Offshore Wave Power in the US: Environmental Issues

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1. Introduction and Summary

E2I, the Electric Research Power Institute (EPRI) and Global Energy Partners LLC (Global) "the Project Team" are collaborating with state energy agencies and utilities from Maine, Massachusetts, San Francisco-California, Oregon, Washington, Hawaii, and the Department of Energy (DOE) National Renewable Energy Laboratory (NREL) to define system designs for wave energy conversion device power plants at one site in each of those states. The overall project objective is to demonstrate the feasibility of wave power to provide efficient, reliable, environmentally friendly and cost-effective electrical energy and to create a push towards the development of a sustainable commercial market for this technology.

Various natural processes might be affected if significant amounts of wave energy are removed from the coastal ecosystem, including sediment transport and the functioning of near shore biological communities. Marine mammal and seabird populations also could be affected by the physical presence of wave energy structures. Depending on the type of conversion process, wave power plants might be a potential source of chemical and noise pollution, as well as presenting a visual intrusion on the offshore seascape. Substantial development of the wave energy resource could conflict with other human uses of coastal sea space, and these potential impacts are also reviewed.

Like any electrical generating facility, a wave power plant will affect the environment in which it is installed and operates. There is no actual environmental effects data available at this time (the first full scale prototype machine deployed at sea and generating electricity into the electrical grid occurred in the summer of 2004). There are some studies in Europe that are beginning to examine the potential environmental impacts of wave power and to document demonstrations in a timely fashion (see Section E of the Wave Energy Thematic Network at http://www.wave-energy.net). The Project Team considered the following six environmental issues:

- Withdrawal of wave energy
- Interactions with marine life and seabirds
- Atmospheric and oceanic emissions
- interactions with coastal sedimentary processes
- Visual appearance and noise
- Potential conflicts with other uses of sea space
- Installation and decommissioning

A tabular summary of these issues and their key impacts are summarized in Table 1 and in text immediately following table. An in-depth discussion of each of these issues is contained in the following report sections. The last two sections discuss the environmental benefits of wave energy technology relative to other electricity generation technologies and the key conclusion that, with given proper care in site planning and early dialogue with local stakeholders, offshore wave power promises to be one of the most environmentally benign electrical generation technologies .

Table 1. Summary of Wave Energy Environmental Issues and Impacts

ISSUE/	IMPACT(S)
Withdrawal of wave energy	Wave height reduction on the order of 10-15% immediately behind plant, with diffraction substantially re-establishing longshore uniformity of wave height within 3-4 km behind plant.
Interactions with marine life, seabirds and benthic ecosystems	Wave power plants may provide artificial hauling-out space for seals and sea lions or nesting space for seabirds, enabling larger populations to exist than otherwise might exist under natural conditions. Likewise, submerged surfaces of wave energy devices and associated seafloor structures such as anchors and power cables will provide substrates for colonization by algae and invertebrates, creating "artificial reefs," which may be a beneficial impact. Reduction in wave energy levels shoreward of a wave power plant may alter the community structure of algae communities in the nearshore and intertidal zones, favoring certain species over others, but consequential effects on fish and invertebrates are expected to be negligible.
Atmospheric and oceanic emissions	Expected to be of concern only for devices with closed-circuit hydraulic systems, where working fluid may leak or be spilled during transfers.
Interaction with coastal sedimentary processes	Lowering of wave energy levels reaching the coast may reduce longshore sediment transport, possibly reducing erosion in the vicinity of the plant while increasing erosion "downcoast." This impact is likely to be significant only for devices located within 1 or 2 km of the shoreline.
Visual appearance and noise	Visual appearance and noise emissions are device-specific. Submerged devices and slack-moored floating devices with low freeboard will not be visible from shore or visible only in exceptionally calm and clear weather. Taut-moored or fixed devices with high freeboard will be visible more often. Airborne noise is likely to be a concern only with oscillating-water-column devices having pneumatic turbines. Underwater noise may have adverse impacts on marine mammals.
Conflicts with other uses of sea space:	. Potential conflicts with recreational use (particularly surfing), commercial shipping, commercial fishing, dredge-spoil disposal, and other activities may be avoided with early dialogue during the wave power plant site selection process.
Installation and decommissioning	The main installation impacts will be associated with the laying of submarine power cables and associated shore-crossing; other impacts can be avoided by careful planning. Decommissioning concerns include shock to pinniped or seabird populations that rely on devices for hauling out or nesting and disposition of fixed and floating structures. These likewise can be avoided by careful planning.

Environmental Benefits

Wave energy can have a number of other benefits in both the environmental and social areas. For example, in remote coastal areas, including small islands, it can help reduce the reliance on auxiliary (diesel) power stations. In addition to the resultant reduction of the emission of combustion gases to the atmosphere, the transport of the fuel to the site, often by water, is largely eliminated, which in turn reduces the environmental risks associated with this means of transportation. Currently, many remote coastal areas receive their electricity via overhead transmission lines, which are often perceived to have adverse visual impacts. Again, such impacts would be reduced by having separate wave power installations serving individual coastal communities.

The First U.S. Offshore Wave Energy Device Environmental Assessment (EA)

The first U.S. Wave Energy Project Environmental Assessment (EA) evaluated the potential environmental impacts of a proposed phased installation and operational testing over a two year period of up to six Wave Energy Conversion (WEC) buoys off North Beach at Marine Corps Base Hawaii (MCBH) Kaneohe Bay (the Proposed Action).

Ten potentially affected resources were identified for this project and none were found to be significantly impacted by the proposed installation and operational testing of the WEC buoy and ancillary equipment. These resources were: shoreline physiography, oceanographic conditions, marine and terrestrial biological resources, land and marine resource use compatibility, cultural resources, infrastructure, recreation, public safety, and visual resources

Based on information gathered during the preparation of the EA, the Navy found that the proposed installation and operational testing of up to six WEC buoys at MCBH Kaneohe Bay Oahu Hawaii will not significantly impact human health or the environment and that there will be no cumulative effects from the proposed project

Conclusions

We conclude that, given proper care in site planning and early dialogue with local stakeholders, offshore wave power promises to be one of the most environmentally benign electrical generation technologies. We recommend that early demonstration and commercial offshore wave power plants include rigorous monitoring of the environmental effects of the plant and similarly rigorous monitoring of a nearby undeveloped site in its natural state (before and after controlled impact studies).

