Pathways of Effects for Offshore Renewable Energy in Canada

FINAL REPORT – December 2011

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for

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1.0 Introduction

As a new and emerging industry, marine renewable energy raises a number of challenges for the Government of Canada, including the ability to understand and assess the variety of technologies that are being developed, and the potential environmental and socioeconomic impacts resulting from these technologies. Regulatory authorities, including those within Fisheries and Oceans Canada (DFO), will turn to science experts seeking advice regarding decisions on whether or not to grant approvals for various activities in the offshore renewable energy sector.

In anticipation of future development in this sector, DFO obtained funding support under Natural Resource Canada's Clean Energy Fund (CEF) for *"Supporting an Efficient Regulatory Framework for Ocean Renewable and Clean Energy Initiatives"*. The ultimate aim of this CEF project is to develop a strategic research plan to ensure that marine renewable energy developments are effectively reviewed and located in such a manner as to minimize adverse environmental and socio-economic impacts. The results of the work will help identify priority areas for environmental as well as socio-economic research.

The project includes 5 key stages: development of Pathways of Effects (PoE) logic models for each major form of marine renewable energy (offshore wind, wave, in-stream tidal, and in-river hydrokinetic); identification of major regulatory decision points; development of a regulatory guidance document; completion of a gap analysis between regulatory decision points and existing science; and ranking of research priorities in the form of a strategic research plan for the consideration of DFO senior management.

This report presents work related to the first stage: development of PoE models, that are conceptual representations of predicted relationships between human activities and their associated sub-activities - the pressures - and the environmental effects or impacts that they may have on specific ecological endpoints. Information presented in the PoEs can help regulators, scientists, and developers to identify and understand linkages, information gaps, and research needs.

The attached PoE models and accompanying narrative (assumptions and strength of evidence) were prepared by a team of professional consultants and overseen by a DFO working group, with representation from Habitat, Science, Oceans, as well as a representative from Natural Resources Canada. The draft documents outline potential linkages between activities associated with marine renewable energy and the environmental stressors. The design of the PoE models follows the international Driving Forces-Pressures-State-Impact-Responses (DPSIR) framework adopted by the Organization of Economic Co-operation and Development, and originally developed by the United Nations Environment Program.

The PoE linkages were based on a review of strategic environmental assessments, expert panel reports, environmental assessments, monitoring reports, scientific literature and the expert judgment of the consultants and the working group members. The PoE models will be shared with industry, other federal departments, provincial authorities, academia, First Nations, and others for their input.

The Working Group also requested a scientific peer review of the final PoE models and supporting narrative (assumptions and strength of evidence), to ensure all of the identified stressors, interactions, receptors and outcomes are supported by science, and the risks associated with marine renewable energy development (offshore wind, wave, in-stream tidal, and in-river hydrokinetic) that are relevant to government regulators are identified. This review was conducted on 3rd and 4th December 2011.

2.0 Approach & Limitations

2.1 Approach

The aim of the project is to develop Pathways of Effects (PoE) logic models clearly identifying the relationship(s) between each of the major forms of marine/offshore renewable energy (ORE) technology (i.e. offshore wind, wave, in-stream tidal and in-river hydrokinetic) and their potential impacts on marine/aquatic ecological components.

The approach was to follow the methodological guidelines outlined in the Fisheries and Oceans guideline documents: *Developing Pathways of Effects for Sector Based Management: Feasibility Analysis* (Grieg and Alexander 2009) and *Draft Pathways of Effects National Guidelines (January 25, 2011)* (DFO 2011).

The PoE models and this report draw and build upon previous work for the National Science Advisory Workshop on Renewable Energy from Currents and Waves (Dartmouth, Nova Scotia, 2009), specifically the Canadian Science Advisory Secretariat Research Document 2009/077: *Current State of Knowledge on the Environmental Impacts of Tidal and Wave Energy Technology in Canada* (Isaacman and Lee 2010) (see Appendix C). The research document provided a comprehensive synthesis and analysis of the existing information on the environmental impacts of renewable energy technologies (specifically wave and in-stream tidal/hydrokinetic), including domestic and international reports and consultations with experts. The purpose of the current work is not to duplicate the content or analysis of the previous report, but to restructure the findings into pathways of effects models, which illustrate the potential linkages between specific stressors and environmental effects; to update the level of available knowledge with any research released since the previous document's publication; and to expand the scope to include offshore wind, marine birds and other aquatic species. Based on the review and analysis of the available information and consultations with experts, a series of high-level and detailed sector-based pathway of effects logic models for wind, wave, tidal and in-river hydrokinetic energy technologies were developed illustrating the potential linkages between activities, stressors and environmental effects. These are supported with a report highlighting the strength of the evidence for the different stressor-effects linkages, including:

- the potential spatial / temporal extent of the different effects illustrated (e.g. near-field or far-field spatial extent, short term or persistent in time);
- the level of knowledge related to different effects;
- environmental conditions and activity characteristics that influence the effect; and
- recommendations for addressing gaps in knowledge.

2.2 Organization of the Pathways

Figure 1 provides the framework for the PoEs for the ORE sector. The framework consists of five basic components:

- Technology categories, activity phases and sub-activities;
- Stressors/pressures;
- Effects on the environment, including:
    a) effects on ecosystem components;
    b) effects on the habitat/ecosystem, with potential indirect effects on ecosystem components; and
    c) cumulative effects (see 2.3)
- Ecosystem components/receptors;
- Valued ecosystem goods & services

The PoEs for the ORE industry cover four broad **technology categories** (Table 1). Linkages specific to particular device types were identified, where possible. The probability and significance of each stressor-effect linkage may vary with the specific technology design. Due to the current evolving and extremely variable nature of the technologies and lack of device-specific performance data, it was not possible to sub-divide the categories further. Thus, it will be important to re-visit these pathways as the designs mature and become more standardized.

Table 1: ORE Technology Categories and Sub-Categories

Technologies	Sub-categories	Mooring systems
In-stream tidal	Vertical and horizontal axis turbines	Weighted, bottom-anchored, surface-anchored, piled
Wave	Point absorbing, oscillating water column, attenuator, overtopping, oscillating wave surge converting devices	Bottom-anchored, coastal-mounted
In-river hydrokinetic	Vertical and horizontal axis turbines	Weighted, bottom-anchored, surface-anchored, piled
Offshore wind	n/a	Piled, bottom-anchored

Development in the ORE sector proceeds through three general **activity phases: Site Investigations, Construction,** and **Operation.** (Decommissioning and Maintenance activities entail similar effects to construction activities, and so for simplicity are included here with Construction) (Table 2). Based on a review of the literature, the main **stressors** or **pressures** on the marine/aquatic environment are identified for each of the three phases.

Table 2: ORE Sector Activity Phases and Associated Stressors

Activity phase	Main Stressors
Site Investigations activities	▪ Physical disturbance/removal of individuals ▪ Acoustic disturbance ▪ Alteration of habitat ▪ Translocation of fauna and flora
Construction (including maintenance and decommissioning)	▪ Physical interaction with infrastructure ▪ Noise, disturbance and light ▪ Release of contaminants ▪ Translocation of fauna and flora
Operations	▪ Release of contaminants ▪ Physical interactions with infrastructure ▪ Noise, vibrations and light ▪ Electromagnetic fields (EMF) emitted from power output cables and devices ▪ Effects of artificial structures ▪ Change in current or wave energy

The PoEs identify two types of potential **effects** linkages:

- effects experienced by the key ecosystem components/receptors;
- changes to the habitat or ecosystem, with corollary effects on ecosystem components/receptors.

While an important consideration, *cumulative effects* are not illustrated in the PoE diagrams (see section 2.3).

The effects and linkages are based on a synthesis of the key issues identified in the general ORE-literature.

The PoEs have been clustered into four **broad ecosystem component/receptor** categories (grouping of marine/aquatic species), which are potentially impacted by ORE sector activities and to which management/mitigation actions can be targeted:

- fish;
- marine/aquatic mammals & turtles (including cetaceans, pinnipeds, sea otters, river otters, sea and freshwater turtles);
- marine/aquatic birds (including birds inhabiting fresh and sea waters, migratory species, and shorebirds); and
- invertebrates & plants.

It is recognized that the probability, nature and significance of specific effects will vary among the ecosystem component categories and specific species within each ecosystem component category.

The models also highlight the linkage of the ecosystem components to **valued ecosystem goods & services**, which are of relevance to Canadian environmental policy and regulatory priorities.

2.3 Scope & Limitations of the Report

An assessment of the potential risk, magnitude and significance of each stressor-effect linkage on the key ecosystem components or specific species is beyond the scope of this phase of the project. However, strategic impact/risk assessments have been performed for several regions in the UK (e.g. FMM 2007; APBMER 2009; Guernsey 2010) and US (Polagye *et al.* 2011), which may provide some insights into the significance of potential stressor-effect pathways on key ecosystem components/receptors by the different technologies deployed in Canada. The PoE models have been designed to provide a broad account of the general characteristics of each ecosystem component category, although it is recognized that the probability, nature and significance of each stressor-effect linkage may vary by species and specific project. The PoE models are designed with the purpose of laying out the key overall, individual stressor-effect linkages identified in the literature and are not meant to provide an exhaustive list of all potential effects. It is recognized that other stressors, effects and linkages are possible, and will depend on the location, technology and practices/protocols used. The general framework model (Figure 1) recognizes the potential for cumulative effects. However, detailed scientific examination of the cumulative effects pathways is not currently feasible based on the present level of scientific knowledge. These issues will be important considerations in future risk assessment efforts.

The literature on environmental effects of ocean renewable energy is sparse and scattered at present, but rapidly growing. A few comprehensive reviews considering more than one ORE technology type have been prepared that provide useful overviews of environmental concern. These include: FMM (2007), Michel *et al.* (2007), APBMER (2009), Boehlert and Gill (2010), Isaacman and Lee (2010) and Polagye *et al.* (2011). Other sources that deal with particular technologies and/or stressors are listed below in the Strength of Evidence tables.

3.0 Offshore Renewable Energy Pathways of Effects Models

3.1 Pathways of Effects Models

A total of nine sector-based models have been developed to illustrate the various pathways of effects related to the ORE sector (Appendix A). Figure 1 presents the overall structure and components of the pathways of effects model. Seven stressors have been identified that apply, to varying degrees, to all ORE technologies (cf. Figure 1). These are:

- Physical alteration of habitat;
- Physical interactions with infrastructure;
- Changes in ambient light and acoustic regimes;
- Changes in current and wave energy;
- Changes in electrical and magnetic fields;
- Release of contaminants; and
- Disturbance and/or translocation of fauna.

General, sector-based models have been developed for each of the three activity phases: Site investigations: Construction (including maintenance and decommissioning): and Operations (Figures 2, 3 & 4). Stressor-based models have been developed to provide greater detail on the operations phase stressors and to illustrate potential variations among the different technology sectors (Figures 5 – 9). As previously mentioned the probability, nature, magnitude and significance of the stressor-effect linkages will depend on a variety of factors, including technology design, local environmental conditions and biodiversity, and the practices and protocols used. Many of the effects may be mitigable through appropriate design and site selection.

Primary effects of stressors are considered under four categories. In two of these categories, the stressor(s) act directly on species and/or populations: 1. Changes to health, survival or reproductive success; and 2. Changes in behaviour. The other two act indirectly on species through: 3. Changes in habitat; and 4. Changes in community structure.

Cumulative effects can occur in three ways: from the multiple deployment of similar devices (e.g. as in an array); from interactions between effects of different stressors; and from other human activities involving the same environment. All stressor effects have the potential to be additive and/or synergistic, but our knowledge of cumulative effects remains very weak.

3.2. Strength of Evidence

The following section and tables (see Appendix B) provide an overview of the currently available information and level of knowledge related to each of the stressor-effect linkages and overall responses of ecosystem components to ORE development activities. For more details and full references (up to 2009), refer to Isaacman and Lee (2010) (Appendix C).

3.2.1 Site Investigations Phase Pathways of Effects Model

The Site Investigations phase includes all activities associated with site investigations and surveys, including seismic and active acoustic surveys, biological survey activities and borehole drilling/benthic surveys. Most of the activities and effects are analogous to those conducted for other marine/aquatic activities, for which the potential environmental interactions are fairly well understood and standard protocols and mitigation measures have been developed. Table 3 summarizes the level of knowledge on the stressor-effect linkages for the three main stressors and the overall effects on the habitat, ecosystem, and ecosystem components/receptors.

Collection of Organisms

Biological sampling activities required for environmental assessments and monitoring may have an effect on local species resulting from the nature and scale of sampling. In recent years, there has been an increase in use of non-destructive techniques for surveying of marine life, including remotely operated video and multibeam bathymetry, which has diminished the degree of disturbance associated with traditional surveys. Nonetheless, these new techniques usually require some physical sampling for species identification and/or biomass verification. Non-lethal sampling techniques such as netting and tagging may result in physical damage, increased stress, or habitat avoidance, and contribute overall to decreased survival or fitness. Even visual surveys might disturb/displace some species due to increased presence of humans or vessels, or changes in light regime. Lethal sampling techniques (including netting, grab sampling etc.) result in the removal of a number of individuals; this may be of particular concern in the case of species at risk. Some benthic sampling techniques (e.g. trawls or grabs) result in changes to benthic habitat over and above the removal of organisms. The risk and effects will be similar to research or monitoring activities conducted for other purposes in aquatic/marine environments, and are reasonably well known. Standard research protocols exist to reduce the potential for impacts on species.

Seismic and Acoustic Methodologies

Acoustic technologies play a key role in obtaining information about the marine/aquatic geophysical and biological environment. These technologies include air guns, sonar, bathymetric techniques, echo-sounders and data transmission devices.

A marine organism's response to acoustic disturbance depends upon its acoustic sensitivity, and the intensity, timing and frequency(-ies) of noise produced by the activity. The greatest concern is with seismic surveys which direct high energy sound pulses (usually from air guns) toward the seafloor (OSPAR 2009). Air guns produce both low-frequency and high-frequency pulses and can radiate in both vertical and horizontal directions.

Research indicates that seismic surveys, and to a lesser extent, other acoustic disturbances caused by scientific research, pose the most concern for marine species. Assuming proper protocols are used, and seismic surveys are restricted, this short-lived phase may not result in significant, long-term impacts on local populations. Site investigations often improve knowledge about the local ecosystem and inform regulators, other resource users, and developers related to environmentally-suitable site selection and design of ORE developments, with long-term conservation benefits.

Considerable research has been conducted on the impacts of seismic surveys on marine organisms, particularly vertebrates (OSPAR 2009). The sudden high amplitude noises produced by seismic, drilling and other active acoustic devices (e.g. some sonar) have the potential to inflict physical damage and behavioural distress responses in many acoustically sensitive species, and may extend over large areas around the activity (FMM 2007; OSPAR 2009). Non-lethal consequences include physiological effects on auditory systems, behavioural responses such as startle, change in feeding/breeding behaviours, and abandonment or avoidance of habitat sites or migration routes. In addition, non-natural acoustic emissions may have masking effects, interfering with acoustic communication in mammals, and predator/prey detection. Recovery may depend on the duration and intensity of the disturbance. Potential effects on marine birds vary according to the reason for their presence in the vicinity of pre-construction activities, whether it is for nesting, feeding, or staging during migration. Diving birds (e.g. eiders, cormorants) may be additionally affected by sub-surface noise generation (seismic surveys, drilling etc.), both through general deterrence and interference with prey detection. In contrast, little is known about invertebrate responses to acoustic techniques, although some research has been conducted into cephalopods (e.g. McCauley *et al.* 2000) and snow crabs (Christian *et al.* 2003).

Physical & Geotechnical Surveys

In addition to acoustic survey techniques as described above, borehole drilling conducted to characterize the geophysical conditions of a site may emit high intensity noise into the environment. These noises and vibrations may result in disturbance of organisms and habitats in the vicinity of the sampling. Moreover, relocated sediment, rock and drilling wastes may smother adjacent habitats, which may be some distance away beneath a downstream plume. The nature and scale of effects will depend on the type of sediment/substrate, flow conditions and the level of disturbance (Isaacman and Lee 2010). Suspended drill cuttings are also associated with a variety of contaminants, such as lubricants and biocides, that can affect water quality.

