Aotearoa Wave and Tidal Energy Association (AWATEA)

Environmental Impacts of Marine Energy Converters

Prepared by AWATEA for the

ENERGY EFFICIENCY AND CONSERVATION AUTHORITY

By

POWER PROJECTS Limited

in association with the

NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH

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Executive Summary

The first marine energy converter was installed in New Zealand waters in late 2006 and consent applications have since been lodged for larger projects in Cook Strait and the Kaipara Harbour. Not all types of marine energy converters will be appropriate in New Zealand. Some may be unsuitable, *e.g.,* barrages or impoundments, but wave and tidal stream devices seem likely to be deployed. Both technologies are maturing rapidly: the world's first commercial tidal stream demonstrator and the first commercial wave farm both became operational in mid-2008. Most project developers have indicated rapid geographic dispersal of their projects, so New Zealand can expect rapid deployment of marine energy technologies in its coastal marine area, once technologies become commercially available and competitive.

It is prudent, therefore, to review the likely environmental effects – physical and biological – of the range of potential wave and tidal stream devices, which may be deployed here. This report is a forecast of the potential environmental effects combined with evidence from overseas device deployments. Most wave and tidal stream devices will be located in high-energy environments and some will float in the water column, so their effects are likely to be impermanent and geographically isolated. Most devices will have almost completely reversible effects with the high-energy waves and tidal currents restoring the environment to its original state. During their operational life times devices or arrays of devices will compete for space with other uses, such as navigation and fishing. Exclusion zones may be required to avoid collisions or entanglements with passing vessels. Long-term or permanent effects may be restricted to anchor points drilled into the seabed.

International experience to date has indicated that marine energy converters may have little effect on their environment and, indeed, may be little affected themselves. The longest continuous device deployment, the SeaFlow tidal turbine in Lynmouth, Devon, has suffered virtually no corrosion or bio-fouling since being deployed in mid-2003.

Physical effects that have been identified include the installation of fixed structures, visual and noise impacts, hydrodynamic changes, potential chemical effects and, obviously, the extraction of energy. The scale and nature of effects will change during the project cycle. Environmental impacts on biota include habitat modification, collision threat, noise and electromagnetic fields. Other structures, such as breakwaters, navigation buoys and fish farms have been installed in New Zealand coastal waters without problem or are being developed with adaptive management processes. Similarly, establishment of marine energy 'farms' may become commonplace.

Extensive environmental monitoring has been undertaken at a number of international projects and interactions with fish and diving birds is limited. Nonetheless a programme of baseline measurement, operational monitoring and implementation of mitigation measures through adaptive management will be required for domestic projects. Effects on animal species may vary from overseas experience and early deployments in New Zealand will contribute to international knowledge and understanding of the effects of marine energy converters.

This report provides an early-stage review of likely effects of marine energy converters to inform project developers, territorial authorities and interested parties. Deployments will be required tomeasure effects and develop risk mitigation strategies. Eventually, comprehensive risk management experience will develop through active management of new deployments.

PART 1: ENVIRONMENTAL IMPACTS OF MARINE ENERGY CONVERTERS

1.1 INTRODUCTION AND PURPOSE OF STUDY

The Energy Efficiency and Conservation Authority (EECA) is seeking advice on the potential environmental impacts of marine energy converters (MECs), which may be deployed in New Zealand waters in coming years. Marine energy converters are defined as all forms of marine energy conversion devices, which are described in Part 2 of this report.

The overall purpose of this report is to provide an overview of three areas:

1. The range of marine energy converters under development and particularly those likely to be deployed in New Zealand waters
2. The likely physical environmental impacts of marine energy converter deployments
3. Likely environmental impacts on the biota of marine energy converter arrays.

The domestic marine energy sector is a very dynamic one. Since April 2008, five key events relating to marine energy have occurred in New Zealand:

10 April 2008	The first resource consent for a tidal stream prototype project was granted
26-30 May 2008	Consent hearings for resource consents for a utility-scale tidal stream project were held
29 May 2008	The first award under the Marine Energy Deployment Fund (MEDF) was made
5 June 2008	The first wave device prototype was deployed in Wellington Harbour
24 July 2008	The second round of funding under the MEDF commenced

Given that devices are being deployed and consents for prototype and utility-scale projects are awarded or are going through the consenting process, it is timely to review the likely environmental effects of marine energy converters. No study of this kind has been undertaken in New Zealand before but there is a wealth of information being generated by overseas MEC deployments and consent approvals.

1.2 LAYOUT OF THE REPORT

This report is laid out in three parts. Following this introduction, the contents of the following parts are as follows:

Part 2 The range of energy sources in the marine environment and their potential products of harnessing these sources are described. Emphasis is placed on the most likely devices to be deployed in New Zealand waters. The section ends with a review of the effects of arrays of devices and of current projects publicly announced here in New Zealand.

Part 3 The general physical effects of the deployment of marine energy converters are described. Progressive changes of potential impacts can be attributed to successive development stages from pre-deployment monitoring to decommissioning.

Part 4 This part deals specifically with potential impacts on marine biota.

1.2.1 Background to the Report

The Aotearoa Wave and Tidal Energy Association (AWATEA) was commissioned by the Energy Efficiency and Conservation Authority (EECA) to prepare this report, which was written and compiled by Dr. John Huckerby of Power Projects Limited. The National Institute of Water and Atmospheric Research (NIWA) was sub-contracted to draft the section on effects of marine energy converters on the biota (Part 4).

This report draws heavily on two reports:

Development of Marine Energy in New Zealand

(Power Projects Limited, June 2008)

and

Environmental impacts of marine energy devices

(NIWA report AWA09401, October 2008)

This report incorporates relevant detail from these two reports and summarizes the current environmental issues faced by developers and stakeholders in deploying marine energy converters in New Zealand waters.

1.2.2 Acknowledgements

AWATEA would like to acknowledge the Energy Efficiency and Conservation Authority for commissioning this report and Power Projects Limited for writing it. Trevor Willis, Leigh Torres and Sean Handley of NIWA in Nelson are thanked for their report and their contribution to Part 4 of this report.

Declaration of Interest

Power Projects Limited is a co-founder and current participant in the Wave Energy Technology – New Zealand (WET-NZ) R & D programme. This is a consortium R & D programme with Industrial Research Limited (IRL) and the National Institute of Water and Atmospheric Research Limited (NIWA). Between 2004 and 2008 the consortium developed a point absorber device, which has been deployed in Pegasus Bay off Christchurch and, more recently, Evans Bay in Wellington harbour. The project has just received additional funding for a further six years.

PART 2: MARINE ENERGY TECHNOLOGIES

2.1 MARINE ENERGY SOURCES

There are a number of different potential ways of extracting energy from the oceans. None has yet achieved the status of commercial viability internationally, although most have been under consideration and development since the oil price shocks of the 1970s. Not all of these potential energy sources will have application in New Zealand, because resource and environmental issues will have an impact.

There are seven principal marine sources, from which energy could be extracted. Internationally, all of these sources are currently being investigated to differing degrees but technologies – at various stages – are being developed to harness them (Table 2.1). By far the biggest international investments are going into developing conversion technologies for wave and tidal stream energy, although planning pressure is driving increasing consideration of offshore wind in North European Atlantic coast settings.

Energy Source	Conversion Technology	Products
Waves		Electricity Hydrogen Bio-fuels Heat Potable water (& Combinations of above)
Open ocean swells	Point absorbers; attenuators	
Breaking waves	Oscillating water columns (OWCs); overtopping devices	
Tides		
Tidal rise and fall	Barrages; impoundments	
Tidal/ocean currents	Turbines; reciprocating devices	
Heat	Ocean Thermal Energy Conversion; geothermal energy	
Osmotic power	Reverse osmosis	
Marine biomass	Farming and harvesting	
Offshore winds	Offshore wind turbines	

Table 2.1: Marine Energy Sources and Products

2.1.1 Wave Energy

Wave energy can be separated into two potential extractable sources: open ocean swells and breaking waves. Open-ocean swells result from the aggregated effects of wind currents blowing across the surface of the ocean, particularly in major storms. Swells result from the constructive interference of waves resolving into larger waves with bigger amplitudes (*i.e.,* wave height) and longer wavelengths (*i.e.,* longer periods between wave peaks). Breaking waves result from the incidence of these ocean swells on the seabed, as waves approach the coast.

Devices, which extract energy from waves, are called '*oscillating water column'* devices (OWCs) or '*overtopping*' devices (see Sections 2.2.3 and 2.2.4). Both are sometimes lumped together as '*termina*tor' devices. Devices, which extract energy from open ocean swells, are classified as either '*attenuator*' devices or '*point absorber*' devices (see Sections 2.2.6 and 2.2.7).

2.1.2 Tidal Energy

Like wave energy, tidal energy can be split into two basic forms: tidal rise and fall and the resultant tidal stream or ocean currents arising from that rise and fall and modifications by weather conditions. Tidal rise and fall is controlled by the relative position and gravitational attraction of the moon and, to a lesser extent, the sun on the world's oceans. The tides follow a diurnal cycle slightly longer than a normal day, and a seasonal cycle, which gives rise to neep and spring tides. Tidal currents arise to accommodate the diurnal rise and fall, although local weather effects and local seabed topography can modify them. Whilst the astronomical control on tidal rise and fall enables an extended forecast of high and low tides, this certainty does not extend to tidal stream currents because of the weather effects. For example there are diurnal tidal effects in Cook Strait, which can be forecast, *i.e.,* tide tables. However, resultant currents can be severely affected by local weather conditions to the extent that, in severe storm conditions, the tide does not '*turn*', as would be expected (Stevens *et al.,* 2006).

Conversion technologies, which can harness electricity from tidal rise and fall and from tidal currents, are quite different. There are two basic tidal rise and fall technologies, although their conceptual operation is similar. These are tidal barrages and tidal impoundments. Tidal barrages are essentially barriers across rivers, estuaries or bays, which disrupt the normal tidal rise and fall, holding back the rising or falling water such that water level on one side of the barrier or impoundment is out of synchronization with the water level on the other side. As the point of maximum difference is reached the barrage or impoundment mechanism is opened, allowing flow across it. The flowing water is used to generate electricity and can be utilized on both the ebb and the flood tide.

Tidal barrages are an ancient technology. There is evidence of small tidal barrages being used to generate rotary motion for corn grinding in post-Roman times and the oldest tidal-powered corn mill (Eling Mill near Southampton) has been continuously operational since the 9^{th} Century.

The only modern era marine energy device of any scale is the Rance River barrage on the estuary of that river near St. Malo in northern France. This barrage became operational in 1967 and has a generation capacity of 240 MW. Originally it only operated on the ebb tide but was converted to both ebb- and flood tide operation in 1997. There are two other smaller working examples at Annapolis Royal (20 MW) in Nova Scotia and Kislaya (0.4 MW), near Murmansk, Russia.

2.1.3 Geothermal Heat (Ocean Thermal Energy Conversion)

The Tonga-Kermadec Arc contains active submarine volcanism extending from the Bay of Plenty coast northwards to the end of New Zealand's Exclusive Economic Zone. Apart from White Island, active submarine vents are interspersed with hydrothermal vents ('black smokers'), which may be debouching sulphide minerals and precious metals, as well as abnormally hot geothermal fluids (>300 ºC). Proposals to investigate energy generation from these fluids, using heat exchange technologies, are under discussion.

