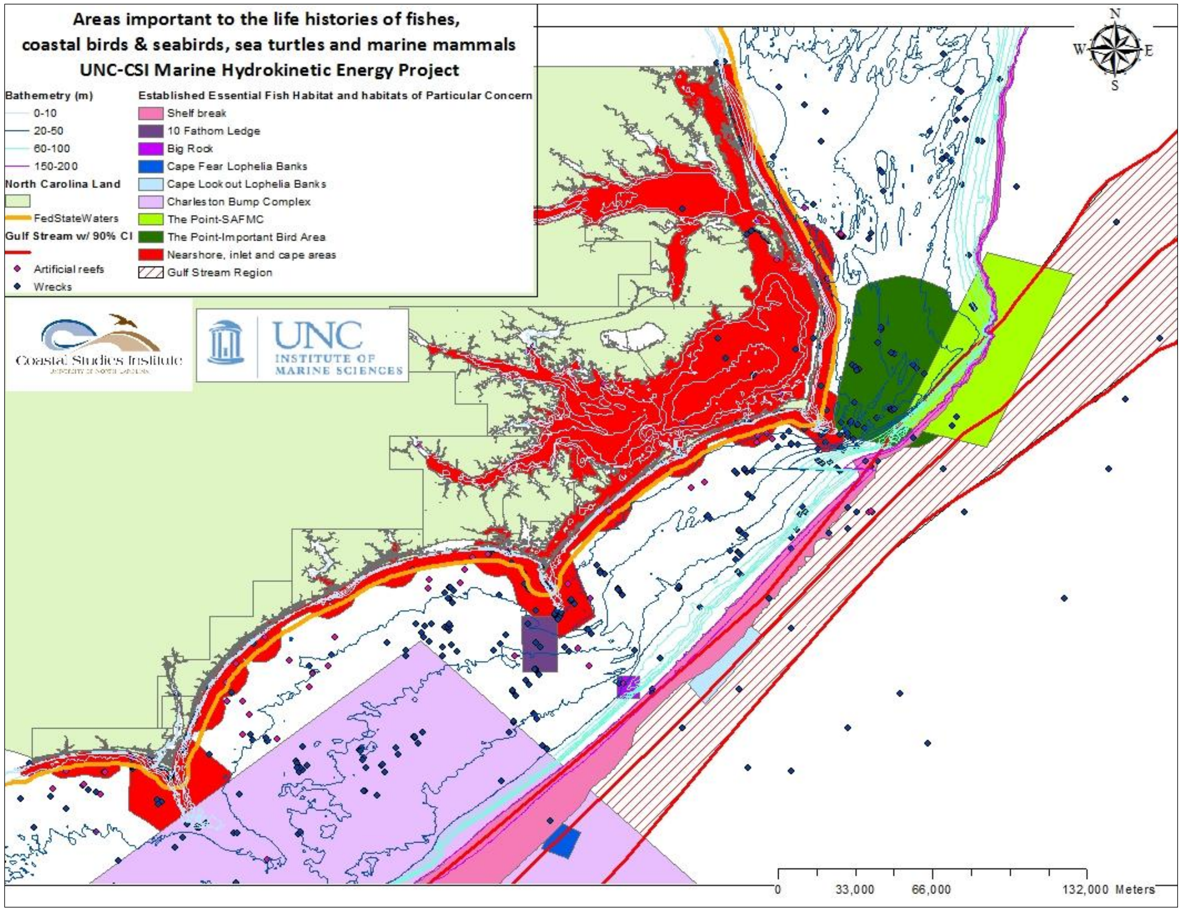

Figure 2. Map illustrating locations of coastal and offshore areas of North Carolina that are biological “hotspots” where key habitats occur that are important to managed and protected species. Note: hard bottom and *Sargassum* habitats are insufficiently represented on this map. The mapping of hard bottom habitat is incomplete because it is understudied; the Generalized Geology map (Fig. 3) indicates our understanding of where hard bottom habitat is likely to occur. *Sargassum* is a mobile habitat that generally occurs along the western wall of the Gulf Stream along the North Carolina coast (see text for more detail).

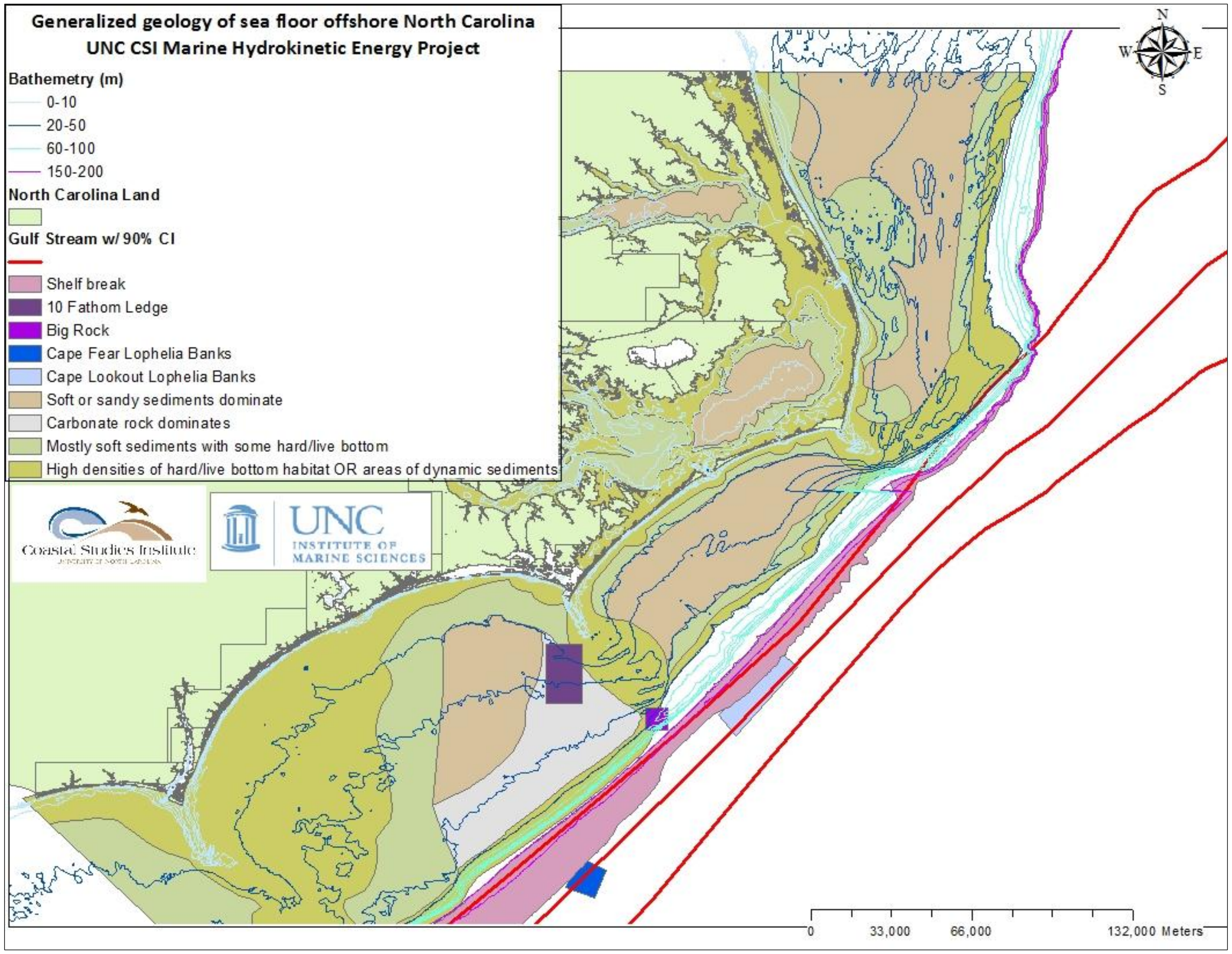

Figure 3. Map illustrating the generalized geology of the North Carolina Continental Shelf. (Modified from Riggs and Ames 2009, with additional GIS data from South Atlantic Fisheries Management Council).

Generalized geology of the North Carolina Continental Shelf

There exists some general knowledge of the geologic framework of the NC Continental Shelf. A spatially explicit break-down of the degree of this information is provided in detail by Riggs and Ames (2009). Key information for this hydrokinetic energy study was obtained with permission from Riggs and Ames (2009) and adapted for Figure 3. Locations of known hard bottom habitat, *Lophelia* deep-water coral banks, the shelf break (SAFMC) and the Gulf Stream were also mapped. Hard bottom habitat becomes more prevalent as one travels south along the NC continental shelf, with the highest densities occurring south of Cape Lookout. Sediments tend to be most dynamic in the broad vicinity around each of the three capes. The area of hard carbonate rock in Onlsow Bay was identified by Mixon and Pilkey (1976) and incorporated into the Riggs and Ames (2009) maps. Mixon and Pilkey (1976) provide a detailed assessment of submerged coastal plain geology, but only for the Cape Lookout area.