3.2.2 Construction Phase Pathways of Effects Model

The construction phase includes all activities associated with construction, maintenance and decommissioning. Most of the activities and effects are analogous to those conducted for other marine/aquatic activities, in which the potential environmental interactions are fairly well-understood, and standard protocols and mitigation measures have been developed. Table 4 outlines the level of knowledge on the stressor-effect linkages for the four main stressors and the overall effects on the habitat, ecosystem, and ecosystem components/receptors.

Release of Contaminants

Construction activities may result in the release of various chemicals at concentrations above toxicity thresholds. These may include petroleum hydrocarbons in fuel and lubricants; biocides used in antifouling agents; drill cuttings; and gravel and other construction materials. The risks are similar to other construction activities in the marine environment, and will depend on the types of practices and protocols applied at particular projects and the sensitivities of local species.

Physical Interactions with Infrastructure

During construction, a variety of structures may be installed in the marine environment, and a significant increase in local vessel traffic is to be expected. Such installations may be temporary or more permanent. The effects of ORE structures and temporary structures necessary for construction activities are expected to be similar to infrastructure used in many other marine activities, such as the oil and gas industries, or in harbour and shoreline developments. New infrastructure may act in many ways, and have both positive and negative effects: the subsurface structures of offshore wind farms, for example, may increase habitat and biological diversity or productivity as well as remove or modify existing benthic habitat. The probability, nature, and magnitude of effects are expected to be similar to other marine/aquatic development activities and depend on the device and installation design, on the equipment, techniques and mitigation measures being used, and on local environmental conditions.

Increased vessel traffic associated with construction may represent a substantial change to pre-existing traffic conditions, and may be short-term or prolonged. Vessels involved in construction or deployment activities may be rather different from those previously common in the area. For example, barges, drilling rigs or deployment vessels may be required to maintain station precisely for prolonged periods of time, for which they are fitted with dynamic positioning capability: shrouded bow and stern thrusters have recently been shown to represent an important new hazard to some marine fauna such as mammals (Thompson 2011). Consequences for fauna range from lethal and sub-lethal effects associated with contact between animals and infrastructure, to more indirect effects through changes in behaviour, (e.g. avoidance, startle, interference with communication etc.), and interspecific interactions.

Noise, Disturbance and Light

Similar to the Site Investigation phase, potential site preparation activities causing disturbance may include increased vessel traffic, human presence, dredging, drilling, cutting, pile-driving and cable placement. The level and frequency of the noise, vibrations, and other disturbances from human presence produced at ORE projects is expected to be comparable to those produced by construction activities for other marine activities. A marine organism's response to noise disturbance depends on its acoustic sensitivity and the level and frequency of noise produced by the activity. Although temporary, the sudden high amplitude, intermittent noises produced by many construction-related activities have the potential to inflict physical damage or behavioural distress responses in many acoustically sensitive species, at least in the immediate vicinity of the activity (FMM 2007; Isaacman and Lee 2010). Sounds created during impact pile-driving comprise very high sound pressure levels of more than 250 dB (OSPAR 2009). Behavioural responses include startle, change in feeding/breeding behaviours, masking effects (e.g. acoustic communication, predator/prey detection, navigation), and abandonment or avoidance of habitat sites or migration routes. Recovery may depend on the duration and intensity of the disturbance.

Changes in ambient light may result from a number of activities during construction. These include vessel safety lighting during night-time operations, strobe-lighting for navigation, increased turbidity associated with sediment mobilization, etc. Effects are variable: increased turbidity or, alternatively, prolonged and amplified light levels may both affect primary productivity and predator-prey interactions. In general, the consequences are expected to be similar to other marine construction activities.

Physical Alteration of Habitat

The amount of permanently lost benthic or coastal habitat (in the direct footprint of the piles, anchors, bases or transmission cables) is likely to be small for single or small-scale wave or tidal systems, with slightly more expected for wind devices (due to size of piles). However, large-scale arrays could occupy a substantial area of habitat. Moreover, coastal-mounted wave systems may have a significant direct impact on coastal habitats, depending on the size of the device (Isaacman and Lee 2010). Many suitable ORE locations are in areas of high ecological value: even the loss of a small area may be significant if located on critical, rare and sensitive areas, such as spawning/breeding grounds or tidal marshes (FMM 2007).

In addition to the structures themselves, installation may involve trenching/excavation, drilling, site preparation (e.g. levelling or substrate/vegetation removal), in-filling, substrate disturbance and smothering (by resettled suspended sediments or relocated excavated materials), with temporary or potentially long-term effects on sensitive benthic habitats species (e.g., scallop) and spawning populations (Isaacman and Lee 2010). Risk and effects should be similar to other construction activities in aquatic/marine environments.

The nature and temporal scale of effects will depend on the type of sediment/substrate, flow conditions, and the level of disturbance (Isaacman and Lee 2010). For example, effects are expected to be minor in areas over bedrock or with high natural turbidity, but more significant over sedimentary substrates

Translocation of Flora and Fauna

Increased vessel traffic, especially if associated with specialized vessels brought in from other distant coastal environments, may be expected to increase the risk of introductions of non-native species, which might include invasive alien species (IAS). The consequences of IAS introductions may be expected to appear through interspecific interactions such as competition for habitat, predator/prey interactions, etc. New habitat created as part of ORE infrastructure may favour establishment of IAS.

Habitat, Ecosystem and Population Responses

Changes in pelagic habitat conditions (e.g. turbidity, nutrients, oxygen and light levels, temperature and flow conditions) can alter the productivity and transport of plankton and macrophyte spores with possible feedback consequences for water quality (i.e. oxygen levels) and food web interactions. In addition to direct effects on species, the loss of or change in structure of critical or sensitive benthic or coastal habitat can alter the type, quality and abundance of nutrients, predator species, prey (plankton, larvae, invertebrates, forage fish etc,), shelter, and spawning and nursery grounds, with a cascade effect on aquatic ecosystems and populations (Isaacman and Lee 2010; Shields *et al.* 2011).

The health, fitness, and/or abundance of species associated with the development site may be directly or indirectly affected, either positively or negatively, through one or more of the above pathways. The response will depend on the level, timing and duration of direct disturbance to organisms and habitat and may be especially significant if the site is critical habitat. Moreover, increases or decreases in species diversity or recruitment may result, including some local species extirpations.

3.2.3 Operations Phase Pathways of Effects Models

The operations phase includes all potential stressors/activities occurring as a result of the presence or operation of the device during its deployment, except those related to maintenance (covered in the construction phase model). Tables 5-10 outline the level of knowledge on the stressor-effect linkages for six main stressors and the overall effects on the habitat, ecosystem, and ecosystem components/receptors.

Physical Interactions with Infrastructure (Table 5)

Physical interactions with ORE structures include physical contact (e.g. collision, strike), exposure to sudden pressure changes (e.g. cavitation) or shear forces, and the physiological effects associated with increased exertion in attempts by animals to avoid contact with infrastructure. The probability of encounters with components, with or without injury, is both device and species dependent. Planktonic organisms are considered less likely to make physical contact with structures because of their entrainment in the main flow, but they may be nonetheless susceptible to cavitation and shear forces. Nekton, on the other hand, may experience additional consequences resulting from attempts to avoid entrainment. Artificial reef effects (see Table 8), lights, hydraulic conditions and other factors may attract certain species to the vicinity of ORE structures, increasing their risk of interaction. A species' ability to detect and evade a device depends on:

- Detection ability – influenced by device and environmental conditions (natural and device-generated turbulence, turbidity and noise) and sensitivity of species. Masking effects from device-generated noise, EMFs, and turbidity may affect a species' ability to detect ORE devices sufficiently early to avoid physical interaction.
- Device/array design - effect of ducting, gaps, blade speed, size, and trapping (ability to evade multiple obstacles). Due to the absence of turbine blades, less concern has been placed on the risk of injury from contact with wave devices, although designs that involve compression of a fluid or overtopping might have their own risk features.
- Attraction/avoidance/evasion behaviours.

- Placement: e.g. where, in the water column, the device operates relative to species' normal movement patterns, and the cross-sectional area sampled by the ORE relative to the overall cross-sectional area at that location.
- Size of organism. In general it is assumed that the risk of physical contact increases with body size, although non-contact consequences of physical interaction (e.g. physiological effects of cavitation or shear forces) may be greater for smaller individuals, as found in studies of hydroelectric generators.

Noise, Vibrations and Light (Table 6)

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 ORE system, which is technology-, and environment-specific. Physical effects could include temporary or permanent hearing loss or increased stress (leading to behavioural effects or reduced health/fitness). Behavioural responses include startle (e.g. during start up), change in feeding/breeding behaviours, masking effects (e.g. acoustic communication, predator/prey detection, navigation), abandonment or avoidance of habitat sites and changes in migration patterns.

This stressor is likely the highest threat to less mobile organisms or in critical habitat areas since mobile organisms may be able to avoid/move away from low-frequency persistent noises. Birds, for example, are able to avoid/move away from wind turbines and thus are unlikely to remain near an unacceptable offshore noise for an extended period (e.g. Dong *et al.* 2006). However, there could be risks if the turbine operation is audible in critical onshore habitat such as that used for nesting, roosting etc. Shorebirds and shallow-feeding pelagic species (e.g. phalaropes) might be deterred from foraging in the vicinity of offshore wind farms either because of noise or turbulence effects.

Electromagnetic Fields (EMF) (Table 7)

The effect from EMFs generated by underwater power cables, and/or the ORE devices themselves, will depend on the sensitivity of local organisms to electric or magnetic fields and the size of the area in which the field can be detected. Subsea transmission cables are widespread and transect many commercial fishing grounds but little information on their effects is available.

The emission strength decreases with distance from the source; however, the level of dissipation depends on the technology (type of cabling, shielding and mode of transmission – AC or Dc current) and substrate conditions (e.g. if buried) (Isaacman and Lee 2010). Accurately measuring the EMF characteristics emitted by transmission cables in marine environments has proved difficult and thus few data are available, especially for cables used for OREs. Cables deployed perpendicular to current flows may represent barriers for demersal fish on migration routes or feeding forays. There is also uncertainty related to the effectiveness of burial and shielding for reducing EMF detectability above the seafloor.

This stressor is likely of highest concern for organisms living on or near the seafloor (eggs, larvae, benthic species or feeders), especially those with limited mobility or in critical habitat areas, since mobile pelagic species may be able to avoid/move away from areas with EMFs. Many fish and mammal species detect and use electric or magnetic fields to orient, navigate, find prey or mates, or to cue particular life stages (FMM 2007). Thus, EMFs emitted from underwater transmission cables may mask natural EMF-cues, thereby affecting the health, behaviour or migration of EMF-sensitive species. Since they live on the seafloor where the field strength is highest, benthic organisms, especially those with limited mobility or in critical habitat area, may be especially at risk of exposure to cable-generated EMFs.

Effects of Artificial Structures (Table 8 & 10)

In addition to the effects of removal of energy from the system (see below), the physical presence of artificial structures could modify local hydraulic, sediment transport (re-suspension and deposition) or scour (erosion) patterns by acting as a physical impediment to the flow of water in the water column. The nature and scale of near-field effects will depend on existing hydrodynamic, sediment/substrate and geological conditions, and the design of the technology. For example, systems placed over areas of scoured bedrock (e.g. many gravity-based systems) may cause minimal disruption in near-field sediment dynamics compared to those in soft-sediment areas. Floating and surface-mounted devices (e.g. suspended from bridge or barge) are expected to cause only slight local sediment flow disturbance and scour primarily around the moorings and anchors (if present). Floating structures may also affect light penetration, or influence local interspecific interactions as a result of shading. Seafloor-mounted ORE may have larger impacts on sediment flow, scour and turbidity around the bases of individual devices and entire arrays, and, depending upon local flow conditions, may have effects at some distance away from ORE devices. Coastal-mounted wave systems will likely have primarily local effects on coastal and intertidal areas. In addition, scour due to exposed transmission cables, especially in high energy environments, could be an issue for coastal and shoreline habitats.

The increased habitat structure and diversity created by marine energy infrastructure (foundations, anchors, scour protection and exposed transmission cables) can provide alternative habitat and foraging opportunities (prey species – e.g. epibenthic colonizers) for fish and crustaceans (artificial reef effects) (Isaacman and Lee 2010). New habitat may favour successful establishment of species that did not previously inhabit the area, with consequent effects on other species and their interspecific interactions. Some local species may be attracted to arrays by higher prey abundances and others deterred due to reductions in availability of preferred prey or increases in predators. The exact factors affecting the response of fish and crustacean communities to new structures are uncertain and may vary by site.

Without antifouling measures in place, aquatic structures can become colonized by benthic, epibenthic or encrusting organisms (Isaacman and Lee 2010). The introduction of new hard surfaces and change in wave/tidal and sediment regimes can create conditions favourable to the development of a new epibenthic community structure. The abundance, diversity and type of species that become established and their effect on existing community structure depends on the existing conditions (benthic habitat structure, wave/tidal conditions, water chemistry, species in surrounding areas) and the stability of the structure (e.g. mobile vs. static components). Estuaries are often rich in potential epibenthic species: however, areas with high wave or tidal flow (typically characteristic of wave and tidal sites) or soft sediment areas may be less favourable to diverse epibenthic community development.

Arrays may serve as physical barriers to previously accessible critical habitats, areas or migration routes, especially when distributed across entire channels. The probability and significance of the effect on populations that use those areas depend on the configuration of the array (number, type and complexity of structures that could pose obstacles), how species react to the array and the importance of the area or route (Hagerman and Bedard 2004).

Sizeable surface floating components of ORE developments (e.g. platform-based wind turbines or suspended tidal or in-river devices) may make appealing haul-outs or resting/nesting sites for pinnipeds, otters, turtles and marine birds (Hagerman and Bedard 2004), especially in conjunction with increased prey availability due to artificial reef effects (Isaacman and Lee 2010). Lights on surface structures may also attract mammals, turtles and birds to these structures, whereas noise, EMFs, deterrent devices and other factors may discourage them.

Change in Current or Wave Energy (Table 9 & 10)

The nature and scale (spatial and temporal) of the effects of changing current or wave energy levels are system-, site- and technology-dependent. Effects depend on existing hydrodynamic and geophysical conditions, the type(s) and number of device(s), the efficiency of the technology's conversion performance (i.e. amount of energy extracted), and the scale and dynamic characteristics of the system in which the ORE is installed. Many aquatic species and habitats are dependent on specific habitat conditions and thus are sensitive to significant hydrodynamic and sediment process changes (Isaacman and Lee 2010). Changes in turbidity, nutrients, and oxygen or light levels associated with decreased current or wave energy can alter the suitability of pelagic habitat (as well as downstream benthic and coastal habitats) for local species. In general, extracting energy from a dynamic system may have effects far beyond the immediate vicinity of the development.

Many species depend on particular hydrodynamic and water quality conditions to cue and drive spawning, feeding, development and movement patterns. As well, changes in turbidity can interfere with predator/prey detection and navigation in species which rely on visual cues (e.g. many cetaceans - FMM 2007).

Near-field effects depend on the size and location (e.g. open area vs. channel; relative cross-sectional area sampled by the devices to that of the locality) of the deployment, on existing hydrodynamic, sediment/substrate and geophysical conditions, and on the nature and magnitude of changes in the hydrodynamic regime (tidal, current, wave patterns) due to the removal of energy. Changes in pelagic habitat conditions such as turbidity, nutrients, oxygen and light levels, temperature and flow characteristics, can alter the productivity and transport of plankton and macrophyte spores with possible feedback consequences for water quality (e.g. oxygen levels) and food web interactions.

Changes in current flow have variable implications for sediment erosion and deposition patterns and pelagic habitat characteristics both near- and far-field. The nature and scale of effects depend on existing sediment/substrate and geophysical conditions, with soft bottom and vegetated habitats being especially sensitive. ORE systems placed over areas of scoured bedrock will likely result in only minor disruption in near-field sediment dynamics compared to those placed near soft sediment areas. Changing sediment suspension and deposition patterns due to scour, turbulence, associated with increased or decreased current velocity, can lead to the detachment or smothering adult benthic organisms, eggs and larvae, and change benthic feeding or spawning habitat (Isaacman and Lee 2010).

Coastal-mounted wave systems may have considerable direct local effects on coastal and intertidal areas. In addition, however, reduced wave action from other wave and tidal devices further from shore could alter sediment, debris and nutrient transport patterns, with consequent changes to shoreline morphology and coastal habitats, including increases or decreases in shoreline erosion (Defeo *et al.* 2009). If properly sited, it is possible that coastal wave conversion structures could improve shoreline stabilization, where needed.