The thermal energy of ambient temperature ocean water can be converted into electrical energy by a process called ocean thermal energy conversion (OTEC). OTEC is based upon heat exchange between deep ocean water (~2 ºC), pumped to the surface, and warm shallow or surface water (~20 ºC). The process requires a significant heat difference between these two sources of water. Such differences occur in tropical latitudes either side of the Equator, somewhat distorted by major ocean currents such as the Gulf Stream. However, outside the Tropics the temperature difference is too small to enable sufficient electricity to be produced economically from the heat exchange process.

OTEC projects have been trialled in Hawaii and a 30 kW device OTEC plant is being tested in Japan. Mexico is considering the installation of some large-scale OTEC plants to produce both electricity and potable water. Ambient temperature OTEC installations are unlikely to be economic in New Zealand but harnessing the hydrothermal vents has real potential.

2.1.4 Osmotic Power

Energy can be extracted from ocean water through the salinity difference (or gradient) between salty seawater and freshwater. Statkraft, the Norwegian electricity transmission grid operator and utility, has recently embarked on a research project to build the world's first osmotic power device (Statkraft, 2006). The prototype develops only 35 kW, so commercial development of osmotic power is probably a considerable time from commercial development. Osmotic power may be a commercial prospect for New Zealand in future.

2.1.5 Marine Biomass

Early interest in marine biomass was demonstrated in the 1970s by proposals to '*farm*' kelp on the Pacific coast and to harvest and process it to produce oil. The concept was researched but no trials were conducted and commercial development did not proceed. Since then other marine biomass projects have been or are now under consideration, including the harvesting and processing of marine algae to produce bio-fuels. Such projects could be attractive to New Zealand because of its very large Exclusive Economic Zone (potentially the 4th largest in the world).

Marine biomass would provide a fuel, most likely restricted to transport applications. It is unlikely that it would be economic to produce the bio-fuel, only to further convert it to electricity for wider uses.

2.1.6 Offshore Winds

In European Atlantic and North Sea coast countries, offshore wind farms have been developed since 1991 (Vindeby, Denmark) and the United Kingdom (Blyth Harbour, 2003). Currently the largest offshore wind farm is Horns Rev off the north coast of Denmark (80 x 2 MW Vestas V-80 turbines), although a 341-turbine array, called the London Array, is under construction in the North Sea, roughly 70 km ENE of London. The London Array will eventually have the same capacity as the Huntly Power station, *i.e.,* 1,000 MW. However, a slightly larger project has already been proposed off the North Devon coast. If built, the Atlantic Array will have 350 turbines with a generation capacity of 1,500 MW (providing power to over 1 million homes).

Most offshore wind projects are based upon effectively adapting onshore wind turbine generators for offshore use and developments are limited to shallow water applications. The drivers for offshore applications are better wind resources (smoother flows with less damaging turbulence), decreasing onshore space for projects and, perhaps most importantly, reduced difficulty in planning consents caused by local opposition.

New Zealand has not yet reached the capacity of its onshore wind opportunities – as indicated by the nearly 4,000 MW of onshore wind projects that have been built (322 MW by end-2007) or proposed to date. However, opposition to onshore wind farms has grown and consenting is becoming more difficult and costly. Unfortunately, New Zealand's coastline does not shelve like the North Sea coast and any future offshore wind projects in New Zealand may have to be close to shore, somewhat negating the benefits of offshore sites. It is worth noting, however, R & D is under way on floating wind turbine generators, which, if successful, would free New Zealand developers to locate their arrays further offshore (Economist Technology Quarterly, 7 June 2008).

2.1.7 Products of Marine Energy

A range of potential products can be produced using marine energy generation, including electricity, hydrogen (by on-site electrolysis), heat, bio-fuels (of various types) and potable water (Table 2.1). The vast majority of devices are being designed with electricity as the intended end product. Some devices, such as the Australian CETO will deliver both electricity and potable water, whilst Oceanlinx is intending to build both electricity-producing and water-producing designs, following its successful prototype deployment at Port Kembla, south of Sydney.

2.2 WAVE ENERGY DEVICES

2.2.1 Classification

Although fewer than tidal stream devices, an impressive number of wave energy design concepts is currently under development. The European Marine Energy Centre currently lists 51 wave energy device developments (EMEC, 2008). Even this number is probably an under-estimate, as the authors of this report are aware of devices not listed in the compilation. Despite the number of wave energy devices that have been proposed, there is no commonly agreed standard classification. The classification listed below breaks devices down on three criteria:

1. Environmental location of the device,
2. Intended operational water depth, and
3. Physical construction or energy extraction methodology (Table 2.2).

Location	Water Depth (m)	Classification	Manufacturer	Device
Onshore	0	Oscillating Water Column		PICO plant, Azores
		Overtopping		Tapchan, Norway
Nearshore	1 - ~25	Oscillating Water Column	Oceanlinx	Oceanlinx
		Surge devices	Aquamarine	Oyster
		Overtopping/ terminator	Wavedragon	Wavedragon
Offshore	~25+	Attenuator	Pelamis WavePower	Pelamis
		Attenuator	C-Wave	C-Wave
		Attenuator	Raft designs	Martifer
		Point Absorber	Ocean Power Technologies	PowerBuoy
		Point Absorber	AWS II	AWS II
		Point Absorber	Finavera Renewables	AquaBuOY
		Point Absorber	Wavebob	Wavebob
		Point Absorber	Carnegie Corp.	CETO II
		Point Absorber	WET-NZ	“WaveWobbler”

Table 2.2: Simplified Classification of Wave Energy Converters

Other classifications are possible. For instance, oscillating water column and overtopping devices are sometimes called '*terminator*' devices, because they resist the waves to absorb energy, whilst attenuator and point absorber devices can be classified as '*compliant'* devices.

Note that the listing of devices in the previous table indicates that the devices are in active development. It is clearly not an exhaustive listing, nor is it intended that they devices listed are representative, other than of their generic classes.

2.2.2 Energy Distribution in Waves

Energy in waves takes two forms: potential energy and kinetic energy. Kinetic energy is the physical energy created by the position of the water mass, relative to the energy collector. Potential energy is due to gravity and its extraction involves the movement of the water from a higher to a lower potential energy position, usually converting the potential into mechanical energy in the process. The most obvious form of potential energy is the extraction of energy from the rising and falling of passing waves (Figure 2.1).

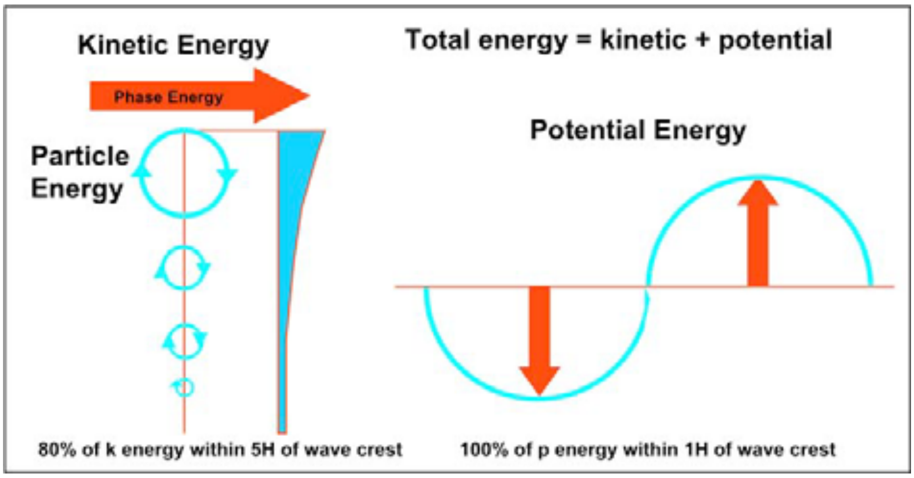

Figure 2.1: Energy Distribution in Waves

Kinetic energy is the energy produced by movement. Although waves appear to have a linear unidirectional movement, the particle motion in waves is approximately circular – the waves are notionally rotating cylinders moving to the shore. This circular motion is the reason why breaking waves at the beach appear to push and pull, as much as lift and drop, swimmers in the surf. Extraction of kinetic wave energy is achieved by using devices, such as turbines, which partially – but not completely – resist the circular wave motion. Surfers hitting the perfect wave are extracting both kinetic and potential energy on their graceful journeys to the beach.

The energy contained in waves can be resolved into three motion vectors:

1. Heave – the vertical component of motion
2. Surge – the horizontal component of motion
3. Pitch – the rotational component of motion

Wave energy converter designs are based upon extracting energy from one or more of these components of motion. Some devices are designed to extract energy from one particular vector, *e.g.,* heave or surge, whilst others seek to extract energy from a combination of these vectors.

Wave/swell environments are extremely complex, since a sea state is composed of local and immediate wind-sea interactions, old-wind seas generated some hours ago and long period swells from distant storms of several days. All of these may arrive from different directions and lead to very complex sea-states. Extracting energy from this complex sea-state, incident on a wave energy converter, is thus a complex problem.

In the following sections, devices are described in their respective environmental position, *i.e.,* relative to the coastline: onshore – nearshore – offshore.

2.2.3 Oscillating Water Column Devices

The structure of an oscillating water column device (OWC) is a fixed volume chamber, open below the water surface but closed above, except for a single outlet. The chamber is located either on the beach (or cliff) or nearshore, where waves are breaking. The basic operational principle is that the breaking wave causes a rise of water level within the chamber, which compresses the air above the water surface and forces it out of the single outlet and, in so doing, turns a turbine. As the wave recedes, the water level in the chamber drops and air is sucked back into the chamber. With the right configuration the turbine will continue to rotate. Energy is thus extracted from both rising and falling waves.

The first OWC device was the Pico Plant in the Azores, which was first commissioned in 1973. It suffered frequent operational problems and was abandoned during the 1990s. The plant has been significantly refurbished since 2000, although operation is still discontinuous (Neumann *et al.,* 2007).

Two other devices, Wavegen's LIMPET device and Australian Oceanlinx device (formerly Energetech) are both OWC devices, which have been discontinuously operational since 2000. The key differences between the devices are that firstly, Wavegen's LIMPET is coast-attached (Figure 2.2), whilst the Oceanlinx device is nearshore (Figure 2.3).

Figure 2.2: The LIMPET OWC Device on Islay, West Coast of Scotland

Secondly, LIMPET uses a fixed blade turbine, called a Wells Turbine, which rotates in the same direction, regardless of the direction of the air current, whilst the Oceanlinx turbine establishes the unidirectional turbine rotation by rapidly variable pitch blades, which change direction as the air direction changes.

Figure 2.3: Oceanlinx Prototype under Test at Port Kembla, NSW, Australia

2.2.4 Overtopping Devices

Overtopping devices are relatively simple devices, based upon a low-head hydro design. Water from advancing waves is captured in a reservoir slightly above sea level, held and returned to the sea through conventional low-head hydro turbines, which generate power.

The earliest overtopping device was a tapered channel (Tapchan) excavated into cliffs in Norway. Breaking waves accelerated up the tapered channel and slopped over into a lower reservoir before being fed back to the sea. More recently, a couple of nearshore, bottom-sitting Danish devices, called WavePlane and Wave Dragon, have been proposed and are under development. Wave Dragon has had a measure of success and full-scale deployments are planned (Figure 2.4).

