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Current State of Knowledge on the Environmental Impacts of Tidal and Wave Energy Technology in Canada

L'état actuel des connaissances sur les répercussions environnementales des technologies de transformation de l'énergie marémotrice et houlomotrice au Canada

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ABSTRACT

Canada's vast, highly energetic coastal waters make ocean renewable energy, particularly wave energy conversion (WEC) and tidal in-stream energy conversion (TISEC), technologies an attractive option to help meet the country's future energy needs. As with other marine developments, activities associated with construction, operation and decommissioning of ocean renewable energy technologies have the potential to impact marine ecosystems and organisms, both at local (near-field) and regional (far-field) scales. To support the development of policy and regulations to govern the Canadian TISEC and WEC industry, a scientific overview of potential environmental impacts associated with the deployment of these marine energy devices was conducted. Identified issues of concern included changes in physical processes (wave, current and sediment transport regimes), habitat loss and alteration, contaminants, electromagnetic fields, noise and vibrations and the physical interaction between energy conversion devices and living organisms. Consideration is also given to the application of potential mitigation measures and the identification of knowledge gaps and research needed to address future regulatory compliance requirements in Canada. Due to the novelty of WEC and TISEC technologies, there is still a great deal of uncertainty surrounding their potential environmental implications. The review of current scientific publications and technical reports indicate that few TISEC or WEC devices have undergone comprehensive environmental impact assessments using predictive numerical models and/or field trials. Practical experience with these technologies in Canadian waters is almost non-existent. The limited number of scientific publications or systematic research data available creates a major hurdle for evaluating environmental risks associated with emerging ocean renewable energy technologies. This document identifies the major issues of concern that require further scientific study to support the development of policy, regulations and operational guidelines to ensure the protection of our marine environment and the organisms that live in it.

RÉSUMÉ

La grande énergie des vastes eaux côtières du Canada fait de cette énergie renouvelable, en particulier les convertisseurs d'énergie marémotrice dans les cours d'eau (TISEC) et les convertisseurs d'énergie houlomotrice (WEC), une option intéressante pour aider à combler les futurs besoins énergétiques du pays. Tout comme pour d'autres activités marines, les activités liées à la construction, à l'exploitation et à la désaffectation des technologies de transformation de l'énergie renouvelable des océans peuvent influer sur les écosystèmes et les organismes marins, tant à une échelle locale (à proximité) que régionale (à distance). Afin d'appuyer l'élaboration de politiques et de règlements pour régir l'industrie canadienne de TISEC et de WEC, un aperçu scientifique des répercussions environnementales possibles liées au déploiement de ces dispositifs d'énergie de la mer a été présenté. Les questions préoccupantes déterminées incluaient les changements dans les processus physiques (vagues, courants et régimes de transport des sédiments), la perte et la perturbation de l'habitat, les contaminants, les champs électromagnétiques, les bruits, les vibrations et les interactions physiques entre les dispositifs de transformation de l'énergie et les organismes vivants. On examine également l'application de mesures d'atténuation éventuelles et la détermination des lacunes dans les connaissances et la recherche nécessaires pour répondre aux futures exigences de la conformité réglementaire au Canada. Étant donné que les technologies de WEC et TISEC sont nouvelles, un climat de grande incertitude continue d'entourer leurs incidences environnementales possibles. L'examen des publications scientifiques et des rapports techniques actuels indique que peu de dispositifs de TISEC ou de WEC ont fait l'objet d'évaluations approfondies quant aux incidences environnementales à l'aide de modèles de prévision numérique et/ou d'essais sur le terrain. L'expérience pratique de ces technologies dans les eaux canadiennes est quasi inexistante. Le nombre limité de publications scientifiques ou de données de recherches méthodiques disponibles crée un obstacle important pour évaluer les risques environnementaux liés aux nouvelles technologies de transformation de l'énergie renouvelable des océans. Le présent document présente les principales questions préoccupantes nécessitant une étude scientifique plus approfondie pour appuyer l'élaboration de politiques, de règlements et de lignes directrices opérationnelles pour assurer la protection de notre milieu marin et des organismes qui y vivent.

INTRODUCTION

With the rapid worldwide development of ocean renewable energy technologies, particularly wave energy conversion (WEC) and tidal in-stream energy conversion (TISEC) devices, harnessing the waves and tides of Canada's vast, energetic Atlantic, Pacific and Arctic coastal waters is emerging as a potentially promising source of renewable energy that could enable the country to reduce its reliance on fossil fuels. However, due to the novelty and diversity of WEC and TISEC technologies, there is still a great deal of uncertainty surrounding their potential environmental implications. To ensure that these technologies are consistent with Canada's conservation and sustainability priorities, it is essential to acquire a firm understanding of the potential environmental implications for all three Canadian coasts.

The aim of this overview document is to address the following questions:

- What is the current state of scientific knowledge on the known environmental impacts of these technologies and is it applicable in the Canadian context?
- What forms of mitigation measures have been applied to these technologies and how effective have they proven to be?

The ultimate goal is to identify and summarize what is known about key environmental concerns and knowledge gaps applicable to informing the development of environmental guidelines for use by the Canadian TISEC and WEC industry.

The document covers impacts to benthic organisms and habitats, fish and fish habitat, and marine mammals and sea turtles related to all stages of TISEC and WEC development including installation, operations and decommissioning. Other potential marine renewable energy technologies, such as tidal barrages and lagoons and wind power, were outside the scope of this review.

In the current study, two search methods were used to acquire information on the current state of knowledge on environmental impacts of these devices: a detailed library and web-based search of published "peer-reviewed" and "grey" literature (i.e., scientific/technical, monitoring and assessment reports and studies); and an e-mail request to technology developers (especially those with Canadian interests) for information on any completed or planned environmental research initiatives related to their devices. Despite a good response rate from developers and the availability of numerous documents on the subject, the survey indicated that there was limited additional research conducted on these technologies to date.

RESOURCE POTENTIAL IN CANADA

There have been only a few attempts to assess the potential wave and tidal energy available for extraction from Canadian waters (Garrett and Cummins 2004, 2005; Cornett 2006; Sutherland et al. 2007; Blanchfield et al. 2008; Karsten et al. 2008). Those that do exist establish only a theoretical maximum extractable power, which is likely much higher then the practical upper limit (environmental and technological limitations). Modeling methodologies, underlying assumptions and efficiency claims by device developers are highly variable, and there is considerable uncertainty as to the size of the energy resources and what fraction of the energy can actually be harvested. For a general picture, Cornett (2006) estimated that the annual mean wave power along the 1,000 m isobath off the Pacific coast is approximately 37,000 megawatts (MW), whereas that along the Atlantic coast is approximately 146,500 MW. Although the Atlantic estimate is greater, the high potential areas are far off shore and thus probably less feasible for extraction compared to the Pacific coast. Cornett (2006) estimated the total tidal energy on the three coasts at more than 42,000 MW, with more than 190 sites as having potential to generate more than 1 MW. Most of the resource is found in Nunavut. High potential sites (>1 MW) are also identified in British Columbia, the Bay of Fundy and Cape Breton. Potential environmental impacts from the extraction of wave and tidal energy within the regions will be linked to the scale of overall commercial development.

CURRENT STATE OF RESEARCH

To date, the majority of WEC and TISEC devices are still in the conceptual stage or have only been subjected to wave tank tests or short-term intermittent sea trials. However, a few technologies are more mature and have been demonstrated for prolonged periods at sea. These include: the MCT (Marine Current Turbine) SeaFlow™ system deployed in the Bristol Channel, UK, in 2003; the Kobold vertical axis turbine launched in the Strait of Messina, Italy, in 2002; six grid-connected Verdant Power Free Flow™ tidal turbines installed in the East River, New York (Roosevelt Island Tidal Energy [RITE] project) since 2007; and coastal-mounted (oscillating water column) WEC demonstration systems in Scotland (Limpet) and Portugal (Pico Plant).

Governments of many countries, including Wales (ABPmer 2005), the United States (Michel et al. 2007), Scotland (Faber Maunsell and Matoc [FMM] 2007) and Canada (Jaques Whitford 2008), have recently undertaken comprehensive environmental reviews/assessments to begin to understand the potential impacts and regulatory needs raised by this rapidly emerging industry. The *Scottish Marine Renewables Strategic Environmental Assessment* has been one of the most comprehensive scientifically-based assessments of the potential environmental risks of, and sensitivities of marine species and habitats to, particular changes arising from wave and tidal energy development activities off the coasts of Scotland (FMM 2007).

Regardless, few TISEC or WEC technologies have been examined in terms of environmental effects, either through numerical modeling or field testing, and few developers have plans in place for future comprehensive environmental research or monitoring programs (beyond basic regulatory requirements). Where projects have been coupled with more rigorous environmental studies or monitoring programs, details are typically not released by developers to outside researchers or the public. Of the few available environmental assessments and monitoring reports, most provide only rudimentary analyses, observations or discussions of potential impacts.

Information on the effectiveness of mitigation techniques at the few existing international pilot projects is entirely lacking. Although certain inferences may be drawn from experiences and research associated with other commercial energy recovery initiatives in coastal regions such as wind farms, oil and gas platforms and tidal barrages, TISEC and WEC devices present many novel conditions and, therefore, the implications are not directly comparable.

The limited number of peer-reviewed scientific publications, systematic monitoring and pre-deployment baseline studies available creates a major hurdle for evaluating emerging ocean renewable energy technologies for unacceptable environmental impacts, such as impacts on “species-at-risk” (i.e., SARA species), harmful alteration to sensitive fish habitat or disruption to migration routes for commercially important species. Uncertainties related to natural inter- and intra-annual variation and climate change will further complicate the delineation between marine energy technology-induced changes and those caused by natural or other anthropogenic sources. Additional scientific knowledge is needed for the development of effective guidelines and regulatory procedures to ensure the health and sustainability of the marine environment and the organisms that live in it. The novelty, complexity and design-, location- and scale-specific nature of the potential impacts imposed by these diverse technologies emphasize the need for progressive research, risk assessment and adaptive management.

CURRENT STATE OF TECHNOLOGIES IN CANADA

Practical experience with these technologies in Canadian waters has been limited to date. Sea trials have been on going at the 65 kW Pearson College-Encana-Clean Current tidal turbine deployed at Race Rocks Ecological Reserve in British Columbia since 2005. However, until 2008, its operation was intermittent, and very little research was conducted to quantify the levels of environmental impacts associated with its operation. A long-term monitoring program for this facility is planned to begin in the near future. A number of demonstration projects are beginning to emerge in Canada. The Canoe Pass Commercialization Project, to demonstrate two 250 KW EnCurrent tidal turbines, has been proposed for the Campbell River, BC. Verdant Power is currently planning the Cornwall Ontario Renewable Energy (CORE) project in the St. Lawrence River, which will demonstrate a redesigned Free Flow turbine, and is expected to grow to a commercial-scale array. A TISEC demonstration facility for multiple devices is under development in Minas Passage, Bay of Fundy. A comprehensive strategic environmental assessment (SEA) was recently completed by the Nova Scotia and New Brunswick governments for tidal energy projects to be located in the Bay of Fundy (Jones 2008; Offshore Energy Environmental Research Association 2008). This SEA background report (Jacques Whitford 2008) provides a detailed review of available information on baseline conditions in the region, and a general exploration of the potential risks and research needs specifically related to local conditions, but does not include any new technical assessments or modeling. On the Pacific Coast, WEC proposals have been announced for a 4 MW demonstration facility in Ucluelet and a SyncWave™ demonstration project near Tofino.