Far-field effects depend primarily on the natural dynamics of the system, its morphology, and associated mixing, erosion and deposition processes. Changes in vertical mixing may have important effects on the productivity of coastal ecosystems, and the foraging behaviour of fish, birds and mammals. Areas of strong vertical mixing (including upwelling and downwelling areas) are critically important feeding sites for many species. Removing energy from the system may decrease the spatial extent or degree of vertical mixing, even at distances far removed from the site of the energy conversion, influencing the vertical transport of plankton or epibenthic organisms, for example. These potential far-field effects represent a new challenge in that their assessment cannot be based upon experience from other marine activities, depend upon the application of suitable, verified models, and may be difficult to detect in practice because of extensive natural variations in the marine environment.

As seen with hydropower development in cold regions, increased tidal turbulence and changes in current flows from tidal/in-river hydrokinetic turbines could lead to reduced ice coverage in rivers which normally freeze over in winter, reducing the habitat suitability for certain ice dependent species (e.g. tomcod) or improving it for others.

Release of Contaminants (Table 10)

Operation of ORE systems may result in the release of various chemicals at concentrations above toxicity thresholds. These may include petroleum hydrocarbons in fuel and lubricants; biocides used in antifouling agents; and heavy metals released from sacrificial anodes for corrosion protection. The risks will depend on the types of materials used and practices applied at particular projects, and the sensitivity of local species. Moreover, changes in tidal and wave action could disturb and re-suspend sediments already laden with contaminants.

3.3 Conclusion on Strength of Evidence and Current Knowledge on Pathways of Effects

To date, investigations of the potential effects and interactions of ORE on the environment have been primarily based on limited available information and general assumptions regarding the technology design, environmental processes and interactions, and comparisons with other aquatic activities. Numerous reports are available summarizing the potential effects of ORE and highlight the gaps in knowledge and research priorities (e.g. FMM 2007; Michel *et al.* 2007; ABPMER 2009; Amoudry 2009; Boehlert and Gill 2010; Isaacman and Lee 2010; Polagye *et al.* 2011). Although much research has been conducted on the environmental impacts of hydroelectric dams and tidal barrages, most of the findings are not expected to be directly applicable to the operational phase of ORE devices, even those in rivers, due to substantial differences in design, modes of operation and the environments in which they are deployed. Although some inferences may be drawn from knowledge about general marine/aquatic physical and ecological processes and other marine/aquatic development activities, the availability of reliable research and monitoring results on the majority of operational phase stressor-effect linkages is presently insufficient to yield clearly identified cause and effect relationships, assess cumulative or synergistic effects or draw solid conclusions regarding the probability, magnitude, nature or significance of ORE energy development on specific ecosystem components or species. This is due, in part, to the novel nature of ORE technologies and low number of long-term deployments. There is much more supporting evidence for construction, decommissioning and maintenance-related stressor-effect pathways, as many of these are directly transferable from other development activities occurring in aquatic environments (e.g. oil and gas, cable laying, marine transportation). However, a large number of research activities on various environmental concerns, particularly related to fish and marine mammals (mostly porpoises and seals), turbine strikes, EMFs, noise, and hydrodynamics, are currently underway in Canada and elsewhere (e.g. cf. American Fisheries Society [AFS 2011; BOEM 2011; RPS 2011), which may provide valuable data and insights for future risk assessment efforts.

4.0 Recommendations

The development of the PoE provides an important tool for understanding the potential environmental implications of ORE development in Canada and will help guide the identification of priority areas for government scientific research and policy development. Several major gaps in knowledge related to the environmental impacts of ORE in Canada have been identified through this and previous exercises (DFO 2009; Ryan 2010). Moreover, several workshops have been held with scientific experts to identify the priority areas for research.

The recommended next steps are to:

- assess the risk (probability and significance) of the potential issues in a Canadian context;
- identify the provincial and federal responsibilities and regulatory mechanisms related to each of the issues; and
- utilize this information to perform a gap analysis to identify priorities for government research and policy.

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Appendix A: Pathways of Effects Models

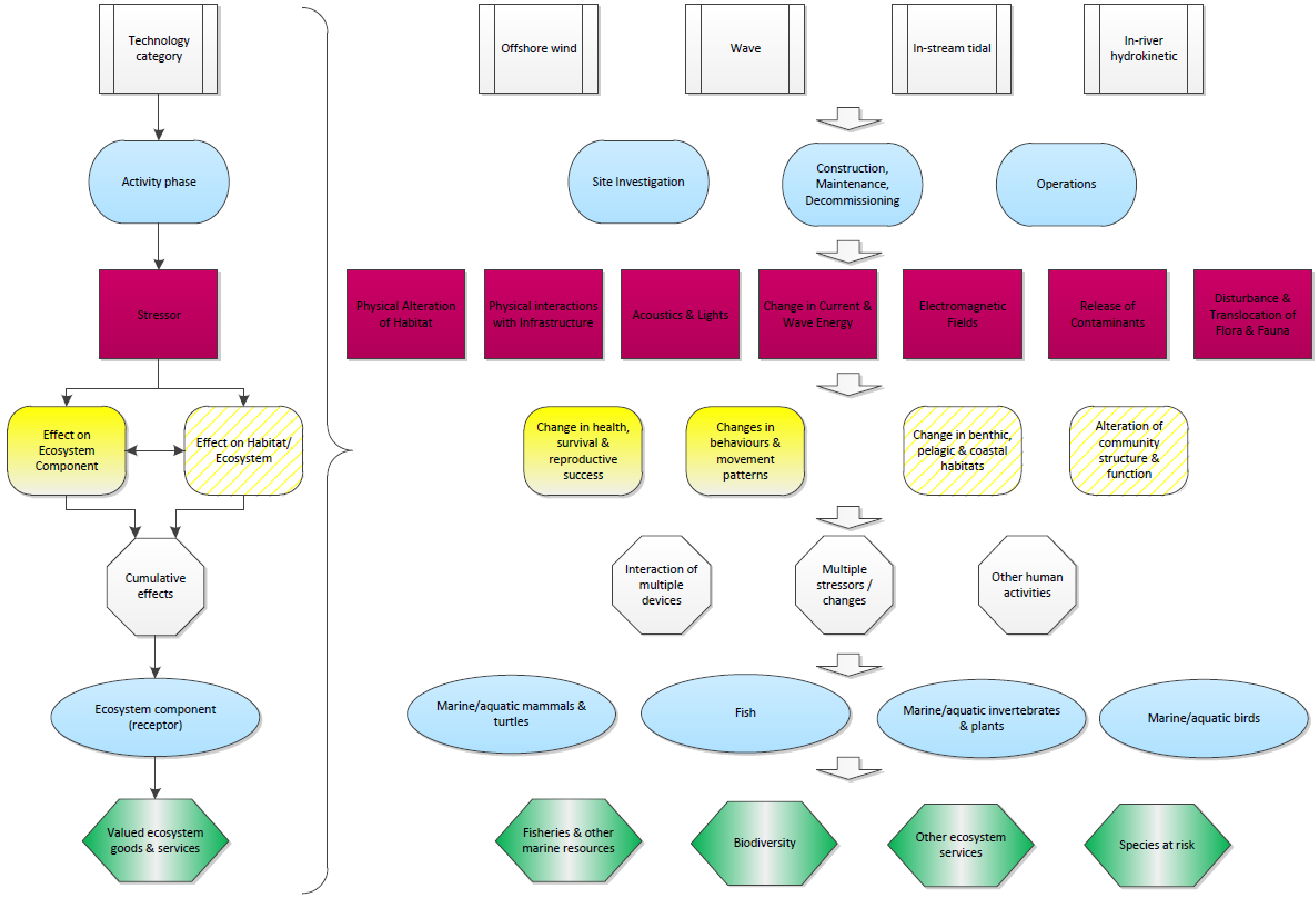

Figure 1: Framework for Pathways of Effects Logic Models for the Offshore Renewable Energy Sector