2. Withdrawal of Wave Energy[i]

Offshore wave power plants will not present an impervious barrier to waves traveling shoreward. Gaps between devices and less-than-100% absorption efficiency will allow considerable wave energy to pass through the plant. Given the potential sensitivity of the surfing community to this effect, the Project Team estimated the amount of wave energy that would be withdrawn by the commercial plant design at Waimanalo Beach, Oahu, Hawaii.

The commercial design used 180 Pelamis devices divided into 4 clusters of 45 units each with each cluster configured as three rows, with15 Pelamis device per row as shown in Figure 1. The total width of the wave power plant is 12 km and includes 600 meter navigation lanes between e clusters.

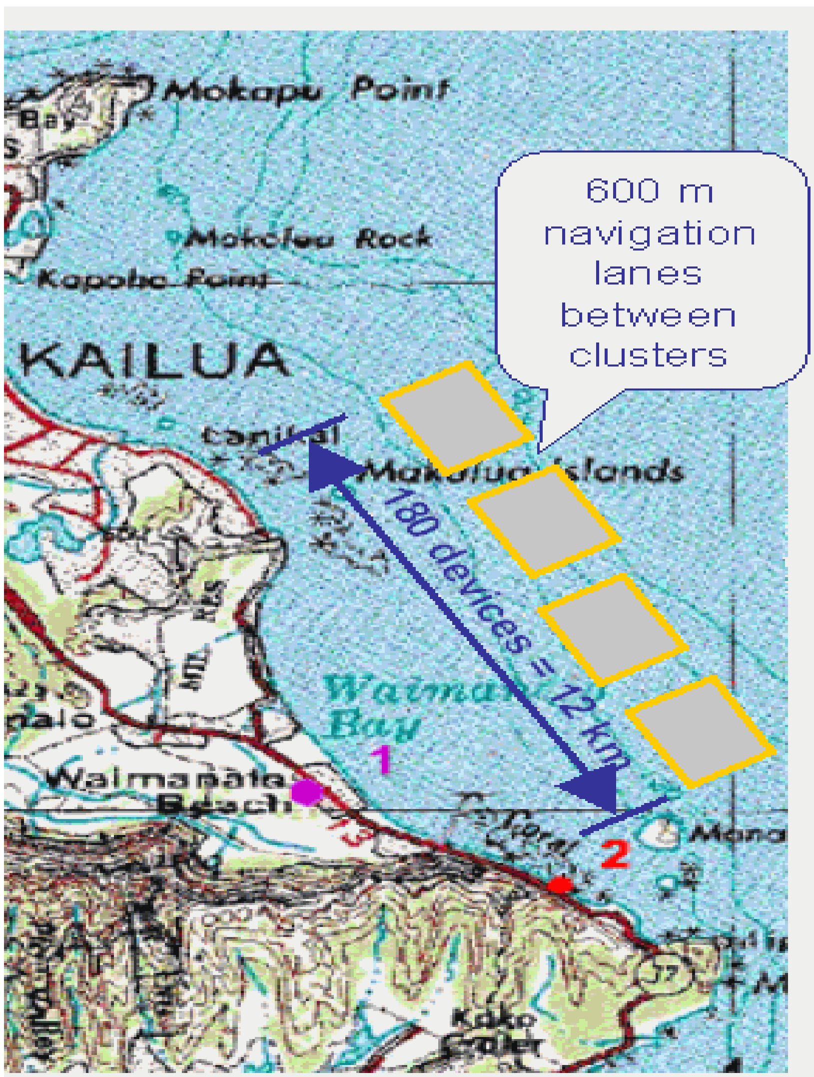

Figure 1. Commercial Wave Power Plant Design at Waimanalo Beach, Oahu, Hawaii.

The total reduction in wave height was found to be 12% immediately behind the plant. This result is illustrated in Figure 2 showing one cluster of 45 Pelamis units

Undiminished wave energy that passes to either side of the plant will spread into the lower-energy zone immediately behind the plant by diffraction. By the time the waves reach shoaling and breaking depths, their height will have been somewhat re-established by this process, at the expense of adjacent waves, thereby resulting in a broader region of lesser impact. The Pelamis, and other floating wave energy devices preferentially absorb energy from shorter-period waves, having less effect on the longer-period swell that produce the spectacular surfing waves on Oahu's north shore. Overall, then, we expect that the reduction in height of surfing waves would be in the range of 5-10%. Suitable before-and-after monitoring of the first commercial plant sites must be undertaken to accurately measure this effect. And, early dialogue with the surfing community is required in order to a find a balanced and reasonable solution for the coexistence of wave power production and surfing.