Risks to fish and invertebrate eggs and larvae

The diverse life histories and reproductive strategies of saltwater fish and harvested invertebrates make for a large amount of temporal and spatial variability in larval abundance, and density. This variability is important when considering the development of hydrokinetic energy resources. Areas with high seasonal abundance of eggs and larvae (e.g., spawning grounds) as well as critical nursery areas and larval transport pathways should be avoided in locating hydrokinetic energy projects. Areas where high risk of conflict exists for fish and invertebrate eggs and larvae due to interactions with MHK devices are mapped in Figure 4.

Shallow estuarine habitats are certainly some of the most vital areas necessary to the completion of fish and invertebrate life cycles. During the fall and winter, many species of estuarine-dependant fishes spawn in offshore areas. Their larvae are transported shoreward where they enter nursery areas within estuaries (e.g., Fahay, 1975; Warlen and Burke, 1990; Forward and others 1999). In the summer months, offshore spawning peaks for many species of reef-associated fish (e.g., red snapper) as well as many crustacean species (e.g., blue crab) (Ogburn and others 2009, R.B. Forward, Jr., pers. comm.). Subsequently, their larvae are transported into the estuary to take refuge in inshore waterways and shallow habitats. While the particular spawning locations and seasons for fish and invertebrate species vary greatly, the usage of estuarine nursery habitats is a major commonality for the majority of saltwater fishes. Estuarine waters with their multifarious habitats – salt marshes, seagrass beds, oyster reefs, and other shallow estuarine areas – serve as nursery areas for more than 75% of the species important to fisheries off the southeastern U.S. Atlantic coast (Fox 1992). MHK energy devices whose moving components might physically damage larvae or juveniles or impair nursery habitat would be incompatible with these nursery areas, thus undesirable and imprudent from both an ecological and economic standpoint.

Placement of current devices in inlets where tidal velocities are highest, while probably beneficial to the generation of energy, is problematic because of the important role that inlets play in larval development. Larval transport through an estuarine inlet corridor and subsequent up-estuary movements are critical for successful completion of the life cycle. Successful ingress depends upon larval behavior, lateral position relative to the estuary inlet and estuarine physics (Churchill and others 1999). These inlet pathways to nursery habitats are limited in number along much of the Atlantic coast and act as bottlenecks to recruitment for many species of fish and invertebrates (Taylor and others 2009). Evidence suggests that shallow nearshore ocean habitat along barrier islands is also of great importance, both in its role as an ocean ecotone (Able 2005) and as a natural funnel of larvae to tidal inlets (Luettich and others 1998). Larval ingress and egress to and from the estuary, if obstructed or significantly modified by MHK devices, could have undesirable, negative effects on many important estuarine-dependant fishes and harvested invertebrates.

Within areas just outside of inlets and along the nearshore zone, potential conflicts are related to the high egg and larval densities associated with spawning offshore. There is a known association between fish spawning on the outer continental shelf and thermal fronts of the Gulf Stream that determine the densities of larvae that occur in the inner shelf (Powell and Robbins 1994, Govoni pers. comm.). As the Gulf Stream meanders along the NC coast, cold-core filaments spin off towards shore; these are associated with the upwelling of nutrients and provide a productive feeding environment for spawning fish. These filaments also serve to transport larvae to inner shelf waters (Powell and Robbins 1994). Powell and Robbins (1994) found that frontal waters were generally (but not consistently) associated with high densities of ichthyoplankton. They also determined that the greatest abundance of fish larvae during the peak spawning period (late fall to early spring) were in open shelf waters between 31 and 42 meters depth. Unlike more well-defined estuarine nursery habitats and inlet boundaries, defining the spatial constraints of potential conflicts with eggs and larvae becomes exceedingly difficult in the coastal ocean. While a large number of estuarine-dependant fishes spawn on the continental shelf in association with the Gulf Stream thermal fronts, the location of a given front (and of spawning aggregations) is variable from year to year making it impossible to locate as a fixed position on a map (J.J. Govoni pers. comm.).

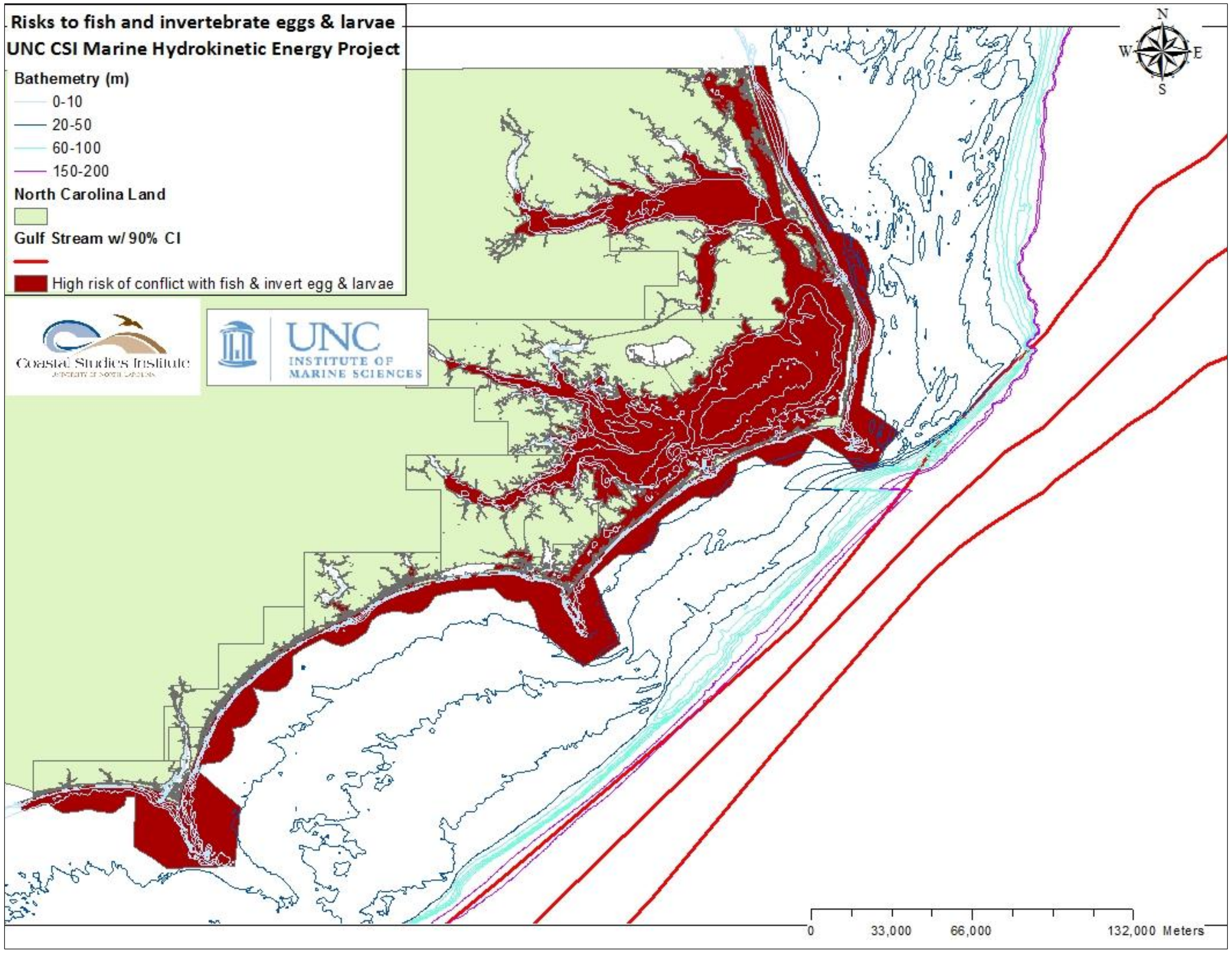

Figure 4. Map illustrating North Carolina coastal areas where risk of conflicts between fish and invertebrate eggs and larvae with marine hydrokinetic devices is highest.

Risks to coastal birds and seabirds

Areas where coastal birds and seabirds are known to occur in high abundances represent locations where conflict between birds and MHK devices is greatest (Figure 5). Avian species found off the NC coast can be classified into two groups: (1) coastal birds- those generally found within the coastal ocean (0 - 6 mi from shore); and (2) pelagic seabirds- those generally found offshore (≥ 25 mi from shore). Both bird groups utilize the 6 – 25 mi zone, but, to a lesser degree (Lee 1986; UNC 2011). In addition, flocks of migrating species that usually navigate by following the contour of the coast are sometimes blown off-course and have been observed further offshore than expected (Baird and Nisbet 1960). Piscivorous and scavenging birds are likely to occur in higher densities in association with biological hotspots. Some of these hotspots are stationary such as hard bottom habitat and The Point, where the Gulf Stream and Labrador Currents converge, some hotspots are dynamic in their geographic location such as the Gulf Stream with its floating *Sargassum*, and some hotspots are dynamic in location and ephemeral, such as the eddies and cold-core rings that spin off from the Gulf Stream. As top predators, birds are attracted to the fishes as prey and therefore closely tied to biologically productive hotspots.

