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ASSESSMENT OF TIDAL AND WAVE ENERGY CONVERSION TECHNOLOGIES IN CANADA

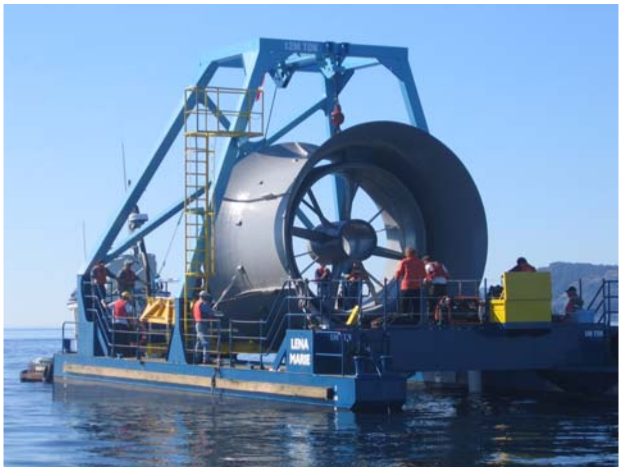

Figure 1. Example of a tidal power device (Race Rocks, BC).

Context:

Canada's vast and highly energetic Atlantic, Pacific and Arctic coastal waters make ocean renewable energy, particularly tidal in-stream energy conversion (TISEC) and wave energy conversion (WEC), technologies an attractive option to help meet the country's future energy needs. However, due to the novelty and diversity of these technologies, there is still a great deal of uncertainty surrounding the feasibility and potential environmental impacts associated with their deployment and operation. In support of commercial development of the industry, a review of scientific knowledge is required for the development of policy and regulations consistent with Canada's conservation and sustainability priorities.

Fisheries and Oceans Canada (DFO) hosted a National Science Advisory Process meeting on 21-22 April 2009 to determine the current state of knowledge on the environmental impacts of tidal and wave energy conversion technologies and their application in the Canadian context based on published reports. The objectives of the meeting included identifying potential mitigation measures and determining the feasibility of developing a relevant Canadian Statement of Practice at this time.

SUMMARY

- A small number of tidal in-stream (TISEC) and wave (WEC) energy conversion technology demonstrations are in place internationally, and a number have been recently initiated in Canada. Much of the development work on these technologies is driven by the private sector. To ensure that these technologies are consistent with Canada's conservation and sustainability priorities, it is essential to acquire a firm understanding of their potential environmental implications and, thus, feasibility for deployment in Canadian coastal waters.

- TISEC and WEC technologies have the potential to result in changes to current flows, wave exposure, and associated sediment and coastal processes that could have direct and indirect effects on marine and coastal ecosystems. The extent of the effect of any project

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would depend on the technology characteristics, project scale, distance from the coast, and natural coastal structure and processes (hydrodynamic and sedimentary).

- Changes to habitat characteristics resulting from the deployment of marine energy conversion technologies will vary by size, design, and location but may include direct loss or alteration of existing benthic and pelagic habitat, as well as marine organism responses to the addition of artificial structures. Comprehensive analysis of the relationships between changes in physical processes associated with TISEC and WEC development and risks to habitats and wildlife populations has not been conducted to date.

- Like other marine industries, TISEC and WEC development has the potential to degrade local water quality (through increased suspended sediment concentrations and introduction of oil, lubricants, antifoulants and other contaminants), with long-term implications for marine life.

- While there is a global effort to study the effects of noise in the marine environment, there have been very few directed studies of the response of fish and marine mammals to noises and vibrations produced by operational TISEC and WEC devices. Long-term physiological, behavioural, and population-scale impacts of noise are still poorly understood. Sound intensities, frequencies and patterns, and therefore threats, will be technology and environment-specific.

- There is considerable uncertainty regarding the effects of electromagnetic fields on marine organisms. Reliable evidence of responses of marine life to existing underwater cables in Canadian or international waters is lacking. There is some evidence suggesting that EMF levels that could be emitted from underwater cables (and other electrical devices) associated with TISEC and WEC arrays may be detectable by some species. 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.

- There is an absence of peer-reviewed articles within the scientific literature addressing the impact of physical encounters (either directly with structures, e.g., strikes and entanglement, or indirectly, e.g., through pressure changes) between marine life and WEC or TISEC technologies at existing facilities. The risk of such encounters and the effectiveness of potential mitigation measures to avoid impacts of encounters are unknown.