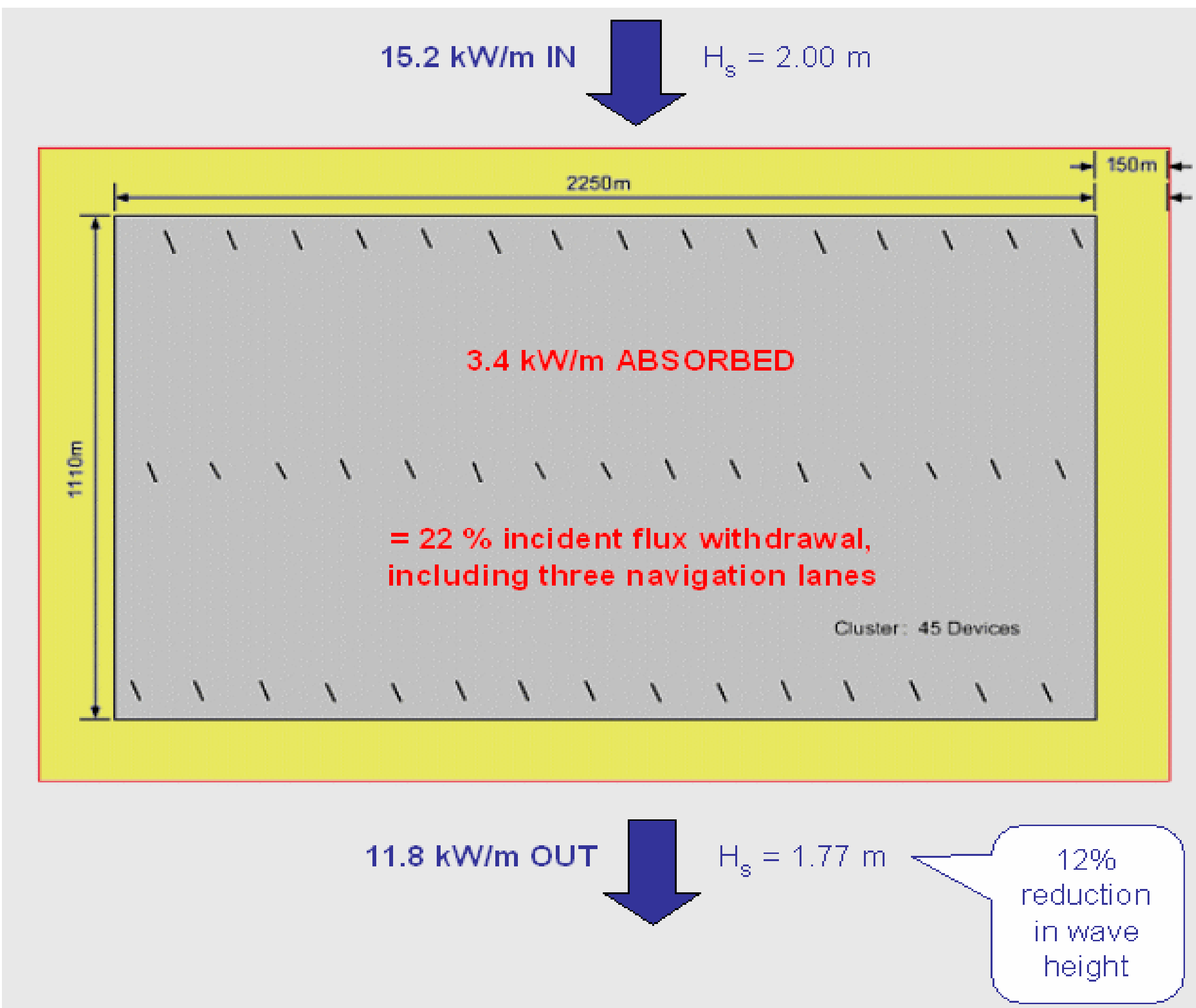

Figure 2. Wave Height Reduction for One Cluster of 45 Pelamis WEC Devices

There are also potential effects on near shore biological communities due to withdrawal of wave energy.. Reduced or withdrawn wave energy could increase the competitive advantage of faster-growing algae and kelp species over wave-resistant species (e.g., giant kelp over bull kelp, fleshy algae over coralline algae). While algae and kelp species composition might be changed, we believe that it is unlikely that wave energy withdrawal will have significant effect on invertebrate and fish communities

3. Interaction with Marine Life, Seabirds and the Benthic Ecosystem

3.1 Interaction with Marine Life and Seabirds

Although marine mammals and seabirds are highly migratory, wave power development could still have an impact on these populations. For example, gray whales will have to swim around wave energy devices located in their coastal migratory path. Pinnipeds (seals and sea lions) may attempt to haul out on floating wave energy devices with low freeboard. Finally, seabirds that commonly nest on offshore rocks and stacks may attempt to colonize caisson-based wave energy devices, since these are intended to be unmanned, with only occasional service visits. These potential impacts are described separately below.

Along the west coast of North America, the gray whale is noted for its annual migrations between feeding grounds in the Arctic seas off Alaska and calving grounds in the coastal lagoons of Baja California. The following description of gray whale movements was compiled from environmental impact statements prepared for offshore oil and gas leasing by the U.S. Department of the Interior (60)[ii].

The southern migration takes place in November and December. Southbound migrating whales may travel up to 185 km per day, requiring at least 30 days to complete their entire journey. Aerial surveys report the majority of whales within 2 nautical miles (3.7 km) of the shoreline.

The northern migration occurs in two pulses - the first in March and April, the second in May. Northbound whales tend to move closer inshore as they travel farther north. Off southern California, the majority of whales occur within 1.5 nautical miles (2.8 km) of the shoreline, while in the northern third of the state, they occur "literally in the surf zone" (60). The second pulse consists entirely of mother/calf pairs, which stay extremely close to shore throughout their journey, traveling within kelp beds or just seaward of the breakers.

Any wave power plant that can be sited more than 4 km offshore will have virtually no impact on gray whale migration, provided that construction activities which cross their path (seafloor surveys, laying of submarine power cables) are carried out at times of the year when whales are not migrating. Such activities would almost certainly be carried out in calm-weather months (July through September), so interference should not occur.

As mentioned earlier, caisson-based plants are only economical in water depths less than 20 m, which generally lie within 2 km of shore along PG&E's service area. Installation of such devices may involve destruction of the kelp forest refuge for northbound mother/calf pairs. Furthermore, if the noise emissions from wave energy conversion machinery are perceived as threatening, the whales may give the plant a wide berth. Gray whales have readily acclimated to the noise of offshore oil production platforms, however, which are often used by human observers to watch the migrations [iii].

There is no doubt that pinnipeds will attempt to haul out on any floating wave energy device that has a freeboard of less than one or two meters, at least during calm weather (Figure 3). Steller sea lion and harbor seal populations may particularly benefit from such artificial hauling areas, since their peak use of natural coastal land area peaks during the calmer summer months, when floating wave energy devices would be easier to board. Although such an impact might be positive from a pinniped's point of view, it may create other, negative impacts. For example, it has been reported that sea lions hauling out on a new jetty will follow sport fishing charter boats as they leave harbor and steal the catch of frustrated anglers [iv]. This could create a problem if a wave energy device is sited close to a popular sport fishing area. Device inspection, maintenance, and repair could be difficult where large numbers of seals or sea lions are hauled out near docking

Figure 3.   Hauling out of seals (left photo) and sea lions (right photo) on buoys is so common that it is a typical subject of commercial photographers.

If large-scale development of the wave energy resource creates a significant amount of new hauling area, pinniped populations may increase over the long term, with many animals relying on this artificial space. This could cause problems when a plant is decommissioned at the end of its service life, since the natural environment would not have the carrying capacity for these population additions. One solution to this potential problem would be to deploy a new plant as the old one is taken out of service, in a module-by-module fashion. If a wave power plant is not to be replaced, then its decommissioning should be phased over several years, so that the pinniped population can gradually adjust to the loss of carrying capacity.