Figure 2.4: ~1/4-scale Wave Dragon in Nissum Bredning, Denmark

2.2.5 Surge Devices

Surge devices generally sit on the seabed in a nearshore setting and extract energy from the surging of passing waves (surge is the horizontal component of the wave motion). Surge devices consist of a base, which sits or is anchored to the shallow seabed, to which is attached by a hinge mechanism an arm or a baffle, which pivots in response to the surging movement of passing waves. There are at least three such devices under development, including Oyster (Figure 2.5), WaveRoller and BioWave. Development of a fourth surge device, EB Frond, is currently on hold.

Figure 2.5: Aquamarine's Oyster Surge Device Design

A variant of this surging design is a pressure-sensitive device, which reacts to pressure changes of passing waves, rather than kinetic movement. The prototype design of the CETO device was a pressure-sensitive design but this device has been redeveloped as a more conventional point absorber design (Section 2.2.7).

2.2.6 Attenuator Devices

An attenuator device is essentially a floating device, which works in parallel to the wave movement direction and effectively rides the crests and troughs of swell waves. Movement along the length of the device can be controlled to produce energy. They are probably the most common device design. Because the devices have to span the wavelength (*i.e.,* the distance between two swell crests), they are usually very large (Figure 2.6).

Since the cross-sectional area of the device orthogonal to the swell crests is relatively small, the device experiences lower forces than a terminator device (such as an OWC or overtopping device). Attenuator devices can look markedly different but their basic principle of energy extraction is the same. The most well known attenuator device is Pelamis, the P750 prototype version of which is shown in the figure below. Three of these devices have been sold to a Portuguese utility, Enersis, and are in the process of being deployed at a site of the Portuguese coast, called Aguçadoura. The deployment was due in 2006 but has been delayed due to problems, reportedly with the device mooring system. Pelamis Wave Power is also constructing devices for Scottish Power Renewables for a deployment of 4 x 750 kW devices at the European Marine Energy Centre (the Orcadian Wave Farm) and a further deployment of up to 7 x 750 kW devices at the proposed Wave Hub facility in Cornwall (the West Wave project).

Figure 2.6: The Pelamis P750 Prototype in Leith, Edinburgh (workers show scale)

There are also a number of different floating '*raft*' designs undergoing testing, *e.g.,* the Portuguese Martifer raft. However, development of raft designs has slowed relative to other design concepts.

2.2.7 Point Absorber Devices

Perhaps the second most common generic device design – after the attenuator devices – are point absorbers. Point absorbers have a physical analogy to conventional maritime navigation buoys. They are usually largely submerged, axi-symmetric and anchored to the seabed.

Point absorbers essentially have two key parts – a large spar, which either sits on the seabed or floats in the water column below the level of wave particle motion and a surface or near-surface float, which reacts to passing wave crests and troughs. As such point absorbers extract the heave component (*i.e.,* the vertical motion) of wave kinetic energy, although newer devices are being built which strive to extract energy from all three modes – heave, surge and pitch).

The devices have a small cross-section relative to an advancing wave front and thus do not extract as high a proportion of the passing energy as attenuator or terminator devices. However, their relative small areal footprint lends them particularly well to deployment in arrays and, as we shall see, most developers plan that individual devices will have low unit generation capacities (100 kW to 1 MW) but achieve utility scale by deployment in arrays. A high proportion of current academic research on point absorbers is dedicated to establishing array designs.

The most developed point absorber is the PowerBuoy developed by a New Jersey company, Ocean Power Technologies (OPT). Early versions of this device have been deployed since 1994 and the company is now involved in a number of deployment projects. The company listed on the Alternative Investment Market of the London Stock Exchange (AIM) in 2003 and listed on the NASDAQ in 2007.

The PowerBuoy device is fairly representative of the generic concept of point absorber device geometry – a central axi-symmetric spar with a separate float (Figure 2.7).

Figure 2.7: 40 kW PowerBuoy Ready for Deployment

Another device currently under development is the Irish WaveBob device. This device has been trialled at the Galway Bay wave testing centre over the last two years and the company has recently opened an office in the United States as it looks to expand operations there. Again the WaveBob device comprises a central spar linked, in this case, by hydraulic arms to a separate float (Figure 2.8). Wavebob differs from the PowerBuoy in that the former is an entirely floating device, slack-moored to the seabed, whilst the PowerBuoy has a central spar, which rests on the seabed. The device has been significantly modified suffering damage in 2007.

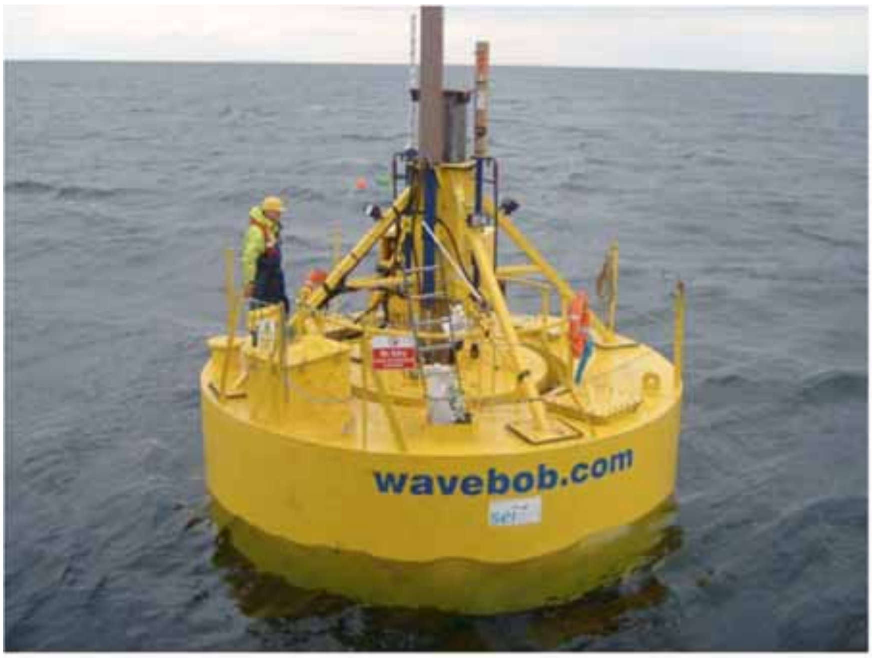

Figure 2.8: 1/4-scale WaveBob Prototype in Galway Bay, Ireland

2.3 TIDAL ENERGY DEVICES

2.3.1 Classification

A large number of tidal energy design concepts is currently under development. Putting aside barrages and impoundments, one compilation of devices (including tidal fences) indicated that over 70 tidal/ocean current devices were under development (Hales, *pers. comm.*). The European Marine Energy Centre lists 52 tidal current device developments (EMEC, 2008). Both numbers are probably a significant under-estimate, as neither includes device developments in New Zealand (of which there are at least eight) and possibly many other countries.

Despite the number of designs that have been proposed for tidal and current energy converters, there is no commonly agreed standard classification. The classification listed below breaks devices down on two criteria:

1. The source of the tidal energy to be harnessed,
2. The physical construction or energy extraction methodology (Table 2.3).

Conversion Technology	Manufacturer	Examples
Tidal Rise and Fall		
Barrages	Various	Rance River
Impoundments	Tidal Electric	None
Fences	Blue Energy	None
Tidal/Ocean Current Devices		
Horizontal Axis Turbines	MCT	SeaGen, SeaFlow
	SMD Hydrovision	TidEL
	OpenHydro	EMEC deployment
Shrouded HA Turbines	Lunar Energy	RTT 1000
Pressure Devices	HydroVenturi	Prototype trial, UK
Vertical Axis Turbines	Various	Various prototypes
Oscillating Hydrofoils	Engineering Business	Stingray

Table 2.3: Simplified Classification of Tidal Energy Converters

2.3.2 Barrages

Barrages are effectively low-head hydroelectric devices, which harness the artificial phase difference created between the rising and falling tides on the seaward side of the barrage and water being either impounded or excluded from the landward side of the barrage. Tidal barrages comprise a series of gates, which are open during the flood tide and close at high water. As the tide falls on the seaward side of the barrage, the gates are opened and the conventional hydroelectric generators are used to generate electricity.

Presently, the largest working example is the 240 MW tidal barrage on the Rance River in Northern France (PPL, 2005), although there are also smaller operational schemes in eastern Canada (Annapolis Royal: 20 MW) northwestern Russia (Kislaya: 0.5 MW). China also has five small barrages, associated with irrigation schemes, with a cumulative total of 4 MW.

Tidal barrages continue to be developed. The world's largest scheme – 254 MW at Si-hwa in South Korea - is currently under construction and is due to be commissioned in 2010 (Figure 2.9). At least two other major barrage projects – at Garolim and Incheon Bay - are under consideration or development in South Korea.

Figure 2.9: Si-hwa Tidal Power Plant, Korea (Artist's impression)

The UK Government has also revived a 30-year old plan to build a barrage across the tidal estuary of the River Severn between Wales and England. A recent review by the Sustainable Development Commission has shown that this huge scheme – 8,500 MW – may be viable (SDC, 2007). The UK Department of Business, Economic and Regulatory Reform is conducting further evaluation to establish the potential of Severn Estuary barrage.

Tidal barrages have high initial capital costs but are cheap to operate as there are no fuel costs and the main structure requires relatively little maintenance. Silting behind the barrage and the potentially serious environmental change caused upstream of the barrage can be problematic for consenting.

In New Zealand a number of tidal barrage proposals have been made, particularly in the five major harbours on the west coast of the North Island (Hokianga, Kaipara, Manukau, Aotea and Raglan harbours). However, the average tidal range (2 – 3 m) is small, there are significant potential environmental challenges, not least of which is the presence in some of these harbours of the rare Hector's and very rare Maui's Dolphins. Conflicting uses, such as commercial, customary and recreational fishing, are likely to make barrages a difficult, if not unattractive, option in New Zealand.

2.3.3 Impoundments & Constrictions

Tidal impoundments are man-made enclosures, which entrap rising flood tides, restrict their exit at high tide to create an artificial hydraulic head, which can be used to generate electricity. TidalElectric has proposed a 432 MW tidal impoundment off the North Wales/Liverpool Bay coast (PPL, 2005). This scheme involves building an impoundment wall in shallow offshore conditions and creating three compartments, which will be drained separately to smooth the power flow (Figure 2.10).

Impoundments require relatively shallow water offshore, since the principal component is a sea wall, requiring large volumes of material to be dumped and worked into the impoundment. Such structures will be critically sensitive to water depth, as it will control the volume of material required. Since most of New Zealand's coasts are reasonably steeply shelving, there are few, if any, locations where impoundments would be practical. The relatively low tidal range is also a negative factor as the natural tidal range controls the maximum hydraulic head that can be achieved within the impoundment. For these reasons, tidal impoundments will not be considered further.

Figure 2.10: TidalElectric's 3-pool Tidal Impoundment Proposal

Tidal constrictions occur across natural harbours with narrow mouths. The large natural harbours of the west coast of the North Island (see maps in Part 5 of this report) are good examples. The natural constrictions at their mouths cause acceleration of tidal stream velocities and cause significant head differences between the harbour water level and the open sea level (effectively a phase difference between the harbour and the ocean).

Woodshed Technologies has proposed harnessing this phase difference with their Tidal Delay® technology, not by placing devices in the harbour mouth but by laying or burying water pipes across narrow isthmuses between the harbour and the open sea. The pipes will be full of water and will act as siphons. Turbines within the pipes will generate electricity from the two-way flow of water as the tides rises and falls.