- While the importance of being able to evaluate the potential for cumulative impacts, including the interaction among multiple energy conversion technologies and the interaction of those technologies with other human activities over time, is recognized, there has been no attempt to predict or model these interactions due to limited data and no requirement for this information under regulatory compliance procedures.

- There is not yet sufficient information on the scope of impacts from the wide variety of TISEC and WEC technologies that have been, and are continuing to be, produced to develop a relevant Statement of Canadian Practice. However, this issue should be re-visited as experience and knowledge from demonstration projects is gained.

- Broad-scale research priorities to assist in the development of policy and regulations related to TISEC and WEC include: development of science-based monitoring protocols for marine energy extraction (pre and post deployment); development of new monitoring technologies; development and evaluation of technologies and protocols for the assessment of environmental effects; development, evaluation, and validation of relevant models; and collection and archiving of relevant baseline data.

- Priority topics requiring science research include: modeling of ocean processes, e.g., tidal movements, waves, sediment behaviour and dynamics; habitat surveys and analysis in areas of interest; modeling and field investigation of marine organism physiological, behavioural and population-scale responses to marine energy development; assessment of resilience of benthic and pelagic communities and the time scales of recovery from disturbance; evaluation of mitigation, restoration and enhancement options; and modeling of cumulative and synergistic interactions among multiple arrays and between arrays and other marine activities.

INTRODUCTION

A National DFO Science Advisory Process meeting was held 21-22 April 2009, with participants from provincial and federal governments, industry, and universities, to assess the potential impacts of wave and tidal energy conversion technologies (including all system aspects, from construction through to decommissioning) on Canadian marine and coastal environments. Other potential renewable energy technologies, such as tidal lagoons and offshore wind power, were outside the scope of this review.

A small number of tidal (TISEC) and wave (WEC) energy conversion technology demonstrations are in place internationally, and some are starting to emerge in Canada. For example, the Pearson College – EnCana - Clean Current Tidal Power Demonstration Project was deployed at Race Rocks Ecological Reserve in British Columbia in 2005. 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 comprehensive strategic environmental assessment (SEA) was recently completed for tidal energy conversion projects to be located in the Bay of Fundy, and a demonstration facility for multiple devices is under development in Minas Passage. The Canoe Pass Commercialization Project, to demonstrate two 250-kw EnCurrent tidal turbines, has been proposed for the Campbell River, BC. Two WEC systems have been tested to date in Newfoundland. The WET EnGen device of Wave Energy Technology Inc. was tested in open water in 2004 and again in 2006 with a 20-kw device. There are plans to install a 40-kw WET EnGen at Sandy Cove, NL as a pre-commercial demonstration project. The Wave-Power Pump developed by the College of the North Atlantic has been deployed periodically for testing in the Burin Peninsula of NL. Its purpose is to pump seawater to an onshore facility. On the Pacific Coast, proposals have been announced for a 4-mw WEC demonstration facility in Ucluelet and a SyncWave Power Resonator™ demonstration project near Tofino on the west coast of Vancouver Island.

Much of the development work on these technologies is driven by the private sector. To ensure that these technologies are consistent with Canada’s conservation and sustainability priorities, it is essential to acquire a firm understanding of their feasibility for deployment and potential environmental implications for all three Canadian coasts.

Several comprehensive assessments of the state of knowledge on the environmental implications of marine renewable technology have been conducted by other countries in the last several years, including the “Worldwide Synthesis and Analysis of Existing Information Regarding Environmental Effects of Alternative Energy Uses on the Outer Continental Shelf” prepared for the U.S. Minerals Management Service, and the “Scottish Marine Renewables Strategic Environmental Assessment”.

These projects, reports, and other available studies, such as Strategic Environmental Assessments for the Bay of Fundy, have been used to complete the following assessment.