Caisson-based devices will have sufficient freeboard to discourage even the most determined pinniped, since conversion machinery has to be placed high enough to prevent its inundation by extreme storm waves. In order to be compatible with coastal recreation, airborne noise emissions from such devices will have to be muffled, and unless the residual noise frightens them away, birds may attempt to colonize this high-and-dry space.

The same concern regarding plant decommissioning, described above for pinnipeds, applies to this potential impact as well. In addition, care must be taken to avoid disturbing seabird nesting areas during plant service visits, particularly in breeding and brooding seasons.

Although marine mammals are highly migratory, wave power developments could still have an impact on their populations:

- Some whales have coastal migratory paths, which could be disrupted by wave energy installations. Observations have shown that such installations may constitute barriers that could be difficult to detour around or avoid (Perrin et al 1994).
- Pinnipeds (seals and sea lions) may attempt to haul out on floating wave energy devices with low freeboard. This could cause unforseen interaction between specific populations of these species and human activities, e.g. interference with sport fishing. It should be possible to avoid such problems through careful site selection.
- Cetaceans (whales, dolphins, porpoises) may be disturbed by noise emissions from some types of wave energy devices; such emissions are expected to be low. In the case of the offshore oil industry, certain species of whale, e.g. gray whale, appear to have readily acclimated to the noises from offshore production platforms (Richardson et al 1991).

As with marine mammals, seabirds are also highly migratory, and are therefore liable to be impacted by wave energy schemes. Seabirds that commonly nest on offshore rocks and stacks may attempt to colonize on caisson-based wave energy devices, since these are intended to be unmanned with only occasional service visits. Therefore care would have to be taken to avoid the nesting of rare species on such devices

3.2 Interaction with the Benthic Ecosystem

The installation of wave energy devices could have impacts on the local ecosystem since offshore construction activity will disturb the sea-bed. This will particularly affect benthic species, where disturbances could alter the composition of the community for some time, and will also reduce the transparency of the water column, thereby influencing other flora and fauna. The disturbance of the marine environment is often more critical close to the shore since this is where many commercial shellfish fisheries are located. However, the impacts are generally not likely to persist for longer than one season, providing that ecologically sensitive areas, such as breeding grounds for fish and other marine species, are avoided. In addition to impacts resulting from the construction of the device, impacts could also result from laying electrical transmission cables. Some guide to the potential level of impact can be gained from the experience of the offshore oil industry in laying oil and gas pipelines. The laying of such pipelines causes a disturbance corridor of about five meters across (European Commission, 1995), though effects due to suspended sediment levels from the dredging operations may affect organisms across a wider area. However, after completion of the laying of the pipeline the area is rapidly re-colonized. Therefore, little long-term damage is expected from cable laying on the sea-floor

Kelp beds are the near shore benthic ecosystem most likely to be affected by wave power development. There are two predominant species of kelp that form beds off the west coast of North America: the giant kelp (*Macrocystis pyrifera*) and the bull kelp (*Nereocystis leutkeana*). The giant kelp is found from Alaska to Baja California, but only forms forests south of Point Ano Nuevo. The bull kelp is found from Alaska to Santa Barbara, but only forms forests north of Point Conception. The two species differ in both their appearance and life history.

Giant kelp plants consist of numerous fronds emerging from a holdfast that is attached to the seafloor. Each frond consists of a long stem-like stipe, with numerous blades along its entire length. At the base of each blade is a small gas-filled bladder that floats the frond off the bottom. The life history of *Macrocystis* is perennial, with new fronds constantly replacing old ones, which slough off after a few months. The plant itself may live for several years, provided that the holdfast isn't destroyed by grazing sea urchins or uprooted by storm waves.

The appearance of bull kelp is markedly different. A single stipe emerges from the holdfast and terminates in a single large float, which in turn gives rise to numerous long, streaming blades. This growth habit is more resistant to uprooting by storm waves than that of giant kelp.

Forests formed by both species of kelp, including mixed stands, provide shelter and food for a variety of marine life. Kelp beds support both commercial and sport fisheries. Some fish graze the kelp directly, while others are carnivores that eat the grazers. Kelp beds are also the favored habitat of the California sea otter, as well as providing temporary refuge for northward migrating gray whales. Both of these marine mammals are endangered species.

The most serious impact of wave power development on kelp would occur if a wave energy device was actually sited within a bed. Not only would the kelp in the "footprint" area of the device be destroyed, but any kelp seaward of the device would have to be removed. This would be particularly important during the summer months, when incident wave energy is low to begin with, and the kelp's surface canopy is well developed.

Siting a wave power plant behind a kelp bed is akin to siting a wind farm behind a grove of trees. Computer simulations of a large storm wave (6.1 m high, 20-second period) passing through a small kelp farm in 15 m water depth indicated an 80% reduction in wave height, to 1.2 m [v]. Plant spacing in this simulation was 1.1 m, which is comparable to that measured in natural stands of kelp off the Monterey Peninsula [vi].

If a wave power plant can be sited seaward of the zone in which kelp grows, then no kelp would have to be removed. The seaward margin of kelp growth is limited by the amount of light reaching the seafloor, which depends on water clarity. In turbid waters, giant kelp beds are limited to depths of 15 to 20 m, whereas in clear waters, they may extend to depths of 25 to 30 m

Siting a caisson-based wave power plant seaward of the kelp is unlikely to be economical, due to the increase in survival wave heights and higher platform overturning moments. Caisson-based wave energy devices thus have a high potential for disturbing kelp beds. Floating devices that can be sited well seaward of the kelp are expected to have much less impact. A comparative study of kelp beds along a natural wave exposure gradient off the Monterey Peninsula (59) suggests that the following changes might occur as a result of extensive offshore wave energy development:

- In regions where the two forest-forming species co-exist, *Nereocystis* tends to be excluded because it is shaded out by the large, perennial surface canopy of *Macrocystis*. In areas of high wave exposure, however, *Nereocystis* predominates, since its growth form is more resistant to breakage by waves. To the extent that offshore wave energy development reduces storm wave action it will increase the competitive advantage of *Macrocystis* in mixed stands, allowing it to grow more abundantly off exposed coasts that were formerly dominated by *Nereocystis*.
- The thinning of *Macrocystis* canopies by wave action on exposed coasts allows not only *Nereocystis* to grow more abundantly, but it also permits the increased growth of understory kelps, such as *Pterygophora* and *Laminaria*. As already indicated, offshore wave power plants could act to increase the abundance of *Macrocystis*, which would then shade out these understory kelps.
- Coralline red algae are more resistant to wave action than fleshy red algae, but because the latter grow more rapidly, they will out compete the coralline forms in protected coastal waters. Therefore, offshore wave energy development might increase the abundance of fleshy red algae in coastal areas that were formerly dominated by coralline algae.