Woodshed Technologies became a public unlisted company in Australia in January 2008 and has a project, through its wholly-owned UK subsidiary, CleanTechCom Limited, with another UK company to establish a trial Tidal Delay® project across the Churchill barriers between the southern Orkney Islands.

2.3.4 Tidal Fences

Tidal fences are man-made structures across narrow harbour mouths or similar sites, where tidal flows are constricted and the tidal stream velocities are accelerated. Rather than blocking or constricting the tidal flows, tidal fences contain vertical axis turbines (although horizontal axis turbines would be possible) and capture energy from the passing tidal stream. They are thus essentially passive devices, which have limited effects on the natural tidal flows. They also offer the opportunity for roads to be carried across the tidal fence.

The best example is a tidal fence is the Canadian Blue Energy range of devices. Their Ocean Turbine is based upon a Davis Hydro turbine design, which is a vertical axis turbine with vertical blades. The blades rotate in a single direction, regardless of tidal flow direction. The turbines are housed in large concrete caissons, which are moored to the seabed and can be joined to form a '*fence*' across a river or estuary mouth. Because they do not constrict flow (except coincidentally), the implications for upstream siltation are much less serious than for barrages. The Ocean Turbine has been proposed at a range of scales and six prototypes have been trialled but no commercial version has yet been built. The company is currently working to build a 20 kW demonstration device, although no date has been set for deployment.

Tidal fences are discounted for early New Zealand deployment for similar reasons to tidal barrages and impoundments – conflicting uses in harbour mouths (shipping and fishing access) and difficulties of getting consents in what will be very environmentally sensitive areas.

2.3.5 Horizontal Axis Turbines

EMEC lists over 70 active projects to develop tidal devices, which include 21 horizontal axis devices, although both numbers are probably under-estimates. Although there are significant differences in details this class of device is conceptually similar to the standard wind turbine generator, *i.e.,* a single monopole tower with an upwind rotor and turbine, connected through a gearbox to a horizontal axis generator.

There are a number of horizontal axis tidal stream turbines under development.

The best known and most advanced of which are:

1. Marine Current Turbines' SeaFlow (Figure 2.11) and SeaGen (Figure 2.12)
2. SMD Hydrovision's TidEL device
3. Clean Current Power Systems (Canada)
4. Hammerfest Strøm (Norway)

Marine Current Turbines is the clear industry leader in terms of ocean deployments. It has had a 300 kW prototype, called SeaFlow, installed off Lynmouth in Devon, UK, since 2003 (Figure 2.11).

Figure 2.11: The 300 kW SeaFlow Prototype at Lynmouth, Devon

More recently, MCT has successfully installed the first utility-scale tidal stream turbine in Strangford Lough, Northern Ireland. The SeaGen device incorporates two 600 kW generators, powered by two 16 m twin-bladed turbines, mounted on a cross arm, attached to a bottom-resting monopole tower. The device was finally installed in April 2008 (Figure 2.12). The device is presently being commissioned and is due to feed electricity into the Northern Ireland grid in August-September 2008. This is thus the largest grid-connected tidal stream device yet deployed.

Figure 2.12: SeaGen Deployed in Strangford Lough, Northern Ireland; April 2008

2.3.6 Shrouded Turbines

There are a number of devices that use shrouds (*i.e.,* Venturi tubes) to accelerate the natural flow, because the available energy in a tidal stream flow is proportional to the cube of the velocity of the flow. The most commonly cited of these devices is the Lunar Energy device, which is based on a Scottish design (Rotech RTT). Crest Energy originally intended to deploy this device in its project (2.5.2).

Other shrouded devices include the Underwater Electric Kite and the '*TNEI*' device. The TNEI device is of interest in New Zealand because Neptune Power has proposed it as the device it will utilize for its proposed project in Cook Strait, for which it submitted an initial resource consent application in August 2007 (2.5.1).

2.3.7 Open-Ring Turbines

Open ring turbine designs have been proposed but only two are presently under development. These are the Clean Current Turbines device and the OpenHydro device or "*Open-Centre Turbine*", which was deployed and is currently under test at the European Marine Energy Centre in Orkney. In both cases the device consists of an open-centred ring blade system with a separate generator on the circumference of the ring of blades. The centre of the ring is open and large enough to allow the unimpeded passage of fish and possibly small marine mammals. In the case of the OpenHydro prototype, the device can be raised and lowered into the current. When viewed at EMEC in May 2007, the device was awaiting commissioning (Figure 2.13).

Figure 2.13: OpenHydro's Open-Centre Turbine at EMEC, May 2007 (© PPL)

In 2007 OpenHydro announced that it had won a tender to supply its Open-Centre Turbines to a project underwritten by the Nova Scotia Government, followed shortly by another announcement that it will also supply the technology to Alderney Renewable Energy in the UK Channel Islands. The Canadian development will be at a new tidal testing centre being established in the Bay of Fundy by Nova Scotia Power.

The OpenHydro device is interesting in the New Zealand context because it is the newly chosen technology of Crest Energy for its proposed project in Kaipara Harbour (Section 2.5.2).

2.3.8 Pressure Devices

There is one pressure device, called the HydroVenturi device, which is under development in the United Kingdom. The device is a submerged Venturi tube laid on the seabed or in the water column. The Venturi tube accelerates flow within it in exchange for a decrease in hydrodynamic pressure. The current small-scale prototypes have been trialled in rivers. Other pneumatic pressure devices are being developed.

2.3.9 Vertical Axis Turbines

The second largest group of devices, after horizontal axis devices, are vertical axis devices. These devices are based on the "*Darrieus*" rotor design for wind turbines, although such wind turbines are no longer under development. There are a number of such devices, including the Kobold Turbine, currently deployed in Sicily (Figure 2.14), Edinburgh Designs' variable-pitch blade design and the Blue Energy tidal fence (see Section 2.3.4).

Figure 2.14: Enermar's Kobold Turbine, Straits of Messina, Italy (© PPL)

There are at least two New Zealand-based projects, which were developing vertical axis tidal turbines. One of these projects was never made public and is currently on hold, whilst the other, Tidal Flow Seamills, is planning the deployment of a small-scale prototype device (see Section 2.5.5).

2.3.10 Oscillating Hydrofoils

There is a class of tidal stream devices, which seek to extract energy by use of oscillating or reciprocating hydroplanes. The best known of these is Stingray, which comprises a support base and a single hydroplane (although multi-plane devices were contemplated). Unlike all of the tidal devices listed above, which are passive in operation, the Stingray required active control. The device operates by active control of the angle of attack of the hydroplane, which caused it to rise or fall due to pressure from the passing current (Power Projects, 2005). The rise and fall of the hydroplane caused a pumping action in a connecting hydraulic arm, which drove a turbine and generator.

The UK designer of Stingray, the Engineering Business, successfully tested a 150 kW version of the device in Yell Sound in the Shetland Isles. However, despite attracting some Government R & D funding, the company announced in 2005 that it was discontinuing development of the device.

2.3.11 Marine Energy Devices in New Zealand

There is a wide range of options for extracting energy from waves, tides and ocean currents. Although there are some generic designs for extracting energy, most of the technologies are immature and there remains significant divergence in design. There is as yet no common design, as there is for wind turbine generators. Indeed there is unlikely to be a single design for marine energy converters, because there are so many different forms of marine energy extraction and an even greater number of mechanisms to extract that energy.

Some devices extract products other than electricity. They are not considered further here. Some extraction methodologies will most likely remain inappropriate for New Zealand conditions – OTEC, tidal barrages – and they are not considered further. Others are at an early stage – osmotic power and marine biomass – and commercial developments of other technologies may precede them.

Wave and tidal/ocean current devices have the best potential to contribute to New Zealand's medium-to-long-term electricity portfolio. It would not be appropriate or without risk to select specific manufacturers' technologies but the potential of generic technologies for deployment in New Zealand can be ranked (Table 2.4).

Energy Source	Conversion Technology	Comment
Waves		
Breaking Waves	Onshore Oscillating Water Column	Likely in new breakwater designs
	Nearshore Oscillating Water Column	Possible but difficult to consent
	Overtopping Devices	Possible but difficult to consent
	Surge Devices	Possible but limited by steeply shelving coastline
Open Ocean Swells	**Attenuators**	Possible but navigation problems for large arrays
	Point Absorbers	Probable widespread deployment of arrays
Tidal/Ocean Currents		
Tidal Rise and Fall	Barrages	Prohibitively expensive; potentially impossible to consent
	Impoundments	Very unlikely due to steep shelving coastline
	Fences	Unlikely due to competing uses; very difficult to consent
Current Devices	**Horizontal Axis Turbines** (including shrouded & open-centred turbines)	Probable widespread deployment of arrays
	Vertical Axis Turbines	Possible, subject to successful design
	Pressure Devices	Possible
	Oscillating Hydrofoils	Technology problematic

Table 2.4: Potential of Marine Energy Converter Technologies in New Zealand

NOTE: Devices in **bold red** are considered most likely to be deployed in NZ

2.4 SIZE OF INSTALLATIONS

Installations may range from individual devices, which range widely in size, to multiple unit arrays of devices, equivalent to wind farms.

2.4.1 Individual Devices

Currently, the largest individual operational wave devices are 750 kW Pelamis units and the largest tidal current device is the Seagen 1.2 MW unit (with twin-turbines). Most developers have started with small experimental devices (2 – 100 kW) and the more mature have gone on to plan or to develop 0.5 – 1.0 MW devices. Typical unit device sizes are planned to be 1 MW, although this may increase over time. As marine energy technologies mature, they are likely to follow two trends:

1. Increasing unit size (just as wind turbines are now substantially larger than 25 years ago)
2. Increasing generation capacity (early wind turbines could generate 25 kW; modern units have capacities of 3 – 5 MW).

If marine energy converters follow these trends, MEC deployments will move towards increasing generation capacity of arrays, accompanied by declining numbers of units in each array. The overall effects should be to reduce the number of arrays and the areal 'footprint' of arrays with time.

2.4.2 Arrays

As with wind farms, commercial deployments of marine energy converters are likely to be in arrays or 'parks': multiple devices operating in close proximity to increase total production, smooth electricity flows and provide redundancy in the event of device failures. The size of arrays and the area they take up are yet to be determined, although the range will be from single devices up to 200 units. Oddly the two largest projects proposed are both in New Zealand:

1. Crest Energy is seeking consents for a 200 x 1 MW tidal current turbine array in the outer part of the Kaipara Harbour.
2. Neptune Power plans for an eventual (*i.e.,* by 2022) array of 300 x 3 MW units

Both of these proposals are extremely ambitious not only in themselves but also in terms of other international developments, the largest published equivalent being only 100 MW.

It is likely that marine energy converter arrays will occupy relatively little sea area, as compared to wind farms. This is because the energy density in seawater is significantly greater than that of air. Consequently, marine energy converters are likely to be smaller than wind turbines and can thus be packed more densely than wind turbines. A tidal current turbine with a 16 m rotor diameter may produce as much power as a wind turbine with a 45 m diameter rotor. Rules of thumb for wind turbine arrays are that the individual turbines should be located at least 6 rotor diameters downwind of each other and three rotor diameters laterally. Applying the same rules to tidal current turbines demonstrates the significant increase in packing density possible.