Bird conflict maps indicate the relative abundance patterns of coastal, migratory and sea birds. The bird species at greatest risk include those that dive within the pelagic and benthic zones to forage. Most plunge diving seabirds are probably restricted to the top few meters of the water column (Adams and Walter 1993). However, Northern Gannets (*Sula bassana*, now *Morus bassanus*), common to NC offshore waters, had a mean observed diving depth of 19.7 (± 7.5) m, with a maximum recorded depth of 34 m below the surface (Brierley and Fernandes 2001). Members of the alcids, which occur offshore NC during the winter season, can dive much deeper. For example, Piatt and Nettleship (1985) found that common murres, Atlantic puffins, black guillemots and razorbills dove down to depths of 50 m, 60 m, 120 m, and 180 m below the surface, respectively. Other species at risk of conflict with MHK devices are those that forage for benthic mollusks that are attached to hard substrata, and include scoters and common eiders.

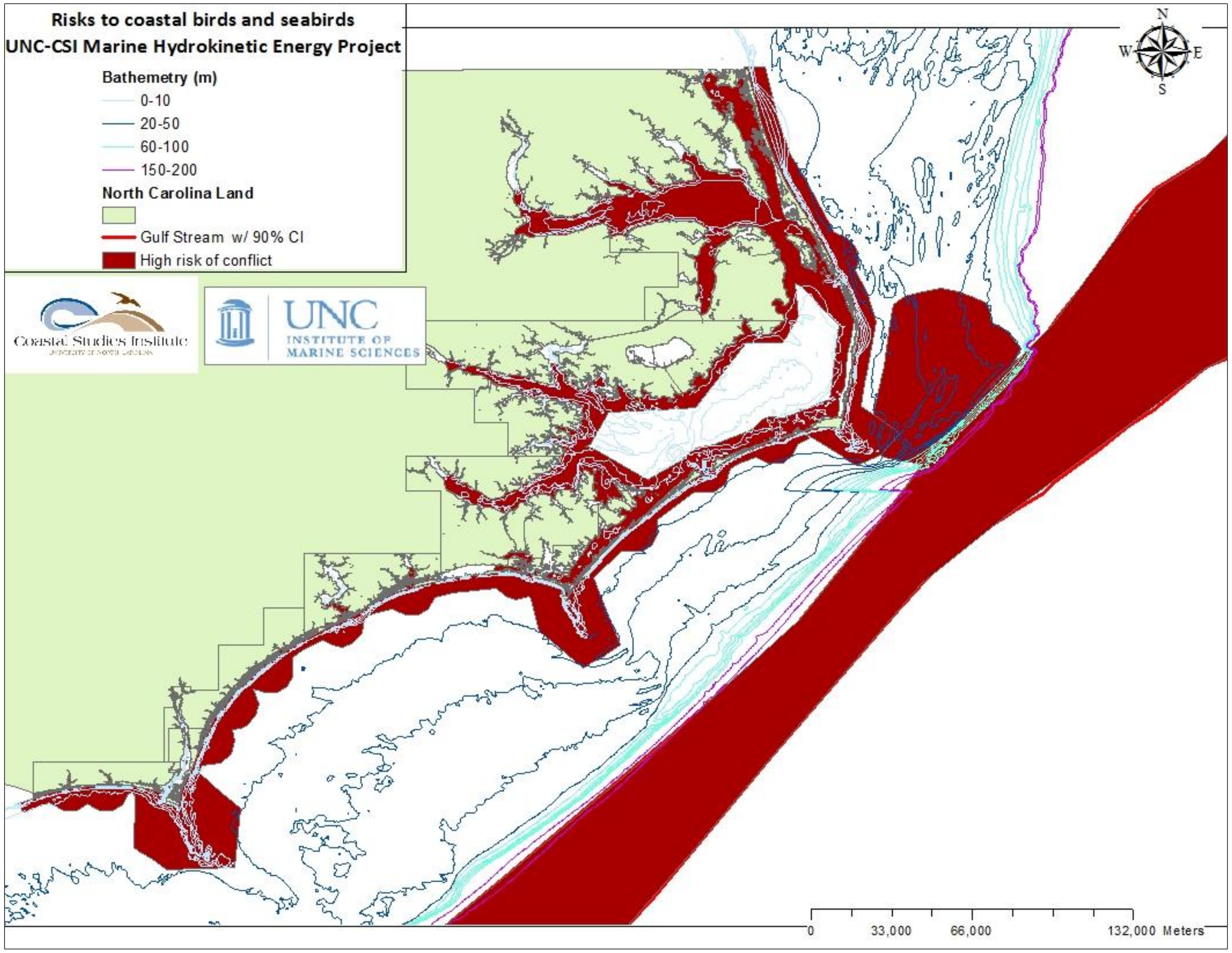

Figure 5. Map illustrating areas where high abundances of coastal birds or seabirds occur, suggesting where high risk of conflict between birds and marine hydrokinetic devices exists.

Wildlife surveys: sightings per unit effort

Sightings per unit effort (SPUE) maps depict the frequency of sea turtles (Figure 6) and marine mammals (Figure 7) in 10,000 km^2 areas off the coast of NC, normalized for sampling effort (km). Development of the SPUE method began during the Cetacean and Turtle Assessment Program (CETAP) in 1982 and was provided by Brooke Wikgren (pers. comm.). A 10,000 km^2 grid was used as an overlay for SPUE calculations.

Sighting and effort data were accessed via the Ocean Biogeographic Information System (OBIS) website (Intergovernmental Oceanographic Commission (IOC) of UNESCO 2012). Only spatial data that included both sightings and sighting effort were used for SPUE calculations. Data sets used include the following OBIS datasets: UNC-Wilmington Right Whale Surveys (2005-2006, 2008), Aerial surveys (1998-1999, 2001-2002, 2006-2007), and Aerial surveys for monitoring of proposed Onslow Bay USWTR (2007-2011) (William McClellan lab, UNC-W); Southeast Fisheries Center (SEFC) Atlantic Surveys- Atlantic bottlenose dolphins (1995), cetacean (1992, 1995), marine mammals and apex predators (1992, 1998, 1999) (NOAA SEFC); Sargasso 2004-Seabirds (Hal Whitehead lab, Dalhousie University); Duke/UNC Consortium Hatteras Eddy Cruise 2004 (David Hyrenbach lab, Duke University Marine Lab); Duke University Marine Laboratory Vessel Observations of Onslow Bay for the USWTR project (2007-present; Kim Urian lab); Cape Hatteras 04-05 (LaBrecque 2005); BLM CETAP Air (1978-1982), OPP (opportunistic sightings; 1935-1982), and Ship (1978-1980) (Robert Kenney lab, University of Rhode Island). These datasets were merged and sighting and effort data for sea turtles or marine mammals were identified and isolated.

Kemp's ridley (*Lepidochelys kempii),* green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), and loggerhead (*Caretta caretta*) sea turtles were observed in the OBIS datasets used to compose Figure 6. Hawksbill sea turtles (*Eretmachelys imbricata*) were not listed in the OBIS datasets used, but they are common off the NC coast (USFWS 2012).

Marine mammals included in the OBIS datasets and used to construct Figure 7 include the following genera or species: sperm whale (*Physeter catodon*), pygmy and dwarf sperm whales (*Kogia* sp.), Cuvier's beaked whale (*Ziphius cavirostris*), northern right whale (*Balaena glacialis*), minke whale (*Balaenoptera acuto-rostrata*), fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera novaeangliae*), killer whale (*Orcinus orca*), Long-finned pilot whale (*Globicephala melas*), Risso's dolphin (*Grampus griseus*), bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), spinner dolphin (*Stenella longirostris)*, striped dolphin (*Stenella coeruleoalba)*, and spotted dolphin (*Stenella frontalis*); and several generic groups of dolphin, rorquals, cetaceans, and baleen whales also listed in the OBIS datasets. Sei whale (*Balaenoptera borealis*), West Indian manatee (*Trichechus manatus*), grey seal (*Halichoerus grypus*), and harbor seal (*Phoca vitulina*) are among the species of marine mammals that are found in the waters off NC not listed in the OBIS datasets used here.

Omission of species that are present in the waters off the NC coast in OBIS sighting datasets highlights one of the limitations of the SPUE methodology, which is that some organisms may not seen by humans conducting surveys from boats and planes above the surface of the water. The lack of a sighting of particular species in an area does not unequivocally indicate its absence at the time of sampling or at times not represented by survey efforts.