TIDAL BARRAGES AND LAGOONS

Tidal barrage systems have been operational for decades and the environmental effects have been fairly well studied, particularly at La Rance (France) and the Annapolis Tidal Generating Station (Nova Scotia) (e.g., Daborn 1984; Daborn et al. 1993; Retiere 1994). Research at Annapolis has focused on fish passage, biofouling and the impacts on vertical mixing and sediment dynamics (e.g., Daborn 1984; Daborn et al. 1993). The overall conclusion of the many studies in the Bay of Fundy and elsewhere is that barrage-type tidal power installations have significant and generally adverse environmental effects, particularly upon fish, birds and sediments.

At present, tidal power lagoons are purely conceptual; there are no practical examples at any scale. The structure and mode of operation of this system are quite different than other devices, and, therefore, predicting environmental implications can only be based on expert opinion and assumptions. However, to generate enough energy to be cost-effective, a lagoon system will require a large area (i.e., direct footprint) (likely 4 km at minimum), within which there will be significant habitat changes. The most advanced proposals and inquiries have been contemplated for Wales, particularly Swansea Bay (Baker and Leach 2006). Tidal lagoons are primarily suited for meso- and macro-tidal environments; in Canada, these areas are found primarily in the Atlantic region (e.g., the Bay of Fundy), Ungava Bay and James Bay. Although not currently a priority, an assessment of the impacts of this technology should be revisited if and when more information and interest emerges.

PHYSICAL PROCESSES

CURRENT KNOWLEDGE ON POTENTIAL IMPACTS

Changes in wave exposure and current flows and the subsequent effects on sediment dynamics and coastal erosion could have direct and indirect effects on marine and coastal habitats and wildlife (see Ecological Effects Section).

Although some numerical modeling has been attempted, due to the dynamic and variable nature of waves within and between marine systems, the potential effect on wave climate, sediment and coastal processes of WEC devices is complex and poorly understood. Moreover, to date, few TISEC and WEC designs have been rigorously explored in terms of their effects on current velocity and patterns and sediment processes. Nevertheless, due to the generally advanced understanding of fluid dynamics and sea shelf models, it may be possible, with accurate data on site characteristics, to develop more reliable predictions of the influence of tidal energy extraction on local and regional tidal regimes (Jacques Whitford 2008).

Despite extensive modeling of the effects of offshore wind farms on wave and tidal regimes and coastal processes, the findings are not directly applicable to wave and tidal devices, due to substantial differences in design, modes of operation and environments in which they are deployed.

Wave and Tidal Effects

Several studies have been completed to investigate the maximum energy extraction potential of WEC and TISEC devices under particular physical situations (Garrett and Cummins 2004, 2005; Sutherland et al. 2007; Blanchfield et al. 2008; Karsten et al. 2008). Many of these also examined, to a lesser degree, the effects on wave climate and tidal flow. However, results are site- and design-dependant, and, therefore, effects at one site are not necessarily indicative of effects at another. Project specific data and models are needed to develop confident predictions for proposed deployments.

According to numerical modeling undertaken for the Scottish SEA (FMM 2007) and UK Wave Hub facility (Halcrow Group 2006), a wave energy facility absorbing 100% wave energy could result in a reduction in wave height at a shoreline 20 km away of between 3 and 13%, depending on the types and density of the devices at the facility. However, both studies noted that the results should be considered highly conservative since it is unlikely that any device would be operated to extract all wave energy. Similarly, based upon modeling of the effects of an array of 180 Pelamis-type wave energy conversion generators spread over 12 km of shore, Hagerman and Bedard (2004) estimated that the total reduction in wave height at the shore would be about 12%, although the value would obviously vary as a function of distance of the devices from shore. These models have yet to be validated under actual ocean conditions.

Systematic modeling undertaken at the Wave Hub facility indicated a possible local reduction in current velocities of up to 0.8 meters per second (m/s), depending on the WEC device, as a consequence of wave energy extraction (Halcrow Group 2006). Due to physical flow interference and the extraction of tidal energy, TISEC devices, to some extent, are likely to alter current patterns around the device and reduce downstream velocity. Modeling for a proposed scale-up of the Verdant Power RITE project in New York from 6 to 30 turbines (equal to 2 MW energy extraction and 1 MW useable energy) indicated small downriver current velocity reductions of ~0.07 m/s, significant changes in flow directions downstream of the system, and a slight increase in water level at the channel inlet (0.0012 m) (Verdant Power 2008). The extent of influence would depend on the device; however, the effect is expected to be fairly localized (FMM 2007). For example, wake measurements at the 300 kW Seaflow™ tidal turbine deployed off the UK coast indicated that the tidal impact became undetectable 200 m downstream of the rotor (Frankael 2006).

Sediment and Coastal Processes

As a result of hydrodynamic changes, TISEC and WEC developments could modify local sediment transport patterns (re-suspension and deposition) or scour (erosion) due to the effect of: 1) physical structures that alter the flow of water; and 2) removal of energy from the system by the devices. Floating WEC devices are expected to cause only slight local sediment flow disturbance, and scour primarily around the moorings and anchors. Seafloor-mounted WEC and TISEC systems are expected to have larger impacts on sediment flow, scour and turbidity around the bases of individual devices and entire arrays. Coastal-mounted WEC systems will likely have a significant local effect on coastal and intertidal areas. However, there is currently no published information from existing systems to verify the presence and level of predicted effects and their impact on ecosystem productivity.

In addition to local effects, changes to wave patterns caused by wave energy extraction could have far-field affects on sediment deposition and erosion patterns along long stretches of coastline (FMM 2007; Michel et al. 2007). Moreover, according to analysis by FMM (2007), modified current flows due to TISEC devices deployed in enclosed sites, such as bays and inlets, could influence wave patterns and, thus, influence coastal erosion processes; however, the effect is expected to be minimal for devices deployed in open ocean sites. The extent of the effect of any project would depend on the device characteristics, distance from the coast and natural coastal structure and processes, with soft coastlines being particularly sensitive. As an example, modeling for the Wave Hub suggested that the facility should have no discernable effect on the coast 20 km away (<0.2 m change in beach level during extreme storms), which is less than typical natural seasonal changes (Halcrow Group 2006).

MITIGATION

Several recommendations have been made for the mitigation of effects associated with changes in wave climate, current flow patterns, sediment dynamics and associated impacts (FMM 2007; Michel et al. 2007). Based primarily on alterations in project design and installation, they include:

- Avoid projects that would have negative impacts on soft coastal habitats and other habitats sensitive to changes in wave and current flows (e.g., tidal marshes).
- Select site appropriate technologies and array designs.
- Provide appropriate spacing between devices to reduce hydrodynamic interactions and create lower impact zones for marine life passage.
- Provide adequate spacing between devices to reduce hydrodynamic interactions.
- Install scour protection structures around pilings to reduce erosion and sediment re-suspension.

There is no practical evidence of the effectiveness of these measures and there have been no suggestions for operational or decommissioning stage physical impact mitigation.

CANADIAN APPLICABILITY AND KNOWLEDGE GAPS

Since they were based on highly conservative assumptions (energy extraction levels) and/or specific environmental and device characteristics, results from the existing modeling (e.g., Wave Hub) and monitoring (RITE project) investigations are not likely representative of those for other projects. Predictive modeling will need to be done on a case by case basis. Existing hydrodynamic and sediment process models are likely appropriate for predicting the effects of individual WEC and TISEC devices on wave and current energy and sediment dynamics in various Canadian climates such as the Bay of Fundy (Jacques Whitford 2008). However, effective modeling requires an accurate understanding of site specific hydrodynamics and sediment transport processes (Jacques Whitford 2008), which may be sufficient for only a few marine and coastal areas in Canada. Moreover, current models do not address multiple device interactions and cumulative effects of large-scale arrays, and therefore cannot accurately predict the likely detrimental effects associated with full-scale deployments.

There have been some studies investigating the tidal energy resource potential in British Columbia and the Minas Basin (Nova Scotia) (Sutherland et al. 2007; Blanchfield et al. 2008; Karsten et al. 2008). However, at present, with the exception of a relatively new program in the Minas Basin (P. Smith and T. Milligan, Fisheries and Oceans Canada, Dartmouth, NS; A. Cornett, National Research Council, Ottawa, ON, pers. comm. 2009), little effort has been given to the study of hydrodynamic and sediment effects in the context of WEC and TISEC development within Canada. Furthermore, due to the limited number of operational and/or test devices deployed, there has been little research on the interactions of individual devices or array designs under Canadian environmental conditions. The latter would be beneficial for informing and facilitating the: 1) pre-assessment identification of potentially suitable locations and complementary technologies for demonstration and full-scale projects; 2) development of effective models to estimate consequences of extracting energy in terms of environmentally acceptable or meaningful thresholds accounting for natural variability and future changes (e.g., climate change); and 3) exploration of potential measures to mitigate impacts of energy extraction on wave and tidal flows and associated sediment transport and erosion effects.

Additionally, due to the absence of empirical data or effective models, there is a great deal of uncertainty about the ecological implications (e.g., direct or indirect effects on habitats or species) of changes in physical processes.

ECOLOGICAL IMPACTS

CURRENT KNOWLEDGE ON POTENTIAL IMPACTS

The extent and nature of habitat alteration due to marine energy development will be size-, design- and location-specific, and includes direct loss, disturbance and smothering of benthic, pelagic and coastal habitat and addition of artificial structures. Due to the complexity and limited understanding of marine and coastal ecological processes and interactions, especially those in high-energy environments, it is difficult to develop accurate forecasts of the short-term or long-term effects of these technologies on marine biodiversity and ecological integrity. Moreover, environments suitable for TISEC and WEC technologies are typically high-energy systems, and it may be challenging to distinguish impacts from natural variability. To date, rigorous pre- and post-installation habitat and species productivity analyses or predictive models do not appear to have been conducted for most existing or proposed TISEC or WEC projects.

Construction-related Effects

Marine energy (and other industry) environmental assessments generally classify construction-related disturbance to marine habitats as temporary and low on the scale of impact (AquaEnergy Ltd. 2006; Argo Environmental Ltd. 2006). This hypothesis is supported by data in monitoring reports for existing wind farm and TISEC demonstration projects, which reported no significant long-term impacts to benthic habitats due to construction activities, although recovery of disturbed areas took several years (Archipelago 2006; Dong et al. 2006). However, benthic disturbance, excavation and smothering (by resettled suspended sediments or relocated excavated materials) can have potentially significant long-term and far-field adverse effects on sensitive benthic (e.g., seagrass) and pelagic habitats, species (e.g., scallop) and spawning populations (e.g., herring) (FMM 2007). At one Danish wind farm, Birklund (2005) found that cable trenching, with the temporary deposit of excavated materials adjacent to the trench, impacted an area of benthic habitat along the route 10 times greater than the footprint of the trench itself, and benthic communities were slow to recover. This was believed to be attributed to a delay in backfilling the trench, which allowed the establishment of an invasive and persistent macroalgal benthic community in the disturbed areas.