ASSESSMENT AND ANALYSIS

Impacts on Physical Processes

TISEC and WEC technologies have the potential to result in changes to current flows, wave exposure, and associated sediment and coastal processes that could have direct and indirect effects on marine and coastal ecosystems. TISEC and WEC technologies may modify local sediment transport patterns (including erosion, re-suspension and deposition) by localized hydrodynamic changes due to presence of physical structures and from energy extraction. In addition to local effects, changes to energy flows (e.g., currents or waves) caused by energy extraction (for example, in the dynamic Gulf of Maine / Bay of Fundy system) could have far-field affects on tidal range, sediment deposition and ecosystem productivity. Similarly, erosion patterns along long stretches of coastline could be changed.

The extent of the effect of any project would depend on the technology characteristics, its location, scale, and natural coastal structure and dynamical processes. Project-specific baseline data and models would be needed to develop confident predictions for proposed deployments.

Impacts on Habitat Characteristics

Changes to habitat characteristics resulting from the deployment of marine energy conversion technologies will be size, design, and location specific but may include direct loss or alteration of existing benthic and pelagic habitat, as well as changes to marine organisms associated with the 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, long-term, near-field or far-field effects of these technologies on marine biota and ecological integrity. Environments suitable for TISEC and WEC technologies are typically high-energy systems, and it may be challenging to distinguish impacts from natural variability.

Many WEC, and to a lesser extent TISEC, devices consist of sizeable surface floating components, which may make appealing haul-out sites for pinnipeds. However, where arrays are placed in naturally open areas, narrow corridors or mouths of bays, changes to habitat characteristics may impede seasonal migratory movements and possibly exclude marine organisms from areas necessary for carrying out important life-history processes, including mating, spawning, nesting, and feeding areas.

The alteration of wave and current flows and associated sediment and erosion processes from TISEC and WEC development may or may not have long-term impacts on the structure of marine and coastal communities by changing sediment re-suspension or deposition patterns due to scour or decreased current velocity, thus changing turbidity levels, and eroding or smothering benthic or coastal habitats; reducing downstream flow of nutrients and food supply for benthic filter feeders; or indirectly changing the type of prey available for other marine wildlife. Comprehensive analysis of the relationships between changes in physical processes associated with TISEC and WEC development and risks to habitats and wildlife populations has not been conducted to date.

Impacts on Water Quality

Like other marine industries, TISEC and WEC 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, 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 deleterious health effects or mortality to fish, and increased turbidity could hinder the prey detection ability of species that rely on visual cues. 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.

TISEC and WEC development could also expose ecosystems to toxic pollutants common to marine industry, including fuel and oil spills, antifouling agents, heavy metals, and lubricants. Moreover, development activities could mobilize sediments already laden with contaminants accumulated from other marine and land-based undertakings.

Impacts of Noise and Vibrations

The constant low-intensity sounds from operating TISEC and WEC have been compared to light to normal density shipping and a conventional ferry or subway, respectively.

While there is a global effort to study the effects of noise in the marine environment generated by seismic air-guns as well as shipping traffic, there have been very few directed studies of the response of fish and marine mammals to noises and vibrations produced by operational TISEC and WEC devices. Modeling studies have indicated that construction and operational noise levels and frequencies produced by individual TISEC and WEC devices could potentially cause temporary or permanent hearing loss in porpoises, seals, and some fish, as well as interference with communication. However, there is practically no information of the effects on benthic invertebrates, whales, sea turtles, or other marine mammals. The highest impacts would be to animals in close proximity to sudden high intensity noises, more often produced during construction activities, such as from pile driving or geophysical surveys. However, there have been no studies to determine whether these noises have actually caused any immediate or long-term physical damage. Since mobile animals are able to move away from sound sources, 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 demonstration TISEC and WEC projects, not full-scale arrays.

Long-term physiological, behavioural, and population-scale impacts of noise on marine mammals, fish, sea turtles and invertebrates are still poorly understood. Sound intensities, frequencies, and patterns, and therefore threats, will be technology, scale and environment-specific.

Impacts of Electromagnetic Fields (EMFs)

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 suggesting that EMF produced by underwater cables (and other electrical devices) associated with TISEC and WEC arrays may be detectable by elasmobranches, as well as by some bony fish, invertebrates, marine mammals, and sea turtles. 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 from marine life to existing underwater cables in Canadian or international waters is 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 as related to the health and behaviour of lobsters and other Canadian species of ecological and commercial concern.