Cell colors in Figures 6 and 7 represent the SPUE (sightings/km). White cells represent areas for which effort transects did not pass. Increasingly darker shades of grey depict increasingly greater SPUEs.

Existing human uses

The map showing existing human uses of the NC Continental Shelf that may conflict with MHK development (Figure 8) combined data from several different sources. The coordinates of the Monitor National Marine Sanctuary were obtained from the NOAA website. The locations of shipwrecks were obtained from the NC Department of Cultural Resources and the Division of Marine Fisheries; the latter also supplied coordinates for artificial reefs. Dredged material disposal site coordinates were obtained from the U.S. Environmental Protection Agency website.

The locations of major shipping routes were provided by the U.S. Coast Guard (USCG). It important to note that the USCG has requested that a 1-nautical-mile buffer be maintained along each side of every major shipping route when planning for offshore wind energy development; this buffer will likely also apply to or may be expanded for MHK energy development. The USCG and BOEM are also considering how to incorporate the Automated Identification System (AIS) data from vessels into offshore wind energy planning (see Vessel Traffic Data and Maritime Concerns presentations http://www.boem.gov/Renewable-Energy-Program/State-Activities/North-Carolina.aspx). This discussion between BOEM and USCG regarding use of AIS data represents a change in the criteria used by USCG for wind energy lease block approval compared to other states where Wind Energy Areas have already been defined and Calls for Information and Nominations have been previously published in the Federal Register e.g., Virginia, Maryland, Delaware and New Jersey (http://www.boem.gov/Renewable-Energy-Program/State-Activities/Index.aspx). To date, it is unclear which data serve best to guide offshore energy developers in avoiding conflicts with shipping traffic. Our map shows shipping routes because there is precedence for their use in marine spatial planning. Dive and fishing boat corridor designation was based upon information obtained during a stakeholder meeting of the Morehead City area fishing and diving community (Voss and others 2012).

Military exclusion zones and Marine Corps Base Camp Lejeune training and live-fire range areas mapped included the Pentagon-approved GIS data obtained from BOEM for Voss and others (2012) with air space, radar and estuarine-sited components deleted. It was determined that only in–water military uses of the NC Continental Shelf would likely conflict with MHK development.

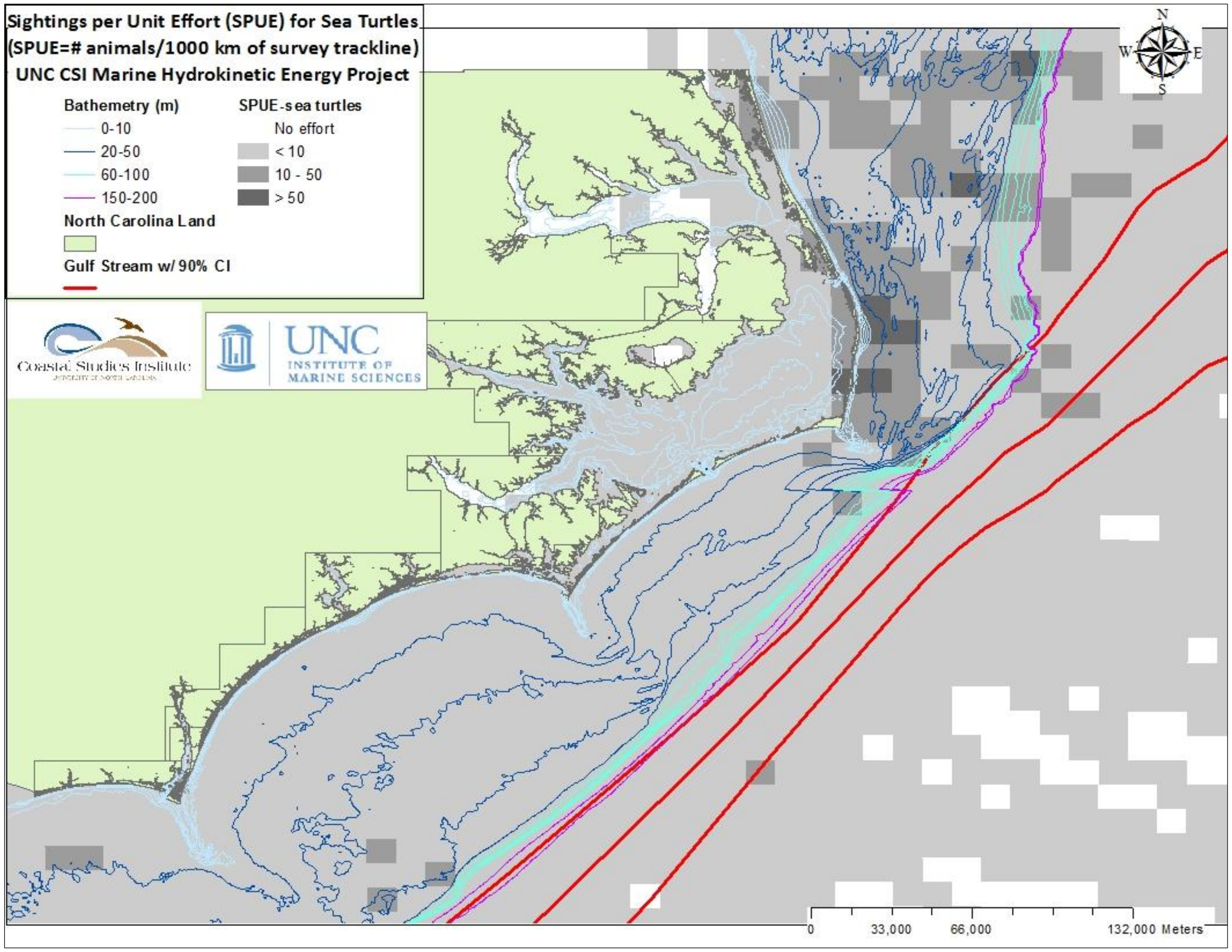

Figure 6. Map of Sightings per Unit Effort (SPUE; # animals sighted/1000 km of survey trackline) for sea turtles off the NC coast. This SPUE map provides an indication of sea turtle frequency per 10, 000 km^2 area off the NC coast. Sighting and survey effort data were accessed via the OBIS database (ICO 2012).