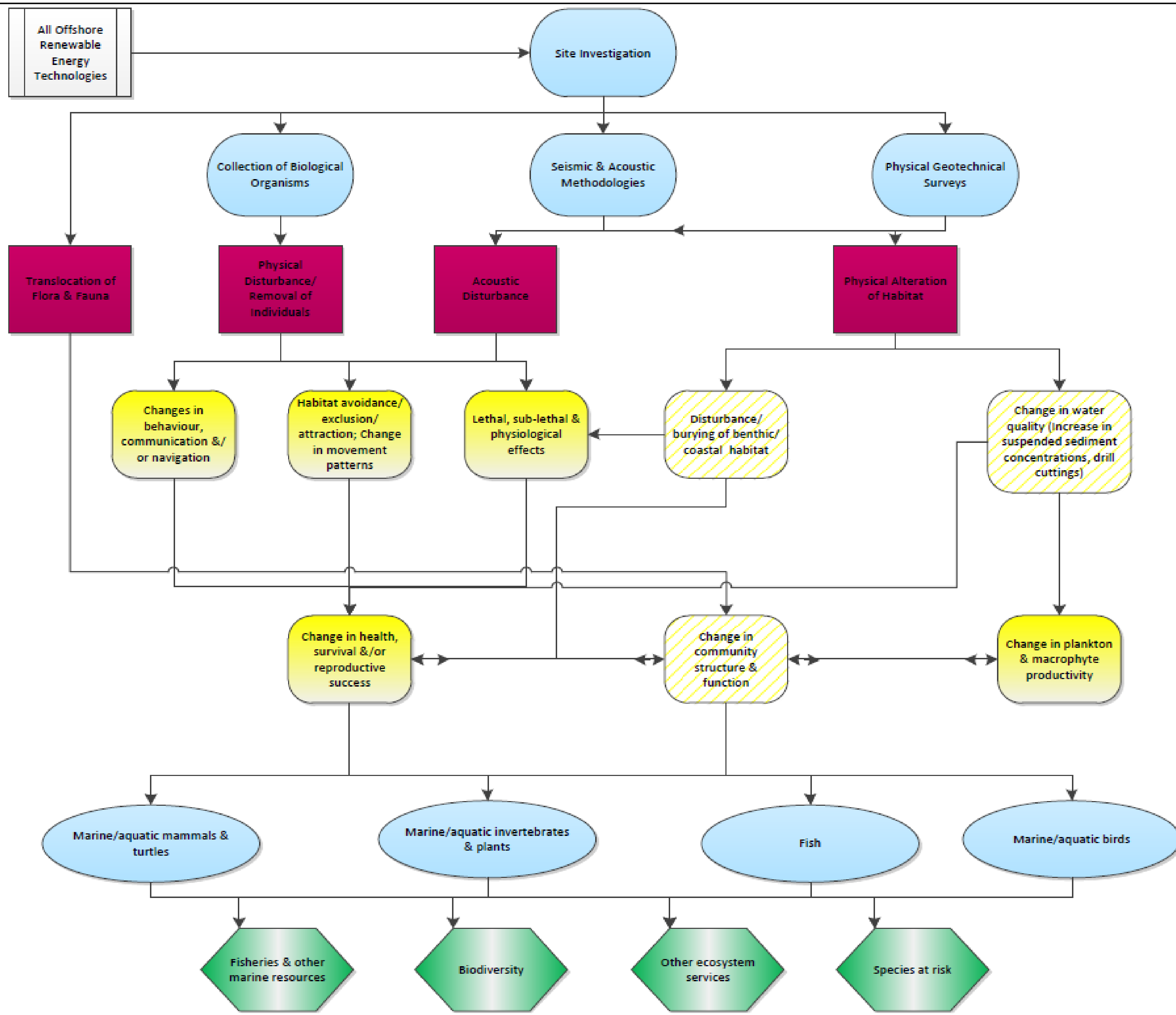

Figure 2: PoE Model for Site Investigations Phase

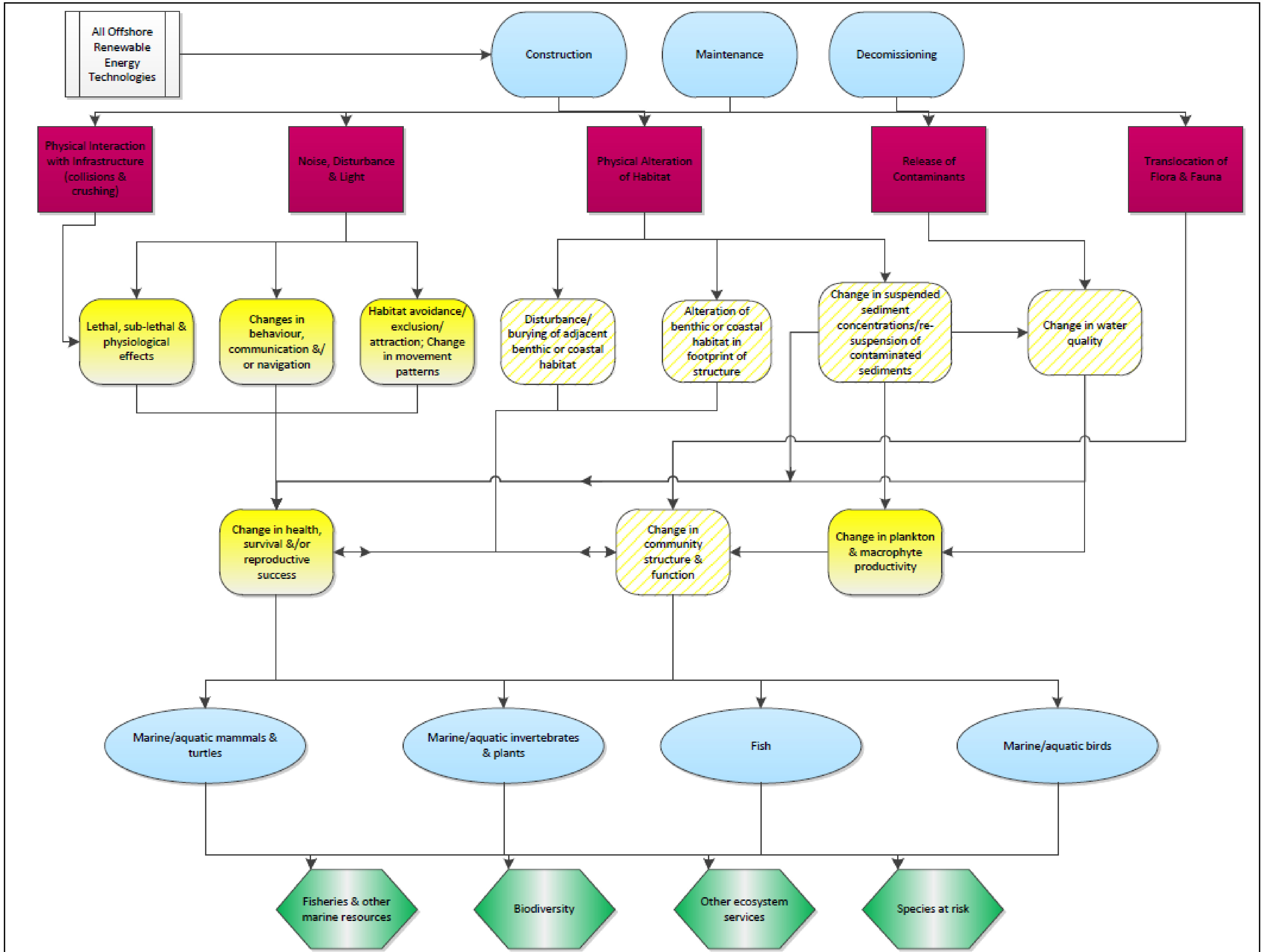

Figure 3: PoE Model for Construction, Maintenance and Decommissioning Phase

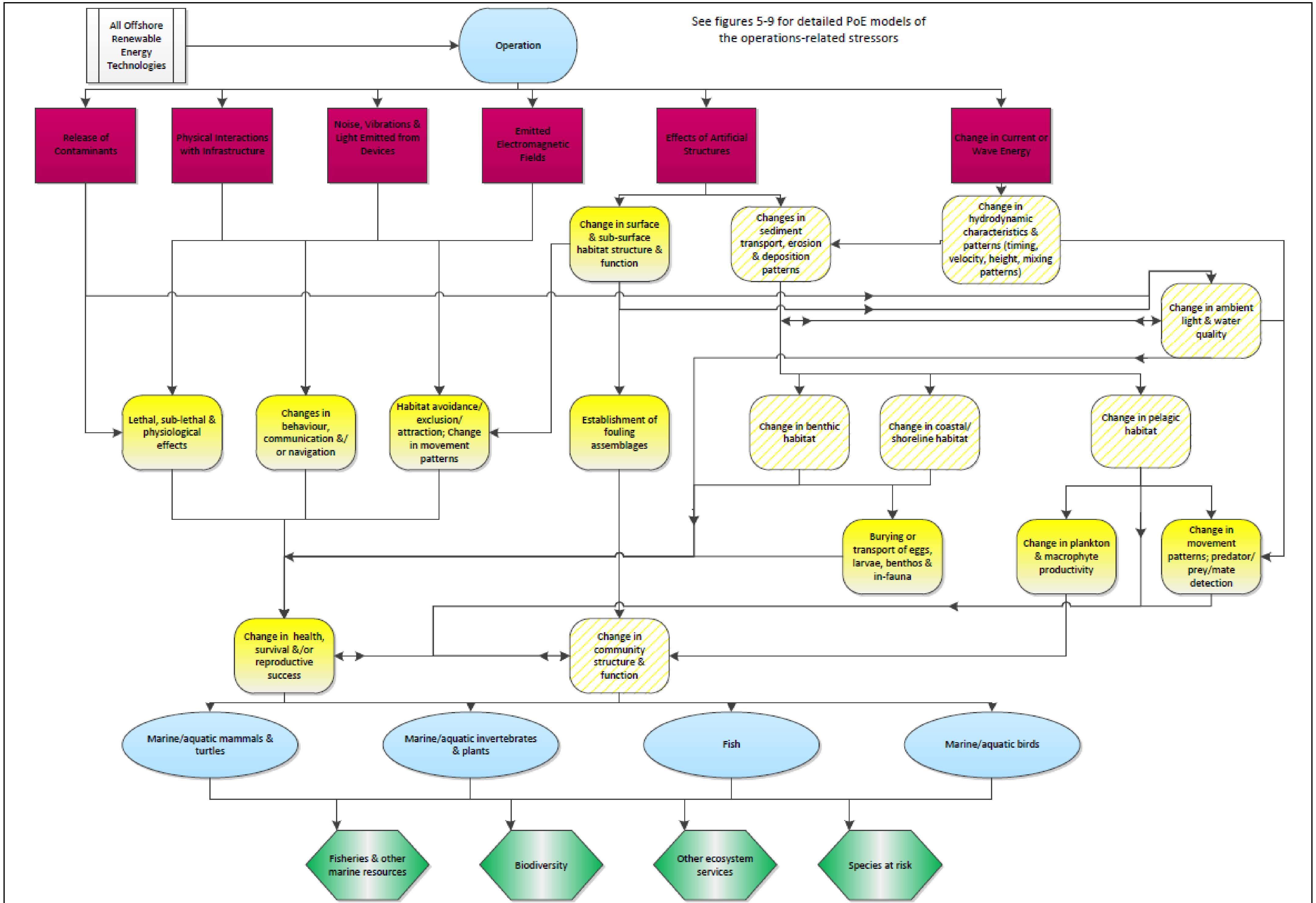

Figure 4: PoE Model for Complete Operations Phase

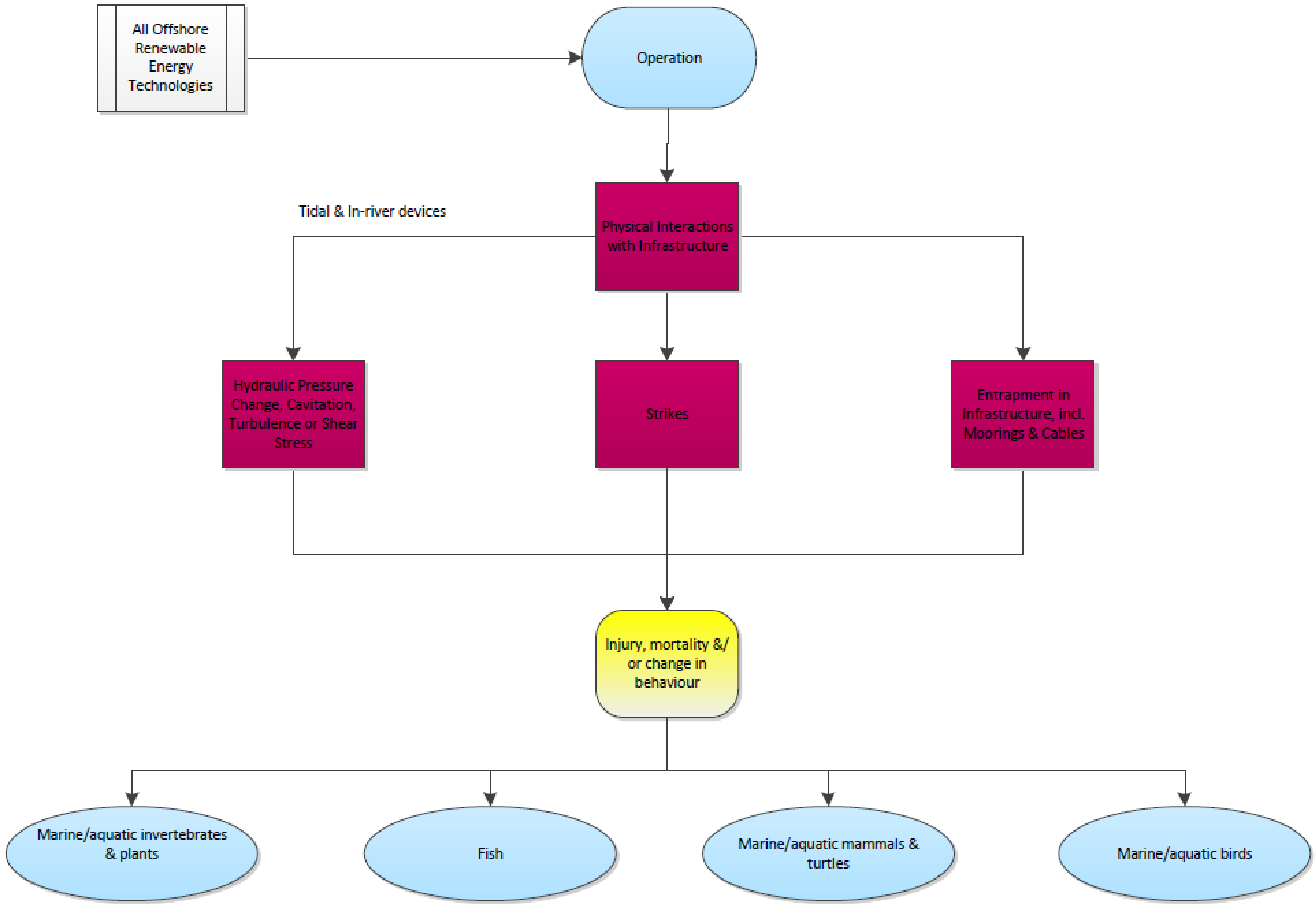

Figure 5: PoE Model for Physical Interaction with Infrastructure Stressor in Operations Phase

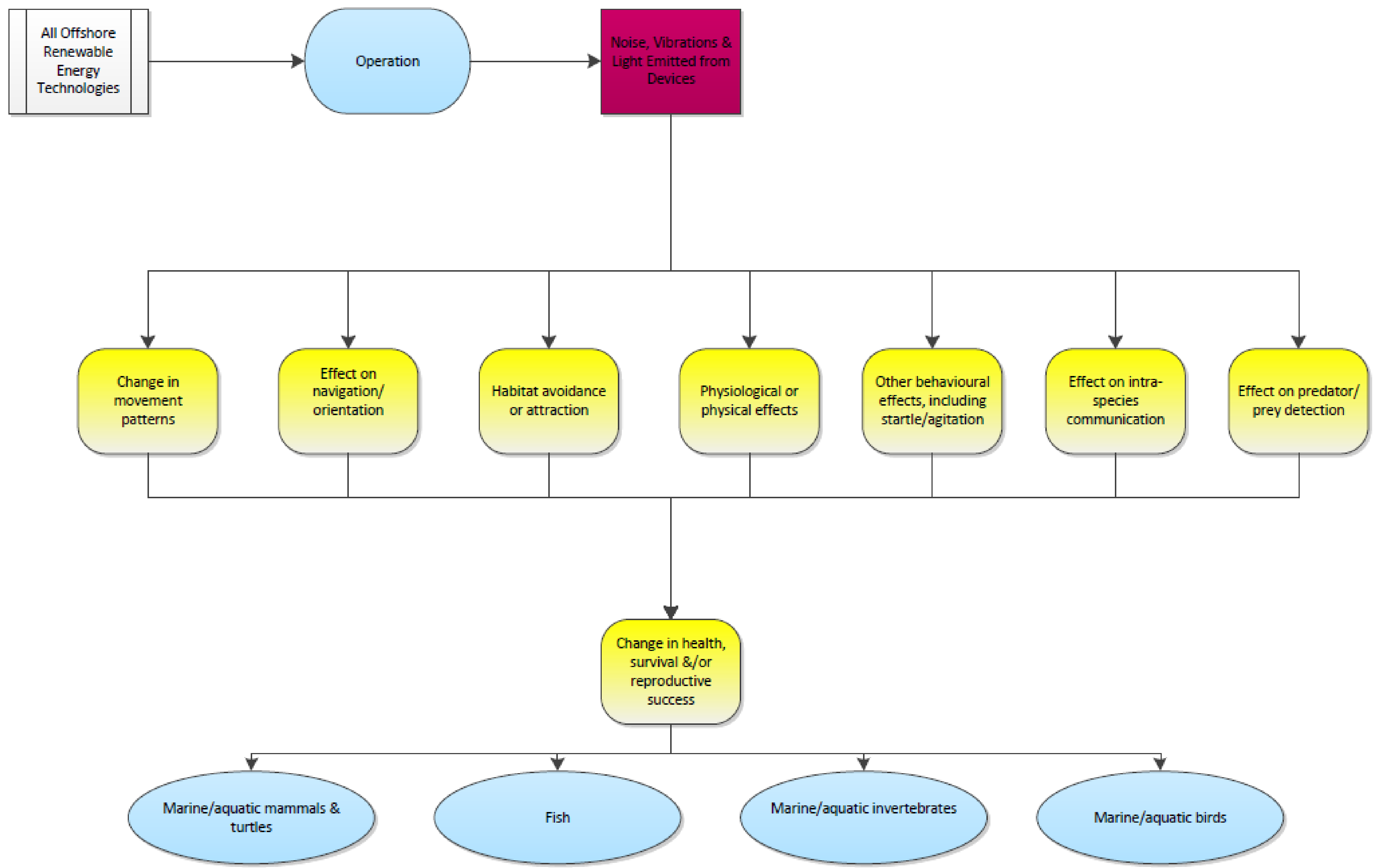

Figure 6: PoE Model for Noise, Vibrations & Light Stressor in Operations Phase

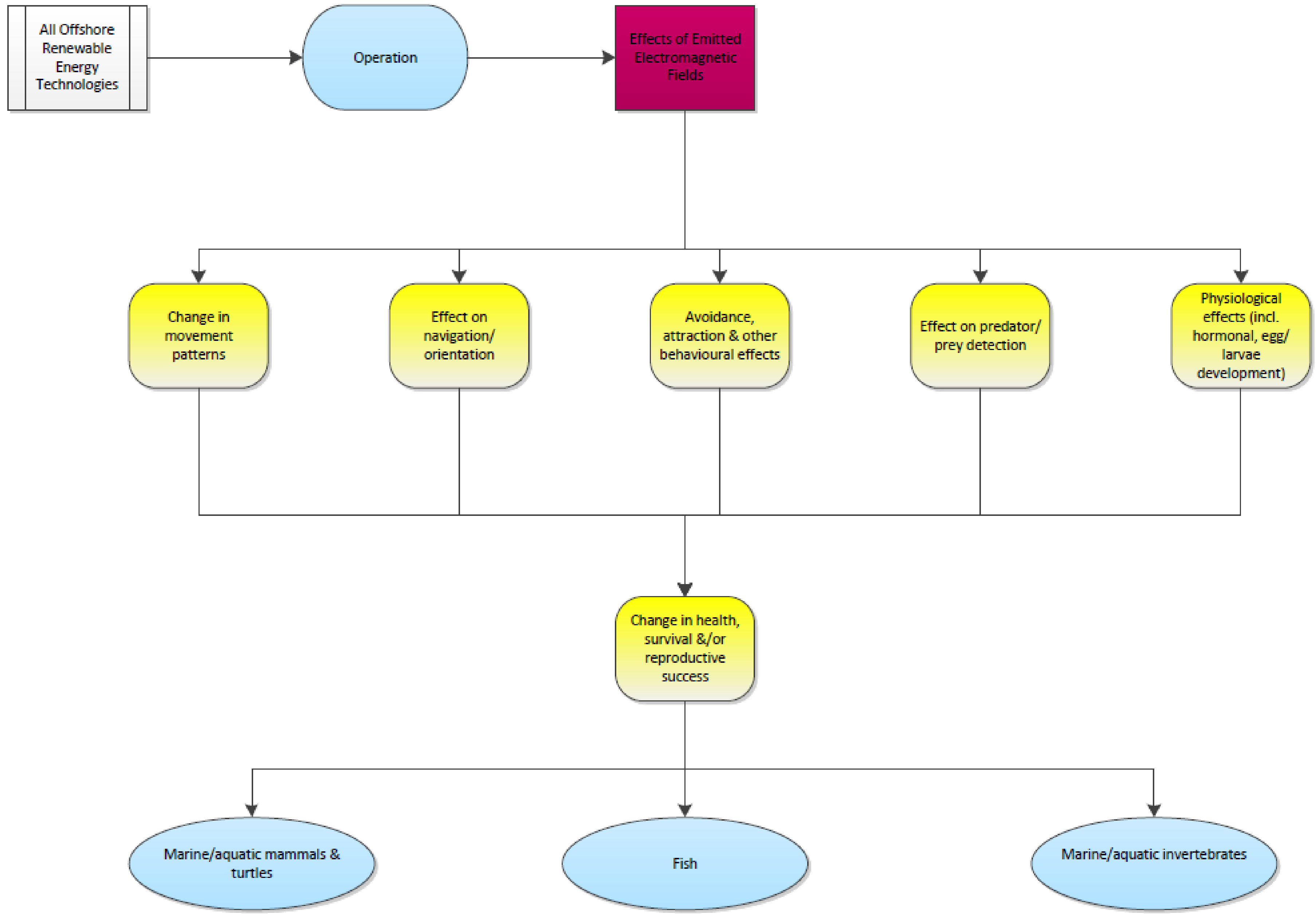

Figure 7: PoE Model for Electromagnetic Field Stressor in Operations Phase

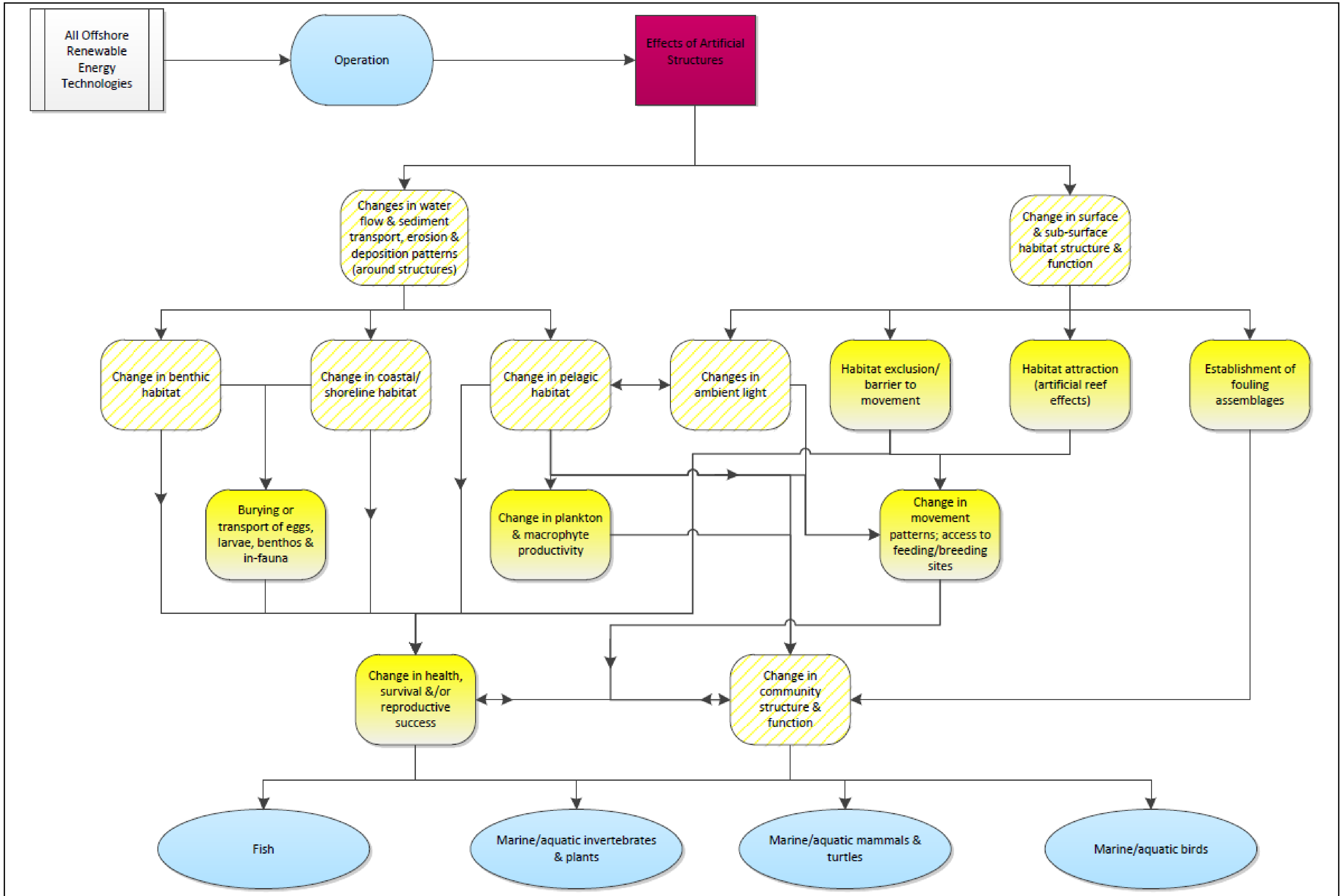

Figure 8: PoE Model for Effect of Artificial Structures Stressor in Operations Phase