It is possible to forecast therefore that New Zealand may see wave and tidal current arrays in future, which have substantial numbers of units and very large generation capacity. However, all developers will start with single devices and move – through incremental developments – to large arrays. The scope and scale of environmental effects may therefore become apparent during the progressive development of arrays and their effects addressed by adaptive management.

2.4.3 Exclusion Zones

It is likely that most wave and tidal current device arrays will have exclusion zones within and around them to provide a safety barrier from other activities, such as fishing and navigation. Exclusion zones are likely to be marked by cardinal buoys and navigation lights, noted on shipping charts in future and advised through Notices to Mariners. Whilst other human activities are likely to be excluded in the area of marine energy converters arrays, the exclusion zones may create *de facto* marine reserves, in which marine life can flourish. The size of the exclusion zones – beyond the outermost devices in an array – is yet to be determined.

2.5 NEW ZEALAND PROJECTS

Currently Power Projects Limited is aware of 25 marine energy projects being undertaken in New Zealand – probably an under-estimate. Six of these are research projects or proposals to establish testing centres, research centres or other facilities. The remaining 19 are split evenly between device development and device deployment projects, the latter seeking to utilize devices developed overseas. They are also split evenly between wave and tidal current device projects. The projects are generally all early-stage and most owners regard their projects as confidential. However, seven projects have made applications for resource consent applications or publicized the intent of their projects to do so.

2.5.1 Neptune Power Limited in Cook Strait

The Neptune Power proposal to establish a tidal stream project in Cook Strait garnered a great deal of publicity in 2006 and 2007. In July 2007 Neptune submitted a brief application for consents to establish a single trial turbine at a site near Karori Rip off the south coast of Wellington (and slightly out of the main part of Cook Strait). The site is probably close to the site envisaged for deployment by Tidal Flow Seamills (see Section 2.5.5).

Neptune Power reviewed their plans at a workshop convened by the Electricity Commission, where they unveiled ambitious plans to deploy 900 MW of tidal stream devices off Cape Terawhiti by 2021 (Neptune Power, 2007).

On April 10 2008 Neptune Power was granted a non-notified consent to install a single prototype device with an export cable connecting to the onshore Vector distribution network (GWRC, 2008). The consent documents indicate that Neptune Power plans to deploy its prototype device in late 2009. The proposed site for the prototype deployment is somewhat east of the site proposed for the utility-scale development.

2.5.2 Crest Energy Kaipara Limited in Kaipara Harbour

Auckland-based Crest Energy originally proposed to deploy the Lunar Energy tidal stream turbine in the Kaipara Harbour in applications for resource consents submitted to Northland Regional Council in July 2006 (Crest Energy, 2006). Crest Energy planned to use 200 units in an extended array. However, new consent applications were submitted in mid-2007 and parts of the original applications were withdrawn. The new applications indicate that Crest Energy is now planning to deploy the OpenHydro ring turbine device (Section 2.3.7) and will move to an incremental development. Although Crest Energy's decision to move to the OpenHydro device may delay deployment of the Lunar Energy device in New Zealand, the latter may eventually be deployed here in other projects.

Northland Regional Council finally held hearings on Crest Energy's consent applications in the week of 26 – 30 May 2008. A decision on the granting of the consents is expected within 3 months. During the week of the hearings, the Minister of Energy announced that Crest Energy would be awarded $1.85 million for the deployment of the first three devices from the Marine Energy Deployment Fund, subject to grant of a resource consent for the project.

2.5.3 Energy Pacifica Limited in Tory Channel

Energy Pacifica Limited is an Auckland-based company, which has announced plans for a tidal current device array in the outer part of Tory Channel at the top of the South Island. Tory Channel is an important waterway, providing an easterly access route into the Marlborough Sounds and being the navigation route of the inter-island ferries. Energy Pacifica has not yet settled on which turbine design it will use but its resource consent application shows that any seabed-mounted tidal turbines will have significant freeboard below the inter-island ferries.

2.5.4 Wave Energy Technology – New Zealand

The Wave Energy Technology – New Zealand (WET-NZ) project is a consortium R & D programme funded by the Foundation for Research, Science and Technology. The partners are two Crown Research Institutes, Industrial Research Limited and the National Institute of Water and Atmospheric Research, together with Power Projects Limited, the co-author of this report.

The WET-NZ consortium has developed a point absorber wave device, a quarter-scale version of which was deployed in Pegasus Bay off Christchurch in December 2006. The device has been significantly modified between open ocean deployments during 2007-08. The longest continuous deployment was for 35 days and the device has survived a number of storms. In early 2008 a second version of the device was fabricated to enable parallel testing to continue; the second device has yet to be deployed. However, in May 2008 the original device was withdrawn from Pegasus Bay, refurbished and redeployed at Evans Bay in Wellington Harbour, where it was tested for about 30 days

2.5.5 Other Projects

Three other projects have indicated their intent to deploy marine energy converters in New Zealand:

1. **Tidal Flow Seamills**

   This project was first proposed publicly in 2004 but further developments have not been forthcoming. The proposed new vertical axis turbine was to be installed near the Karori Rip, a well-known tidal current off the south coast of Wellington. Power Projects Limited understands that a small-scale version of the device has been fabricated and Tidal Flow Seamills intends to test this device later in 2008. Details of the device have not been published so determining any specific environmental effects is not possible.

2. **Natural Systems Limited**

   Natural Systems Limited has acquired the New Zealand and South Pacific licence for the HydroVenturi device. Natural Systems' focus is on small-scale hydro opportunities on rivers and canals, rather than open ocean currents (Natural Systems, 2006). It has a proposed a prototype site on a Canterbury canal race. The HydroVenturi technology is still at an early stage of development. Delays in device development and the focus on run-of-river or canal applications may mean that it is some time before larger-scale tidal stream applications are realized. The HydroVenturi device is passive with no submarine moving parts so the environmental effects of this device may be limited.

3. Power Generation Projects Limited

Power Generation Projects (PGP) proposed to establish an array of Pelamis devices on the west coast of the North Island. PGP has made no public release on developments since that time. The Pelamis devices have been deployed in Portugal during 2008 so environmental effects should be observable.

2.6 ENVIRONMENTAL ISSUES WITH PROPOSED DEVICES FOR NZ DEPLOYMENT

Given the three types of wave and tidal stream devices thought most likely to be deployed in New Zealand, the most likely environmental effects can be identified as follows:

- General physical effects
    - Hard structures and energy extraction
    - Noise effects
    - Visual impacts
    - Hydrodynamics
    - Chemical impacts
- Environmental impacts on biota
    - Habitat modification
    - Collision
    - Noise effects
    - Electromagnetic Fields

Space taken up by marine energy ‘farms’ may have impacts on competing uses for that space, including navigation, fishing and aquaculture.

The remainder of this report is taken up with describing the effects of these environmental impacts and their potential mitigation.

PART 3: PHYSICAL ENVIRONMENTAL IMPACTS

Environmental impacts may occur over short- or long-term time scales. Short-term impacts will generally occur during facility construction, whereas long-term impacts tend to be of lower intensity, but occur over the operational life of an installation.

Short term impacts may include:

- Disturbance of the substratum during anchor placement and cable laying, leading to local habitat destruction and increased turbidity,
- Noise during construction due to ramming, drilling and dredging operations,
- Increased vessel activity during construction and turbine maintenance periods.

Long term impacts may include:

- The physical presence of structures and flow-on effects on local habitat,
- Operational noise and vibration emitted from turbines,
- Electromagnetic field emissions from cables,
- Collision with turbine blades and/or floating structures (*e.g.*, attenuators or point absorber devices – see below),
- Entanglement of large animals with underwater cabling or anchor lines

Although prototype projects may be relatively short-term and deployments may be temporary, the duration of commercial projects is difficult to determine. Since resource consents are typically available for 35 years, it is likely that applicants will be seeking maximum terms. Longer term projects are likely to have limited effects, since they will have met resource consent requirements to remain in place, but long-term monitoring will be required to assess cumulative effects.

The following sections summarize potential impacts of marine energy installations and discuss mitigation measures for those most likely to be significant, concentrating on submarine devices as the most likely to be implemented in New Zealand. The first section covers general impacts created by deployment of MECs and their ancillary equipment. Succeeding sections deal with specific impacts in more detail.

3.1 GENERAL ENVIRONMENTAL IMPACTS

3.1.1 Location of Wave and Tidal Stream Projects

The distribution of wave and tidal current resources around New Zealand's coasts is quite dissimilar. Wave resources sufficient to be attractive for commercial energy generation (>30 kW/metre of wavefront) can be found off most south- and west-facing coasts (see maps in Power Projects, 2008). Tidal resources are much more restricted. With the exception of the well known harbours and narrows (such as Tory Channel and French Pass), open ocean tidal current velocities sufficient for energy generation (>1 m/sec average velocity for mean spring tides), occur in only three regions: Cape Reinga, eastern Cook Strait and around Stewart Island (Power Projects, 2008).

The generic wave devices identified in Table 2.4 are open-ocean devices, whilst the generic tidal current devices could be located in the open ocean or in harbours and estuaries. Open ocean wave devices will be located in water depths of *c.* 50 m, since bottom friction at shallower depths tends to reduce available nearshore wave energy. Thus wave device arrays are likely to be located at least 1 - 2 km offshore. Early projects will, however, seek to be as close to the coast as possible to reduce submarine cable lengths, which can be a substantial proportion (~30%) of total project costs. Maximum depths may be 100 m, simply because operating in deeper water increases mooring costs and requirements for larger, more specialized vessels.

Open ocean tidal turbines will tend to be located in water depths of more than 25 m, since device heights range from 25 to over 50 m. They too will be located at least 1 – 2 km offshore with the same countervailing consideration with respect to submarine cables. In Cook Strait the 25 m isobath is located 1 – 2 km from shore. Harbour-based tidal turbines may be limited to those harbours, which have sufficient water depth – usually near their mouths – to accommodate the turbines.

3.1.2 Area Requirements for Marine Energy Converters

The area required for a <4 MW array of wave or tidal current devices will depend on the type of the device selected and the packing density of these devices required. To some extent packing density will be a function of specific sites, particularly for tidal current sites, where individual device siting can be critical, as well as the selection of particular technologies.

To demonstrate how little space might be required, the following ~4 MW arrays will be proposed:

4 MW point absorber array

40 x 100 kW point absorber devices	=	4 MW
Device diameter	=	4 m
Device spacing	=	100 m
Exclusion zone around outer perimeter	=	500 m

The physical area taken up by these devices equates to 0.31 km^2, which increases to 2.46 km^2, assuming the required 500 m exclusion zone on all sides.

4 MW Tidal Turbine Array

4 x 1 MW point absorber devices	=	4 MW
Device diameter	=	16 m blades
Device spacing	=	100 m and 50 m*
Exclusion zone around outer perimeter	=	500 m

*Assuming 2 rows of two turbines with devices 50 m apart across-current, and 100 m apart down-current

In this case, this wholly submarine array will occupy 0.1 km^2, increasing to 1.2 km^2 with the required 500 m exclusion zone. It remains to be seen whether such a navigation exclusion zone will be required for a completely submerged tidal turbine array.