Habitat Characteristics

Most single or prototype WEC and TISEC devices are only in direct contact with a small area of the seabed and/or coast compared to wind, tidal lagoon or tidal barrage systems. In light of this small “footprint”, environmental assessments generally conclude that the amount of permanently lost benthic, pelagic or coastal habitat to be insignificant (AquaEnergy Ltd. 2006; FMM 2007; Michel et al. 2007). This may be valid where construction is on scoured bedrock with very limited habitat potential, but even the destruction of a small area may be significant if sited on critical, rare and sensitive areas, such as spawning grounds (e.g., herring), tidal marshes, seagrass and corals (FMM 2007). Many suitable WEC and TISEC locations are in areas characterized by a great diversity of benthic organisms that are of importance to fish, and, thus, elimination of this habitat may be of significance. Moreover, depending on the design, large-scale systems may encompass a sizeable area of habitat and have effects that extend well beyond the immediate area of the project. Furthermore, where arrays are placed in naturally open areas or narrow corridors or mouths of bays, the change to a structure-oriented habitat may impede seasonal migratory movements and, thereby, possibly exclude marine mammals and fish from important spawning, feeding or nesting areas (Hagerman and Bedard 2004; FMM 2007).

Some compensation for loss of existing habitat features may be achieved by incorporating habitat enhancement features into the design of the development (e.g., rip rap scour protection) as has been done at Danish offshore wind farms (Dong Energy et al. 2006). Moreover, the increased habitat structure and diversity created by marine energy infrastructure (foundations, anchors, scour protection and exposed transmission cables) can also provide an attractive habitat alternative for invertebrates, fish and shellfish (FMM 2007; Michel et al. 2007).

Epibenthic Organisms

Biofouling communities are typically comprised of plant and animal species that normally inhabit firm bottom substrates and that colonize the hard surfaces of new structures either as spores or larvae or as adults migrating in from surrounding areas. Without antifouling measures in place (see Water Quality and Contaminants Section), marine structures typically become covered by epibenthic organisms, often at higher biomass and/or abundance levels in comparison to pre-existing or surrounding areas. The rapid establishment of epibenthic communities on various structures after installation has been reported at WEC and TISEC projects, wind farms, and other offshore structures (Carney 2005; Continental Shelf Associates 2005; Page et al. 2005; Archipelago Marine Inc. [Archipelago] 2006; Dong Energy et al. 2006; Leonhard et al. 2006a; Langhamer et al. 2009).

Estuaries are notoriously rich in potential epibenthic species; however, areas with high wave or tidal fluctuations (typically characteristics of WEC or TISEC sites) and/or turbidity may be less favourable to diverse epibenthic community development (Jacques Whitford 2008). Epibenthic communities on structures, especially those constructed on soft substrates, often consist of species not previously found in the area (i.e., species that prefer hard surfaces) (Carney 2005; Continental Shelf Associates 2005; Page et al. 2005; Dong Energy et al. 2006; Leonhard et al. 2006a). These species can be native, but studies indicate that marine structures are especially susceptible to colonization by aquatic invasive invertebrates, particularly in harsher environments such as brackish waters (Lu et al. 2007). Some species, such as mussels, barnacles and tunicates, can completely overgrow marine surfaces created by humans, forming monocultures that may persist for years (Thorpe and Picken 1993; Dong Energy et al. 2006; Langhamer et al. 2009). During a five year monitoring program, the surfaces at one Danish wind farm (Horns Rev) developed a much higher species richness compared to the surrounding soft-sediment habitat; whereas, foundations placed at another nearby farm (Nysted) were occupied by a monoculture of Common mussels (*Mytilus edulis*) (Birklund 2006; Dong Energy et al. 2006). The exact reasons for the dissimilarity are uncertain, although differences in salinity or species presence at the time of initial colonization may have been determining factors.

Fish and Shellfish

Through artificial reef effects, marine energy conversion developments could benefit fish and shellfish productivity by providing increased habitat complexity and an increased abundance of prey species (Wilson et al. 2003; Hagerman and Bedard 2004). Although studies have confirmed that many marine industry structures attract high fish abundances compared with pre-existing or surrounding conditions, they are also often found to support a lower or different species diversity (Wilson et al. 2003; Leonhard et al 2006b; Wilhelmsson et al. 2006). The exact factors involved are uncertain and may vary by site. One explanation may be the change in foraging opportunity and risk of predation, with some species being attracted to arrays by higher prey abundances and others deterred due to reductions in availability of preferred prey or increases in predators (Hagerman and Bedard 2004; FMM 2007; Michel et al. 2007). Contrary to expectations, the infrastructure at the two Danish wind farms failed to materialize an increase (or decrease) in fish abundance or diversity during the five year monitoring program. It was postulated that some benthic communities formed on the structures, such as the monoculture of the mussels at Nysted, may not be particularly attractive to fish.

Marine Mammals

Many WEC, and to a lesser extent TISEC, devices consist of sizeable surface floating components, which may make appealing haul-out sites for pinnipeds (Hagerman and Bedard 2004). Through predator-prey interactive feedback, changes in local fish and invertebrate populations can have long-term and far-reaching implications for marine and coastal biodiversity, including marine mammals, bird and sea turtle populations. However, there does not appear to be any published data directly linking marine mammals or sea turtle responses to changes in prey availability around marine structures (Hagerman and Bedard 2004; Michel et al. 2007).

Effects of Changes in Physical Processes

The alteration of wave and current flows and associated sediment and erosion processes from WEC and TISEC development may also have long-term impacts on the structure of marine and coastal communities by (Jacques Whitford 2008):

- Changing sediment re-suspension or deposition patterns due to scour, turbulence or decreased current velocity, thus changing turbidity levels, affecting pelagic species and eroding or smothering benthic or coastal habitats;
- Reducing downstream flow of nutrients and food supply for benthic filter feeders; and
- Indirectly changing the type of prey available for other marine wildlife.

Comprehensive analysis of these risks and relationships between changes in physical processes and habitats and wildlife populations associated with WEC and TISEC development has not been conducted to date. Furthermore, marine energy conversion devices deployed in enclosed areas (e.g., inlets, rivers) may have a proportionally greater influence on wave climate or tidal velocities and patterns, and, in turn, effects on marine wildlife, than those in open areas.

Pilot Study on Biological Effects of Wave Power Structures

Langhamer et al. (2009) is the only peer-reviewed structured research study published on the association of marine organisms with marine energy conversion structures. This recent study investigated the use of foundations by fish and shellfish (artificial reef effects), and epibenthic (fouling) colonization on the foundations and buoys (representing point absorbers) over a three year period at the pre-operational Lysekil Project, a wave power test park on the Swedish west coast. The key findings were:

- The most dominant epibenthic organisms on the foundations were sea squirts (*Ascidiaceae*), calcareous serpulid worms (*Pomatoceros triqueter*), hydroids, red algae and barnacles (*Balanus* sp.), with a higher biomass on vertical compared to horizontal surfaces.
- Few fish and shellfish were reported associated with the foundations. Species were those typically associated with hard bottom habitats, of which crab, occupying holes in the piles, were the most common. A few (3) lobsters were found in cavities under the foundations. Although a higher average abundance and diversity of fish species were noted on foundations than in bare hard bottom sites 10 m from foundations, the difference was not statistically significant and was less than is typical in other complex natural and artificial habitats in the area.
- Buoys were dominated by mussel (*Mytilus edulis),* which constituted approximately 85% of total biomass. Epifauna biomass appeared affected by wave and tidal conditions, being higher on more exposed buoys compared to those in more sheltered areas.

It should be noted that without data during operational periods or rigorous comparison with pre-installation or control site habitat conditions or biotic communities, the study results are limited in terms of drawing confident conclusions regarding what, if any, impact this type of WEC system has and will have on resident species or overall habitat productivity.

Verdant Power's RITE Demonstration Project Fish Monitoring Program

Results from a comprehensive fish monitoring program conducted at the RITE demonstration project in East River, New York, showed a significantly lower abundance of fish in the vicinity of the turbines (Verdant Power 2008). Fish presence and movement was mostly detected inshore of the array (out of the direct influence of turbines and in lower water velocity), especially during turbine operation. Fish movements tended to correspond with non-operational periods, when current speeds were lower. Although there are limitations in the report (e.g., comparisons with pre-deployment or control site), these observations suggest that fish behaviour and movement in the East River is influenced by tidal currents and may be affected by the turbines.

Scottish SEA

Based on an assessment of the available data on tolerance and recoverability potential, FMM (2007) rated 21 fish, 13 shellfish, and 4 marine mammal groups found in coastal waters off Scotland in terms of their sensitivities (see Table 1 for sensitivity criteria) to habitat exclusion, substratum loss, smothering and changes in wave exposure and current flow (Table 2).

MITIGATION

The effectiveness of mitigation procedures to counter the adverse effects of WEC and TISEC developments are largely unknown. Measures of efficacy are likely case-specific due to differences in environmental conditions, technological design and species diversity. The following mitigation measures have been proposed in the marine energy conversion literature (e.g., FMM 2007; Michel et al. 2007; Verdant Power 2008):

- Evaluate and redesign projects at the planning and assessment phases to reduce their footprint and avoid sensitive areas on the seafloor (e.g., as was done at the proposed Makah Bay AquaBuOY™ wave energy pilot project in the US [AquaEnergy Ltd. 2006])
- Avoid projects that would have negative impacts in areas with rare or sensitive habitats or species.
- In all cases, some level of substrate disturbance is expected to occur. Reduce impacts by the use of best management practices that are frequently cited within environmental assessments, including sediment and erosion control measures, limited use of machinery in-water and avoiding work during critical spawning, nursery and migration periods.
- Locate devices and cables to avoid disturbing important habitats such as coral, seagrass, spawning and nursery habitats, migratory routes and areas frequented by species at risk.
- Restore substrate and habitat features as soon as possible after construction or decommissioning is completed.
- Incorporate locally-appropriate habitat enhancement features into the device design.
- Apply horizontal directional drilling methods to route cables through sensitive habitats, such as seagrass beds.
- Design mooring systems that minimize anchor, chain and cable sweep disturbance of the seafloor. Consideration of dynamic positioning technologies to reduce the need for using anchors in sensitive areas.
- Ensure adequate spacing between devices to reduce hydrodynamic interactions and create lower impact zones for marine life passage.

CANADIAN APPLICABILITY AND KNOWLEDGE GAPS

Current and proposed Canadian WEC and TISEC demonstration locations, such as Race Rocks Ecological Reserve, Bay of Fundy and St. Lawrence River, are highly complex and productive ecosystems supporting many rare and sensitive habitats and species that may be adversely affected by the presence of these developments. Through habitat alteration, WEC and TISEC developments could significantly alter the levels of marine productivity and biodiversity, depending on initial site conditions, technology design and species involved. Some generalizations on direct impacts to benthos and fish communities may be ascertained from available short-term observational reports at US and European wind farms and offshore oil platforms. However, long-term systematic studies and predictive modeling analyses on the impacts to habitat structure, biodiversity and ecosystem productivity are needed, with particular consideration of the unique conditions presented by WEC and TISEC devices. Research also appears entirely lacking on the regional-scale responses of migratory populations to changes from open to structure-oriented environments.

Within Canada, programs have been initiated at a limited number of sites to conduct comprehensive habitat assessments, especially related to designated species-at-risk. The scope of such studies must be expanded to provide coverage to proposed WEC or TISEC project sites, when applicable. However, at the present time, despite an increase in effort, the level of confidence provided by the results of numerical risk analysis may remain limited until understanding of ecological-technological interactions, that will largely be derived from future field studies, improves.