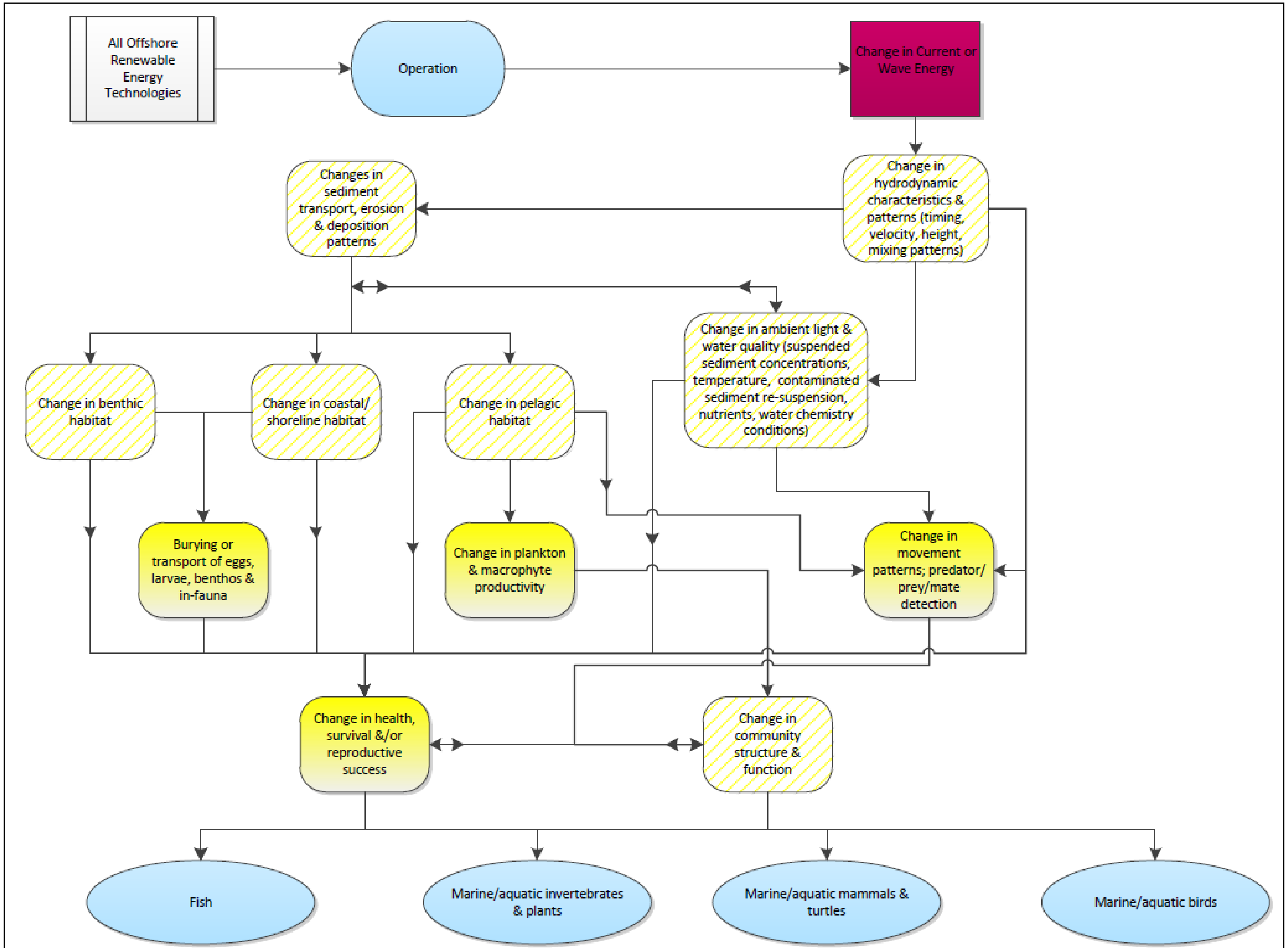

Figure 9: PoE Model for Change in Current or Wave Energy Stressor in Operations Phase

Appendix B: Strength of Evidence Tables

Table 3: Strength of Evidence for Site Investigations Phase Stressor-Effects Linkages
*See Figure 2

Effect	Available Evidence	Direct Linkages
Acoustic Disturbance		
Lethal, sub-lethal and physiological effects **Changes in behaviour, communication &/or navigation** **Habitat avoidance, exclusion, or attraction** **Change in movement patterns**	**OSPAR (2009)** provides an overview of the sound profiles associated with various research technologies in the marine environment and a review of the scientific research on the physical and behavioural impacts on fish and marine mammals. **<u>Affected Ecosystem Component: Fish (A)</u>** Extensive literature has been published on the sound sensitivity and detection ability of fish. Studies conducted by **Thomsen *et al. (*2006) and Popper & Hastings (2009)** suggest that many fish species can detect a variety sounds throughout the low to high amplitude range. Extensive research has been conducted on the impact of seismic surveys on fish. According to **OSPAR (2009)**, research indicates that impulsive sounds such as those produced by seismic surveys (air guns) can: ▪ Reduce egg and larval growth and survival up to a distance of 5m (e.g. anchovy); ▪ Cause temporary and permanent hearing loss (e.g. pink snapper); ▪ Induce behavioural changes up to large distances, including alarm, habitat abandonment/ avoidance, and changes in swimming depth (e.g. herring and cod). Little is known on the impacts of other types of acoustic devices. Although inconclusive, limited research suggests that active acoustic devices producing low-frequency signals may elicit avoidance or masking effects in acoustically sensitive species **(OSPAR 2009)**. **<u>Affected Ecosystem Component: Marine / aquatic mammals & turtles (A)</u>** Extensive literature has been published examining the behavioural impacts of low-frequency sound of the type produced by seismic surveys/air guns on fish, marine mammals and turtles. This issue has yet to be critically considered in relation to riverine freshwater aquatic animals.	Changes in Organism Health, Survival & Reproductive Success

Effect	Available Evidence	Direct Linkages
	According to **OSPAR (2009)**, research indicates that impulsive sounds such as those produced by seismic surveys (air guns) can induce behavioural responses including: ▪ Avoidance behaviours in several species of baleen whales, female humpback whales, dolphins and other cetaceans ▪ Temporary reduction or cessation of vocalization in whales ▪ Temporary avoidance and changes in swimming behaviour in harbour and grey seals and sea lions at low receiving levels (i.e. up to long distances from the source) and sea turtles ▪ Avoidance and changes in swimming patterns in sea turtles (**McCauley *et al.* 1999**) Little research has been conducted on lethal or sub-lethal effects of low-frequency sound of the type produced by seismic surveys/air guns. According to **OSPAR (2009),** there is some circumstantial evidence suggesting a potential link between whale stranding (e.g. beaked whales) and seismic surveys, but there is currently no scientific evidence to substantiate this link. Experimental studies by **Finneran *et al.* (2002) & Lucke *et al.* (2008)** found that seismic-type noise could cause temporary hearing loss up to 5m in belugas and harbour porpoises. Little is known on the impacts of other types of acoustic devices. Although inconclusive, limited research suggests that active acoustic devices producing low-frequency signals may elicit avoidance or masking effects in acoustically sensitive species **(OSPAR 2009)**. **<u>Affected Ecosystem Component: Marine / aquatic birds (A)</u>** Current knowledge is lacking to effectively assess the probability, nature or magnitude of the effect. According to **OSPAR (2009),** there appears to be no research on the underwater hearing abilities of marine birds or their sensitivity to intense anthropogenic underwater sound. **<u>Affected Ecosystem Component: Invertebrates (A)</u>** Recent research suggests that cephalopods are sensitive to intense low-frequency sounds. In an experimental study, **Andre *et al.* (2011)** found that exposure to short-term, low-frequency sounds resulted in permanent and substantial lesions in sensory hair cells of statocysts in four species of cephalopods.	

Effect	Available Evidence	Direct Linkages
	Experiments by **McCauley *et al.* (2000)** suggest strong alarm (ink squirting) and avoidance responses in cephalopods to air gun sounds. Some circumstantial evidence exists of mortality (from extensive ear and internal organ damage) of giant squid due to nearby seismic surveys (**Guerra *et al.* 2004**). However, the cause-effect link is inconclusive. **Lee-Dadswell (2011)** predicted that seismic impulses would be unlikely to cause lethal effects on snow crabs, although some tissue damage might occur from membrane separation caused by resonant responses to seismic vibrations. Little research is published on the impacts of noise on other marine invertebrates. Based on the available information, **Vella *et al.* (2001)** predicted that marine benthic invertebrates could be affected by powerful, low-frequency sounds if within a few metres of the source; however, supporting biological knowledge and experimental evidence are insufficient.	
Physical Disturbance / Removal of Individuals		
Lethal, sub-lethal and physiological effects **Changes in behaviour, communication &/or navigation** **Habitat avoidance, exclusion, or attraction;** **Change in movement patterns**	**Affected Ecosystem Component: All Organisms (A)** The risk and effects will be similar to research or monitoring activities conducted for other purposes in aquatic/marine environments. Standard research protocols exist to reduce the potential for impacts on species.	Changes in Organism Health, Survival & Reproductive Success
Physical Alteration of Habitat		
Disturbance/ burying of benthic / coastal habitat	**Affected Ecosystem Components: Invertebrates & Plants (A)** **All Organisms (B)** Risk and effects should be similar to other activities in aquatic/marine environments. Standard research protocols exist to reduce the potential for impacts on species.	Changes in Organism Health, Survival & Reproductive Success Change in Community Structure & Function
Change in water quality (Increase in suspended sediment	**Affected Ecosystem Component: All Organisms (A & B)** The risk and effects should be similar to other construction-type activities in aquatic/marine environments.	Changes in Organism Health, Survival & Reproductive Success

Effect	Available Evidence	Direct Linkages
concentrations, drill cuttings)		Change in Plankton & Macrophyte Productivity
Change in plankton & macrophyte productivity	**Affected Ecosystem Component: Invertebrates & Plants (A)** **All Organisms (B)** There has yet to be any published research examining this issue or its possible implications.	Change in Community Structure & Function
Change in community structure & function	**Affected Ecosystem Component: All Organisms (B)** Research and monitoring related to site investigation activities have yet to tackle long-term changes in community structure or ecological processes; however, risk and effects should be similar to other activities in aquatic/marine environments.	Changes in Organism Health, Survival & Reproductive Success
Changes in Organism Health, Survival & Reproductive Success		
Individual & population-scale changes	**Affected Ecosystem Component: All Organisms** Research indicates that seismic surveys, and to a lesser extent, other acoustic disturbances caused by scientific research pose the most concern for marine species. Assuming proper protocols are used, and seismic surveys are restricted, this phase is not expected to result in a significant, long-term impact on local populations. Site investigations should improve knowledge about the local ecosystem and inform regulators and developers related to environmentally-suitable site selection and design of ORE developments, with long-term conservation benefits.	Change in Community Structure & Function

*All effects are relevant for Wave, Instream tidal, In-river hydrokinetic and Offshore wind technology categories

**Type of Effects Linkage: A – Direct effect on ecosystem components; B - Effect on the habitat/ecosystem, with indirect effects on ecosystem components

Table 4: Strength of Evidence for Construction Phase Stressor-Effects Linkages
*See Figure 3

Effect	Technology	Available Evidence	Direct Linkages
Release of Contaminants			
Change in water quality	All	**Affected Ecosystem Component: All Organisms (A & B)** Toxic effects and release risk from substances commonly used in the marine transport and construction industries are well-examined in the literature. The risk and effects should be similar to other construction activities in aquatic/marine environments. Sensitivity ratings of species/habitats to contaminant exposure related to ORE are presented in **FMM (2007) and ABPMER (2009)**. A recent review of the potential impacts on water quality of ORE is presented in **Kadiri *et al.* (2011).** DFO has Standard Operating Procedures and well established guidelines to guide the construction of low risk works in the water.	Changes in Organism Health, Survival & Reproductive Success Change in Plankton & Macrophyte Productivity
Physical Interaction with Infrastructure			
Lethal or sub-lethal effects	All	**Affected Ecosystem Component: All Organisms (A)** The risk and effects are expected to be similar to other construction activities in aquatic/marine environments. See **Wilson et al (2007)** for review of the risks.	Changes in Organism Health, Survival & Reproductive Success
Physical Alteration of Habitat			
Alteration of benthic or coastal habitat in footprint of structure	All	**Affected Ecosystem Component: Invertebrates & Plants (A)** **Fish (A)** **All Organisms (B)** Systematic research into the long-term significance of habitat alteration due to the installation of these projects is lacking.	Changes in Organism Health, Survival & Reproductive Success Change in Community Structure & Function
Disturbance/ burying of adjacent benthic or coastal habitat	All	**Affected Ecosystem Component: Invertebrates & Plants (A)** **Fish (A)** **All Organisms (B)** Few monitoring data on long-term impacts to benthic habitats due to construction activities are available in the literature. Monitoring reports available from offshore wind farms and an in-stream tidal demonstration site suggest	Changes in Organism Health, Survival & Reproductive Success Change in Community Structure & Function