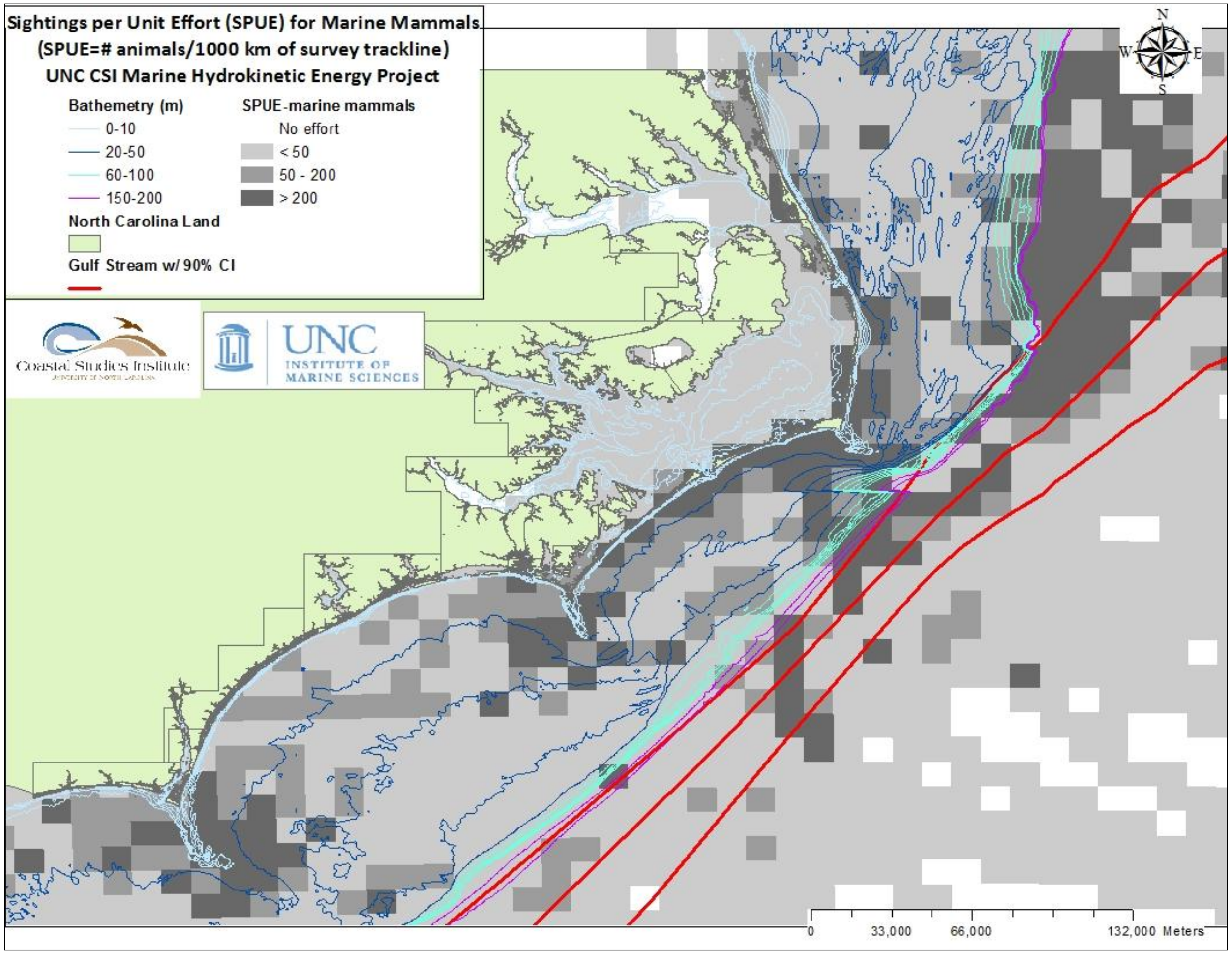

Figure 7. Map of Sightings per Unit Effort (SPUE; # animals sighted/1000 km of survey trackline) for marine mammals off the NC coast. This SPUE map provides an indication of marine mammal frequency per 10, 000 km^2 area off the NC coast. Sighting and survey effort data were accessed via the OBIS database (ICO 2012).

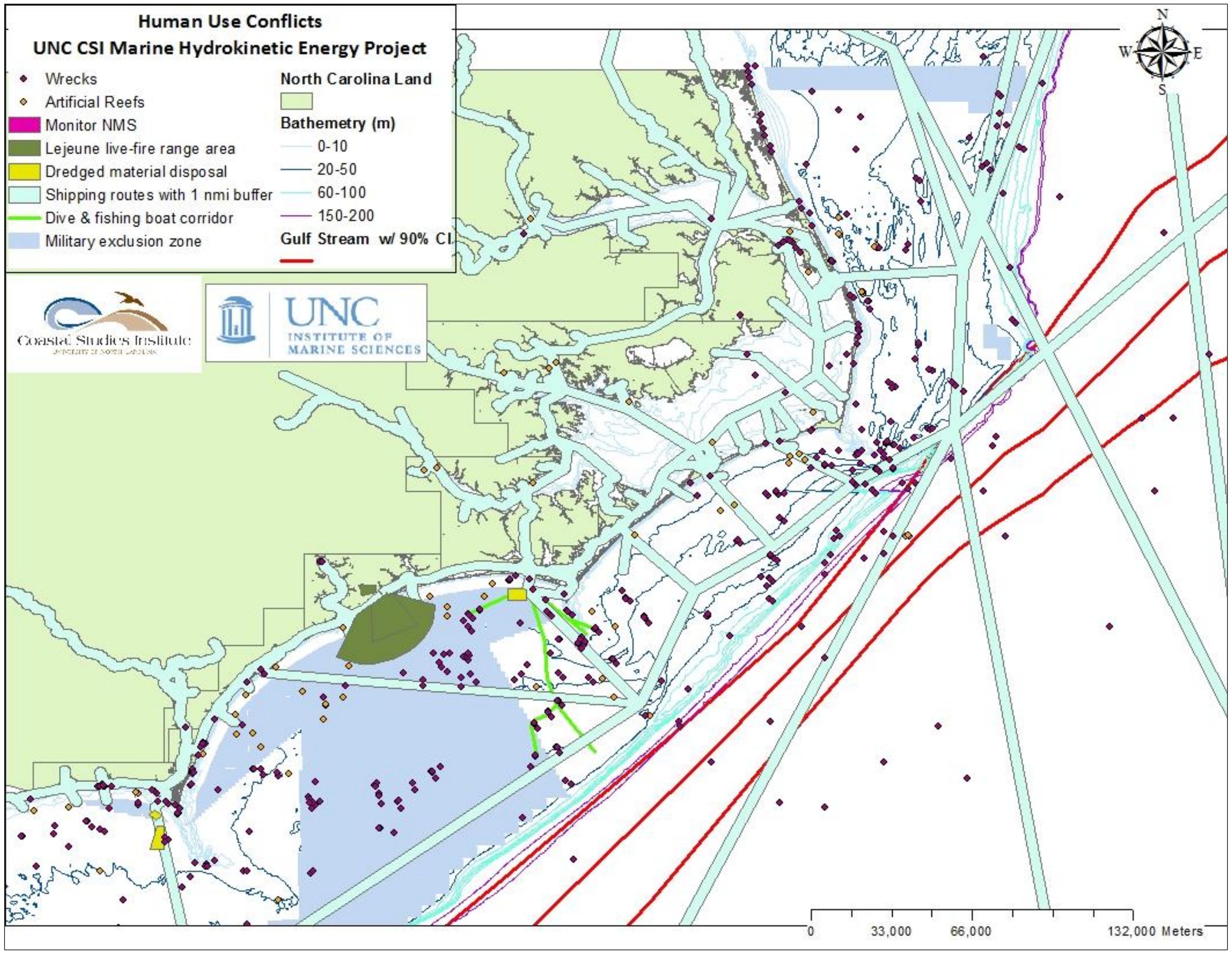

Figure 8. Map showing existing human uses of the North Carolina Continental Shelf that should be considered in the planning of marine hydrokinetic energy development. This map does not show BOEM Wind Energy Areas of interest, as these are currently under review.

Assessing risk of impacts of marine hydrokinetic devices to Species of Concern

The progress that we have made to date in assessing potential risks to species of concern includes completing a review of the suite of currently described, alternative MHK devices so as to identify, from their locations relative to the sea surface and their operations, all possible mechanisms of injury, broadly defined, for each group of species of concern. This process successfully identified the mechanisms by which injuries may possibly occur. We also conducted a review of where on the NC continental shelf the different life stages of each group of species of concern are located, and thus, where risks posed by MHK devices may be relatively high, moderate, or low. This progress, along with eventual knowledge of the spatial distribution of the energy resource and current understanding of spatially explicit conflicts with existing human uses, allows development of a preliminary spatially explicit plan for where commercial-scale development of MHK installations might best be located on the continental shelf off of NC. Such spatially explicit GIS planning aids the assessment of feasibility analyses for entities considering MHK energy development and helps start governmental planning processes. Nonetheless, the risk assessment required for federal and state permitting under NEPA will require results of further, more explicit risk assessments for groups of valuable organisms and for individual species of concern.

The groups of species of concern include all marine mammals, all sea turtles, most seabirds, commercially and recreationally important fished species (which includes some invertebrates as well as fishes), and perhaps some critical prey or habitat-providing species. All marine mammals are protected under the Marine Mammal Protection Act (MMPA), and several are also listed under the Endangered Species Act (ESA), including the West Indian manatee (*Trichechus manatus)*and North Atlantic right whale (*Eubalaena glacialis*). All five species of sea turtles found in North Carolina are listed under ESA: loggerhead (*Caretta caretta*), green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), Kemp's ridley (*Lepidochelys kempii)*, and hawksbill (*Eretmachelys imbricata*) sea turtles. Seabirds, as well as any terrestrial birds that may access deployments of MHK devices, are a key focus of the U.S. Fish and Wildlife Service reviews of permit applications. Several such seabirds are also listed as threatened or endangered under ESA, including the piping plover (*Charadrius melodus*), least tern (*Sternula antillarum*), and the Bermuda petrel (*Pterodroma cahow*): others are identified as species of concern at the state level. For exploited fishes, shrimps, crabs, and squids, and for many of the key forage species on which they rely, risks change across different life stages while locations of eggs, larval, juveniles, and adults also differ, requiring risk assessments that target separate life stages. Some fishes are listed under ESA, including two species of sturgeon (the second more abundant one, Atlantic sturgeon (*Acipenser oxyrinchus*), was just listed in February 2012) and require more in-depth risk assessment. The fish habitat of most relevance to assessing risk of impacts of MHK devices is the floating *Sargassum*, an Essential Fish Habitat under federal regulations enforced by NOAA and subject of comment by the North Carolina Division of Marine Fisheries under the state Coastal Habitat Protection Plan. NOAA also protects the deepwater *Lophelia* corals, which may be at risk from methods of anchoring MHK devices at the seaward edge of the present zone of interest extending out to the 200 m isobath.

Rigorous risk assessment for species of concern often cannot be completed to the standards required by federal resource agency reviewers charged with protecting those species during the NEPA process without inclusion of tests of potential impacts of actual devices or their analogs under realistic environmental conditions. Such high standards often pose the contradiction that if such tests are required before a permit is granted for a pilot deployment of the device, then how can the device's impact under field conditions be tested? We suggest future research pursue the testing of how the various types of organisms of concern respond behaviorally to operating prototypes of available MHK devices under field conditions of variable and measured current flows and wave conditions. Controlled experiments of how pelagic *Sargassum* and associated fishes and invertebrates from the western wall of the Gulf Stream interact with operating prototypes of select MHK devices of interest under realistic and variable current and wave conditions should also be conducted.