4. Coastal Sedimentary Interaction

The shoaling and breaking of waves carries water into the surf zone over a broad stretch of coastline. When waves arrive at an angle of more than 5 to 10 degrees to the coast, the longshore component of this mass transport sets up a continuous current that is powerful enough to carry sand in suspension and in sheets along the bottom (bedload transport). Longshore movement of sediment by waves is referred to as littoral drift and is often conceptualized as a "river of sand" flowing along the coast.

Major sediment sources for littoral drift are coastal rivers and streams, as well as sand carried shoreward by the net mass transport of shoaling waves. Once sediment enters the littoral drift, it works its way down the coast until it reaches a barrier. In some cases, this can be a submarine canyon that cuts across the shelf, while in others, it can be a cape or rocky headland. The combination of one or more riverine sediment sources, a coastal zone of active longshore transport, and a downcoast barrier constitutes a littoral cell.

Man-made structures that extend across the surf zone, such as jetties and groins, intercept the littoral drift, causing deposition upcoast of the structure. Beaches downcoast of the structure no longer receive sand, but longshore currents continue to carry sand away, causing erosion. A structure does not have to be attached to the shoreline to have such an effect. For example, in 1934, a detached breakwater, 600 m in length was constructed parallel to the coast, about 600 m offshore Santa Monica, California. Because the breakwater blocked the wave energy necessary to maintain littoral drift, sediment could no longer be transported and was deposited in the lee of the breakwater. Although no structure was built across the surf zone, longshore sediment transport was interrupted, and erosion occurred downcoast of the breakwater[vii].

Wave power plants could have a similar effect, by absorbing energy from waves before they reach the surf zone. The degree of potential impact depends on the process (floating or fixed structure), how closely individual devices are spaced, and how far offshore the plant is located.

Floating devices have a low potential impact, because any wave energy that is not absorbed will pass through the plant and continue to travel shoreward, where it can power the littoral drift. Furthermore, the undiminished wave energy that passes to either side of the plant will spread by diffraction into the lower-energy area immediately behind the plant.

Wave diffraction behind offshore breakwaters and islands is a well-documented phenomenon and can be readily observed from the air. It occurs as wave energy is transferred laterally along wave crests from a region of large wave height to a region of low wave height. Thus, while a noticeably calmer area might develop immediately in the lee of an offshore wave power plant, the waves would be substantially re-established by diffraction 3 to 4 km shoreward of the plant. The effects at the coast probably would not even be measurable until several plants were deployed.

Caisson-based devices have a higher potential impact, since the caissons will reflect any incident wave energy that is not absorbed, and because they would be sited much closer to shore. A distinct low-energy "shadow zone" could be created behind a row of such devices. Therefore, care must be taken to locate caisson-based wave power plants near the downcoast boundary of a littoral cell rather than near its sediment sources.

Waves and currents have an important effect on the movement of small solid objects, in particular sand, on the sea bed and at the shoreline. This can lead to littoral drift, which results in the erosion of shorelines at some locations and the building up of new shore-fronts at others. Man-made structures have been used in attempts to control this drift, e.g. jetties and groins, which extend across the surf zone reducing the current and thereby protecting important areas, such as tourist beaches, from erosion. Clearly wave energy installations will affect these coastal movements, depending on their type, size and location:

- Floating devices will have a different impact to fixed, near-shore devices because any wave energy in high seas that is not absorbed by the floating device will pass by it and is therefore available to power the littoral drift.
- Caisson-based devices have a higher potential impact than floating devices, since the caissons will reflect any incident wave energy that is not absorbed; and because they would be sited much closer to shore, a distinct, low-energy “shadow zone” could be created behind a row of such devices.
- Wave energy that passes either side of small-scale installations will spread by diffraction into the lower-energy area immediately behind the plant.

In view of these impacts, care should be taken in selecting the location of wave power plants, especially near-shore, caisson devices. We recommend that the effects of large-scale schemes should be model-tested as part of pre-project activities.

5. Atmospheric and Oceanic Emissions

The possible sources of pollution from a wave power plant depend on the particular conversion process. Devices that incorporate a closed-circuit hydraulic system have the potential for a hydraulic fluid spill, whereas devices that use seawater or air as a working fluid are free of this concern. On the other hand, all devices may have to use toxic chemicals to inhibit marine biofouling. Finally, high-frequency noise may be a problem with devices that utilize a Wells turbine. These three potential sources of pollution are discussed below.

The potential impact of hydraulic fluid spills can be mitigated to some extent by using a water-based fluid, which also reduces the on-board fire hazard. In addition, isolation valves that can be reliably controlled from shore would minimize the volume of any spill once a leak is reported by the plant monitoring system.

If fouling control is necessary, than it can be accomplished either by periodic cleaning (requires divers) or the use of antifouling coatings (requires drydocking). If the coating option is selected, then the use of an organotin compound, such as tri-butyl tin (TBT), would almost certainly be considered, since it entails a recoating interval of six to seven years, compared with one or two years for copper-based paints. Reference [viii] presents a complete review of the environmental problems and legal regulations associated with the use of organotin coatings. The typical legal limit for average TBT release rate is 5 micrograms per cm^2 of hull wetted surface area per day. U.S. Navy experience has been that release rates well below this level (on the order of 0.1 micrograms/cm^2/day) are fully effective in preventing hard fouling [ix]. Therefore, even if antifouling coatings are required for a wave energy device, an environmentally acceptable solution to the problem appears to exist.

Flexible reinforced rubber surfaces (e.g., a hose pump, flexible bag, etc) cannot be coated. This is a potential problem of particular importance to the hose pump, since fouling on the interior hose walls would reduce overall conversion efficiency due to increased fluid friction losses. Based on the fouling of OTEC heat exchanger inlet structures and test loops that occurs when seawater pumping stops for any length of time [x], hose interiors would be especially subject to fouling during periods of summer calm. Ocean test experience suggests, however, that even a small amount of hose flexing is adequate to prevent fouling organisms from taking hold.