Impacts of Physical Encounters

There are currently no scientific peer-reviewed reports that address the impact of physical encounters (either directly with structures, e.g., strikes and entanglement, or indirectly, e.g., through pressure changes) between marine life and WEC or TISEC technologies at existing facilities. The risk of such encounters and the effectiveness of potential mitigation measures to avoid impacts of encounters are unknown. Models suggest that most organisms may be able to avoid individual pilot-scale turbines and other moving parts without incurring serious harm. However, given the range of designs and unknown detection distances within a turbulent environment, there is uncertainty regarding direct or indirect physical encounters. Large-scale arrays and multiple developments within close proximity may form a more complex and difficult obstacle to avoid, and the risk of trapping or entanglement in tethering lines and cables could pose a significant and yet unevaluated hazard. Other sources of potential encounter-related mortality or injury include rapid pressure changes (e.g., eye and gas bladder damage), hydraulic shear (e.g., causing decapitation) and cavitation, particularly to organisms passing near or through TISEC turbines. To some extent, these effects will be specific to the device and design used.

In combination with other marine hazards, such as fishing gear and shipping, encounter-related mortality could have implications for population dynamics and stability of species inhabiting Canadian waters, including whales, sea turtles, sharks, and salmon.

Cumulative Impacts

While the importance of being able to evaluate the potential for cumulative impacts, including the interaction among multiple energy conversion technologies and the interaction of those technologies with other human activities over time, is recognized, there is currently insufficient information to predict or model these interactions. To date, there have been no published studies or models investigating the actual or potential long-term and regional impacts due to existing or proposed TISEC or WEC technologies.

Mitigation Measures

Some examples of possible measures to mitigate effects of tidal and wave energy conversion technologies include:

Siting Considerations

- 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).

- Avoid projects that would have negative impacts in areas with rare or sensitive habitats or species.
- 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.
- Avoid placing cables in or across areas with critical habitats or migration pathways of EMF sensitive species.
- Avoid locating project in areas with high levels of contaminants in sediments.

Timing Considerations

- Schedule installation, maintenance, and decommissioning activities to avoid known migration, breeding, and nursery periods.

Design Considerations

- Provide appropriate spacing between devices to reduce hydrodynamic interactions and create lower impact zones for marine life passage.
- Install scour protection structures around pilings to reduce erosion and sediment re-suspension.
- Use appropriate sediment control measures.
- Incorporate locally-appropriate habitat enhancement features into the device design.
- Design mooring systems that minimize anchor, chain and cable sweep disturbance of the seafloor. Consider use of dynamic positioning technologies to reduce the need for using anchors in sensitive areas.
- Use non-toxic antifouling materials based on physical non-stick properties instead of biocides; minimize the need of antifouling agents through regular through mechanical/manual removal; avoid using antifouling agents in sites where biofouling may not be problematic.
- Minimize use of loud activities, such as pile driving or drilling, where possible. 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; however, they may only be effective in shallow water.
- Use a soft start/ramp up procedure (gradually increasing sound level allowing organisms to move away).
- During construction or decommissioning, use marine mammal observers or other observation methods to halt activities when animals are in the vicinity or if an animal is seen to be at risk. In practice, this may or may not be practical.
- Consider burying cables below the seafloor, especially along important migration routes, where appropriate.
- Design surface structures to prevent use as a haul-out, avoid designs that create underwater or surface traps, reduce blade sharpness, or add shock absorption padding.

Operational Considerations

- Use fuel and oil spill prevention and contingency planning.
- Use non-toxic lubricants on device mechanisms.
- Use protective netting, grids or acoustic deterrent devices to exclude animals from development areas.

Decommissioning

- Cut above-ground pilings and other structures instead of excavating to reduce disruption of benthic habitat.

- Restore substrate and habitat features as soon as possible after construction or decommissioning is completed.
- Create or enhance habitat features that will benefit native local species.

There have 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.

Sources of Uncertainty

Due to the novelty and diversity of TISEC and WEC technologies, there is still a great deal of uncertainty surrounding their potential environmental implications. The major knowledge gaps include:

Physical Processes
- Device and site-specific predictions and interactions with hydrodynamic and sediment processes.
- Consequences of extracting energy in terms of environmentally acceptable or meaningful thresholds relative to natural variability (including future changes, e.g., climate change).
- Baseline information on dynamic processes.