3.75 MW Pelamis Attenuator Array

5 x 0.75 MW point absorber devices	=	3.75 MW
Device diameter	=	3.5 m
Device spacing	=	250 m
Exclusion zone around outer perimeter	=	500 m

This array thus occupies 0.14 km^2, increasing to 2.30 km^2 with the required 500 m exclusion zone on all sides.

In summary, small arrays of marine energy converters (<4 MW) will occupy relatively small amounts of open ocean, ranging from 1.2 km^2 to 2.46 km^2. The unit generation capacity of devices becomes important in the case of small arrays, as can be seen in the difference between the 0.1 MW and 1.0 MW devices in the first two cases. In any event <4 MW wave or tidal device arrays will take up relatively small areas of open sea. Whilst the area taken up may have most impact on competing uses for the sea space, these calculations show that the area that will be impacted by placement of marine energy converters is small and thus the ‘scale of effects’ will be limited.

3.1.3 Hard Structures

Marine energy converter installations require not only the conversion devices themselves but also moorings, anchors and export cables. These hard structures may provide collision hazard for vessels, marine mammals and fish. Moving parts such as turbine blade tips may also be potential areas for risk, although generally rotate at low speeds (10 – 35 rpm; *i.e.,* 1/10 the speed of a ship’s propeller), which most marine life will be sufficiently agile to avoid.

Current modification around seabed-attached devices, foundations and anchors may cause local scouring and downstream sedimentation, although these effects are likely to be small and areally restricted, largely because areas of high currents tend to be swept clear anyway. Wave devices are likely to have little seabed footprint.

3.1.4 Energy Extraction

Energy extraction from wave and tidal stream currents may have some downstream effects. However, both extract energy from very energetic environments and the proportion of energy extracted is relatively small. Estimates of extracted energy for wave devices indicate that between 0.8 and 2.9 MW per kilometre of coastline could be extracted by wave farms, the figure being dependent on choice of wave device in an array (Previsic, 2008). These figures were based upon deep-water wave power density of 30 MW/km of coastline, almost identical to the power density of any New Zealand south- or west-facing coast. Thus electricity generation is approximately 2 – 10 % of the available energy, which is sufficiently low to have little impact on wave height (a potential concern for surfers) or downstream sedimentation.

Wave height reductions may be up to 10 – 15% behind wave arrays but wave height is restored by diffraction within 3 – 4 km downstream of the array (EPRI, 2004). Energy extraction by submarine tidal/ocean current turbines is likely to be less serious, although the effects of turbulence may be greater.

Turbulence caused by tidal current turbines, particularly rotating blades, may cause local scouring and affect natural current flows. Energy extraction may cause some downstream increase in sediment deposition and may affect natural movement patterns. Again these effects may be minimal and monitoring, which will be required as a resource consent condition, should provide evidence of any effects.

3.1.5 Substratum Disturbance

Construction activities will disturb the seabed and re-suspend sediment, resulting in small-scale destruction of habitat and local increases in turbidity. Smothering effects by sediment inputs have been shown to have significant impacts on local benthic assemblages (Thrush *et al.,* 2004). For tidal devices moored in high current areas, the sea floor generally consists of coarse material, such as sands and gravels grading to bedrock at the highest current velocities, and therefore local turbidity is unlikely to be increased for more than one tidal cycle – if at all. The extent of direct physical disturbance will depend on the construction methods used to anchor the generating devices, and whether cabling networks are to lie on the bottom or be buried. It is envisaged that this disturbance will be compensated over time by epifaunal colonisation of exposed parts of the anchoring structure. This will increase local biodiversity. For wave devices that could be moored using various types of anchor devices (*e.g.,* Stevens *et al.,* 2008) over soft sediment habitats, impacts would expect to be similar to offshore aquaculture developments or oil and gas platform impacts. Infaunal colonisation of disturbed surface sediments is generally rapid where no major structural changes are made to the sediment (Lu & Wu, 2007), and in well-sorted sands, no long-term restructuring of habitat is likely to occur as a result of cable burial.

3.1.6 Construction and Operational Noise

Noise and vibration brought about by construction activities, especially pile driving and cable laying, may cause damage to the acoustic systems of species within 100 m of the source, and are expected to cause mobile organisms to avoid the area (Nedwell & Howell 2004). Pile driving may transmit sound waves at up to 200 dB (Nedwell et al. 2003), which has the potential to cause damage to fish species with swimbladders and harm the hearing of pelagic species, although this may regenerate over time. Tests during wind farm construction in Denmark found no evidence that fish would be damaged by sound from pile-driving (Engell-Sørensen & Holm Skyt, 2001).

All marine mammals are potentially vulnerable to disturbance by anthropogenic noise (*e.g.,* Croll et al. 2001; Nedwell & Howell, 2004; Nowacek *et al.,* 2007). Significant noise levels may arise from construction if pile-driving, explosive or seismic work is undertaken. Although short-term, these may be damaging to any marine mammals in the area (Madsen *et al.,* 2006). In two separate monitoring projects at offshore wind farms in Denmark, Henriksen *et al.,* (2004) and Tougaard *et al.,* (2003) found a pronounced effect on the behaviour and abundance of harbour porpoises during pile driving activities. Specifically, fewer animals exhibited foraging behaviour and a distinct short-term reduction of echolocation activity was documented up to 15 km from the impact area. These effects were, however, short-lived once construction ceased. (Carstensen *et al.,* 2006). Other studies have addressed the effects of sound pulses from airguns and indicate that high-level impulsive sounds have a greater effect on cetaceans than pinnipeds (McCauley & Cato, 2003; Gordon *et al.,* 2004).

Operational noise is likely to be quite limited as most device designs under evaluation will produce little noise.

3.1.7 Vessel Activity

Throughout the history of any offshore development there will be an increase in vessel traffic through surveying, construction, and maintenance (see Section 3.6). Such traffic increases the risk of vessel strike on marine mammals and aquatic birds (most notably little blue penguins *Eudyptula minor* and shags *Phalacrocorax spp.*). The primary source of noise is from the propeller, although hull noise may become significant at low speeds.

3.1.8 Extreme Weather

Extreme weather resulting in heavy seas will be problematic for surface-piercing or floating devices in terms of survival, general wear and tear and access for repairs and maintenance. Submarine current conditions are likely to be less variable and extreme. Nonetheless, all devices will need to be designed to survive these conditions, whilst operating efficiently in a range of normal conditions. Project developers will need contingency plans to address issues such as anchors dragging and unintentional movement of devices, particularly around vulnerable infrastructure such as the HVDC cables crossing Cook Strait.

3.2 VISUAL IMPACTS

Most types of marine energy converters are likely to have very limited visual impact.

3.2.1 Wave Devices

Most forms of wave devices will be located some distance from shore and partially, if not fully, submerged. For these reasons their visual impacts may be limited to navigation warning lights at night with little or no evidence of their presence during daylight. Nearshore devices, like oscillating water column or terminator devices, which have bulky superstructures above the waterline will be more visible, particularly in nearshore locations. Wavedragon, the developer of a large terminator device, is planning its first project in South Wales but the devices will be at least 5 km from shore and their visual impact from the beach will be limited.

3.2.2 Tidal Current Devices

Tidal current devices may be either fully marine or have some above-surface structures of limited size. They may be located closer to shore than wave devices and are much more site-specific (tidal current resources are very location-specific). However, the visual impact of tidal devices from nearby coastlines may be negligible. If the devices are fully submarine, then the only evidence will be the presence of navigation markers.

3.3 NOISE

3.3.1 Noise Effects

Wave energy facilities are unlikely to generate noise beyond ambient. Madsen et al. (2006) reviewed measurements of underwater noise taken from wind turbines and found considerable variability in the noise production from different types of installation, depending on how the system was constructed. Neither Madsen et al. (2006) or Wahlberg & Westerberg (2005) could foresee any problems caused by sound from wind farms for marine mammals or fish, respectively. Underwater turbines may produce low frequency sound from the action of the turbines. Propagation levels are unknown, but the total noise production is likely to be less than that produced by a passing ship (*e.g.,* Madsen et al. 2006), and in high current conditions is unlikely to exceed ambient sound levels.

3.3.2 Noise Mitigation Measures

In order to reduce the impacts of noise, it would be helpful to have prior knowledge of the sound level and frequency range of noise a marine energy facility will generate throughout the different phases of construction and operation as well as some background baseline data. The following mitigation techniques can be utilized to reduce the negative impacts of noise from a marine energy facility.

1. Decoupling of noise generating equipment from water when possible during construction (*i.e.,* remove the equipment from the water).

2. When noise is to be generated in discrete events, acoustic warnings or 'ramping up' of the sound may give marine mammals time to leave the area. The 'ramping up' of a sound source may allow animals to move out of the area prior to noise levels that may cause harm. However, there is some concern that this 'ramping up' may also enable an animal to become habituated to the sound. In addition to lower level warning sounds, the use of acoustic alarms to clear the area of marine mammals may be effective. However, acoustic alarms will also introduce more noise into the marine environment and could contribute to masking and

other negative effects of anthropogenic sounds. These techniques have been used during seismic reflection surveys, underwater sound experiments and industrial construction/deconstruction activities and would require evaluation on a case-by-case basis and constant re-evaluation.

Minimize received sound levels during construction through the use of air bubble curtains or equipment sound dampeners. Bubble curtains have been shown to inhibit sound transmission through the water during pile driving activities by containing or reflecting underwater noises (Wursig *et al.,* 2000). Bubble curtain techniques introduce specifically sized air bubbles into the water surrounding the pile in a controlled manner, thus dampening the shock waves by creating an impedance mismatch and helping to minimize the effects on aquatic life. Air may be released in a variety of ways, including through a ring around the pile (Figure 3.1). Wursig *et al.,* (2000) found the greatest sound reduction from the bubble net curtain from 400 to 6400 Hz, the frequency range used by many cetaceans. The authors suggest that this mitigation technique can be effective in cases where loud human noises occur in discrete areas, such as during construction or explosive detonations. This technique may be limited by depth and, more importantly, for a marine energy facility, by turbulent water. Equipment modifications such as dampening, can also be effective used to reduce noise due to vibration (Figure 3.2). Another possibility is the redesign of a particular piece of equipment to achieve quieter noise levels.

The lack of noise production by the operating turbine may increase the risk of collision by marine mammals relative to a "noisier" system. Noise producing systems, such as "pingers" may be required to warn approaching mammals should any evidence of collision risk be obtained.

Figure 3.1: Bubble Net Curtain Air Release Rings (left) and in use (right)

Figure 3.2: Sound Dampening During Pile Driving

3.4 HYDRODYNAMICS

Both wave and tidal current devices will be deployed in moving water. The presence of temporary or semi-permanent devices and their ancillary equipment may cause some changes to the hydrodynamic environment.

3.4.1 Seabed Morphology

Changes to seabed morphology are unlikely to be significant, since most devices that require seabed anchors or moorings will be located in areas where there is a hard substrate without much or any sedimentary cover. Whilst drilling may be required for foundations or anchors, the long-term effect is likely to be limited.

3.4.2 Erosion and Scouring

For wave devices, which have bases resting on the seabed, there may be some erosive and scouring effects around bases and anchoring points. Erosion and scouring is likely to be limited to the areas immediately around and possibly underneath the devices. Tidal stream devices are likely to be located in areas of constant scouring and removal of deposited sediment. Local modification of the tidal current by placement of seabed-mounted tidal stream devices and/or their moorings may cause turbulence in the current, which may give rise to very localized scouring and downstream sedimentation. In both cases, the effects of erosion and scouring will be limited and are unlikely to be permanent – sites will recover quickly, once the devices and ancillary equipment is removed.