There are no peer-reviewed publications on the efficacy of habitat mitigation measures that have been developed for WEC or TISEC devices. As a precautionary measure, it is suggested that accepted mitigation measures used for the deployment of other ocean structures be undertaken (e.g., drilling platforms used for offshore oil and gas exploration and production) until specific techniques for WEC or TISEC devices are developed and validated.

WATER QUALITY AND CONTAMINANTS

CURRENT KNOWLEDGE ON POTENTIAL IMPACTS

Like other marine industries, WEC and TISEC development has the potential to degrade local water quality, with long-term implications for marine life. Substrate disturbance due to construction/maintenance/decommissioning activities, scour effects, and changes in wave exposure and current flows can lead to increased suspended sediments and turbidity, especially in areas with finer substrates such as sand or silt. Sediment re-suspension may directly cause reduced growth of filter feeding organisms (e.g., by altering the nutritional value of suspended particles), deleterious health effects or mortality to fish (e.g., by clogging gills) and a reduction in prey capture success (e.g., by reducing vision) (FMM 2007; Jacques Whitford 2008). While this may be a lesser problem in areas of bedrock, drilling could release a plume of fine material comprised of sharp, angular drill fragments that are potentially more damaging to filter-feeding fish and shellfish compared with natural sediment particles.

Additionally, the construction and operation of WEC and TISEC systems may result in the release of various chemicals at concentrations above toxicity threshold limits. These may include: petroleum hydrocarbons in fuel and lubricants used during construction and operations; biocides used in antifouling agents; and heavy metals released from sacrificial anodes for corrosion protection. Moreover, development activities could mobilize sediments already laden with contaminants accumulated from other marine and land-based undertakings. The effects of common contaminants on marine life are well established in the scientific literature (Stewart and White 2001; Haggerty et al. 2003; Johannessen et al. 2007). Typically, WEC and TISEC environmental assessment reports discount the risks from accidental spills and other contaminant exposure due to the relatively low quantities expected to be used, standard mitigation practices and strong dilution and dispersion processes characteristic of marine systems in which TISEC and WEC devices are likely to be located (Archipelago 2006; Argo

Environmental 2006; FMM 2007; Michel et al. 2007). However, the risks may be significant depending on the types of materials and practices applied at particular projects and the sensitivities of local species.

Based on an assessment of the available data on tolerance and recoverability potential, FMM (2007) rated select species found in North Atlantic waters off Scotland in terms of their sensitivities (see Table 1 for sensitivity criteria) to increased suspended sediment and turbidity and contaminant exposure. For contaminant sensitivity, seals (near breeding sites) and razor shell received a medium rating; green crab (*Carcinus maenas*), cockle, mussel, periwinkle and cetaceans were rated low or very low; and all fish and remaining shellfish were rated as unknown. Seals were rated highly sensitive to increased suspended sediment and turbidity (due to reduced visibility); and baleen whales, dolphins, Atlantic herring, king and queen scallop, cockle, mussel and Norway lobster received medium sensitivity ratings.

Antifouling Agents

Of particular concern related to WEC and TISEC devices is the use of antifouling agents. To reduce erosion and fatigue and maintain operating efficiency, it may be necessary to prevent or remove biofouling communities on most types of WEC and TISEC devices. The most common measure used for biofouling management by marine industries is antifouling coatings/paints. Standard antifouling coatings contain biocides (traditionally, organotins [butyltins] or copper), which are designed to kill organisms that have attached to structure surfaces. Butyltins have been banned in Canada, the US and much of Europe in accordance with the 2005 *International Convention on the Control of Harmful Anti-Fouling Systems on Ships* due to its known toxicity, bioaccumulation, environmental persistence and physiological (endocrine disruptor) effects on target and non-target marine organisms (Haggerty et al. 2003; Johannessen et al. 2007; Michel et al. 2007; Jacques Whitford 2008). Currently, copper-based coatings, which are also known to leach toxic metals into the marine ecosystem, are the predominant antifouling material used by marine industry. Some less and non-toxic antifouling systems, mostly based on the use of non-stick coatings, are being applied or are in development by the shipping and offshore oil and gas sectors (Argo Environmental 2006; FMM 2007), but their effectiveness and applicability on marine energy conversion devices in Canadian waters or elsewhere has yet to be demonstrated.

MITIGATION

The measures to mitigate pollution risks due to WEC and TISEC devices are most likely consistent with the recommended management practices currently used by other offshore industries. Current mitigation measures recommended by the ocean renewable energy technology assessment literature include (Argo Environmental 2006; FMM 2007; Michel et al. 2007):

- Use sediment and erosion control measures, limit in-water use of machinery and avoid work during critical spawning, nursery and migration periods.
- Use fuel and oil spill prevention and contingency planning.
- Use non-toxic lubricants (e.g., vegetable-based oils) on device mechanisms, as is planned for the proposed TISEC demonstration project in New Zealand (Argo Environmental 2006).
- Avoid locating project in areas with high levels of contaminants in sediments.

Available options for the mitigation of impacts associated with antifouling practices are limited. Non-toxic management alternatives are in development; however, there is currently no information available on practical applications of these control methods on existing marine energy structures. The following mitigation measures have been recommended in marine energy conversion assessment literature (Argo Environmental 2006; FMM 2007; Michel et al. 2007):

- Follow best practices by using only small quantities of modern low-toxicity antifouling systems in accordance with the *International Convention on the Control of Harmful Anti-Fouling Systems on Ships, 2005.*
- Give preference to TISEC and WEC designs that avoid the need for toxic antifouling materials.
- Avoid using antifouling agents in sites where biofouling may not be problematic (e.g., areas with high current velocities).
- Avoid locating projects in areas with rare or sensitive habitats or species.
- Minimize the need of antifouling agents through regular mechanical/manual removal. However, the practicality and cost-effectiveness of mechanical removal will be device- and environment-specific.

CANADIAN APPLICABILITY AND KNOWLEDGE GAPS

There has been considerable research on the risks and impacts of exposure of marine ecosystems and organisms to various pollutants commonly used in marine industries in Canadian waters, many of which would be applicable to WEC and TISEC technology. Quantitative analysis techniques are available to estimate the potential release risk and fate of contaminants at TISEC and WEC developments, as well as sediment mobilization and resettlement rates. Acceptable release levels will depend on the exposure probability and sensitivity of nearby marine life, and the rate of dispersion.

Fouling community development has been studied on numerous marine structures and in various marine climates in the US and Europe. In Canadian eco-regions, the issue is a major concern that has been linked to the operational cost of offshore oil and gas facilities (e.g., fouling of the Terra Nova FPSO [Floating Production, Storage and Offloading] vessel). There does not currently appear to be any models available to predict biofouling potential or assess associated operational and ecological risks applicable to Canada. Plans are in place to study biofouling on different structural materials and the effects of different types of anti-fouling agents at the Race Rocks tidal demonstration project (Jacques Whitford 2008). Further research (modeling studies and small-scale sea trials) will be necessary to analyze the effectiveness and environmental safety of less toxic biofouling resistant materials and manual management methods at potential Canadian sites.

NOISE AND VIBRATIONS

CURRENT KNOWLEDGE ON POTENTIAL IMPACTS

A major concern cited in the TISEC and WEC development literature is the potential physiological, behavioural and population impacts of construction/decommissioning- and operation-related noises and vibrations on marine wildlife.

Reponses to construction or operational noise can include short-term behavioural responses (such as startle or moving away from source), masking effects (interfering with prey detection, social communication or navigation), impeding migration, habitat avoidance, temporary or permanent hearing damage and fatality (Nedwell and Howell 2004; Popper et al. 2003/4; Thomsen et al. 2006).

Sources of construction-related noises include increased boat traffic, dredging, drilling, pile driving and cable placement. The level and frequency of these sounds would be comparable to those produced by construction activities for other marine activities. According to the literature, the short duration, high amplitude noise from pile-driving may pose the greatest sound-related risk to marine organisms from marine energy conversion projects (Popper et al. 2003/4; Thomsen et al. 2006). However, it should be noted that this activity is not a component of all TISEC and WEC projects.

The constant low-intensity sounds from the operation of (some) WEC and TISEC prototype/demonstration-scale systems have been compared in the literature to light to normal density shipping (Geo-Marine 2003) and a conventional ferry or subway (Parvin et al. 2005 cited in Argo Environmental 2006; Verdant Power 2008). However, the level and frequency spectrum of operational sound generated by WEC and TISEC systems would depend on the device characteristics and configuration and size of the system. Little data have been published regarding measured sound levels or frequencies produced by WEC or TISEC devices and systems, especially in actual marine environments.

A marine organism’s response to generated noise will depend on its acoustic sensitivity and the level and frequency of ambient background noise compared to that produced by the WEC or TISEC system. There has been considerable published research related to the sound detection ability of various marine organisms, particularly cetaceans. Summaries of the current knowledge are available in Michel et al. (2007) and Richards et al. (2007). While there is a global effort to study the effects of noise in the marine environment generated by seismic air-guns and shipping traffic, there are very limited data available to form any solid conclusions on the noise-related responses of marine life to WEC or TISEC systems (especially operational). No comprehensive long-term examinations have been done to assess or interpret responses to the few existing operational deployments. Nevertheless, there have been numerous studies that may provide some insights on the potential impacts of sounds produced by WEC and TISEC devices.

Verdant Power’s RITE Demonstration Project Fish Monitoring Program

As part of their environmental monitoring program, Verdant Power (2008) measured the sound levels emitted from the four operational tidal turbines at the 1 MW RITE project in the East River, New York. The results indicated that the noise levels produced by the turbines were comparable to those of a subway (which is also a noise source in the river) in the immediate vicinity of the array. The study provided a basic comparison of the measured noise with the known hearing and impact thresholds of local fish species. It found that the sound produced by the array was likely detectable by all fish species (~30 dB above hearing thresholds), but was well below levels expected to cause hearing damage to all test species considered except tautog *(Tautoga onitis)*. No attempt was made to assess actual physiological or behavioural responses of fish to the array sounds.

Underwater Noise Study Supporting Scottish SEA

A study undertaken for the Scottish marine renewables SEA modeled the potential for permanent and temporary hearing damage to result from operating a single generic 1 MW TISEC or WEC device (Richards et al. 2007). This study did not consider damage from long-term exposure, behavioural responses or cumulative noise generated by large-scale installations.

The study predicted:

- The most sensitive organism would need to spend 30 minutes within 16 m of a tidal turbine to suffer permanent hearing damage and eight hours within 934 m to suffer temporary damage.
- Due to the lower noise level, the risk of permanent hearing damage from a wave device would be insignificant and the most sensitive organism would have to spend eight hours within 6 m of the device to any suffer temporary damage.

Moreover, it noted that a (mobile) organism is unlikely to remain in close proximity to a severely loud noise source long enough for serious damage to occur. A more likely response would be to startle, drive away or impede migration of sensitive marine organisms. These types of responses are supported by observational reports from existing marine energy conversion deployments (see below).

Marine Current Technology's Seaflow™ Tidal Turbine Prototype, UK

A study was undertaken to model the effects of noise generated by the 300 kW Seaflow™ tidal turbine prototype deployed off the coast of Lynmouth, UK. Parvin et al. (2005 cited in Argo Environmental 2006) compared operational sound level measurements emitted by the prototype with the estimated detection ranges and impact thresholds of fishes, seals and porpoises.