Habitat Alteration
- Baseline information on habitat.
- Response of marine organisms (including species at risk as a high priority, migratory populations, and residents) to the presence of TISEC and WEC devices and any resulting ecological changes.
- Influence of habitat alteration on species at risk.
- Resilience of benthic communities and the time scale of recovery from disturbance.
- Effects of hydrodynamic and sediment process changes on habitats and populations.
- Effectiveness of mitigation and remediation measures.
- Impacts of decommissioning and infrastructure removal.

Contaminants
- Background sediment contaminant levels at potential sites.
- Mechanisms for contaminant release from sediments.
- Fate and effects of contaminants, if any.
- Efficacy and secondary effects of antifouling systems.

Noise
- Background noise levels.
- Behavioural and physical effects of noise.
- Characterization of noise and vibrations sources, and their transmission.
- Effectiveness of noise mitigation measures.

EMF
- Behavioural and physiological impacts of cables and other electrical components of TISEC and WEC devices.
- Characterization of EMF levels of pilot and full-scale devices.
- Effectiveness (from an ecological cost benefit perspective) of cable burial.

Contact or Pressure Change

- Risks to marine organisms of physical encounters and injury with different device designs and environmental conditions.
- Operational implications of interference from ice, logs and other debris.

CONCLUSIONS AND ADVICE

There is not yet sufficient information on the scope of impacts from the wide variety of wave and tidal energy conversion technologies that have been, and are continuing to be, produced to develop a relevant Statement of Canadian Practice, especially given the diverse range of potential deployment environments. However, this issue should be re-visited as experience and knowledge from research and demonstration projects are gained.

Broad-scale research priorities to assist in the development of policy and regulations related to TISEC and WEC include:

- Development of standardized science-based monitoring protocols for marine energy extraction (pre and post deployment).
- Development of new monitoring technologies.
- Development and evaluation of technologies and protocols for the assessment of environmental effects.
- Integration of physical and biological research and monitoring activities.
- Development, evaluation, and validation of relevant models.
- Collection and archiving of relevant baseline data.

Priority environmental parameters requiring science research include:

- Modeling of ocean processes, e.g., tidal movements, waves, sediment behaviour and dynamics, in areas of high potential for energy development, in order to establish:
  - The dynamic processes that may be affected by energy extraction.
  - Likely changes resulting from energy extraction and physical interactions.
  - The potential for cumulative effects to arise from energy resource developments.
  - The parameters to be addressed in monitoring programs.

- Habitat surveys and analysis in areas of interest:
  - Identification of sensitive sites, including location of critical habitat of species at risk.
  - Habitat alteration, including changes in hydrodynamic regimes.

- Modeling and field investigation of marine organism physiological, behavioural and population-scale responses to marine energy development. Specific priority concerns include:
  - Contaminants, especially antifouling materials.
  - Electromagnetic field effects from cabling and other electronic components.
  - Noise and vibrations, including ambient sound levels.
  - Risk of mortality.
  - Avoidance behaviour in the vicinity of TISEC and WEC devices.
  - Changes in migration and distribution.

- Assessment of resilience of benthic and pelagic communities and the time scales of recovery from disturbance.

- Evaluation of mitigation, restoration and enhancement options.
- Modeling of cumulative and synergistic interactions among multiple arrays and between arrays and other marine activities.

Due to the private sector-driven nature of this emerging industry, developers are in a good position to undertake applied environmental research. Currently, developer-commissioned data are typically difficult for outside researchers to access. Thus, it is essential that researching these issues be a coordinated effort between developers, universities, colleges, provincial and federal government agencies, and other stakeholders and that information is readily accessible to all parties.

There is also a recognized need to develop and maintain national and regional georeferenced, interoperable, standards-based databases that enable access by governments, developers, academics, NGOs and the general public. This need extends beyond the application for TISEC and WEC projects.

It was also suggested that a risk assessment process, including stakeholder consultation, should be pursued to identify which of the above key environmental parameters require immediate investments in monitoring and research and those that can be dealt with in the longer term. Some of the information needed to pursue this may already have been collected in support of marine and coastal planning.

SOURCES OF INFORMATION

Isaacman, L., and K. Lee. 2009. Current state of knowledge on the environmental impacts of tidal and wave energy technology in Canada. DFO. Can. Sci. Advis. Sec. Res. Doc. 2009/077.

FOR MORE INFORMATION

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