If hose fouling does become problem, there are commercially available rubber formulations that contain TBT, and these could be used to line the interior (and exterior, if necessary) of the hoses during manufacture. Because the TBT is chemically incorporated into the rubber's structure, its release rates are much lower than the problem-causing TBT paints, yet still effective in preventing fouling [xi]. Again, there appears to be an environmentally acceptable solution to any problem that may arise.

Emissions could occur as a result of bad practice or accidents. For example, schemes that utilize hydraulic systems could spill oil if the hydraulic circuits are breached (but fail safe systems should prevent the oil from reaching the surrounding water and, in some schemes, sea water could be used instead of oil). Spillages and sewage discharge from lay barges or construction vessels are possible. Some schemes might require the use of anti-fouling agents, many of which are toxic to aquatic species. However, environmentally safe options for antifouling coatings exist, while conventional toxic antifouling agents could be employed in a safer manner, such as by being incorporated into a rubber coating applied to affected areas.

6. Visual Appearances and Noise

6.1 Visual Appearance

The visual impact of a wave power plant depends on six factors:

- Offshore distance of the plant
- Elevation of the shoreline observer
- Coastal weather conditions
- Size (waterplane area and freeboard) of the individual devices that make up the plant
- Color contrast between the devices and the sea
- The presence of natural or other artificial structures in the offshore seascape

An observer 6 feet (180 cm) tall, standing at the surf's edge (i.e. at mean sea level) has an offshore horizon of 5.2 km, which can be seen even in light haze (International Visibility Code 6, range of 2-10 km). In the United States, this corresponds quite closely with the three-nautical-mile (5.6 km) geographical limit, which marks the boundary between waters under state control and the Outer Continental Shelf (OCS), which is under federal jurisdiction.

Shoreline and near-shore wave energy schemes can be observed from a large distance, unless obscured by the shoreline topography or atmospheric conditions. Near ship fairways safety requirements will necessitate the use of navigation lights and high contrast colors for the benefit of navigation. In addition, the onshore transmission schemes (transformer stations, overhead lines, etc.) associated with all wave energy schemes will also have a visual impact. Therefore, all but the smallest schemes may prove to be environmentally unacceptable along coastlines with important aesthetic values (e.g. wilderness areas or tourist spots). The UK Isle of Islay device has shown that a single, isolated device in a tourist area can prove a tourist attraction but the reverse is likely to be true with deployment on a larger scale. Offshore schemes will have less visual impact, providing the onshore transmission schemes are buried (which is expensive) or re-routed to avoid such visually important areas.

For shallow water (>20 m) wave energy devices along northern California and in Hawaii, such depths generally lie within 2 km of the shoreline, where a wave energy device might be visible in any weather condition better than thin fog (International Visibility Code 5). On the other hand, along the mid-Atlantic coast of the United States, the 20 m depth contour is typically more than 10 km offshore, where a wave power plant would be obscured by any natural sea haze that might be present.

Floating wave energy devices can be anchored anywhere on the continental shelf; beyond the so-called shelf break, however, the bottom falls off rapidly, and mooring costs become prohibitive. Along continental coastlines, the shelf break generally lies more than 10 km offshore, but off volcanic islands the shelf is much narrower. Thus in Hawaii, a floating wave power plant would be visible from shore, even to an observer standing at sea level, and even if some haze was present.

Floating WEC devices with low freeboard and small waterplane area have low visual impact on the seascape, even for a wave power plant located relatively close to shore. Unless the buoys were painted a highly contrasting color, however, the plant would not immediately draw one's attention. Figure 4 shows an example of a highly contracting colored WEC device and how, even with, the visibility drastically drops with increasing distance.

Figure 4. Example of the Visibility of a Low Freeboard High Color Contrast WEC Device

Because of the high level of fishing activity in offshore shelf waters, floating devices will have to be appropriately marked as a navigation hazard. In addition to lights, sound signals, and radar reflectors, highly contrasting day-markers will be required. The U.S. Coast Guard specifies that such markers be in the form of a diamond-shaped sign, 3 feet by 3 feet (0.9 m on a side), with black lettering on a white background and an orange reflective border. While such a sign meets the requirement of being visible within one nautical mile (1.8 km), it would be below the perceptual threshold of most observers beyond a distance of 4 nautical miles (7.4 km). Therefore, navigation markers on offshore wave power plants are expected to have negligible visual impact when viewed from shore.

Regarding visual impact, wave power projects are much less likely to raise “not in my back ocean” (NIMBO) concerns than offshore wind projects

6.2 Noise

The Wells turbines of onshore and near-shore OWCs can emit uncomfortable levels of noise (in effect, they can act as a siren). Experience has shown that this can be reduced to acceptable levels (or possibly eliminated altogether) by careful design and/or acoustic muffling.

Airborne noise from Wells turbines used in oscillating water column (OWC) devices has been reported from a variety of different prototype installations. The most complete report comes from a 150 kWe, caisson-based OWC prototype that is now operating near Trivandrum, on the southwest coast of India [xii]. In the caisson itself, the noise is too loud for normal conversation. Measurements indicate a sound intensity of 70 to 90 decibels (db) at the seaward end of the breakwater, where the caisson is located. On shore, 650 m from the caisson, the measured intensity is less than 60 db. The sound in the nearby villages has been likened to that of a small single-engine airplane flying overhead.

Even if airborne turbine noise is muffled by a silencer, the sound may also carry into the surrounding water, potentially interfering with military acoustic tracking operations. Underwater noise would also be generated by hydraulic machinery.. It should be noted, however, that noise from wave power plant machinery will generally increase in proportion to the ambient background noise associated with surface wave conditions, thus tending to minimize its noticeable effect.

7. Conflicts with Other Uses of Sea Space

All such potential conflicts are site specific, and to a lesser extent, process-specific, depending on a device's conversion efficiency and its clearance requirements relative to adjacent devices, both of which combine to determine the amount of sea space occupied by a wave power plant of given capacity. Most problems can be avoided by early consultation with those involved in any foreseeable conflict.

From an economic standpoint, the most important uses of near shore and shelf waters where a wave power plant might be deployed are offshore fossil-fuel production and commercial fishing (including kelp harvesting). The revenues associated with coastal recreation and tourism are also significant; although visual intrusion is the most obvious conflict, sport fishing and recreational boating might also be adversely affected by large-scale wave power development. Use of coastal sea space by commercial shipping traffic and for military exercises or scientific research represents other potential sources of conflict. Finally, the designation of certain ocean areas as marine sanctuaries may preclude wave power development within their boundaries.