The study predicted that:

- The noise during operation is below the levels at which fatality and injury of fish, seals or porpoises are likely to occur.
- The operational turbine noise may be audible to some fish species and cause a mild aversion reaction to fishes up to a few metres in proximity to the device.
- At short range, the common seal and harbour porpoise are likely to experience a mild avoidance reaction within 15 m and 108 m of the device, respectively, and a strong aversion reaction within 1 m and 9 m, respectively.

There is no reporting of subsequent on-site monitoring to validate these predictions.

Scottish SEA

Based on analysis of the available data on tolerance and recoverability potential, FMM (2007) rated species found in North Atlantic waters off Scotland in terms of their sensitivities (see Table 1 for sensitivity criteria) to marine noises. Seals, dolphins, porpoises, Atlantic cod and Atlantic herring received a high rating; baleen whales were rated as medium; and Atlantic salmon, thornback ray, sole and plaice rated low. All other fish and shellfish species were classified as either not sensitive or unknown.

Race Rocks Ecological Reserve (BC) Tidal Power Demonstration Project Environmental Monitoring Report

At Race Rocks, visual surveillance detected only minor behavioural responses in harbour seals and sea lions during and immediately after construction (Archipelago 2006). The only reported reaction was the occasional, and temporary, abandonment of haul-out sites in relation to human and boat traffic or drilling activity, with the majority of individuals appearing tolerant of drilling, vessel operation and cable placement. However, monitoring was strictly limited to visual observations taken only during and a few months following construction. No observations are published on the response to operation of the TISEC deployment.

Wind Energy Research

In a study on limited species, Thomsen et al. (2006) established that Atlantic cod and herring should be able to detect pile driving noise and may experience masking effects up to 80 km from the source; whereas Atlantic salmon are much less sensitive to noise in that acoustic range. Most fish species within close proximity to pile driving sounds can experience serious physical damage including instant or delayed mortality and hearing damage (Popper et al. 2003/4; Thomsen et al. 2006). Seals and porpoises were predicted to be able to hear piling noise up to a distance of 80 km and behavioural responses were estimated to occur up to 20 km (Thomsen et al. 2006). Permanent hearing damage could occur within 400 m for common seal and 1.8 km for harbour porpoise.

Multiple techniques, including visual, satellite and acoustic tracking, were used to monitor responses of harbour porpoises and seals at two Danish wind farms (Dong et al. 2006; Tougaard et al. 2006a, b). The researchers found:

- A clear decrease in abundance and acoustic activity of harbour porpoises at both sites during construction, especially pile driving. The porpoise population at one farm returned to pre-construction numbers within two years of operation; whereas, the population at the other remained well below baseline. The reasons for this are unclear at present, but may depend on ambient background conditions.
- Seals exhibited a significant, but temporary, aversion response to pile driving activity, but not other construction activities, with a large decline at one site and a total abandonment of a several kilometres area around the other.
- No significant behavioural responses to operational noise were observed in seals at either site.
- Seals showed a significant aversion reaction to increased vessel (boat and airplane) activity during construction (Sundberg and Soderman 2001).

In a simulation study, Koschinski et al. (2003) recorded wind turbine noise from an existing Swedish wind park and played it back in Fortune Channel, BC, in order to observe the effect on local harbour porpoises and harbour seals. The researchers concluded that harbour porpoises and seals could detect the low-frequency simulated wind turbine noise up to 100 m and 1 km away, respectively. The former appeared to exhibit some avoidance behaviour and investigated the source of the noise with sonar, while the latter responded by surfacing and moving away from the sound.

Marine Invertebrates

Sessile benthic invertebrates are limited in their ability to move away from sound sources and, therefore, may be more vulnerable to both sudden, high intensity construction noises and continual low-intensity operation sound than more mobile organisms. In reviews of the scientific literature, Vella et al. (2001) and Mariyasu et al. (2004) found there has been very little research on the impacts of sound on marine invertebrates. Based on the available information, the former concluded that marine invertebrates are likely to be affected only by powerful sounds if within a few metres of the source; the latter concluded that current information is insufficient to make any inferences as to the impact of marine noise on invertebrates.

MITIGATION

The following are mitigation measures suggested in the literature to deal with construction-related noises (Nedwell and Howell 2004; FMM 2007; Michel et al. 2007). No mitigation measures were found to address operational noises.

- Minimize use of loud activities, such as pile driving or drilling, where possible (e.g., by manual digging). Some devices (e.g., that use dynamic positioning or are attached to the seabed using anchors) do not require these activities.
- Use sound insulation equipment. Bubble curtains have been partly effective at masking sound levels during pile driving (Nedwell and Howell 2004; Michel et al. 2007). However, this technology may be expensive and only effective in shallow water (FMM 2007).
- Use a soft start/ramp up procedure (gradually increasing sound level allowing organisms to move away).
- Schedule installation and decommissioning activities to avoid breeding or migratory periods.
- Use of marine mammal observers or other observation methods to halt activities when animals are in the vicinity.

Some of the provisions in the *Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment* (Fisheries and Oceans Canada 2007) may also be relevant in the case of construction-related noise, particularly pile driving, on marine mammals. Among other conditions, it sets a minimum 500 m safety zone around the project (which is standard in most countries). Furthermore, emerging information and guidelines from the marine shipping and offshore oil and gas industry on mitigation of marine noise will be of major relevance.

CANADIAN APPLICABILITY AND KNOWLEDGE GAPS

There has been very little direct evidence of the response of fish and marine mammals to noises and vibrations produced by operational WEC and TISEC devices in Canada or elsewhere. Modeling studies have indicated that construction and operational noises produced by individual WEC and TISEC devices could potentially cause temporary or permanent hearing loss in porpoises, seals and some fish. However, there are practically no available research or observations on the effects on benthic invertebrates, whales, sea turtles or other marine mammals. The highest impacts would be to animals within close distance to sudden high intensity noises, such as from pile driving or geophysical surveys. However, there has yet to be any evidence of immediate or long-term physical damage to any organism directly caused by marine noises. Since mobile animals are able to move away from the source of the sound, noises may be more likely to cause masking or aversion responses, which have been documented with porpoises and seals at wind farms. To date, noise investigations have been limited to pilot-scale WEC and TISEC devices, not full-scale arrays. Even if the level and frequencies of sound produced by individual devices may be within tolerable ranges, consideration needs to be made to assess the potential additive effects of full-scale arrays and other marine activities on the marine sound environment.

Long-term physiological, behavioural, and population-scale impacts of marine noise on marine mammals, fish, sea turtles and invertebrates are still poorly understood. Sound intensities, frequencies and patterns, and, therefore, threats, will be technology-, and environment-specific. There is need for characterization of noise and vibration sources emitted by different pilot and full-scale systems, and their transmission in specific environments. To facilitate this, the UK-based Wave Energy Centre is coordinating a three year project (2007-2010) to develop, test and validate an acoustic monitoring plan or guideline for wave energy farms and to "characterize noise generation by wave energy prototypes and farms in order to understand their contribution to the background noise at the site and, if this is significant, to identify the parts to the wave energy converters that contribute more to the generated noise, in particular in the frequency range with impact on marine animals, namely marine mammals (Wave Energy Centre 2009)". Results have yet to be released. Analytical techniques are available to predict fish and marine mammal vulnerability to noise in the ranges likely associated with TISEC and WEC developments. The application of models and analytical procedures such as that described by Koschinski et al. (2003) provide a means to predict population level responses to emerging TISEC or WEC technologies in specific locations (e.g., Bay of Fundy).

While several options are presented in the literature to reduce marine mammal and sea turtle exposure risk to severe pile driving and other construction-related noise (Nedwell and Howell 2004; FMM 2007; Michel et al. 2007), there is little discussion on mitigating noise and vibrations associated with TISEC and WEC devices.

ELECTROMAGNETIC FIELDS

CURRENT KNOWLEDGE ON POTENTIAL IMPACTS

Gill et al. (2005), FMM (2007) and Michel et al. (2007) provide comprehensive reviews of the available research on the potential vulnerability of marine organisms to electromagnetic fields (EMFs). Unfortunately, current understanding of the influence of EMFs on marine organisms is sparse and predominantly based on laboratory studies. There have yet to be any rigorous investigations of emissions from WEC or TISEC devices or other typical anthropogenic EMF sources in marine waters.

Many invertebrate, fish, marine mammal and sea turtle species that inhabit Canadian waters can detect and may use electric or magnetic fields to orient, navigate, find prey or mates, or to cue particular life stages (FMM 2007). Based on available data, Gill et al. (2005) analyzed the magnetic and electric field sensitivities of numerous species found in UK coastal waters (Tables 3 and 4). Depending on their range of detection and response thresholds, these species may or may not be affected by EMF levels emitted from underwater cables and generators associated with WEC and TISEC systems.

Although currently limited, there is some empirical evidence to suggest the following potential impacts from underwater export cables:

- EMFs may interfere with prey and mate detection in some fish (e.g., cod) and marine mammals.
- Elasmobranchs may avoid cable areas with *electric* fields of 100 μV/m or greater.
- *Magnetic* fields may cause temporary and significant navigational disruptions (disorientation) to migrating species (e.g., notably Atlantic salmon and other salmonids, and eels), sharks, marine mammals and sea turtles.
- *Magnetic* fields have been found to have physiological and life cycle affects in some fish and sea urchins.

The most EMF sensitive marine organisms are the elasmobranchs (sharks, rays, skates). Many species of elasmobranch are able to detect *induced electric* fields from typical underwater cables (0.5-1000 μV/m) (Gill and Taylor 2001; Centre for Marine and Coastal Science [CMACS]

2003; Gill et al. 2005). Models predict the *electric* field emitted into the seawater from a typical 132 kV cable buried to a depth of 1 m to be approximately 91.25 µV/m (CMACS 2003; Gill et al. 2005); a level just below the threshold limit reported to induce avoidance behaviour level (100 µV/m and greater) in sharks (Gill and Taylor 2001). Moreover, the model shows that although the *induced electric* field produced by the magnetic field decreases relatively rapidly with distance, the *electric* field 20 m from the cable (horizontally or vertically) would still be within the detectable range of an elasmobranch (CMACS 2003).

Meyer et al. (2005) demonstrated experimentally that elasmobranchs (specifically sandbar shark [*Carcharhinus plumbeus*] and scalloped hammerhead [*Sphyrna lewini*]) detected and responded behaviourally (attracted to) to *magnetic* fields between 0.7 and 2.8 times higher (25-100 µT) than the ambient geomagnetic field. Models predict that the direct *magnetic* field estimated from a typical 132 kV cable would only be 1.6 µT at the cable surface (CMACS 2003), well below the range reported by Meyer et al. (2005). However, it is possible that the full detectable range may be larger than reported by Meyer et al. (2005) since there do not appear to be any published data on whether elasmobranchs detect or respond to fields outside of this range. Despite the long-time prevalence of underwater cabling worldwide and some documented avoidance responses to anthropogenic-produced *induced electric* fields in experimental studies (e.g., Kalmijn 1983 [dogfish, blue sharks and stingrays]; Gill and Taylor 2001 [dogfish]), empirical evidence is currently lacking to establish if existing marine cables or other electrical devices have had any significant impacts on elasmobranch behaviour or migration patterns (CMACS 2003; Gill et al. 2005; FMM 2007).