Effect	Technology	Available Evidence	Direct Linkages
		that recovery of disturbed areas could take several years (e.g. **Archipelago 2006; Dong *et al.* 2006**). Risk and effects should be similar to other construction activities in aquatic/marine environments and would depend on the device design, local environment, and equipment, techniques and mitigation measures being used.	
Change in suspended sediment concentrations/re-suspension of contaminated sediments **Change in water quality**	All	**<u>Affected Ecosystem Component: All Organisms (A & B)</u>** Few monitoring data on long-term impacts to benthic habitats due to construction activities are available in the literature. A recent review of the potential impacts on water quality of ORE is presented in **Kadiri *et al.* (2011).** The risk and effects should be similar to other construction activities in aquatic/marine environments and would depend on the amount, timing (e.g. account for key migration, spawning/breeding and nursery periods) and duration.	Changes in Organism Health, Survival & Reproductive Success Change in Plankton & Macrophyte Productivity
Noise, Disturbance & Light			
Lethal, sub-lethal and physiological effects **Changes in behaviour, communication &/or navigation** **Habitat avoidance, exclusion, or attraction** **Change in movement patterns**	All, especially piled devices (from pile driving and cutting)	**<u>Affected Ecosystem Component: Fish (A)</u>** Extensive literature has been published on the sound sensitivity and detection ability of fish. Studies conducted by **Thomsen *et al. (*2006) & Popper & Hastings (2009)** suggest that many fish species can detect a variety sounds throughout the low to high amplitude range. **OSPAR (2009)** provides an overview of the sound profiles associated with various construction-related activities in the marine environment and a review of the scientific research on the physical and behavioural impacts on fish. Extensive literature has been published on the impacts of noise associated with pile-driving on fish Studies suggest that many fish species within close proximity to the short duration, high amplitude pile-driving sound can experience serious physical damage including instant or delayed mortality and hearing damage (**Thomsen *et al.* 2006; OSPAR 2009; Popper and Hastings 2009**). However, empirical studies are limited. A study on selected fish species predicted that Atlantic cod and herring may detect and experience masking effects from pile-driving noise up to 80 km from the source; less sensitive species such as Atlantic salmon and flatfish may also detect pile-driving sound at a distance (**Thomsen *et al.* 2006**).	Changes in Organism Health, Survival & Reproductive Success

Effect	Technology	Available Evidence	Direct Linkages
		An experimental study on sole and cod found a significant movement response to simulated pile-driving sound at various distances (**Mueller-Blenkle *et al.* 2010**), incl.: ▪ Increase in swimming speed; ▪ Movement away from source; ▪ Freezing response (in cod); ▪ Possible habituation to noise after multiple exposures. Little empirical research is available on other sources of construction related noise, disturbance or artificial light in relation to ORE. However, The risk and effects should be similar to other construction activities in aquatic/marine environments. **Affected Ecosystem Component: Marine / Aquatic Mammals & Turtles (A)** The risk and effects of disturbance should be similar to other construction activities in aquatic/marine environments. Extensive literature has been published on the sound sensitivity and detection ability of certain species of marine mammals. **OSPAR (2009)** provides an overview of the sound profiles associated with various construction-related activities in the marine environment and a review of the scientific research on the physical and behavioural impacts on marine mammals related to pile-driving, drilling and dredging. According to **OSPAR (2009),** the limited research suggests the short duration, high amplitude noise from pile-driving poses the highest physical and behavioural threat. While there is currently no evidence of physical injuries, monitoring of disturbance to marine mammals during project construction, it is typically a requirement for project approvals. At this time, results are scarce and inconclusive. Some behavioural responses have been noted, but there is currently no evidence of physical injuries from construction disturbance. Some temporary behavioural responses (e.g. leaving haul-out sites) have been noted in pinnipeds and porpoises due to human presence and vessel activity at the Race Rocks Tidal Demonstration site (**Archipelago 2006**). **Royal Haskonings (2009)** reported no evidence of behavioural disturbance or injury during construction	

Effect	Technology	Available Evidence	Direct Linkages
		or maintenance at the Seagen Tidal Demonstration Project. Researchers at offshore wind farms found that construction noises (esp. pile-driving) can have noticeable effects on pinnipeds and porpoise behaviour, including abandonment of habitat sites, avoidance of the area, change in swimming patterns and decreased acoustic activity (porpoises) to at least 15 km from the construction site (**Dong *et al.* 2006**). Most of the responses were temporary, but it took several years for some populations to return to previous activity levels. This issue has yet to be critically considered in the ORE literature related to riverine freshwater aquatic animals **<u>Affected Ecosystem Component: Marine / Aquatic Birds (A)</u>** **Grecian *et al.* (2010) and Langton *et al.* (2011)** reviewed information relating to the effects of wave and tidal generators on marine birds. Much of the inferred information was extrapolated from studies of offshore wind farms. **Montevecchi (2006) and Poot *et al.* (2008)** address the effects of artificial lighting on marine birds. There is no evidence that noise or disturbance from vessels has any lethal effects on marine birds. **<u>Affected Ecosystem Component: Invertebrates (A)</u>** Recent research suggests that cephalopods are sensitive to intense low-frequency sounds. In an experimental study, **Andre *et al.* (2011)** found that exposure to short-term, low-frequency sounds resulted in permanent and substantial lesions in sensory hair cells of statocysts in four species of cephalopods. Experiments by **McCauley *et al.* (2000)** suggest strong alarm (ink squirting) and avoidance responses in cephalopods to air gun sounds. Little research is published on the impacts of noise on other marine invertebrates. Based on the available information, **Vella *et al.* (2001)** predicted that marine benthic invertebrates could be affected by powerful, low-frequency sounds if within a few metres of the source; however, supporting biological knowledge and experimental evidence are insufficient.	
Population & Ecosystem-scale Responses			

Effect	Technology	Available Evidence	Direct Linkages
Change in plankton/ macrophyte productivity	All	**Affected Ecosystem Component: Invertebrates & Plants (A)** **All Organisms (B)** There has yet to be any published research examining this issue or its possible implications.	Change in Community Structure & Function
Change in community structure & function	All	**Affected Ecosystem Component: All Organisms (B)** Research and monitoring related to construction of ORE have yet to tackle long-term changes in community structure or ecological processes; however, risk and effects should be similar to other activities in aquatic/marine environments.	Changes in Organism Health, Survival & Reproductive Success
Changes in organism health, survival, and reproductive success **Population-scale changes**	All	**Affected Ecosystem Component: All Organisms** Monitoring at several sites has suggested no significant impacts on fish due to construction-related activities or habitat loss at ORE sites; however, some changes in benthic species diversity and marine mammal and bird behaviour were noted. The results are likely site and project specific and are not unique to ORE development activities. Long-term systematic studies are lacking.	Change in Community Structure & Function

Type of Effects Linkage: A – Direct effect on ecosystem components; B - Effect on the habitat/ecosystem, with indirect effects on ecosystem components

Table 5: Strength of Evidence for Physical Interactions with Infrastructure Stressor-Effects Linkages in the Operations Phase
*See Figure 4 & Figure 5

Effect	Technology	Available Evidence	Direct Linkages
Strikes			
Lethal, sub-lethal and physiological, effects **Changes in behaviour, communication &/or navigation** **Habitat avoidance, exclusion, or attraction** **Change in movement patterns**	In-stream Tidal Wave In-river Hydrokinetic	**Affected Ecosystem Component: Fish (A)** Several models and risk assessments have been published to predict the potential risk to fish from collisions with wave, tidal and hydrokinetic devices. Analyses of potential factors and risks of collisions with tidal and wave devices are provided in **Wilson *et al.* (2007) and ABPMER (2010). Alden Research Laboratory (2011a)** concluded that data on fish passage through conventional hydroelectric turbines is of limited applicability to hydrokinetic technologies since the two technology types pose substantially different conditions for fish. **Alden Research Laboratory (2011b) and Schweizer *et al.* (2011)** developed models to assess the risk of blade strikes and injury of different sized freshwater organisms with hydrokinetic turbines. These and other earlier models suggest a low risk of strikes for most organisms, with slightly higher risks for larger organisms. However, the models are unverified and do not account for species' behavioural responses, complex obstacles or cumulative effect of arrays (Isaacman and Lee 2010). No models have been published for encounters with wave devices. The few available monitoring and research reports from operational tidal and hydrokinetic deployments have reported no evidence of injury or mortality due to strikes with existing ORE deployments (**Royal Haskoning 2009, 2011;** Zydlewski ***et al.* 2010; FORCE 2011; Verdant Power 2011**). For example, **Verdant Power (2008)** found no evidence of fish encountering infrastructure in its deployment array in the Roosevelt Island tidal demonstration project, although it was not clear if the absence of fish in the vicinity of the turbines was due to avoidance. Several recent experimental studies have been published on fish injury and behavioural responses to hydrokinetic turbines. While there are currently no reports of physical injuries to fish, some behavioural responses have been noted, including active avoidance and changes in movement patterns, as well as signs of disorientation after passing downstream of the turbines. **Normandeau (2009)** conducted a field study of two Hydro Green Energy's horizontal-axis hydrokinetic turbines (suspended from barge) in Mississippi River. Results indicated a low risk of injury or mortality to 5 fish species due to contact with turbine blades.	Table 10: Changes in Organism Health, Survival & Reproductive Success

Effect	Technology	Available Evidence	Direct Linkages
		Castros-Santos and Haro (2011) conducted flume experiments to measure the physical and behavioural responses of juvenile Atlantic salmon and adult American shad to an operating 4-blade Encurrent 5KW vertical axis turbine. Results suggest: ▪ No evidence of injury or mortality for either species; ▪ Slight behavioural response in salmon related to movement patterns and orientation, but no evidence of avoidance response; ▪ Active avoidance response in shad, including reluctance to pass through or by the turbines. **Alden Laboratory (2011b)** conducted a flume study on the physical and behavioural effects on smallmouth bass and rainbow trout of passage through a single vertical cross-flow turbine and a ducted axial flow turbine. Results suggest: ▪ No significant evidence of injury or mortality as a result of passing through either turbine for either species; ▪ Some active avoidance responses in rainbow trout (facing and active swimming against current, moving along walls and floor). There is little information on the risk to larval fish entrained in water flow through a turbine. **Schweizer *et al.* (2011)** suggests there is a low risk of direct damage from blade strikes from hydrokinetic turbines where the rotation rate of the turbine rotor is low. **<u>Affected Ecosystem Component: Marine / Aquatic Mammals & Turtles (A)</u>** Several risk assessments have been published to predict the potential risk to marine organisms from collisions with wave, tidal and hydrokinetic devices. This issue has yet to be critically considered in the ORE literature related to aquatic animals in river environments. Analyses of potential factors and risks of collisions with tidal and wave devices are provided in **Wilson *et al.* (2007) and ABPMER (2010**). While there are currently no reports of physical injuries to marine mammals, this is generally seen as a priority issue: monitoring of marine mammal interactions with devices is typically a requirement for project approvals. The few available monitoring and research reports from operational tidal and hydrokinetic deployments have reported no evidence of injury or mortality due to strikes with existing ORE deployments (**Royal Haskoning 2009, 2011; FORCE 2011; Tollit *et al.* 2011; Verdant Power 2011**); however, timeframes and methods have been limited.	

Effect	Technology	Available Evidence	Direct Linkages
		<u>Affected Ecosystem Component: Marine / Aquatic Birds (diving) (A)</u> **Wilson *et al.* (2007) and Langton *et al.* (2011)** review the potential risk to diving birds of collisions with blades and moving parts of wave and tidal devices. However, there is currently no direct evidence of injury/mortality from collisions in the literature. **Verdant Power (2011)** reported no evidence of collision or injury to diving or migratory birds at the Roosevelt Island Tidal Demonstration Project between 2006 and 2008. **<u>Affected Ecosystem Component: Invertebrates (A)</u>** Investigation of this issue is currently sparse. There is little information on the risk to plankton and invertebrates entrained in water flow through a turbine. **Schweizer *et al.* (2011)** suggests there is a low risk of direct damage from blade strikes from hydrokinetic turbines where the rotation rate of the turbine rotor is low.	
Lethal, sub-lethal and physiological, effects **Changes in behaviour, communication &/or navigation** **Habitat avoidance, exclusion, or attraction** **Change in movement patterns**	Offshore Wind	**<u>Affected Ecosystem Component: Marine / Aquatic Birds (all) (A)</u>** **Desholm and Kahlert (2005), Petterson (2005), Dong *et al. (*2006) and Peterson *et al.* (2006)** report on bird interactions with offshore wind farms. No direct evidence of strikes with offshore wind turbines was recorded, and there is some evidence that marine birds in migration took evasive action when approaching Danish wind farms. Avoidance was lower during night time flights, although it is not clear whether this was due to lower detection of the farm, or distracting effects of infrastructure lighting (cf. **Jones and Francis 2003**). However, as the technologies are similar, the effects of offshore wind farms are likely to be comparable to that of onshore wind, on which substantial research has been conducted.	Table 10: Changes in Organism Health, Survival & Reproductive Success
Entrapment in Infrastructure, incl. Moorings & Cables			
Lethal, sub-lethal and physiological effects **Changes in behaviour, communication &/or navigation**	All moored / anchored devices with cables extending through water column; Ducted devices	**<u>Affected Ecosystem Component: Fish (A)</u>** Investigation of this issue is currently sparse. **Normandeau (2009)** conducted a field study of two Hydro Green Energy's horizontal-axis hydrokinetic turbines (suspended from a barge) in Mississippi River. Results indicated only one incidence of injury due to entanglement in cables.	Table 10: Changes in Organism Health, Survival & Reproductive Success

Effect	Technology	Available Evidence	Direct Linkages
Habitat avoidance, exclusion, or attraction **Change in movement patterns**		There are no other published accounts of entanglement in ORE deployments. Analyses of potential factors and risks of collisions with tidal and wave devices are provided in **Wilson *et al.* (2007)** and **ABPMER (2010).** **<u>Affected Ecosystem Component: Marine / Aquatic Mammals & Turtles (A)</u>** Ropes, cables and nets associated with fishing activities are recognised as potentially significant threats to marine mammals (e.g. the Right whale); however investigation of this issue in relation to ORE is currently lacking. There are no published accounts of entanglement in ORE deployments. Analyses of potential factors and risks with tidal and wave devices are provided in **Wilson *et al.* (2007).** **<u>Affected Ecosystem Component: Marine / Aquatic Birds (A)</u>** Investigation of this issue is currently sparse in relation to ORE. **Wilson *et al.* (2007)** and **Langton *et al.* (2011)** review the potential risk to diving birds of interactions with wave and tidal devices. However, there is currently no direct evidence of entanglement in the literature.	
Hydraulic Pressure Change, Cavitation, Turbulence or Shear Stress			
Lethal, sub-lethal and physiological effects **Changes in behaviour, communication &/or navigation** **Habitat avoidance, exclusion, or attraction** **Change in movement patterns**	In-stream Tidal & In-river hydrokinetic (particularly vertical-axis turbines)	**<u>Affected Ecosystem Component: Fish (A)</u>** Systematic research has yet to be published on this stressor in relation to ORE. Analyses of potential factors and risks are provided in **ABPMER (2010)**. While this is a well-recognized concern related to hydroelectric turbines, many researchers expect there is a much lower risk of pressure change, cavitation or shear stress conditions being produced by tidal and hydrokinetic turbines due to differences in design and the slower blade rotations. There has been no reported evidence of injury or mortality due to these factors reported in field or laboratory research **(Normandeau 2009)**. In a laboratory study on the Encurrent 5KW vertical axis turbine, **Castros-Santos and Haro (2011)** noted	Table 10: Changes in Organism Health, Survival & Reproductive Success

Effect	Technology	Available Evidence	Direct Linkages
		that visibly turbulent flow downstream of the turbine. While there was some evidence of disorientation in salmon smolts following turbine passage, it was unclear if the turbulence was a factor. While there is little information on the risk to larval fish entrained in water flow through a turbine, **Schweizer *et al.* (2011)** suggests that these organisms could be impacted by turbulence and shear stress. **Affected Ecosystem Component: Invertebrates (A)** Investigation of this issue is currently sparse. While there is little information on the risk to plankton and invertebrates entrained in water flow through a turbine, **Schweizer *et al.* (2011)** suggests that these organisms could be impacted by turbulence and shear stress.	
For Habitat, Ecosystem and Population Effects Linkages see Table 10			

Type of Effects Linkage: A – Direct effect on ecosystem components; B - Effect on the habitat/ecosystem, with indirect effects on ecosystem components

Table 6: Strength of Evidence for Noise, Vibrations & Light Emitted from Devices Stressor-Effects Linkages in the Operations Phase
*See Figure 4 & Figure 6