In addition to the major activities described above, coastal sea space is also used by submarine communications cables, municipal wastewater outfalls, and designated dump sites. These are so highly localized and few in number that they are not expected to significantly limit wave energy's development potential. Nevertheless, when actually siting a wave power plant, these should be identified early enough so that they can be avoided.

7.1. Fishing

Wave energy schemes take up an area of the sea that would then be excluded from other uses such as fishing. This area would comprise not only the plan area of the devices and their foundations and moorings but also a safety “exclusion” zone around the devices (for fire-and-explosion dangers offshore, such as oil and gas platforms, this is typically 500 m). In addition, there would be areas of the sea bed adjacent to any sub-sea transmission cables that might also be off limits to commercial fishing because of the possibility of damage to cables by bottom fishing gear (although cables in trenches with sufficient protective cover would be safe from such disturbance). However, areas in which fishing is restricted may be beneficial to the fishing industry since there has been increasing interest recently in marine protected areas, i.e. areas closed to commercial fishing for the purpose of conservation management to enhance fisheries (Shackell & Willison 1995).

It is possible that wave energy schemes would be excluded from important fishing areas but this should still leave sufficient coastal regions available to exploit wave energy resources. In practice, the sub-sea parts of wave energy schemes might provide a beneficial refuge for fish (fishing is often better over sunken wrecks) as well as new fish habitat, thereby increasing the abundance of fish in the vicinity (refer to 6.1.2 , above). Overall, wave energy development is not expected to have significant adverse effect on

fishing if sensitive areas are avoided. Nevertheless, discussions with fishermen and other concerned parties should form part of the consultative process prior to the implementation of any wave energy scheme
Early dialogue with fishing communities will identify heavily-fished areas and enable mutually satisfactory siting solutions

7.2. Navigation and Marine Traffic

In general, most wave power plant schemes will, to a varying degree, constitute obstacles to coastal marine traffic. The planners of such schemes should, therefore, take this concern into consideration when the specific location is being decided, especially when it is in the vicinity of shipping lanes, harbor entrances, at pilot stations, and in coastal waters where the sea traffic is frequent. The imposition of safety zones, as well as the use of navigation lights and radar reflectors, will minimize the risk of collision. However, there could be problems with designs that have a small freeboard, such as the Hosepump, and consideration will have to be given to the prevention of collisions with such schemes. The adequacy of moorings should be a prerequisite to obtaining the necessary insurance to deploy floating schemes since if such a device broke away from its moorings it would constitute a major hazard to shipping

7.3 Impacts on Recreation and Tourism

The most important potential influence of wave energy on recreation and tourism is due to visual impact (see Section 6.), which is likely to prove an important obstacle to large-scale deployment of wave energy schemes in areas of tourism or aesthetic importance. This aside, the impact of such schemes on recreation will be location and site specific. The sheltered waters behind wave energy devices could prove attractive to some sports such as scuba diving, canoeing and paddling, whilst on the other hand reducing the size of areas suitable for wind surfing and some types of sailing. Again, prior discussions with interested parties should be undertaken to assess the importance of such considerations

7.4 Other Potential Areas of Sea Space Conflicts

Other potential areas for conflict over sea space include:

- National Marine Sanctuaries (Dept. of Commerce – NOAA)
- National Seashores, National Wildlife Refuges (Dept. of Interior)
- Scientific research reserves (typically state-designated)
- Military warning areas
- Telecommunications cable routes
- Dredge spoil disposal sites

8. Installation and Decommissions

Wave power plant installation issues that must be addressed include routing and shore crossing of submarine power cables. Cable installation activities are likely to occur during the calm summer months, and on the West Coast, this would avoid the peak grey whale migration months of March –May and November – December. Installation concerns include:

- Fabrication yard compliance with appropriate industry regulations
- Underwater routing of submarine power cables and shore crossing
- West Coast installation activities to avoid peak gray whale migration months of March-May and November-December

Decommissioning issues include the disposition of fixed structures on the sea floor, the gradual removal of floating platforms in stages (e.g., if there is evidence of use as haul-out space by seals and sea lions or colonization by seabirds). Decommissioning concerns include:

- Disposition of fixed structures on seafloor (removal likely to cause more damage than leaving in place)
- Disposition of floating structures (minimal duration of temporary storage on shore; removal of working fluids and mechanical and electrical plant in compliance with appropriate industry regulations; proper cleanup of structural elements if to be used in creating artificial reef)
- Gradual removal of low-freeboard devices in stages if evidence of heavy use as haul-out space by seals and sea lions

9. Environmental Benefits

Wave energy can have a number of other benefits in both the environmental and social areas. For example, in remote coastal areas, including small islands, it can help reduce the reliance on auxiliary (diesel) power stations. In addition to the resultant reduction of the emission of combustion gases to the atmosphere, the transport of the fuel to the site, often by water, is largely eliminated, which in turn reduces the environmental risks associated with this means of transportation. Currently, many remote coastal areas receive their electricity via overhead transmission lines, which are often perceived to have adverse visual impacts. Again, such impacts would be reduced by having separate wave power installations serving individual coastal communities.

10. The First U.S. Wave Energy Project Environmental Assessment

The first U.S. Wave Energy Project Environmental Assessment (EA) evaluated the potential environmental impacts of a proposed phased installation and operational testing of up to six Wave Energy Conversion (WEC) buoys over a two year time period off North Beach at Marine Corps Base Hawaii (MCBH) Kaneohe Bay (the Proposed Action). The EA was prepared in accordance with the National Environmental Policy Act of 1969 (NEPA), 42 USC §4321 et seq.; regulations promulgated by the Council on Environmental Quality (CEQ) (40 CFR §§1500-1508); Chief of Naval Operations Instruction (OPNAVINST 5090.1B CH-2); and U.S. Marine Corps Order (MCO P5090.2A).

The affected resources or issues analyzed in detail include: shoreline physiography, oceanographic conditions, marine and terrestrial biological resources, land and marine resource use compatibility, cultural resources, infrastructure, recreation, public safety, and visual resources. The findings for are summarized below

Shoreline Conditions**.** Minimal impacts would occur to shoreline conditions at North Beach, MCBH Kaneohe Bay and the Pearl Harbor site due to the proposed installation. The WEC system would not alter currents or wave directions, and there would be no effects on shoreline erosion or change in sand deposition patterns. At the end of the test period, land equipment would be removed.