There are few studies assessing the sensitivity and health of benthic invertebrates or shellfish found in the vicinity of submarine electrical cables or other EMF producing equipment. As a result, evidence is insufficient to conclude whether EMFs associated with TISEC or WEC systems pose a threat to these organisms. Based on available data, FMM (2007) suspected that marine flora and macro-invertebrates are not sensitive to *electric* or *magnetic* fields. However, while no impact of extended exposure to *magnetic* fields from a high voltage DC underwater cable was observed on the survival or fitness of shrimp, isopods, crab and mussels (Bochert and Zettler 2004), *magnetic* fields of 1-100 µT were found to cause a delay in embryonic development in sea urchins in lab experiments (Cameron et al. 1993). Additionally, Gill et al. (2005) reported some evidence that brown shrimp (*Crangon crangon*) in Baltic waters are sometimes attracted to EMFs of the magnitude expected around wind farms; however, no responses were noted in other benthic species. Responses to high frequency AC EMFs have also been found in barnacle larvae and brine shrimp, including significant cell damage and antennae retraction (interfering with settlement) (Leya et al. 2001).

There is uncertainty regarding whether marine teleost fishes are likely to be affected by the *electric* field level produced by WEC and TISEC devices (FMM 2007). Poddubny (1967 cited in Gill et al. 2005) observed avoidance and slower swimming behaviours in sturgeon (*Acipenser gueldenstaedtii*) in response to electric fields emitted from terrestrial high voltage overhead lines (110 kV) crossing above the water. Conversely, a study cited by FMM (2007) suggested that teleost fishes cannot typically detect *electric* fields of less than 6 V/m, which is significantly higher than a field emitted from an underwater cable at a marine energy conversion array. However, published corroborating data are lacking.

Nevertheless, *magnetic* fields have been found to influence navigation and physiological processes in some fish, including Atlantic salmon, eels, cod, flatfish and sea trout (*Salmo trutta*) (Gill et al. 2005; Hvidt et al. 2006; FMM 2007; Ohman et al. 2007). In laboratory experiments, *magnetic* fields of 1-100 µT have been found to cause delays in embryonic development in some fish (Cameron et al. 1993). There is also some evidence that eels may become disorientated by *magnetic* fields emitted by cables (temporary changes in swimming direction) (Gill et al. 2005; Ohman et al. 2007). Several other studies have also demonstrated effects of underwater cables on fish behaviour. For example, research at the Nysted wind farm in Denmark indicated significant behavioural responses to underwater cables in some species, including impaired migration (Baltic herring, Atlantic cod, eel and flounder), avoidance (eels) and attraction (Atlantic cod) (Dong et al. 2006; Hvidt et al. 2006). Additionally, Westerberg and Lagenfelt (2008) found the swimming speed of eels in the Baltic Sea was significantly lower along an underwater 130 kV AC power cable compared to adjacent areas. However, neither of these studies attempted to ascertain the exact relationship between *electric or magnetic* fields and the observed behavioural modifications. Despite the (limited) evidence to the contrary, FMM (2007) concluded that, based on the available data, navigation and migration of most magnetosensitive fish species are unlikely to be impacted by EMFs at the level likely associated with WEC and TISEC devices.

Although it does not appear that cetaceans detect *electric* fields, there is evidence that some marine mammals and sea turtles use *magnetic* fields for orientation and navigation (Lohmann and Lohmann 1994; FMM 2007; Michel et al. 2007). According to Geo-Marine (2003), it is likely that marine mammals and sea turtles would be able to sense the magnetic emissions from the transmission cable at the Kaneohe, Hawaii wave pilot project. However, there has yet to be any empirical evidence that existing cables have influenced migration behaviour of cetaceans, sea turtles or seals (FMM 2007).

All of the research to date appears to involve the impact of single cables. There do not appear to be any data on EMF levels emitted from large-scale grids or arrays (with multiple cables and generators) or resultant species' responses. However, Gill et al. (2005) suggested that EMF fields from multiple cables in close proximity would act as a single system with a much higher combined (additive) strength, and, therefore, the vulnerability of marine organisms to EMFs associated with large-scale arrays are more uncertain and potentially of greater significance (FMM 2007). Moreover, even if the fields produced by individual devices may be within tolerable ranges, consideration needs to be made to assess the potential additive effects with other marine technologies in the region.

MITIGATION

The following mitigation measures for EMF exposure have been identified in environmental assessment documents associated with the development of WEC and TISEC technologies:

- Avoid placing cables in or across areas with critical habitats or migration pathways of EMF sensitive species (e.g., sharks, salmonids, cod, flatfish, eels, sea turtles, sea urchin beds and cetaceans).
- Consider burying cables below the seafloor, especially along important migration routes, where appropriate (this would not be a viable option for devices installed on bedrock). Based on the contention that *magnetic* fields are only weakly detectable above the seafloor when cables are buried below 1 m (Tougaard et al. 2006c), environmental assessment documents often suggest that burying cables (particularly in conjunction with armouring), where appropriate, will mitigate EMF-associated risk (e.g., Royal Haskoning 2005; Argo Environmental 2006; FMM 2007; Michel et al. 2007). However, there is an ongoing debate regarding the effectiveness of cable burial to reduce above surface EMF emissions. The results of some predictive models and experimental studies maintain that cable burial is ineffective in weakening the *magnetic* field emanating above the seafloor (CMACS 2003 and Gill et al. 2005). Nevertheless, since the strength of *magnetic* and *induced electric* fields

diminishes with distance from the cable, burying the cable may provide a buffer between marine mammals and pelagic fish and the strongest fields, while being less effective for species that spend all or part of their life cycles on or close to the seafloor (CMACS 2003).

- Use effective cable armouring. Armouring technology typically used by marine industry may provide some dampening; however, it is currently difficult and expensive to produce cables with sheaths of sufficiently high permeability and conductivity to effectively lower EMFs escaping into the environment (CMACS 2003).

CANADIAN APPLICABILITY AND KNOWLEDGE GAPS

There is considerable uncertainty regarding the effects of EMFs on marine organisms. There is some evidence from existing wind farms, lab experiments and comparative analyses that suggest that the electric or magnetic field that could be emitted from underwater cables associated with TISEC and WEC arrays may be at a level detectable by elasmobranchs, and some invertebrates, fish, marine mammals and sea turtles. According to FMM (2007), several ecologically important and at risk species located in Canadian waters may be particularly sensitive to EMFs, including sharks, salmonids, cod, plaice, eels, sea turtles and cetaceans. However, to date, reliable evidence of responses of marine life from existing underwater cables and other EMF producing devices in Canadian or international waters are lacking. Although research is scarce on shellfish and invertebrates, organisms that spend all or part of their life cycles in on or close to the benthos may be particularly at risk due to their physical proximity to the EMF source and thus stronger field strengths. This may be of particular importance related to the health and behaviour of lobsters and other Canadian species of ecological and commercial concern.

Some researchers and environmental assessment statements contend that EMFs emitted by TISEC and WEC devices are likely to be negligible compared to ambient levels, especially if the cable is properly buried (1-3 m deep) (CMACS 2003; Geo-Marine 2003; Royal Haskoning 2005; AquaEnergy 2006; Tougaard et al. 2006c; FMM 2007; Michel et al. 2007). However, further research is needed to corroborate this claim since the sensitivity of marine organisms (especially benthic species) is still poorly understood and the EMF levels transmitted by pilot and full-scale systems (including multiple cables and other electrical components) have not yet been characterized.

Future research on the potential impacts of EMFs for the deployment of TISEC and WEC devices may be coupled with studies supported by the offshore oil and gas industry as there is an interest to develop an alternative EMF-based technology to replace air-gun use in seismic exploration.

RISKS OF PHYSICAL ENCOUNTERS WITH DEVICES

CURRENT KNOWLEDGE ON POTENTIAL IMPACTS

Injury to Marine Life

According to Wilson et al. (2007) “a collision [hereon referred to as a strike] is considered to be a physical contact between a device or its pressure field and an organism, that may result in an injury (however slight) to that organism.” If an organism strikes (or is struck by) or becomes entangled with static or moving parts, it could result in minor or severe injury or fatality. Physical disturbance and strike risk from boats and equipment is also a known source of injury and mortality during installation, maintenance and decommissioning of offshore developments (FMM

2007; Michel et al. 2007; Wilson et al. 2007). In addition to mechanical strikes and entrainment, TISEC and WEC (perhaps to a lesser degree) devices may create may create rapid pressure changes (e.g., causing eye and gas bladder damage), hydraulic shear (e.g., causing decapitation) and cavitation, which could be significant sources of mortality for organisms passing through. Although well-recognized at tidal power and hydroelectric turbines (Stokesbury and Dadswell 1991; Dadswell et al. 1986), this issue has yet to be evaluated or considered in TISEC or WEC literature. These sources of strike-related mortality could potentially threaten population stability depending on the frequency of occurrence and the size of the population, especially in combination with other marine hazards, such as fishing gear and shipping.

Despite a high level of concern on this issue, there is almost no observational or empirical information on mechanical strike incidents associated with existing WEC and TISEC devices. Moreover, the risk to a particular species is not easily quantified as it will depend on device design at each location (FMM 2007). Some inferences may be drawn with known risks from other marine activities (e.g., tidal and hydroelectric power barrages, shipping, wind farms) (Wilson et al. 2007); however, researchers caution that comparisons may be limited since TISEC and WEC devices present quite different features than other hazards encountered by marine animals.

Wilson et al. (2007) provides a comprehensive examination of the factors influencing the probability and consequence of fish and marine mammal physical encounters with TISEC and WEC devices, as well as comparisons with shipping- and fish gear-related impacts. The potential to avoid or evade strikes or entanglement with a WEC or TISEC device would depend on (Wilson et al. 2007):

- *Detection ability*. The distance at which an animal can perceive the device and take action may depend on the level of background noise and turbidity and other signature outputs emitted by the devices. Marine mammals may be at risk of entanglement in cables, chains and power lines extending up through the water column since they create lower sensory cues than larger structures.
- *Attraction.* Species may be attracted to devices as artificial reefs, for increased foraging opportunities or by lighting, which could increase the chances of contact with blades or moving parts. However, other factors such as habitat alteration and noise may deter animals from entering into close proximity.
- *Size.* Larger fish species (e.g., sharks) may be more at risk as smaller animals are more likely to follow the streamlines around moving parts and are also less likely to become entangled in cables.
- *Habitat use.* All pelagic fish and marine mammals will be at some risk of strikes or entrapment with all device types and associated structures since they regularly traverse the water column. Surface-floating WEC devices are less of a concern for groundfish and mid-water species. However, they may encounter moorings, cables or devices installed on the sea bed or in mid water.
- *Evasion behaviour*. Marine mammals often respond inappropriately or illogically to novel threats (e.g., curiosity). Thus, it is difficult to speculate if an animal would take appropriate precautionary measures with these unfamiliar devices. Moreover, some marine mammals have limited manoeuvrability when surfacing, and, thus, may have difficulty avoiding structures. Also, high current speeds may reduce fish avoidance time and schooling and grouping species may have reduced manoeuvrability and slower reaction times compared to individuals.

- *Trapping.* Combined structures (e.g., ducts, Venturi devices) and large-scale arrays may restrict movement options, leading to higher risk of entrapment or collision (e.g., an escape response from one device or structure may result in a collision with another).

Considering the above factors, it is clearly evident that site- and technology-specific studies are needed to support future environmental assessments for commercial operations.

The monitoring program for the Northern Ireland MCT SeaGen™ project included rudimentary procedures to assess actual mortality resulting from interactions with the device. To date examinations of dead marine mammals found near the site have shown no evidence of interactions with the device (Royal Haskoning Ltd. 2009). Similar or more rigorous monitoring of this issue at any other deployment sites have not been conducted.