Effect	Technology	Available Evidence	Direct Linkages
Change in movement patterns **Effect on navigation / orientation** **Habitat avoidance or attraction** **Lethal, sub-lethal and physiological effects** **Other behavioural effects** **Effect on intraspecies communication** **Effect on predator / prey detection**	All	**Affected Ecosystem Component: Fish (A)** While extensive literature has been published on the sound sensitivity and detection ability of fish, little systematic research has been has been conducted to assess the physical or behavioural responses of fish to operational ORE noise. Comprehensive reviews of the current knowledge and gaps related to this issue are provided in **Richards *et al.* (2007) and Polagye *et al.* (2011).** Studies conducted by **Thomsen *et al. (*2006) and Popper and Hastings (2009)** suggest that many fish species can detect a variety sounds throughout the low to high amplitude range. However, little data are available on noise characteristics of actual devices, especially in marine environments or for arrays, for comparison with published sound detection and tolerance thresholds in various species. Models developed by **Parvin *et al.* (2005 cited in Argo Environmental 2006), Richards *et al.* (2007) and Verdant Power (2008)** predicted that, while detectable by many fish species, there is a low risk of hearing loss from operational sounds produced by generic pilot-scale wave or tidal devices or arrays. **Verdant Power (2008)**'s model suggested that tautog (*Tautoga onitis*) may be more susceptible. However, these results have not been verified. Specifically, **Richards *et al.* (2007)** predicted: ▪ Possible permanent hearing damage in the most sensitive receptor (species) if it were to spend a minimum of 30 minutes within 16 metres of a generic tidal turbine with a single 1 MW rotor; ▪ Possible temporary and recoverable hearing loss as a result of spending a minimum of 8 hours within about 1 km of of a generic tidal turbine with a single 1 MW rotor; ▪ That a single 1 MW wave energy device similar to Pelamis is unlikely to cause permanent or temporary hearing damage in any species; ▪ Commercial arrays of wave devices like Pelamis, are unlikely to pose a significant risk and that the maximum range for permanent damage for the tidal turbine array is 24 m. **Andersson (2011)** summarized the results of two modeling studies on the effect of wind turbine noise on fish. Findings include: ▪ Wind turbines generate a broadband noise detectable by sound pressure sensitive fish at a distance of several kilometers; ▪ Motion sensitive species will only detect the turbine noise at around a ten meter distance; ▪ Sound levels are only likely to elicit a behavioural response within meters from a turbine. **Halverson *et al.* (2011)** performed laboratory tests on the effect of noise (155 to 163 dB re 1 μPa rms) from a simulated 6-	Table 10: Changes in Organism Health, Survival & Reproductive Success

Effect	Technology	Available Evidence	Direct Linkages
		m diameter OpenHydro turbine on the auditory systems of Chinook salmon. Results after 24 hours of exposure suggest: ▪ No effects on hearing sensitivity as fish pass in close proximity to the turbine; ▪ Some evidence of minor tissue damage (specifics were not provided) expected to provide a low physiological cost to the fish. Limited evidence of effects on fish behaviour and movement patterns, possibly attributable to sound, were noted at Verdant Power's tidal demonstration project in the East River, New York (**Verdant Power 2008**): ▪ Lower fish presence and movement in areas under direct influence of the turbines, with higher activity during non-operational periods; ▪ Data are insufficient to link the effect to a particular stressor. Little research is available on the effect of vibrations or artificial light in relation to ORE. **<u>Affected Ecosystem Component: Marine / Aquatic Mammals & Turtles (A)</u>** While extensive literature has been published on the sound sensitivity and detection ability of certain marine mammals, little systematic research has been has been conducted to assess their physical or behavioural responses to operational ORE noise. Comprehensive reviews of the current knowledge and gaps related to this issue are provided in **Richards *et al.* (2007) and Polagye *et al.* (2011).** Models developed by **Parvin *et al.* (2005 cited in Argo Environmental 2006)** based on comparison of known response thresholds of seals and harbour porpoise with generic pilot-scale wave or tidal device noise predicted: ▪ A low risk of hearing loss; ▪ Behavioural responses up to 1km from the source. However, these results have not been verified. **Richards *et al.* (2007)** predicted: ▪ Possible permanent hearing damage in the most sensitive receptor (species) if it were to spend a minimum of 30 minutes within 16 metres of a generic tidal turbine with a single 1 MW rotor; ▪ Possible temporary and recoverable hearing loss as a result of spending a minimum of 8 hours within about 1 km of of a generic tidal turbine with a single 1 MW rotor; ▪ That a single 1 MW wave energy device similar to Pelamis is unlikely to cause permanent or temporary hearing damage in any species; ▪ Commercial arrays of wave devices like Pelamis, are unlikely to pose a significant risk and that the maximum range for permanent damage for the tidal turbine array is 24 m. Limited responses are reported in the few available monitoring reports.	

Effect	Technology	Available Evidence	Direct Linkages
		Royal Haskoning (2009, 2011) reported no signs of behavioural or physical responses to turbine noise in common seals, grey seals or harbour porpoise. The report also predicted that the measured turbine noise: ▪ Is below that which could cause hearing damage to a marine mammal following a single encounter; ▪ Is high enough to elicit strong avoidance responses at 44m from the turbine. However, the effect is expected to be masked by the high levels of existing background noise at the site. Monitoring reports at two Danish offshore wind farms indicated no significant behavioural changes in porpoise and seal populations during operation (**Dong *et al.* 2006**). One study observed minor behavioural responses (aversion, surfacing and moving away) in porpoise and seals in response to simulated offshore wind farm noise (**Koschinski *et al.* 2003**). Research projects are currently underway in the US and Europe examining the acoustic sensitivity and effects of ORE-generated noise on sea turtles and sea otters (see BOEM 2011; RPS 2011). Little research is available on the effect of vibrations or artificial light in relation to ORE. However, some marine mammals and sea turtles are known to be either attracted or repelled by artificial lights at marine structures (Hagerman and Bedard 2004). **<u>Affected Ecosystem Component: Invertebrates (A)</u>** While some research has been published on high-intensity sounds on invertebrates (see above), little information is available on the impacts of continuous noise, vibrations or light of the type emitted by ORE devices. Based on the available information, **Vella *et al.* (2001)** predicted that marine benthic invertebrates could be affected by powerful, low-frequency sounds if within a few metres of the source; however, supporting scientific evidence is needed to verify.	
Change in movement patterns **Effect on navigation / orientation** **Habitat avoidance or attraction** **Lethal, sub-lethal and physiological effects**	Offshore Wind	**<u>Affected Ecosystem Component: Marine / Aquatic Birds (A)</u>** **Grecian *et al.* (2010) and Langton *et al.* (2011)** reviewed information relating to the effects of wave and tidal generators on marine birds. Much of the inferred information was extrapolated from studies of offshore wind farms. **Desholm and Kahlert (2005), Petterson (2005), Dong *et al.* (2006) and Peterson *et al.* (2006)** report on bird interactions with offshore wind farms. No direct evidence of strikes with offshore wind was recorded, and there is some evidence that marine birds in migration took evasive action when approaching Danish wind farms. Avoidance was lower during night time flights, although it is not clear whether this was due to lower detection of the farm, or distracting effects of infrastructure lighting (cf. **Jones and Francis 2003**). However, as the technologies are similar, the effects of offshore wind farms are likely to be comparable to that of onshore wind, on which substantial research has been conducted. So far, there	Table 10: Changes in Organism Health, Survival & Reproductive Success

Effect	Technology	Available Evidence	Direct Linkages
Other behavioural effects **Effect on intraspecies communication** **Effect on predator / prey detection**		has been little focus on smaller shorebirds or smaller surface-feeding marine birds. **Montevecchi (2006) and Poot *et al.* (2008)** address the effects of artificial lighting on marine birds.	
For Habitat, Ecosystem and Population Effects Linkages see Table 10			

Type of Effects Linkage: A – Direct effect on ecosystem components; B - Effect on the habitat/ecosystem, with indirect effects on ecosystem components

Table 7: Strength of Evidence for Electromagnetic Fields (EMF) Stressor-Effects Linkages in the Operations Phase
*See Figure 4 & Figure 7

Effect	Available Evidence	Direct Linkages
Change in movement patterns **Effect on navigation / orientation** **Avoidance, attraction & other behavioural effects** **Effect on predator / prey detection** **Lethal, sub-lethal and physiological effects**	**<u>Affected Ecosystem Component: Fish (A)</u>** While available research suggests that many fish species are able to detect electric- and/or magnetic fields, data on the effects of underwater cables on fish are inconclusive. There has yet to be any evidence that existing underwater cables have caused significant disruptions to migration patterns, survival and reproductive success in any species. A comprehensive review and annotated bibliography of the available data to 2011 on the responses of marine organisms to EMFs is available in **Normandeau *et al.* (2011)**. The report presents the evidence by species. Based on this review, the report drew the following conclusions: ▪ Electrosensitive species are likely to be able to detect EMFs from both DC and AC cables with higher sensitivity to DC cables. Highly sensitive taxa include elasmobranchs and some teleost fish; ▪ Magnetosensitive species are more likely to be able to detect EMFs from DC cables than from AC cables; ▪ Behavioral responses to EMFs are known for some species but any extrapolation to impacts of exposure to undersea power cables would be speculative; ▪ Since field strength dissipates with distance, demersal species, which are closer to the source, are more likely to be exposed to higher field strengths than pelagic species. **Gill *et al.* (2005)** also provides comprehensive review of the available research on the potential vulnerability of marine organisms to EMFs. The results of several laboratory experiments have been recently published. In preliminary experiments**, Cada *et al.* (2011)** found no evidence that the freshwater fathead minnow *(Pimephales promelas*) was either attracted to or repelled by a DC (static) magnetic field created by a permanent bar magnet. Given the limitations of the experimental design, it is uncertain how these results could be extrapolated to the effects of underwater cables. Further research is planned. **Woodruff *et al.* (2011)** performed laboratory experiments on the physiological and behavioural responses of coho salmon, rainbow trout, Atlantic halibut and California halibut to EMFs of the type expected from cables associated with hydrokinetic turbines. While some indications of developmental, physiological, and behavioral responses to a high and extended EMF exposure were noted, none were statistically significant: ▪ Inconclusive results of coho salmon alarm response experiments identified by decreased swimming activity; ▪ Hormonal tests indicated no evidence of stress, but some decreases in melatonin levels in Coho salmon; ▪ Rainbow trout eggs exposed to 3-mT EMF for extended periods showed some developmental delay at 20 dpf; ▪ Reduced growth and development of Atlantic halibut with late exposures to 3-mT EMFs;	Table 10: Changes in Organism Health, Survival & Reproductive Success

Effect	Available Evidence	Direct Linkages
	▪ No effects on growth or development of California halibut. In a systematic experimental study in the marine environment, **Gill *et al.* (2009**) investigated the responses of three elasmobranch species to simulated EMFs of a type and intensity associated with actual offshore wind turbines. Results indicated that: ▪ responses were variable within and between species; ▪ Catsharks (*Scyliorhinus canicula*) showed a tendency towards attraction and reduced movement (searching behaviour) and Thornback Ray (*Raja clavata*) to increased movement/ searching behaviour. Navigational disruptions and disorientation in response to EMFs of varying types have been documented in some migrating species (e.g., Atlantic salmon and other salmonids, sturgeon, and eels) and sharks (**Gill *et al.* 2005; Ohman *et al.* 2007**). Moreover, impaired migration (Baltic herring, Atlantic cod, eel and flounder), avoidance (eels) and attraction (Atlantic cod) were observed in relation to the cables at wind farms in Denmark (**Dong *et al.* 2006**). **<u>Affected Ecosystem Component: Marine / Aquatic Mammals & Turtles (A)</u>** There has yet to be any evidence that existing underwater cables have caused significant disruptions to migration patterns, survival and reproductive success in any species. A comprehensive review and annotated bibliography of the available data to 2011 on the responses of marine organisms to EMFs is available in **Normandeau *et al.* (2011)**. The report presents the evidence by species. Based on this review, the report drew the following conclusions: ▪ While available research suggests that some marine mammals and sea turtles use magnetic fields for orientation and navigation, there is no direct evidence of effects of EMFs associated with underwater cables on marine mammals, to date; ▪ Magnetosensitive species are more likely to be able to detect EMFs from DC cables than from AC cables. However, since field strength dissipates with distance, demersal species, which are closer to the source, are more likely to be exposed to higher field strengths than pelagic species; ▪ Behavioral responses to EMFs are known for some species but any extrapolation to impacts of exposure to undersea power cables would be speculative. **Gill *et al.* (2005)** also provides comprehensive review of the available research on the potential vulnerability of marine organisms to EMFs. **<u>Affected Ecosystem Component: Invertebrates (A)</u>** While available research suggests that many invertebrate species are able to detect electric- and/or magnetic fields, data on the effects of EMFs associated with underwater cables on fish are inconclusive. There has yet to be any evidence that existing underwater cables have caused significant disruptions to migration patterns, survival and	

Effect	Available Evidence	Direct Linkages
	reproductive success in any species. A comprehensive review and annotated bibliography of the available data to 2011 on the responses of marine organisms to EMFs is available in **Normandeau *et al.* (2011)**. The report presents the evidence by species. Based on this review, the report drew the following conclusions: • There is evidence of electro- and/or magneto-sensitivity in some species of decapods crustaceans; • Electrosensitive species are likely to be able to detect EMFs from both DC and AC cables with higher sensitivity to DC cables; • Magnetosensitive species are more likely to be able to detect EMFs from DC cables than from AC cables; • Behavioral responses to EMFs are known for some species but any extrapolation to impacts of exposure to undersea power cables would be speculative; • Since field strength dissipates with distance, demersal species, which are closer to the source, are more likely to be exposed to higher field strengths than pelagic species. **Gill *et al.* (2005)** also provides comprehensive review of the available research on the potential vulnerability of marine organisms to EMFs. In preliminary experiments**, Cada *et al.* (2011)** found no evidence that common freshwater species of snail *(Elimia clavaeformis)* and clam *(Corbicula fluminea)* were either attracted to or repelled by a DC (static) magnetic field created by a permanent bar magnet. Given the limitations of the experimental design, it is uncertain how these results could be extrapolated to the effects of underwater cables. Further research is planned. **Woodruff *et al.* (2011)** performed laboratory experiments on behavioural responses of Dungeness crab to EMFs of the type expected from cables associated with hydrokinetic turbines. While some indications of detection and behavioral responses to a high and extended EMF exposure were noted, few were statistically significant: • Slight, but not statistically significant, decrease in antennular flicking rate as a measure of EMF detection; • Slight, but not statistically significant, decrease in antennular flicking rate response to food odor after 20 hr, 3-mT EMF exposure as a measure of interference with food detection. However, no effect on feeding behaviour was observed; • Evidence of subtle changes in behaviour after being exposed to EMFs over 3 days, including lower amount of time buried in sand and increases in the number of times crabs changed specific activities between buried, resting and active (e.g. walking, standing, climbing); • Some indication of potential habituation after 48 hours. Results of some early experimental/lab research include: • Magnetic fields (1-100 μT) may affect embryonic development in sea urchins (**Cameron *et al.* 1993);** ▪ High frequency AC EMFs may cause significant cell damage and antennae retraction (interfering with settlement) in barnacle larvae and brine shrimp (**Leya *et al.* 2001**); ▪ **Bochert and Zettler (2004)** found no impact of extended exposure to magnetic fields from a high voltage DC underwater cable on the survival or fitness of shrimp, isopods, crab and mussels;	

Effect	Available Evidence	Direct Linkages
	▪ **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.	
For Habitat, Ecosystem and Population Effects Linkages see Table 10		

*All effects are relevant for Wave, Instream tidal, In-river hydrokinetic and Offshore wind technology categories

**Type of Effects Linkage: A – Direct effect on ecosystem components; B - Effect on the habitat/ecosystem, with indirect effects on ecosystem components

Table 8: Strength of Evidence for Effect of Artificial Structures Stressor-Effects Linkages in the Operations Phase
*See Figure 4 & Figure 8