3.4.3 Sediment Transport and Deposition

As noted above the effects of sediment transport and deposition are likely to be small in most instances, particularly for floating wave devices. Where MECs do cause some changes to natural sediment transport and deposition, these changes are likely to be temporary (during installation and decommissioning) or reversible (on removal).

3.5 CHEMICAL IMPACTS

Chemical impacts of marine energy devices are likely to be small. Materials selection for device fabrication, painting and lubrication will be environmentally sensitive and are likely to follow modern best practice. Given the active environments that marine energy converters will operate in, the chances of accumulation of chemical impacts are likely to be very small.

3.5.1 Water Quality

Whilst most wave and tidal stream devices are designed to have limited chemical components, *e.g.,* lubricating oils), those that do have environmentally friendly lubricants, such as vegetable oils. The only significant threat to water quality may be human-induced spills of chemical components. Whilst these may have a high potential impact, their likelihood is small.

3.5.2 Corrosion

Most wave and tidal energy devices will be protected against corrosion by use of non-corrosive materials, anti-corrosion paints and interventions such as sacrificial anodes. The effects of these materials and paints on the local environment is likely to be small, particularly as the water flux through any wave or tidal stream site is likely to be high.

3.5.3 Bio-fouling

Bio-fouling is the accumulation of sessile biota on the marine energy converters and associated equipment. Bio-fouling is more likely to occur on or in non-moving parts of the equipment, so anchors and mooring cables may be more susceptible than the MECs themselves. Similarly very active environments such as wave breaking zones and areas of high current speed are unlikely to attract much bio-fouling. It would seem that any impact arising from bio-fouling will be small.

Although bio-fouling is likely to be geographically controlled, evidence from Marine Current Turbines' long-term deployment of the SeaFlow device, which has been deployed since 2003, has suffered virtually no bio-fouling. However, there are examples of navigation buoys in New Zealand waters suffering substantial bio-fouling. The only way to establish the extent of bio-fouling on MECs in New Zealand waters may be through monitoring early deployments. In any event, bio-fouling is likely to be a low impact, high likelihood risk.

3.5.4 Anti-fouling and Anti-Corrosion Paints

Paint applications to marine devices are used to prevent fouling and corrosion. The paints are well-established. MECs are likely to finished with similar marine-grade paints

3.6 ENVIRONMENTAL IMPACTS DURING PROJECT STAGES

3.6.1 Pre-deployment Monitoring

Placement of measuring and monitoring devices, such as Acoustic Doppler Current Profilers (ADCPs) or wave-rider buoys is not likely to cause any significant environmental concerns. There is a requirement to notify the local harbourmaster of the intent to deploy and to provide the location of any measurement/monitoring equipment.

3.6.2 Deployment and Commissioning

Deployment and commissioning are transitory activities, when the greatest level of human intervention is required. However, deployment vessels will be on site as briefly as possible, probably in good weather conditions, so environmental risks are probably relatively low.

3.6.3 Operations

The vast majority of project life will be devoted to normal operations. Human intervention is likely to be at a minimum and marine energy converters will operate unattended.

3.6.4 Maintenance and Repair

Marine energy converters are being designed for minimal intervention, even when repairs are required. Some devices are being designed with modular construction techniques, so that key parts, such as turbines and generators, can be easily removed and replaced at sea. This should reduce environmental risks during periods of maintenance and repair, whether scheduled or unplanned.

3.6.5 Unexpected Events

Every project will have to develop a plan for unexpected events. Devices may be broken or break their moorings and begin dragging their anchors. Consents (and funding) for commercial projects will require a Health, Safety and Environment Plan (HSE) to be drawn up. This plan will include contingency planning for a number of unexpected events, including partial and total failures of the marine energy converters and their moorings.

3.6.6 Decommissioning

Like commissioning, decommissioning will require a higher level of human intervention than normal operations but it will, of necessity, be brief. Developers will probably have to demonstrate plans for decommissioning, before consents are granted. Decommissioning may require removal of all equipment back to the level of the seafloor and surveying of the seabed to prove the removal of any debris accumulated during operations. Periodic monitoring of the restoration of any former site to a pre-operational natural state may be required, acknowledging that complete restoration may be impossible (and not appropriate).

3.7 NAVIGATION AND EXCLUSION ZONES

3.7.1 Navigation

There are no designated shipping lanes in New Zealand, although there is a Voluntary Code For Vessels Carrying Oil Or Other Harmful Liquid Substances In Bulk (Maritime NZ, 2006). The code has some advisory routes, which are based on safe operational behaviours and general '*rules of the road*'. Maritime NZ collects ship route tracking data and can advise project developers on conflicting navigation uses.

For marine energy projects, it is obviously vital that developers avoid areas of frequent shipping use. In law there is a presumption that any vessel can go anywhere.

3.7.2 Other Exclusions

There may be a number of other potential exclusion or restricted areas, which marine energy project developers may have to take into account in siting their projects. These include the following:

1. Marine reserves
2. Areas of Significant Conservation Value (ASCVs)
3. Areas of Important Conservation Value (AICVs)
4. Mooring areas
5. Commercial developments
6. Aquifer zones (*e.g.,* Wellington Harbour)

7. Water quality classes (nearshore areas managed for water contact recreation, *i.e.,* swimming or surfing, and shellfish gathering purposes)

Regional council officers can provide advice on the likely exclusion zones, restricted zones and areas of competing areas in their coastal marine areas.

3.8 WIND FARMS

3.8.1 Onshore Wind Farms

To date most wind farms in New Zealand have been built on inland ridgelines. However, this is changing as new wind farms, such as West Wind on the southwest coast of Wellington and a number of other wind farms have been proposed on the Taranaki and Waikato coasts. Coastal turbine placements will have high visual impacts, and may be contentious, except in areas of low public access (such as the West Wind site). Wind farms may have effects on local bird populations, but evidence of negative impacts to date has not been conclusive (Stewart et al., 2007).

3.8.2 Offshore Wind Farms

New Zealand's narrow continental shelf is not amenable to the placement of offshore wind farms with current technologies – the coast shelves too steeply. Although offshore floating wind turbines are under development in Europe, these may not arrive in New Zealand for some time, since the future capacity of wind farms that have been proposed, planned, in consenting or under construction is very large (~4,000 MW) and costs for onshore developments are likely to be lower than offshore wind farms.

PART 4: ENVIRONMENTAL IMPACTS ON BIOTA

This part of the report is based upon consideration of marine energy developments of <4 MW. Most, if not all, early projects will be incrementally developed and some, particularly for remote or island communities may remain small.

4.1 MARINE MAMMALS AND ELASMOBRANCHS

4.1.1 Habitat Modification

Addition of artificial structure to the sea floor may alter local current patterns and cause the scouring of sediment – particularly from near the base of the structure. Where currents are strong, benthic substrata are likely to consist of bare rock or large cobbles as finer sediments tend to be transported to depressions in the sea floor or areas of low water movement. It is thus very unlikely that addition of structures to the seabed in these areas will have any effects on the surrounding benthos. Even if local (10's m) current patterns are disrupted by the presence of an anchor structure, a turbine, or both, effects are unlikely to be felt more than a few metres from the structure. Wave energy devices and floating turbines will be unlikely to have benthic effects beyond that brought about by their anchoring structure.

If larger arrays of tidal turbines or wave generators are put in place, alterations to surface currents may cause coastal erosion problems where situated close to shore, such as in a harbour mouth. Modelling studies will be required to determine the likelihood of this and the optimal placement of turbines to minimise coastal erosion on a case-by-case basis.

4.1.2 Collision

Laist et al. (2001) examined the contributing factors to vessel strikes of marine mammals in 58 collisions. Of 11 species known to be hit by ships, fin whales (*Balaenoptera physalus*) are struck most frequently; right whales (*Eubalaena glacialis* and *E. australis*), humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter catodon*), and gray whales (*Escricbtius robustus*) are hit commonly. In some areas, one-third of all fin whale and right whale strandings appear to involve ship strikes. Their results indicate that all sizes and types of vessels can hit whales, but most lethal or severe injuries are caused by ships 80 m or longer. Whales were usually not seen beforehand or were seen too late to be avoided. Most lethal or severe injuries involved ships travelling 14 knots or faster.

Most large whales occur near the coast in New Zealand waters only seasonally, and tend to follow consistent migration paths (*e.g.,* Dawbin, 1956; Gibbs & Childerhouse, 2000). Collision risk is likely therefore only where large vessels are employed to service a facility placed near a migration path. There are large information gaps concerning the collision risk of marine mammals with static structures. This is most likely due to a lack of instances where marine mammals have collided with non-moving objects.

4.1.3 Noise

Wave energy facilities are unlikely to generate noise beyond ambient. Madsen et al. (2006) reviewed the measurements of underwater noise taken from wind turbines and found considerable variability in the noise production from different types of installation, depending on how the system was constructed. Neither Madsen et al. (2006) or Wahlberg & Westerberg (2005) could foresee any problems caused by sound from wind farms for marine mammals or fish, respectively. Underwater turbines may produce low frequency sound from the action of the turbines. Propagation levels are unknown but the total noise production is likely to be less than that produced by a passing ship (*e.g.,* Madsen et al. 2006), and in high current conditions is unlikely to exceed ambient sound levels.

4.1.4 Electromagnetic Fields

Several marine species use magnetic and electrical fields for navigation and locating prey. Electrical fields (E fields) are proportional to the voltage in a cable, and magnetic fields (B fields) are proportional to the current. All fish are sensitive to a greater or lesser extent to electric fields. Sharks and rays in particular may find their prey using the weak field emitted by fishes (Kalmijn, 1982) and may employ electromagnetic fields for navigation (Paulin, 1995). Electro-sensitive species may be either attracted or repelled by such fields, depending on their strength (Kalmijn, 1982; Gill 2005). If sharks are attracted to fields emitted by the cables, attacks on the cables may cause damage to the cable (Marra, 1989), although the likelihood of such attacks will be considerably reduced if the cable is appropriately shielded.

In a typical industry-standard cable conducting 132 kV and an AC current of 350 A, the size of the B field would be of low magnitude: ca. 1.6 μT (micro-Tesla) and present only directly adjacent to the cable. It has been shown that such a field would fall to background levels (ca. 50 μT) within 20 m of the cable (CMACS, 2003). Some species of shark have been shown to respond to localized magnetic fields of 25 - 100,μT (Meyer *et al.,* 2005). In terms of potential, it has been shown that the electro-sensitivity of two tropical elasmobranchs is in the order of ca. 4 nV (nano-volts) cm^{-1}, and probably detect their prey at a range of 0.25 m (Haine *et al.,* 2001). In the study of Marra (1989), the cables emitted induced E fields of 91 μV from cables buried to 1m. It is entirely possible that benthic-foraging elasmobranchs (especially rays) may detect and react to even weak E fields from AC cables. It is, however, equally likely that the range of influence of the field will be limited, and appropriate shielding measures will reduce the likelihood of deleterious effects. Cables carrying direct current (DC) from individual installations are likely to carry only 10 - 15 kV, which is unlikely to generate any electrical field more than a few cm from the cable, especially if a 3-phase carrier is used. However, high voltage DC cables may produce fields of up to 5 μT at up to 60 m (Westerberg & Begout-Anras 2000). More recently, Westerberg & Lagenfelt (2008) found evidence that a 3-phase 130 kV cable (unburied) may be detected by migrating European eels *Anguilla anguilla* but did not disrupt their migration. Although some marine animals such as turtles may use the earth's magnetic field for navigation (Lohmann & Johnsen, 2000), evidence for marine mammal utilisation is equivocal (Hui 1994). Such limited range fields are unlikely to be detected by pelagic species. Confirmation is needed from experimental studies of New Zealand elasmobranch species' reactions to varying cable shielding and current configurations.