Most theoretical risk assessment models to date have estimated the risk of injury by strikes to be small (Argo Environmental 2006; Fraenkel 2006; Wilson et al. 2007). According to the environmental assessment for a proposed TISEC demonstration project in New Zealand, a seal or dolphin of 50 cm girth will have a one-in-eight chance of touching a MCT SeaGen™ (two-blade 20 m diameter rotor with a max. 10-12 m/s tip velocity) turbine blade if it took no avoiding action away from the rotor (Argo Environmental 2006). The risk would be even less for smaller animals. Similarly, according to Fraenkel (2006), with no avoidance action, there is only a one-in-18 chance of a drifting object of 20 cm cross-section hitting a moving MCT SeaGen™ rotor blade. Most objects of this or smaller size would pass straight through the turbine without making contact with the rotor. Both reports contended that: 1) most animals would likely take some avoidance or evasion response before coming in contact with the turbine, further reducing the chances of collision; and 2) it is unlikely that physical contact with a device would cause serious injury due to the relatively slow speed of the rotor blades and few sharp surfaces (except leading edge of blade). However, the simple modeling applied in environmental assessments to date has not accounted for the roles of trapping or entanglement in tethering lines and cables, ambient environmental conditions, unique behaviours of species and the more complex obstacles formed by large-scale systems.

In an analysis of 21 fish and 13 shellfish species found in UK waters, FMM (2007) concluded that there was insufficient data available to estimate the sensitivity level of any species to mechanical collision with WEC or TISEC devices.. The risk of strikes with moving and static (slightly lower) parts for seals, baleen/sperm whales, dolphins and harbour porpoises was rated as low to medium and medium to high in low and high tidal conditions, respectively. Sensitivity was estimated based on what is known about how the animals use the marine environment (see Table 1 for sensitivity criteria).

Interference with Devices

Damage from impacts with ice, logs and other debris could also pose major, yet currently unexplored, operational challenges for TISEC and WEC development. In Canada, ice damage is a concern on the Arctic and Atlantic coasts; whereas, logs and other debris are of particular impact concern on the Pacific coast. Studies of ice have been conducted in the Bay of Fundy (Sanders and Baddour 2006) and in particular in the Minas Basin (as part of the environmental assessment for the Fundy Tidal Energy Test Facility) (G. Fader, Minas Basin Pulp and Power, NS, pers. comm. 2009) to assess the movements of large neutrally buoyant sediment-bound ice pieces that are formed and released from the intertidal zone.

MITIGATION

Several mitigation measures have been suggested in the literature to reduce strike and entanglement risk, mostly adapted from other industries such as wind farms, offshore oil and gas and the Annapolis Royal Tidal Power Plant. There have been no published accounts of their application or effectiveness at WEC or TISEC sea trials or existing installations.

- Design device for minimal impact. For example, design surface structures to prevent use as a haul-out as was done for the Makah Bay WEC pilot project (AquaEnergy Ltd. 2006), avoid designs that create underwater or surface traps (Wilson et al. 2007), design turbines with large gaps for fish to pass through and reduce blade sharpness or add shock absorption padding.
- Avoid locating devices in sensitive areas such as migration routes and feeding and breeding grounds.
- Schedule installation, maintenance and decommissioning activities to avoid known migration, breeding and nursery periods to reduce direct wildlife-vessel encounters and behavioural disruptions.
- Increase device visibility using blade colouring. The effectiveness of this option would be species-dependant. Some species, such as sea turtle hatchlings, may actually be attracted to colours or lighted installations (Hagerman and Bedard 2004).
- Use acoustic deterrent devices (e.g., pingers or seal scarrers). Underwater acoustic devices at the Annapolis Tidal Generating Station appear to have proved somewhat effective at keeping fish (*Alosa* sp.) away from the turbine entrance (McKinley and Kowlyk 1989; Gibson and Myers 2001). However, the functionality of these devices is species-specific and, in some circumstances, their use may have adverse impacts on fish and marine mammals (FMM 2007; Michel et al. 2007). For example, if set too loud, these devices could exclude fish and marine mammals from valuable habitat.
- Use protective netting or grids to exclude animals from development areas. However, this option may itself become a collision or entanglement hazard (FMM 2007).
- Use marine mammal observers or other on-going monitoring programs to take appropriate actions if an animal is seen to be at risk.

CANADIAN APPLICABILITY AND KNOWLEDGE GAPS

There are currently no published reports of strikes, entanglement or other mortality at WEC or TISEC sea trials or facilities, and the risk of strikes and effectiveness of mitigation measures are unknown. Although some insights into mortality, behavioural responses and mitigation can be gained from experiences in the Canadian shipping and fishing industries, and at the Annapolis Tidal Generating Station, the conditions presented by WEC and TISEC devices are unique and poorly understood. Simple models have suggested that most organisms are likely able to circumvent individual pilot-scale turbines and other moving parts without incurring serious harm. However, the roles of device design (e.g., effect of ducting, gaps, blade speed), trapping or entanglement in tethering lines and cables, ambient environmental conditions, unique behaviours of species and the more complex obstacles formed by large-scale systems and multiple developments within close proximity are poorly understood and have yet to be effectively considered in risk assessments. In combination with other marine hazards, such as fishing gear and shipping, encounter-related mortality could have major implications for the population dynamics and stability of species inhabiting Canadian waters, particularly whales, sea turtles, sharks and salmon. Thus, consideration must be given to the integrated assessment of encounter-related threats associated with marine energy technology and other hazards. Moreover, the presence and movements of ice and other debris are poorly understood;

research is thus needed to assess the operational implications of interference with WEC and TISEC systems in particular regions.

DECOMMISSIONING

CURRENT KNOWLEDGE ON POTENTIAL IMPACTS

After years in operation and the adaptation of the ecological systems, decommissioning of arrays will again cause changes in physical processes, and habitat and biological structure and productivity. Since TISEC and WEC technology is still an emerging field, there has not yet been any practical experience with or analytical consideration of marine energy infrastructure decommissioning.

Most of the activities, and thus potential environmental impacts, related to decommissioning will be similar to those experienced during construction (FMM 2007) including:

- Increased suspended sediment and turbidity from infrastructure removal activities;
- Benthic habitat disturbance and loss due to substrate disturbance, excavation and smothering;
- Risk of contaminant release from vessels and equipment (e.g., oil and gas spills) and re-suspension of contaminated sediment;
- Increased direct disturbance to marine organisms from construction- and vessel-related noises (except pile driving); and
- Risk of collisions with vessels.

The cessation of operations and full or partial removal of structures will also result in:

- Restoration of wave and current energy, with resultant changes in near- and far-field wave exposure, current flow, and marine and coastal sediment and erosion patterns; and
- Change in habitat conditions due to hydrodynamic and sediment changes, structure removal and reduced EMF and noise emissions, which in turn will affect local and regional biological communities that have adapted to the conditions created by the marine energy development.

MITIGATION

Although general industrial decommissioning standards usually call for the complete removal of structures from the environment, this may not always be environmentally preferable (FMM 2007). For example, if removal will cause unacceptable habitat or wildlife disturbance, especially with species at risk or commercial species, or unacceptable risk of re-suspending contaminated sediment. The risks and benefits to wildlife, ecosystem health, fisheries and navigation will need to be analyzed to determine the decommissioning and site restoration activities that will produce the most ecologically and socially beneficial outcomes.

Some general mitigation measures suggested in the literature (FMM 2007) include:

- Mitigate construction-type impacts (would be similar to those for installation(,
- Restore or rehabilitate site, with creation or enhancement of habitat features that will benefit native local species.

- Cut above-ground pilings and other structures instead of excavating to reduce disruption of benthic habitat.
- Maintain enhanced habitat quality (i.e., artificial reef effect from the original structure).

CUMULATIVE, LONG-TERM AND REGIONAL IMPACTS

CURRENT KNOWLEDGE ON POTENTIAL IMPACTS

To date, international emerging marine energy conversion technology research has been limited to the short-term impacts of individual prototype or demonstration-scale devices. Many experts have suggested that full-scale developments may produce more significant and complex effects to marine and coastal ecosystems and native wildlife populations (FMM 2007; Michel et al. 2007). However, there has yet to be any published models or practical research on the cumulative and synergistic impacts of large-scale TISEC or WEC arrays or arrays in conjunction with other nearby offshore industries. Moreover, as with other marine developments, TISEC and WEC technology may have unknown long-term effects that extend well beyond the immediate area of the project. To date, there have been no published studies or models investigating the actual or potential long-term and regional impacts on marine and coastal biodiversity or ecosystem processes due to existing or proposed WEC and TISEC installations.

MITIGATION

There has been no mitigation measures presented in the literature specifically addressing cumulative, long-term or regional impacts. Some mitigation will be achieved by addressing immediate impacts that have been the focus to date.

CANADIAN APPLICABILITY AND KNOWLEDGE GAPS

The energetic regions in which TISEC and WEC projects are likely to be situated, such as the Bay of Fundy, are typically characterized by complex, dynamic, and unique physical and ecological features and processes. Nevertheless, there has yet to be any significant monitoring programs or models developed on cumulative, long-term, and regional impacts at existing or proposed TISEC or WEC projects in Canada or internationally. Uncertainties related to natural inter- and intra-annual variation and climate change will further complicate our ability to differentiate marine energy technology-induced changes from those caused by natural or other anthropogenic sources. Consequently, further research to understand these risks and develop good predictive models is crucial to ensure that these technologies are environmentally beneficial and that they are well-suited to, and will not impair the health of, Canadian marine and coastal ecosystems.

RESEARCH NEEDS

A number of potentially significant environmental impacts and mitigation procedures related to emerging marine renewable technologies have been identified by the international scientific community. However, due in part to the high degree of environmental and design variability between the deployment sites and technologies, robust scientific data, practical experience and, consequently, a solid understanding on potential environmental implications and mitigation options are lacking.

More focused and coordinated scientific efforts are now needed to provide advice for the development of policy and regulations on marine renewable energy to ensure the health and sustainability of our marine environment and the organisms that live in it.

Providing answers to the challenging questions about the effects of energy extraction on the critical processes of Canadian coastal waters requires a holistic, cooperative and multi-disciplinary approach at regional, national and international levels. Due to the private sector-driven nature of this emerging industry, developers are in the greatest position to undertake applied environmental research. Unfortunately, the scope of research by the private sector is usually limited to the minimum level required to meet regulatory compliance. Furthermore, due to competition between commercial developers, data generated by the private sector is not often shared with the scientific community. Coordination of research and sharing of data between developers, universities, colleges, provincial and federal government agencies and other stakeholders will provide the enhanced knowledge base required to accelerate the development of ocean renewable energy industries in a timely manner. Considering the diversity of devices, range of deployment environments and natural variability, there is a need for standardized monitoring protocols to address future regulatory compliance needs and to enable comparison of data between test and commercial facilities and will also lead to improvements in safety, cost and efficacy of operations.

RECOMMENDATIONS FOR POLICY AND REGULATION DEVELOPMENT

The following is a list of proposed next steps and research priorities for the Canadian government in support of the development of environmentally-sustainable marine renewable energy policy and regulations.

Broad-scale priority research issues include:

- Development and validation of new environmental effects monitoring protocols for marine energy extraction activities (pre- and post-development).
- Development and evaluation of new technologies for the assessment of environmental effects arising from energy extraction developments.
- Development, evaluation and validation of environmental risk assessment models.
- Collection and archiving of relevant baseline data.