Concerns over the consequences of exposure to electromagnetic fields emitted by the electric transmission cables are a high-priority need for permitting of all ocean renewable energy facilities. Groups of organisms most at risk would appear to be those that use the earth's magnetic field to guide their long-distance migrations and their homing to natal habitat. In addition, species that employ electric discharges for communication, predation, or protection from enemies seem likely to be influence, perhaps adversely, by imposition of an electromagnetic (EM) signal. Consequently, all sea turtles, American eels, electric rays, by extension other elasmobranchs, possibly sturgeon, and all seasonally migrating fishes represent organisms of high concern. Past research on this problem has been severely constrained by unrealistic limitations of the test arena and inability to evaluate the species of greatest concern.

We suggest additional experiments be conducted that employ burial of a transmission cable, measuring its EMF, and then introducing individuals of those test species of highest concern to test their potential for disorientation by exposure the EM field. The critical aspect of these tests of the hypothetical risks is the ability to examine organism behavior, which no amount of review of concepts can provide. If threatened or endangered species cannot be used, taxonomically and functionally close analogs (proxy species) can be used to provide insight into how individuals of the actual threatened or endangered species might also be expected to behave in response to functioning prototypes of the select MHK devices under realistic and variable current and wave conditions. For example, cultured sliders can be used as proxies for hatchling and small juvenile sea turtles; indeed, sliders are aquatic, swimming turtles that have been previously used (Peterson and others 2012) as proxies for listed sea turtles. Analogous experiments with captive marine mammals or seabirds are impractical and would require a protracted permitting process. For those important groups, rigorous, controlled observations of actual behavioral responses in field test deployments in at-sea locations appropriate for potential commercial development are needed. We have researched and presented here and in previous reports (UNC 2009; Voss and others 2009) the seasonal patterns and spatial locations of important marine mammals and seabirds on the NC coast so as to know the most rewarding time opportunities to observe behavioral reactions of these species of concern to operating MHK devices of interest. For example, endangered right whales transit the NC coast during spring migration from about March 20 to April 1, with childless adults transiting first and mothers with calves following a few days later. The majority of right whales in this seasonal northerly migration are found within 10 km of the coast.

Discussion and conclusions

This report provides a very broad-brush summary of potential conflicts and synergies posed by the installation of commercial-scale MHK energy installations off the NC coast. Presently, there is very little empirical information about the impacts of various MHK energy devices on the marine environment and ecology and its use by humans. More extensive device- and location-specific studies of potential environmental, ecological, and human use conflicts and synergies with MHK energy installations are needed to understand the intensity, extent, and duration of interactions, and they will be required for permitting. For this reason, research investigating the environmental responses to the installation of MHK devices should be an integral component of any ocean energy project and this report highlights the interactions between MHK and NC specific concerns that warrant further empirical study.

Prototype-scale device installations offer the opportunity to measure noise, colonization, impacts on the physical environment, and interactions between humans and other organisms with the devices that can be scaled up to larger, commercial installations even though they may not have a measurable impact on the environment at the ecosystem-scale. Hypotheses can then be drawn from baseline information resulting from monitoring of prototype-scale MHK device interactions with the environment and ecology, which can be tested by empirical and modeling studies of larger installations.

The siting of MHK installations off the coast of NC will be limited by the avoidance protected areas and any probable conflicts between the MHK energy installations and protected species, species of value, and existing human uses of the coast and ocean. The potential for conflict is device-specific; and again, empirical and modeling studies are needed to assess the likelihood for and extent of conflict between particular MHK devices and the species of particular concern, important habitat, and human uses that we have identified. Looking at our maps (Figs. 1-8), there are some areas that pose a greater likelihood for conflict than others and will require more extensive environmental assessment to obtain permits, including the Gulf Stream, nearshore areas, and inlets, among others. Other areas will need to be avoided altogether because they are protected for their ecological and/or cultural value, including areas of hardbottom and artificial reefs, respectively.

Marine hydrokinetic energy has the potential to provide NC with a renewable supply of energy. With proper siting and consideration of conflicts and synergies with the environment, ecology, and human uses of the coast and waters off NC, that source of energy will also be sustainable.

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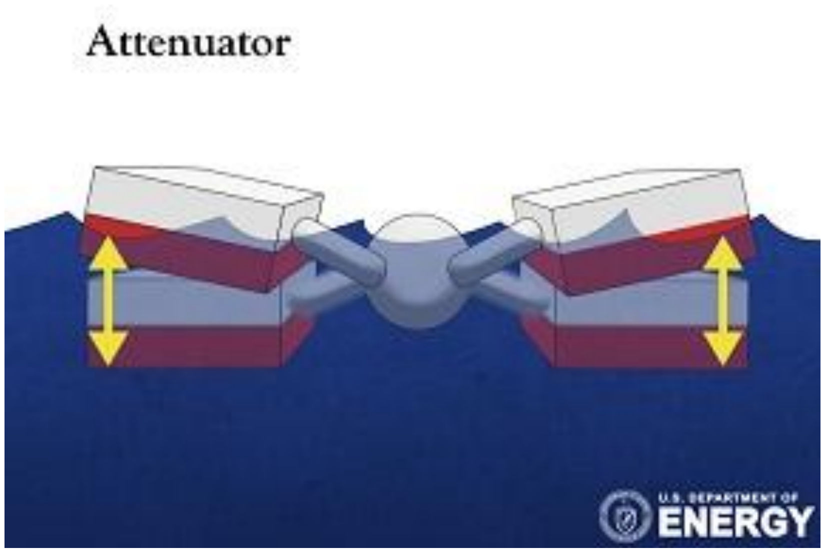
Appendix A
Wave Energy Device-Attenuators

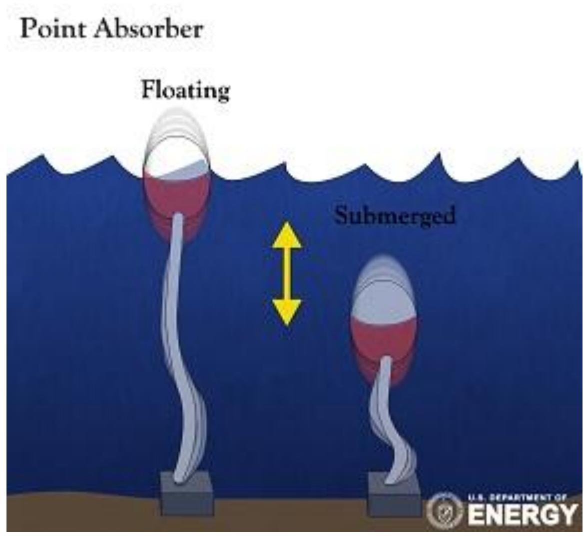


Example: Pelamis

Source: http://www.pelamiswave.com

Appendix B

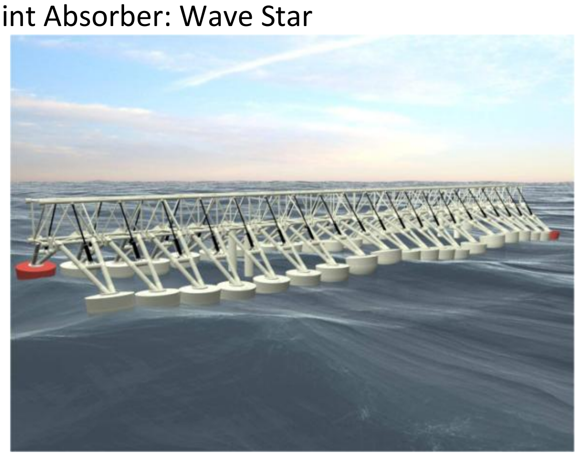
Wave Energy Device-Floating and Submerged Point Absorbers