4.2 IMPACTS ON SPECIFIC GROUPS OF INTEREST

4.2.1 Benthos

Given that tidal generators will be placed in areas of high current flow, the substratum will most likely comprise bedrock or coarse gravels. For these installations, it is unlikely that any scour effects will occur as a result of small-scale alterations to current flow. Scouring effects however could be expected for wave generator installations over soft to medium course sediments, an issue highlighted for offshore wind farm developments (Black, 2008). Movement of the cable carrying power from the generator to the shore may potentially remove epifauna from the substratum, especially where it crosses bedrock.

4.2.2 Marine Mammals (including Hector's & Maui's Dolphins)

There are large information gaps concerning the collision risk of marine mammals with static structures. This is most likely due to a lack of instances where marine mammals have collided with non-moving objects. Some species (*e.g.,* right whales) may be vulnerable to entanglement with mooring lines (S. DuFresne, *pers. comm.*), probably because fine ropes are not easily detectable visually. The probability of large cetaceans failing to detect or avoid a large static structure is considered to be extremely low, particularly for those species that use sonar. The well-developed sensory abilities and agility of seals and dolphins (Table 4.1) make it unlikely that they will be drawn through a turbine, but should this happen it is probable that they will pass through the centre of an open-ring turbine. Unshielded horizontal-axis rotor turbines may produce rotor-tip speeds of sufficient velocity to cause significant damage to animals colliding with them. Such structures may require audible alarm systems to facilitate avoidance by mammals and birds.

	Pinnipeds (seals & sealions)	**Delphinids (dolphins)**	**Large Odontocetes (toothed whales)**	**Mysticetes (filter-feeding whales)**
Sight	Strong (primary sensory system) Deficient colour sensitivity Eyes face forward Binocular	Strong Deficient colour sensitivity 120-130° Panoramic	Strong Deficient colour sensitivity 120-130° Panoramic	Strong Deficient colour sensitivity 120-130° Panoramic
Sound	Passive acoustics only Broad sound production and hearing range (~50Hz – 60kHz)	Active & Passive acoustics High frequency whistles and echolocation (~1 – 150kHz)	Active & Passive acoustics High frequency sound production and hearing range (~1 – 150kHz)	Passive acoustics only Low frequency sound production and hearing range (~10Hz – 10kHz)
Mechano-reception	Tactile Vibrissae follicles (whiskers)	Tactile	Tactile	Tactile
Chemo-reception	Limited olfaction (capable on land) Gustation limited (data deficient)	Very limited olfaction Gustation limited (data deficient)	Very limited olfaction Gustation limited (data deficient)	Very limited olfaction Gustation limited (data deficient)

Table 4.1: Sensory Capabilities of Marine Mammals by Group

The exact placement of marine energy structures may have consequences for species that utilise particular areas, either through site fidelity (animals having a fixed home range) or seasonal use of particular habitat. Dusky dolphins (*Lagenorhynchus obscurus*) have been shown to avoid areas occupied by mussel farms when foraging (Markowitz et al. 2004), and it is likely that the endangered Hector's dolphin (*Cephalorhynchus hectori*) may also be subject to displacement by coastal construction. Hector's dolphin have however, been observed to swim freely within mussel farms in Golden Bay (K. Grange, pers. comm., Figure 4.1). More detailed data on coastal dolphin feeding and breeding sites are required to inform exact siting of marine energy devices.

Figure 4.1: Hector's Dolphins within a Mussel Farm in Golden Bay

4.2.3 Birds

No noise production exceeding ambient levels is envisaged. Risk of collision with the structure is expected to be minimal. Penguins and shags may be attracted to the vicinity if the structure acts as a fish aggregating device. Little blue penguins, *Eudyptula minor*, breed around the New Zealand coast and use nearshore waters as foraging grounds. Although the greatest recorded depth of a little blue penguin dive is 69 m (Ropert-Coudert *et al.,* 2006), their foraging range is usually < 50 m, and most dives are < 30 m (Chiaradia *et al.,* 2007). While it is therefore possible that penguins could encounter an operating turbine, it is unlikely to happen during strong current flow periods when the turbine lies at depths > 50 m. Slow turbine speeds relative to the agility of penguins makes it unlikely that any collisions will occur.

4.3 FISHERIES

There are two main areas in which the functioning turbine may have impacts on fish assemblages: presence of the structure itself, and the emission of electric fields. It is generally true that the addition of material structure increases the physical complexity of the seabed, thereby providing an increased surface area (and thus habitat) for benthic fishes (*e.g.,* Hixon & Beets, 1993; Tupper & Boutilier, 1997). Secondly, a turbine or wave device may act as a fish aggregation device (FAD) for pelagic species. We therefore consider that the generator structure as a whole is likely to aggregate fish densities around the structure.

There is a possibility of fish mortality occurring due to collision with moving turbine blades. This would be most likely under high current (> 2.5 m s-1) flow conditions that would increase the turbine speed and reduce a fish's capacity to manoeuvre. However, Usachev *et al.* (2004) reported a mortality rate of < 1% for fish < 25 cm passing through a tidal turbine of 3.3 m diameter, operating at 72 rpm. Likely damage to fish will depend on the ambient water currents and the speed of the turbine blades, especially tip speed for propeller type turbines.

Electrical fields from DC cables are likely to be extremely weak, as are those from appropriately shielded AC cables. A t the reported voltages, electromagnetic fields from shielded DC cables should not be detectable at > 10 m from the cable (*e.g.,* Talisman Energy Ltd., 2005). Thus any EM fields will be only local in extent and will be unlikely to interfere with the navigation abilities of species that utilise magnetic fields.

4.3.1 Commercial, Customary and Recreational Fishing

Commercial, customary and recreational fishing are important activities in the in New Zealand coastal waters and beyond. Fishing activities range from recreational and customary collection of paua, rock lobster and kina close to the foreshore to deeper-water commercial fishing (*i.e.,* less than 100 m, for hoki and other species) further out in the CMA. The MRA, Fisheries Act and Submarine Cables and Pipelines Protection Act exclude fishing activities from the CPZ, marine reserves and ASCVs.

General information on exclusion zones and fishing management areas for specific species can be found on the Ministry of Fisheries' NABIS on-line map database (www.nabis.govt.nz). Further details on species-specific fishing exclusion zones can be found in reports by the Department of Conservation (Froude, 2004), although the Ministry of Fisheries administers the exclusion zones.

Fishing interests are likely to have concerns regarding both spatial exclusions around marine energy projects and potential effects on fish stocks. It is likely that marine energy projects will require navigation and fishing exclusion zones around them. This exclusion may have an impact not only on fishing but on fishers' access to more distant grounds. There is also a perception that marine energy projects will add to the cumulative impact of closures for other reasons (marine reserves, AICVs). Fishers already face these exclusions as well as specific issues, such as Fisheries Act regulations and a ban on vessels >45 m in length within 1 nm of the coast.

The New Zealand Seafood Industry Council (SeaFIC) advises that fishing activities are likely in all areas of the CMA that are not subject to exclusions. The absence of any indication of active fishing does not mean that areas where marine energy projects may be proposed will not compete for space for fishing or navigation of fishing vessels. Early direct contact with quota owners and other fishers will determine definitively the location of areas that are most important for fishing in any part of the CMA (or alternatively, less important). SeaFIC can direct marine energy project developers to the appropriate quota owners and other fishers.

4.3.2 Fish Farms

Marine energy devices are likely to form new habitats for fishes, through the addition of structure to otherwise featureless habitat. Negative impacts on fished stocks can be envisaged only if arrays form barriers to migration of recruits from juvenile to adult habitat, or if arrays occupy sites of spawning aggregations and consequently disrupt reproductive success. For example, juvenile snapper (*Pagrus auratus*) are known to utilise estuaries in northern New Zealand (Morrison & Carbines, 2006) but it is unknown if an array of submarine turbines at the mouth of a harbour may influence fish movement into and/or out of this habitat. Wave energy devices are unlikely to have any effect. Many species of temperate fishes form aggregations for spawning (including snapper) and it may be imprudent to site turbine arrays at these locations, where known.

4.3.3 Aquaculture

Coastal aquaculture facilities in New Zealand are dominated by Greenshell™ mussels (*Perna canaliculus*) and king (or chinook) salmon (*Oncorhynchus tshawytscha*). Both types of activity require sheltered waters without strong currents or wave action and therefore tidal stream devices are unlikely to impinge on present developments. However, this may change as the aquaculture industry expands into offshore development in more exposed waters (Langan, 2008). It could be envisaged that as limitations on coastal space restrict access for both aquaculture and moored wave energy devices, that there could be advantages in combining the two technologies in the future to reduce impacts and development/legislative costs.

4.3.4 Exclusion Zones

Deployment of marine energy devices will require the limitation of other human activities, both in the vicinity of the devices and around cables. In coastal areas, this may restrict recreational and customary fishing activities. However, it is probable that in some areas an exclusion zone may act as a marine reserve, accumulating high densities of fished species where appropriate habitat is found (Davidson, 2001; Willis *et al.,* 2003). Movement of fish out of the exclusion zone may offset lost fishing area.

PART 5: SUMMARY AND CONCLUSIONS

5.1 SUMMARY

This report is an early-stage review of the potential environmental effect of marine energy converters, which are likely to be deployed in New Zealand waters in coming years. Not all types of devices are likely to be suitable here, in part because of their environmental effects. However, wave and tidal stream devices may have environmental effects, which are limited in geographic spread, potential seriousness and time. Most effects may be limited to the operational life of any device deployment. Floating or bottom-resting wave and tidal stream devices may have no irreversible long-term effects, other than the requirement for drilling anchor points into the seabed.

Physical effects may be restricted to the placement of hard structures and cables, visual impacts, noise and modification of the local hydrodynamic environment. Effects on the biota cannot be defined with certainty. Only deployments and monitoring will identify the interactions of endemic species but international experience to date is encouraging: biota tends to avoid the areas of high energy flux instinctively, in which marine energy converters will be located. Monitoring and mitigation by adaptive management will address specific issues as they arise.

5.2 CONCLUSIONS

Marine energy converters offer the opportunity for New Zealand to harness the energy in its extensive and energetic coastal marine area. In due course, they will contribute to New Zealand's future energy supply security, reduce the country's greenhouse gas emissions and contribute to its economic prosperity. Nonetheless, marine energy converters (or arrays of them) will take up space currently freely accessible to other users, although it may do this in such way that both uses can be accommodated.

It is too early to draw firm conclusions or put in place mitigation measures to deal with the environmental effects outlined in this report. Local effects, particularly on endemic biota, will only be identified by deployments preceded by baseline measurement and combined with operational monitoring and adaptive management.

This report takes the first step to developing a risk management framework, which future project developers and territorial authorities can use to deal with the environmental consequences of the deployment of marine energy converters in New Zealand waters.

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