Oceanographic Conditions**.** No impacts on oceanographic conditions are expected. Implementing the WET test would not affect wave scattering and energy absorption.

Marine Biological Resources**.** Minor impacts would occur to marine biological resources along the cable route and buoy array site at North Beach, MCBH Kaneohe Bay, and the Pearl Harbor site. Installation of the WEC system at the two sites would avoid areas of rich biological diversity and high percentages of coral coverage. No Habitat Areas of Particular Concern (HAPC) have been identified or designated at either site. Marine species listed under the Endangered Species Act as threatened or endangered and that are known to occur at North Beach include the green sea turtle, hawksbill turtle, Hawaiian monk seal, and humpback whale. The U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) concur with the Navy that the Proposed Action is not likely to adversely affect threatened and endangered species under their jurisdictions. The taking of marine mammals protected under the Marine Mammal Protection Act (MMPA) is unlikely during the installation and operation of the WEC system. The potential growth of benthic organisms such as corals on the WEC cable and anchor during the test period would be a beneficial impact.

Entanglemen**t.** Entanglement would be a minimal concern, as installation would occur in shallow water with adequate tension to allow the cable to resist forming loops and contour to the seafloor. Divers would inspect the cable route once it is in place. There would be no risk of entanglement once the cable is rock-bolted to the seafloor. Mooring lines and anchor chains for the four mooring clumps would be pulled taut during installation, minimizing risks of entanglement.

***Entrapment*.** There is minimal potential for entrapment of marine mammals or sea turtles within the buoy since the interior of the structure is free of obstructions, sharp edges, or corners. The size of the opening in the bottom of the WEC buoy provides a ready egress path. As part of the Navy's systems monitoring plan, the system will be examined for entrapment of marine species.

***EMR*.** The small scale and limited area of disturbance indicate that impacts from EMR on marine organisms would be minor and temporary. Impacts of EMR on marine organisms can be expected to range from no impact to avoidance (for bottom-dwelling organisms only) of the vicinity of the WEC cable.

***Electrical Leakage*.** In the unlikely event that damage to the cable causes an electrical fault or short, transient effects on marine organisms and divers (mild discomfort) could occur. Electroreceptive species would likely detect the field and be diverted away from the vicinity of the fault during the short period that the ground fault system actuates.

***Heat Release*.** There would be no impacts to marine life from potential heat release.

Noise. Installation noise produced by drilling holes for rock bolts would be localized, intermittent, and of short duration. Operation of the WEC system is expected to produce continuous acoustic output similar to that of ship traffic. It is unlikely that noise from system installation or operation would have adverse effects on humpback whales, dolphins, and green sea turtles.

***Terrestrial Biological Resources*.** No Federally listed threatened or endangered terrestrial species occur at the North Beach, MCBH Kaneohe Bay, and Pearl Harbor sites. The land cable routes would traverse environmentally non-sensitive areas, and existing structures would be used as equipment shelters.

***Land and Marine Resource Use Compatibility*.** Land use incompatibilities are not anticipated at North Beach, MCBH Kaneohe Bay, and the Pearl Harbor site where sitting on military property minimizes security risks. At Pearl Harbor, the offshore component of the project is located within restricted waters. At MCBH Kaneohe Bay, incompatible marine resource uses where the buoy array would be installed include limited subsistence fishing, commercial fishing, and recreational boating and fishing. The proposed WET test project would not interfere with mission operations at MCBH Kaneohe Bay site.

***Cultural Resources*.** Although the land based segment of the WEC system would be sited within the Mokapu Burial Area, the State Historic Preservation Officer (SHPO) concurred with the Navy that the project would have no effect on historic properties.

Infrastructure. There would be no adverse impacts to existing infrastructure resulting from the installation and operation of the WEC system at North Beach, MCBH Kaneohe Bay, site.

***Recreation*.** At MCBH Kaneohe Bay, there would be no impacts on recreation within the 500- yd (457-m) buffer zone. There would be impacts to recreational activities presently conducted outside the 500-yd (457-m) buffer zone in the vicinity of the buoy array for the two- to five-year duration of the WET test, but these impacts would not be significant. At the Pearl Harbor site, there would be no impacts to recreation because the area is off-limits to public access and recreational activities.

***Public Safety*.** At MCBH Kaneohe Bay, there would be no impacts on public safety within the 500-yd (457-m) buffer zone. There would be potential impacts to public safety outside the 500- yd (457-m) buffer zone due to the presence of the buoy array over the two- to five-year duration of the WET test. The potential hazards will be mitigated by providing appropriate markings on the buoys, implementing a plan to respond to system failures, and implementing communication procedures to increase public awareness of the WET system.

***Visual Resources*.** Impacts on scenic views would be minimal at both North Beach, MCBH Kaneohe Bay, and the Pearl Harbor site. Navigational aids from the buoys would extend approximately 30 ft (9 m) above sea level. At night, safety lights on the navigational aids would be visible in the distance.

Cumulative Impacts. No cumulative impacts are anticipated at the North Beach, MCBH Kaneohe Bay site.

Based on information gathered during the preparation of the EA, the Navy found that the proposed installation and operational testing of up to six WEC buoys at MCBH Kaneohe Bay Oahu Hawaii will not significantly impact human health or the environment and that there will be no cumulative effects from the proposed project.

11. Conclusions and Recommendation

We conclude that, given proper care in site planning and early dialogue with local stakeholders, offshore wave power promises to be one of the most environmentally benign electrical generation technologies. We recommend that early demonstration and commercial offshore wave power plants include rigorous monitoring of the environmental effects of the plant and similarly rigorous monitoring of a nearby undeveloped site in its natural state (before and after controlled impact studies).

Like all energy producing technologies, wave energy has the potential to produce unacceptable environmental impacts. However, as shown above, prior evaluation (e.g. environmental impact assessment), careful selection of the place and time of deployment and prior consultation with interested parties should minimize any environmental impact. Such considerations could (in time) form the basis of "best practice" in deployment of wave energy schemes. For the present, a checklist (Table 2.06.3) of the most important areas to be considered has been drawn up by Hideo Kondo (1998), which is to be completed according to the following categories: (a) may improve; (b) small damage; (c) partial damage; and (d) heavy damage

Concerns covered here remain to be studied in detail, and any demonstration project and first commercial plant (tens to hundreds of devices) must be subject to Before and After Controlled Impact (BACI) studies

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