Example of Single Point Absorber: OPT's PowerBuoy

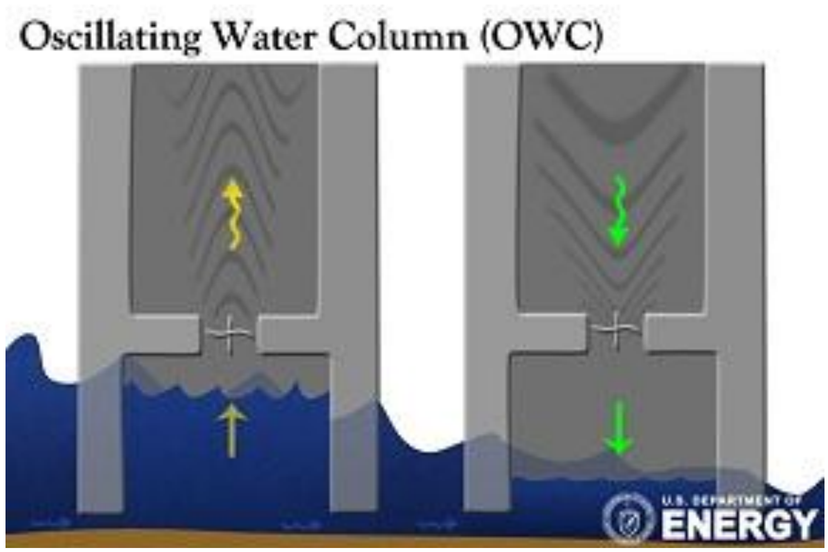
Source: http://www.oceanpowertechnologies.com/tech.htm

Example of a Multi-Point Absorber: Wave Star

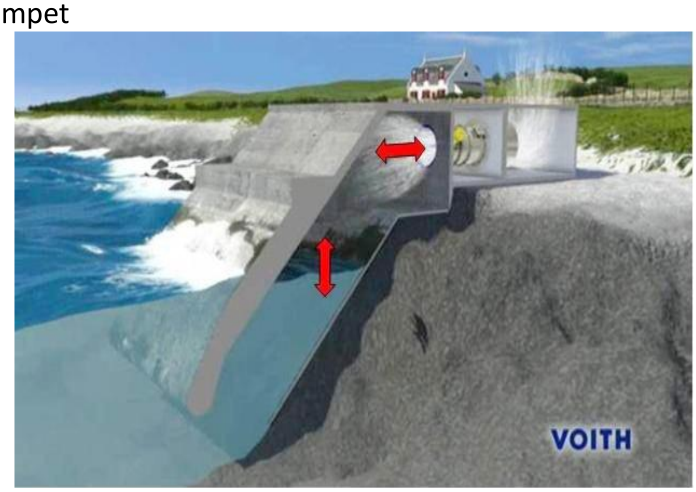


Source: www.wavestarenergy.com

Appendix C
Wave Energy Device-Oscillating Water Column

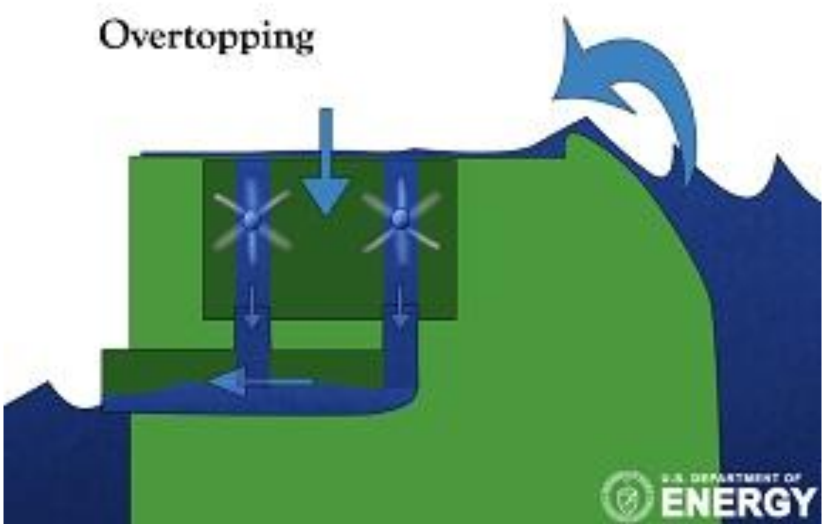


Example: Vioth Limpet



Source: http://www.tacticalmarcomms.com/assets/voith_hydro_pic_2.jpg

Appendix D
Wave Energy Device-Overtopping Terminator

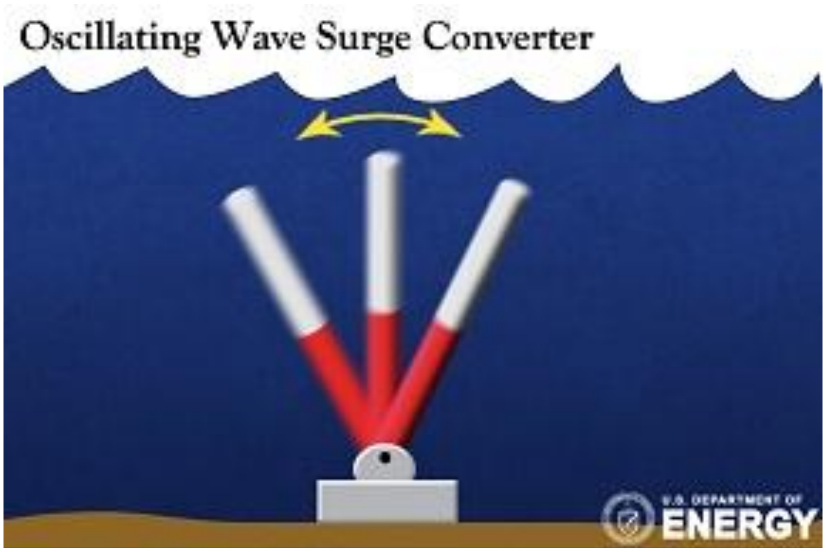


Example: Wave Dragon

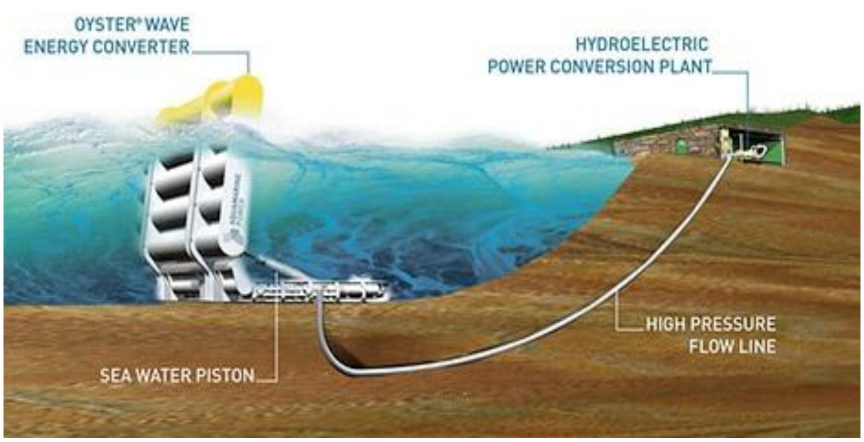
Source: www.wavedragon.net

Appendix E

Wave Energy Device-Surge Converter



Example: Oyster



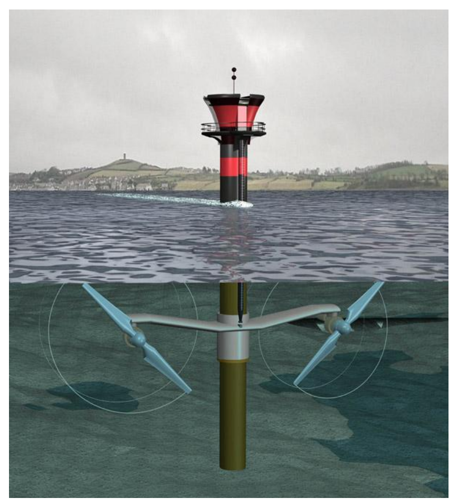
Source: http://www.engadget.com

Appendix F

Current Energy Device-Axial Turbines

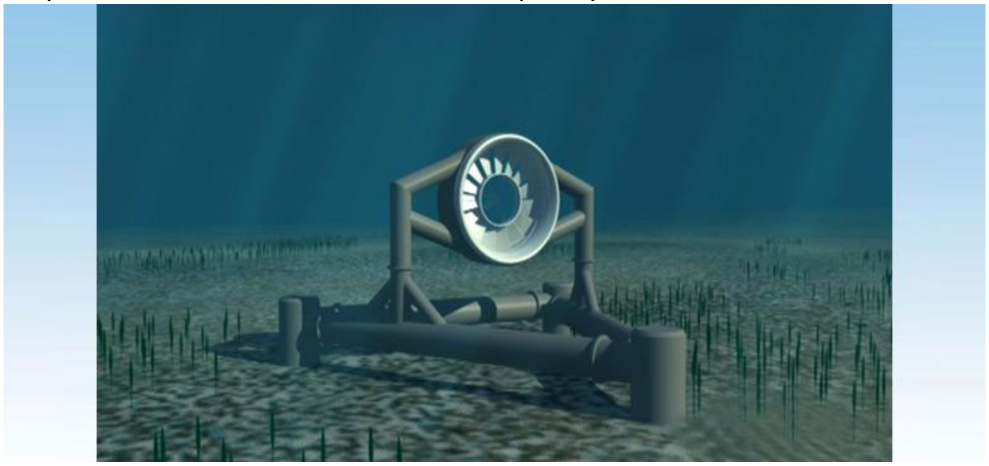
Examples of fixed axial turbines: Hammerfest Strom (left) and SeaGen (right)