Specific priority scientific research topics based on identified knowledge gaps include:

Baseline research and modeling:

- Baseline information on dynamic ocean processes (e.g., tidal and wave movements; sediment behaviour and dynamics) that may be affected by energy extraction in order to establish:
    - the likely changes resulting from energy extraction and physical interactions;
    - the consequences of extracting energy in terms of environmentally acceptable or meaningful thresholds with consideration of natural variability and future changes (e.g., climate change); and
    - the parameters to be addressed in monitoring programmes.

- Baseline habitat surveys and analysis in areas of interest, including identification of sensitive sites.

- Background sediment contaminant levels at potential sites and mechanisms for contaminant release from sediments.
- Characterization of ambient sound and EMF conditions.

Effects modeling, monitoring and field research:

- Device and site-specific interactions with hydrodynamic and sediment processes.
- Operational implications of interference from ice, logs and other debris.
- Local- and regional-scale physiological, behavioural, and population-scale responses of marine organisms (especially species at risk) to marine energy development. Specific priority concerns include:
    - effect of different device designs and environmental conditions;
    - effects of habitat alteration, including changes in hydrodynamic and sediment regimes;
    - fate and effects of contaminants, especially antifouling materials;
    - effects of EMFs from cabling and other electrical components;
    - noise and vibrations effects;
    - risk of mortality (e.g. strikes, pressure changes); and
    - changes in migration and distribution.

- Assessments of resilience of benthic and pelagic communities and the time scale of recovery from disturbance.
- Characterization of noise, vibration and EMF sources emitted by different pilot and full-scale systems, and their transmission.
- Modeling of cumulative and synergistic interactions between multiple arrays and between arrays and other marine activities.
- Monitoring and modeling of long-term effects, including impacts of decommissioning and infrastructure removal.
- Evaluation of mitigation, restoration and enhancement options.

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TABLES

Table 1: Habitat and species sensitivity ratings criteria used in Scottish marine renewables strategic environmental assessment.

Sensitivity Scale	Criteria
Very High	The habitat or species is very adversely affected by an external factor arising from human activities (either killed/destroyed, 'high' intolerance) and is expected to recover only over a prolonged period of time, i.e., >25 years or not at all (recoverability is 'very low' or 'none'). The habitat or species is adversely affected by an external factor arising from human activities (damaged, 'intermediate' intolerance) but is not expected to recover at all (recoverability is 'none').
High	The habitat or species is very adversely affected by an external factor arising from human activities (killed/destroyed, 'high' intolerance) and is expected to recover over a very long period of time, i.e., >10 or up to 25 years ('low' recoverability). The habitat or species is adversely affected by an external factor arising from human activities (damaged, 'intermediate' intolerance) and is expected to recover over a very long period of time, i.e., >10 years (recoverability is 'low', or 'very low'). The habitat or species is affected by an external factor arising from human activities (reduced viability, 'low' intolerance) but is not expected to recover at all (recoverability is 'none'), so that the habitat or species may be vulnerable to subsequent damage.
Moderate	The habitat or species is very adversely affected by an external factor arising from human activities (killed/destroyed, 'high' intolerance) but is expected to take more than 1 year or up to 10 years to recover ('moderate' or 'high' recoverability). The habitat or species is adversely affected by an external factor arising from human activities (damaged, 'intermediate' intolerance) and is expected to recover over a long period of time, i.e., >5 or up to 10 years ('moderate' recoverability). The habitat or species is affected by an external factor arising from human activities (reduced viability, 'low' intolerance) but is expected to recover over a very long period of time, i.e., >10 years (recoverability is 'low', 'very low'), during which time the habitat or species may be vulnerable to subsequent damage.
Low	The habitat or species is very adversely affected by an external factor arising from human activities (killed/destroyed, 'high' intolerance) but is expected to recover rapidly, i.e., within 1 year ('very high' recoverability). The habitat or species is adversely affected by an external factor arising from human activities (damaged, 'intermediate' intolerance) but is expected to recover in a short period of time, i.e., within 1 year or up to 5 years ('very high' or 'high' recoverability). The habitat or species is affected by an external factor arising from human activities (reduced viability, 'low' intolerance) but is expected to take more than 1 year or up to 10 years to recover ('moderate' or 'high' recoverability).
Very Low	The habitat or species is very adversely affected by an external factor arising from human activities (killed/destroyed, 'high' intolerance) but is expected to recover rapidly i.e., within a week ('immediate' recoverability). The habitat or species is adversely affected by an external factor arising from

Sensitivity Scale	Criteria
	human activities (damaged, 'intermediate' intolerance) but is expected to recover rapidly, i.e., within a week ('immediate' recoverability). The habitat or species is affected by an external factor arising from human activities (reduced viability, 'low' intolerance) but is expected to recover within a year ('very high' recoverability).
Not Sensitive	The habitat or species is affected by an external factor arising from human activities (reduced viability, 'low' intolerance) but is expected to recover rapidly, i.e., within a week ('immediate' recoverability). The habitat or species is tolerant of changes in the external factor. The habitat or species may benefit from the change in an external factor (intolerance has been assessed as 'tolerant').

Source: FMM (2007).

Table 2: List of fish, shellfish and marine mammal species with medium and high sensitivity to habitat-related impacts.

Impact	High	Medium
Habitat Exclusion	baleen whales dolphins porpoises	seals
Substratum Loss	Atlantic herring Sandeel	Norway lobster (*Nephrops norvegicus*) Edible crab (*Cancer pagurus*) King scallop (*Pecten maximus*) cockle (*Cerastoderma edule*) periwinkle (*Littorina littorea*) mussel (*Mytilus edulis*) Razor shell (*Ensis* spp)
Smothering	Atlantic herring sandeel King scallop Queen scallop (*Aequipecten opercularis*) cockle periwinkle	mussel
Reduction in Wave Exposure	Periwinkle	plaice cockle mussel
Reduction in Current Flow	Atlantic herring	sandeel mussel seals (locally)

Source: FMM (2007).

Table 3: Potential electro-sensitive species in UK waters.

Electro-sensitive species		**Evidence of Response to E-Fields**
Elasmobranchs (sharks, rays, skates)		
Cetorhinus maximus	Basking shark	
Galeorhinus galeus	Tope	
Lamna nasus	Porbeagle	
Mustelus asterias	Starry smooth-hound	
Scyliorhinus canicula	Small-spotted cat shark	Y
Squalus acanthias	Spurdog	
Alopias vulpinus	Thintail thresher	
Chlamydoselachus anguineus	Frilled shark	
Dalatias licha	Kitefin shark	
Isurus oxyrinchus	Shortfin mako	
Mustelus mustelus	Smooth-hound	
Prionace glauca	Blue shark	Y
Scyliorhinus stellaris	Nursehound	
Centrophorus squamosus	Leafscale gulper shark	
Centroscyllium Fabricii	Black dogfish	
Deania Calcea	Birdbeak dogfish	
Echinorhinus brucus	Bramble shark	
Etmopterus spinax	Velvet belly lantern shark	
Galeus melastomus	Blackmouth catshark Sharpnose	
Heptranchias perlo	sevengill shark Bluntnose sixgill	
Hexanchus griseus	shark	
Oxynotus centrina	Angular rough-shark Smallmouth	
Scymnodon obscurus	velvet dogfish Greenland shark	
Somniosus microcephalus	Smooth hammerhead	
Sphyrna zygaena	Angelshark	
Squatina squatina	Starry ray	
Amblyraja radiate	Thornback ray	
Raja clavata	Norwegian skate	Y
Dipturus nidarosiensis	Sandy ray	
Leucoraja circularis	Shagreen ray	
Leucoraja fullonica	Cuckoo ray	
Leucoraja naevus	Blonde ray	
Raja brachyuran	Small-eyed ray	
Raja microocellata	Spotted ray	
Raja montagui	Undulate ray	
Raja undulata	Arctic skate	
Ambyraja hyperborean	Spinetail ray	
Bathyraja spinicauda	Common stingray	
Dasyatis pastinaca	Common skate	
Dipturus batis	Long-nose skate	
Dipturis oxyrinchus	Devil fish	
Mobula mobular	Common eagle ray	
Myliobatis Aquila	Round ray	
Rajella fyllae	White skate	Y
Rostroraja alba	Spotted/marbled torpedo ray	
Torpedo marmorata	Atlantic torpedo	
Torpedo nobiliana ray		
Chimaeras and Jawless Fish		
Chimaera monstrosa	Rabbit fish	Y
Lampetra Fluviatilis	European river lamprey	Y
Petromyzon marinus	Sea lamprey	Y

Electro-sensitive species		**Evidence of Response to E-Fields**
Bony (Teleost) Fish		
Anguilla Anguilla	European eel	Y
Gadus morhua	Cod	Y
Pleuronectes platessa	Plaice	Y
Salmo salar	Atlantic salmon	Y
Acipenser Gueldenstaedtii	Sturgeon	Y

Source: Gill et al. (2005).

Table 4: Potential magneto-sensitive species in UK waters.

Magneto-sensitive Species		**Evidence of Response to B-Field**
Whales, dolphins & porpoises		
Phocoena phocoena	Harbour porpoise	Y
Tursiops truncatus	Bottlenose dolphin	Y
Lagenorhynchus albirostris	White-beaked dolphin	
Globicephala melas	Long-finned pilot whale	Y
Lagenorhynchus acutus	Atlantic white-sided dolphin	Y
Orcinus orca	Killer whale	
Balaenoptera acutorostrata	Minke whale	
Delphinus delphis	Short-beaked dolphin	Y
Grampus griseus	Risso's dolphin	Y
Physeter macrocephalus	Sperm whale	Y
Megaptera novaengliae	Humpback whale	
Balaenoptera physalus	Fin whale	Y
Stenella coeruleoalba	Striped dolphin	Y
Monodon monoceros	Narwhal	
Delphinapterus leucas	Beluga	
Pseudorca crassidens	False killer whale	
Hyperdoon ampullatus	Northern bottlenose whale	
Ziphius cavirostris	Cuvier's beaked whale	
Mesoplodon bidens	Sowerby's beaked whale	
Balaenoptera borealis	Sei whale	
Balaenoptera musculus	Blue whale	
Eubalaena glacialis	Northern right whale	
Kogia breviceps	Pygmy sperm whale	Y
Lagenodelphis hosei	Fraser’s dolphin	
Peponocephala electra	Melon-headed whale	
Turtles		
Caretta caretta	Loggerhead	Y
Dermochelys coriacea	Leatherback	
Chelonia mydas	Green	Y
Eretmochelys imbricata	Hawksbill	
Lepidochelys kempi	Kemp’s Ridley	
Bony (teleost) Fish		
Anguilla anguilla	European eel	Y
Salmo salar	Atlantic salmon	Y
Scombridae sp.	Tunas & mackerels	Y
Pleuronectes platessa	Plaice	Y
Salmo trutta	Sea trout	Y
Thunnus albacares	Yellowfin tuna	Y
Elasmobranchs (sharks, skates, rays)	All	Y
Chimaeras and Jawless fish	All	Y
Crustacea (some lobsters, crabs, shrimp, prawn)		
Crangon crangon		Y
Idotea baltica		Y
Talorchestia martensii		Y
Talitrus saltator		Y
Molluscs (some snails, bivalves, squid)		
Tritonia diomedea		Y

Source: Gill et al. (2005).