Source:
http://www.hammerfeststrom.com



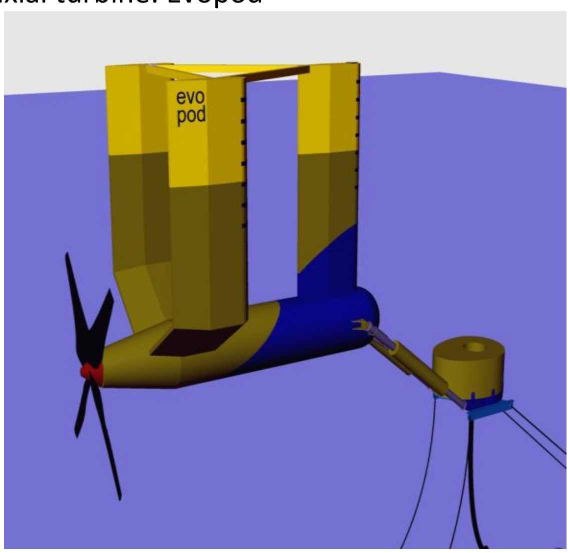
Source:
http://www.seageneration.co.uk

Example of a closed, fixed axial turbine: OpenHydro



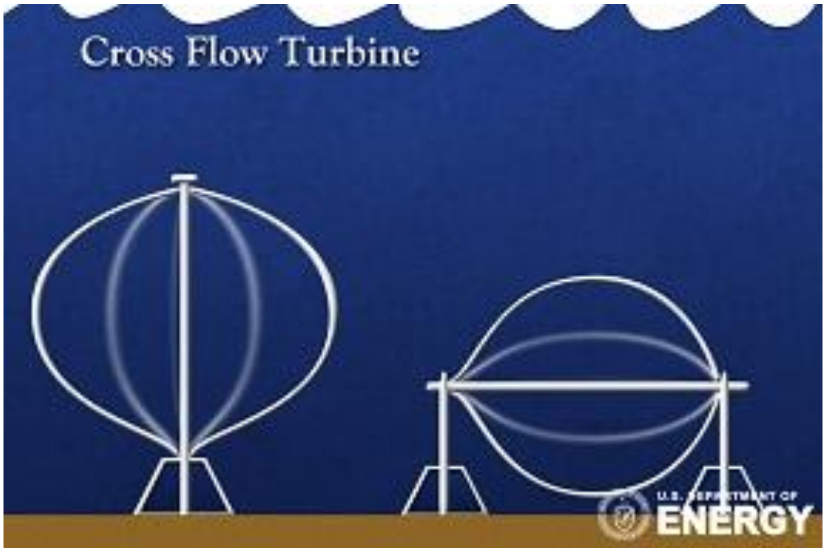
Source: http://www.openhydro.com

Example of a floating axial turbine: Evopod

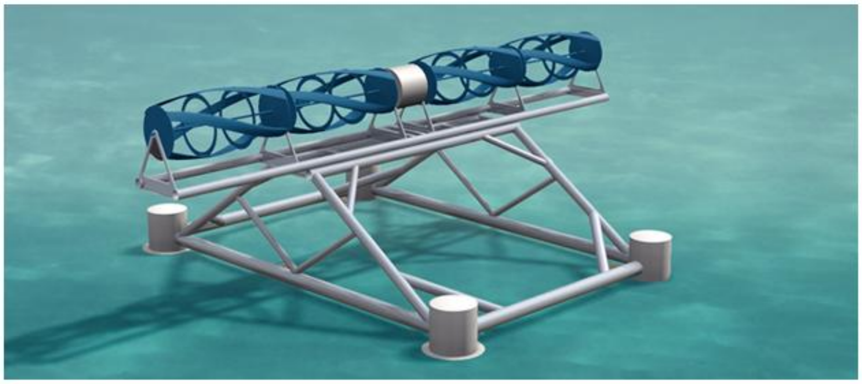


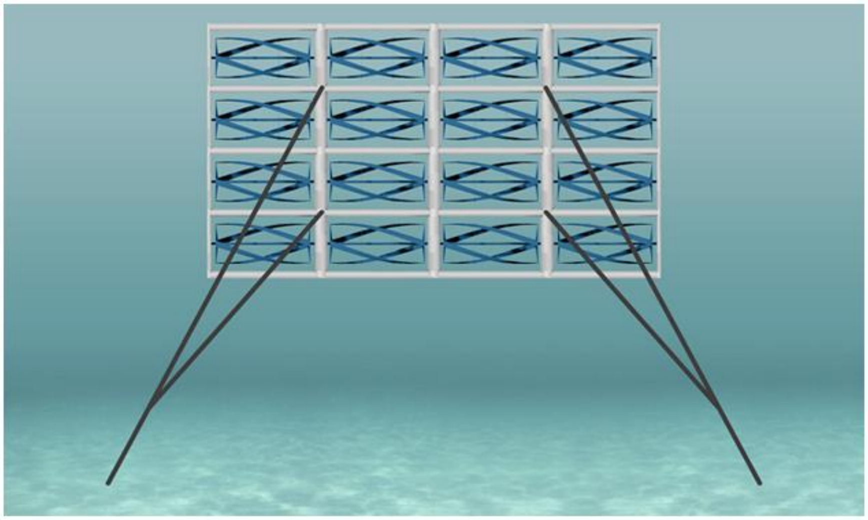
Source: http://www.oceanflowenergy.com

Appendix G
Current Energy Device-Helical/Cross-flow Turbines



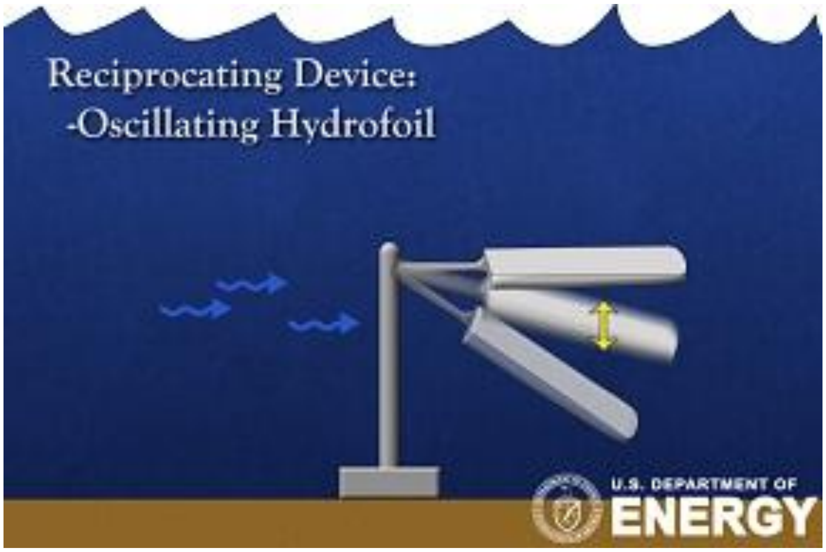
Examples: Devices from Ocean Renewable Power Company



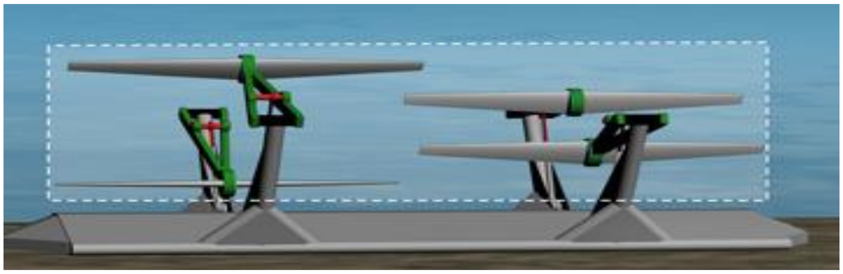


Source: http://www.orpc.co

Appendix H
Current Energy Device-Oscillating Hydrofoils

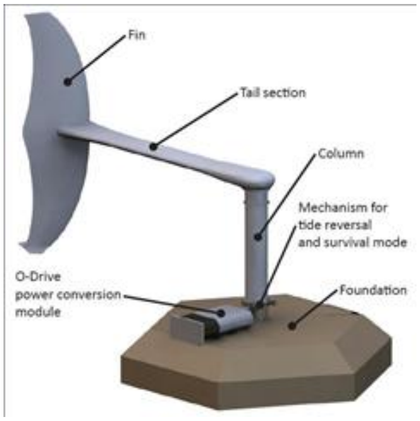


Example: Devices from Pulse Tidal



Source: http://www.pulsetidal.co.uk

Example: bioSTREAM



Source: http://www1.eere.energy.gov/