Effect	Technology	Available Evidence	Direct Linkages
Changes in Water Flow and Sediment Transport, Erosion & Deposition Patterns (around structures, e.g. scour)			
Changes in benthic habitat **Changes in shoreline / coastal habitat**	All	<u>**Affected Ecosystem Component: All Organisms (B)**</u> Extensive examination of the potential risks to habitat and species in the literature (e.g. see **Langton *et al.* 2011; Kadiri *et al.* 2011; Frid *et al.* 2012**). While changes have been predicted, no systematic or long-term data on changes in sediment dynamics are available in the literature. Risk and effects should be similar to other infrastructure in aquatic/marine environments and would depend on the device design, local environment, and equipment, techniques and mitigation measures being used.	Table 10: Changes in Organism Health, Survival & Reproductive Success Table 10: Burying or transport of eggs, larvae, benthos & in-fauna
Changes in Pelagic habitat			Table 10: Changes in Organism Health, Survival & Reproductive Success Table 10: Change in movement patterns; Change in predator/prey/mate detection Table 10: Change in Plankton & Macrophyte Productivity
Change in surface & sub-surface habitat structure & function			
Habitat attraction	All	<u>**Affected Ecosystem Component: Fish (A & B)**</u> Based on experiences with other types of marine infrastructure, there is considerable evidence to support the expected artificial reef effects of ORE structures. Studies suggest that marine infrastructure can attract high fish abundances compared with pre-existing or surrounding conditions; however, they are also often found to support a lower or different species diversity (**Isaacman and Lee 2010; Andersson 2011; Langton *et al.* 2011; Cada *et al.* 2011; Kadiri *et al.* 2011; Nienhuis and Dunlop 2011; Frid *et al.* 2012**). Little systematic or long-term data on the use of ORE structures by local species or changes in community structure are available in the literature. **Andersson (2011)** summarized the results of two field studies on the function of offshore wind foundations as artificial reef effects for fish, algae and invertebrates. Findings on fish include: ▪ After epibenthic colonies began to develop, fish were found to utilize foundations for food, shelter,	Change in Movement Patterns & Access to Feeding/Breeding Sites Table 10: Changes in Organism Health, Survival & Reproductive Success

		and spawning and nursery areas; ▪ Benthic and semi-pelagic species showed a stronger response to the foundation than pelagic species. No changes in fish abundance or diversity were observed during five years of monitoring at two Danish wind farms (**Dong *et al.* 2006**). It was suggested that benthic communities formed on the structures (e.g. mussel monocultures) may not have been particularly attractive to fish. Over a three year study, **Langhamer et al (2009)** found few fish associated with wave device foundations at the (non-operational) Lysekil test park: ▪ Species were those typically associated with hard bottom habitats; ▪ Slightly (not statistically significant) higher average abundance and diversity of fish species noted on foundations than in bare hard bottom sites 10 m from foundations, but was less than is typical in other complex natural and artificial habitats in the area. **<u>Affected Ecosystem Component: Invertebrates & Plants (A & B)</u>** Based on experiences with other types of marine infrastructure, there is considerable evidence to support the expected artificial reef effects of ORE structures (e.g. see **Lu *et al.* 2007; Isaacman and Lee 2010; Andersson 2011; Langton *et al.* 2011; Cada *et al.* 2011; Kadiri *et al.* 2011; Nienhuis and Dunlop 2011; Frid *et al.* 2012**). In general evidence in the literature suggests: ▪ Epibenthic organisms are often at higher biomass and/or abundance levels in comparison to organisms in pre-existing or surrounding conditions; ▪ Structures may attract and support species not previously found in the area (i.e., species that prefer hard surfaces), especially where soft sediments dominate; ▪ In some cases, structures support higher species richness than surrounding soft-sediment areas; ▪ New structures are often initially dominated by opportunistic, short-lived species (e.g. monocultures of mussels, barnacles, tunicates), which may persist or gradually be replaced by more heterogeneous assemblages of secondary colonizers; ▪ Structures may be susceptible to colonization by aquatic invasive invertebrates, particularly in harsher environments such as brackish waters. **Andersson (2011)** summarized the results of two field studies on the function of offshore wind foundations as artificial reef effects for fish, algae and invertebrates. Findings regarding fish include: • Initial colonization of epibenthic assemblages depends on hydrographic parameters, season of submergence, distance to natural reefs or hard bottom habitats, structural material and texture; • After epibenthic colonies began to develop, fish were found to utilize foundations for food, shelter, and spawning and nursery areas; • Benthic and semi-pelagic species showed a stronger response to the foundation than pelagic species; • Change in epibenthic assemblages change local nutrient conditions further affecting the rate and	

		pattern of epibenthic and fish community succession. Over a three year study of the foundations at the (non-operational) Lysekil test park, **Langhamer et al (2009)** found: • Few shellfish associated with wave device; ▪ Species were those typically associated with hard bottom habitats; ▪ Crab, occupying holes in the piles, were the most common; ▪ A few (3) lobsters were found in cavities under the foundations; ▪ An initially low diversity of colonizing species (mainly mussels) was gradually replaced over time with increasing species diversity (including secondary colonizers) on foundation structures; however, mussels continued to dominate on wave buoys (point absorbers).	
Habitat attraction	Offshore Wind Wave, In-stream Tidal & In-river Hydrokinetic with surface piercing or floating structures	**<u>Affected Ecosystem Component: Marine / Aquatic Mammals & Turtles (A & B)</u>** **<u>Marine / Aquatic Birds (A& B)</u>** The potential implications of changes in prey type and abundance in response to habitat structure (artificial reef effects) for marine mammals and birds has been well documented for other types of marine infrastructure (e.g. see **Langton *et al.* 2011; Cada *et al.* 2011; Kadiri *et al.* 2011; Frid *et al.* 2012**). However, clear increases in marine mammal or bird activity, in the vicinity of ORE infrastructure, suggesting attraction to changes in prey, have not been identified in the few monitoring reports available. Pinnipeds and birds have been documented using suitable ORE structures near to coastal habitats when human disturbance is minimal (e.g. **Hagerman and Bedard 2004; FMM 2007; Michael *et al.* 2007**). The significance of the use of these structures on populations has not been examined (e.g. effect on fitness, risk of injury) The potential use of these structures by otters, turtles or other species has yet to be critically considered in the literature.	Change in Movement Patterns & Access to Feeding/Breeding Sites Table 10: Changes in Organism Health, Survival & Reproductive Success
Establishment of fouling assemblages	All	**<u>Affected Ecosystem Component: Invertebrates & Plants (A & B)</u>** See *Habitat Attraction: Invertebrates & plants*	Table 10: Changes in Community Structure & Function

Habitat exclusion/barrier to movement	All	**<u>Affected Ecosystem Component: All Organisms (A & B)</u>** Reactions of various species to the physical presence of other types of marine infrastructure are available in the literature (see Isaacman and Lee 2010). No significant changes in species movement patterns or avoidance have been identified in the few available monitoring reports of non-operational devices, where operational effects are not a factor (**Royal Haskoning 2009, 2011; FORCE 2011; Tollit *et al.* 2011**). Laboratory experiments suggest movement patterns of fish may be affected by flow velocities upstream, along the sides, and downstream of the turbine. **Castros-Santos and Haro (2011)** experiments with an operating 4-blade Encurrent 5KW vertical axis turbine found: ▪ Slight behavioural response in juvenile Atlantic salmon related to movement patterns and orientation, but no evidence of avoidance response. ▪ Active avoidance response in American shad, including reluctance to pass through or by the turbines. **Alden Laboratory (2011)** observed some active avoidance response in rainbow trout (facing and active swimming against current, moving along walls and floor) in response to a single vertical cross-flow turbine and a ducted axial flow turbine. The behaviour of all species to large-scale arrays, or arrays spanning entire channels requires investigation.	Change in Movement Patterns & Access to Feeding/Breeding Sites Table 10: Changes in Organism Health, Survival & Reproductive Success
Change in movement patterns & access to feeding/breeding sites			Change in Community Structure & Function Table 10: Changes in Organism Health, Survival & Reproductive Success
Change in ambient light	Floating structures	**<u>Affected Ecosystem Component: All Organisms (B)</u>** The effect of this factor related to ORE structures on habitat and organisms has not yet been fully investigated.	Change in Pelagic Habitat Change in Movement Patterns & Access to Feeding/Breeding Sites
For further Habitat, Ecosystem and Population Effects see Table 10			

Type of Effects Linkage: A – Direct effect on ecosystem components; B - Effect on the habitat/ecosystem, with indirect effects on ecosystem components

Table 9: Strength of Evidence for Change in Current or Wave Energy Stressor-Effects Linkages in the Operations Phase
*See Figure 4 and Figure 9

Effect	Technology	Available Evidence	Direct Linkages
Change in hydrodynamic characteristics & patterns (timing, velocity, height, mixing patterns)	In-stream Tidal In-river Hydrokinetic	**<u>Affected Ecosystem Component: All Organisms (B)</u>** Many risk assessments of this issue to marine organisms and habitat have been published in the literature (e.g. see **Isaacman and Lee 2010; Langton *et al.* 2011; Cada *et al.* 2011; Kadiri *et al.* 2011; Frid *et al.* 2012**); however, no follow up monitoring results are available to confirm / verify the predictions. There is a lack of published data on hydrodynamic effects at ORE deployments. However, observational accounts of localized wake effects have been reported in some monitoring reports (e.g. 200 m at the 300 kW Seaflow™ turbine deployed off the UK coast [Frankael 2006]). There have been several efforts to model near-field and far-field (**Verdant Power 2008; Karsten *et al.* 2008, 2011; Lalander and Leijon 2011; Polagye and Malte 2011; Shapiro 2011; Shields *et al.* 2011; Ahmadian *et al.* 2012**) effects of tidal (ocean and in-river) devices. The extent of the impact depends on the assumptions made about the local conditions and level of energy extraction. General predictions, include: ▪ Altered current flow patterns/ directions; ▪ Altered (higher) upstream water levels at channel inlets; ▪ Reduced flow immediately upstream; ▪ Reduced downstream velocity with accelerated flow around the device; ▪ Downstream wake effects; ▪ Basin-wide tidal amplitude alterations. A recent 3-D modeling of a 12 diameter circular tidal farm in open shallow water (87 – 606 KW extracted energy) predicted (**Shapiro 2011**): ▪ Low-medium efficiency farms caused localized reductions in current kinetic energy and patterns in the vicinity of the farm; ▪ Higher efficiency farms would result in significant reductions of current energy up to 10–20 km away, especially within the farm area, and noticeable changes in residual currents (speeds and circulation patterns) up to 100 km away. Modeling of the effects of a turbine array in the Severn Estuary and Bristol Channel by **Ahmadian *et al.* (2012)** predicted: ▪ Little effect on water levels; ▪ Reduced velocities inside and both upstream and downstream of the array, more than 25% in some places inside the array; ▪ Increased velocities along the sides of the array, with flow patterns indicating that the flow resistance	Changes in Sediment Transport, Erosion & Deposition Patterns Table 10: Change in Ambient Light & Water Quality Table 10: Changes in Organism Health, Survival & Reproductive Success Table 10: Change in Movement Patterns & Change in Predator/Prey/Mate Detection

		of the turbine array was encouraging flow, and increasing currents, around the array. There has yet to be any published research examining this risk of changes in tidal mixing.	
Change in hydrodynamic characteristics & patterns (timing, velocity, height, mixing patterns)	Wave	**<u>Affected Ecosystem Component: All Organisms (B)</u>** A number of risk assessments of this issue to marine organisms and habitat have been published in the literature (e.g. see **Isaacman and Lee 2010; Langton *et al.* 2011; Cada *et al.* 2011; Kadiri *et al.* 2011; Frid *et al.* 2012**); however, no direct evidence of these interactions are available. There is a lack of published data on hydrodynamic effects at ORE deployments and, at this time, an absence of follow up monitoring results to confirm assessment predictions. There have been several efforts to model near-field effects of wave devices. The extent of the impact depends on the assumptions made about the local conditions and level of energy extraction (e.g. **Hagerman and Bedard 2004; Halcrow Group 2006; FMM 2007; Palha *et al.* 2011; Shields *et al.* 2011**). General predictions, include: ▪ Reduction in wave height at the shoreline (up to 20 km away) of 3-13%; ▪ Reduced current velocity. Current models do not address multiple device interactions or cumulative effects of large-scale arrays, and therefore are unable to predict the likely detrimental effects associated with full-scale deployments.	Changes in Sediment Transport, Erosion & Deposition Patterns Table 10: Change in Ambient Light & Water Quality Table 10: Changes in Organism Health, Survival & Reproductive Success Table 10: Change in Movement Patterns & Change in Predator/Prey/Mate Detection
Changes in sediment transport, erosion & deposition patterns	In-stream Tidal In-river Hydrokinetic Wave	**<u>Affected Ecosystem Component: All Organisms (B)</u>** Many assessments of the risk of this issue to marine organisms and habitat have been published in the literature (e.g. see **Isaacman and Lee 2010; Langton *et al.* 2011; Cada *et al.* 2011; Kadiri *et al.* 2011; Frid *et al.* 2012**); however, no direct evidence of these interactions are available. There is a lack of published data on hydrodynamic effects at ORE deployments. Based on general hydrodynamic and geophysical principles, several researchers have predicted possible near-field disruptions to sediment dynamics, mostly related to tidal and hydrokinetic devices (**FMM 2007; Michel *et al.* 2007; Meredyck 2009; Ahmadian *et al.* 2012; Frid *et al.* 2012**). Modeling of the effects of a turbine array in the Severn Estuary and Bristol Channel by **Ahmadian *et al.* (2012)** predicted significant changes in suspended sediment concentrations within 15 km from the turbine array, with decreased levels upstream, downstream and inside the array and increased, to a lesser degree, along the sides of the array. **Defeo *et al.* (2009) and Meredyk (2009)** have suggested possible far-field effects on coastal sediment	Table 10: Change in Ambient Light & Water Quality Table 10: Change in Benthic Habitat Table 10: Change in Pelagic Habitat Table 10: Change in Coastal/ Shoreline Habitat

		deposition and erosion patterns, resulting from changes to wave patterns caused by: ▪ Wave energy extraction; or ▪ Modified current flows due to tidal/current devices deployed in enclosed sites, such as bays, inlets and rivers. An early model for the proposed Wave Hub demonstration facility predicted that the facility should have no discernable effect on the coast 20 km away (**Halcrow Group 2006).** However, other studies have predicted possible changes in the shoreline due to wave energy extraction (**Defeo *et al.* 2009**). Studies on the Bay of Fundy, NS predicted that a small-scale tidal project (e.g. 10MW reduction in tidal energy flow) in the Minas Passage would result in an increase in sedimentation around the array, but insignificant changes to tidal amplitude and far-field sedimentation (**Karsten *et al.* 2008; Meredyk 2009**). A commercial-scale project (e.g. 20% decrease in flow) could result in significant near and far-field sedimentation.	
For Habitat, Ecosystem and Population Effects see Table 10			

Type of Effects Linkage: A – Direct effect on ecosystem components; B - Effect on the habitat/ecosystem, with indirect effects on ecosystem components

Table 10: Strength of Evidence for Habitat, Ecosystem and Population-scale Response Linkages in the Operations Phase
*See Figures 4 - 9

Effect	Available Evidence	Direct Linkages
Change in water quality (Contaminants)	**Affected Ecosystem Component: All Organisms (A)** No contamination issues have been reported in the few monitoring reports released to date. Toxic effects and release risk from substances commonly used in the marine industries are well-examined in the literature. The major concern in the literature is related to the use of antifouling agents. For example, copper-based coatings, which have been the standard materials used in marine industries, are known to leach toxic metals into the marine ecosystem (Isaacman and Lee 2010). Sensitivity ratings of species/habitats to contaminant exposure related to ORE are presented in **FMM (2007) and ABPMER (2009)**. A recent review of the potential impacts on water quality of ORE is presented in **Kadiri *et al.* (2011).**	Change in Ambient Light & Water Quality Changes in Organism Health, Survival & Reproductive Success
Change in ambient light & water quality (suspended sediment concentrations, temperature, contaminated sediment re-suspension, nutrients, water chemistry conditions)	**Affected Ecosystem Component: All Organisms (A & B)** Many assessments of the risk of this issue to marine organisms and habitat have been published in the literature (e.g. see **Isaacman and Lee 2010; Langton *et al.* 2011; Kadiri *et al.* 2011; Polagye *et al.* 2011; Frid *et al.* 2012**); however, no direct evidence of these interactions are available.	Change in Benthic Habitat Change in Pelagic Habitat Change in Coastal/ Shoreline Habitat Change in Movement Patterns & Change in Predator/Prey/Mate Detection Changes in Organism Health, Survival & Reproductive Success
Change in pelagic habitat	See **Change in Ambient Light & Water Quality**	Changes in Organism Health, Survival & Reproductive Success Change in movement patterns & Change in predator/prey/mate detection

		Change in Plankton & Macrophyte Productivity
Change in benthic habitat	<u>**Affected Ecosystem Component: Invertebrates & Plants (B)**</u> <u>**Fish (B)**</u> <u>**All Organisms (B)**</u> (See Change in Community Structure & Function) Few monitoring data on long-term impacts to benthic habitats due to ORE operations are available in the literature. **Kadiri *et al.* (2011), Shields *et al.* (2011) and Frid *et al.* (2012)** provide an overview of the potential implications of hydrodynamic and sediment changes on benthic organisms and habitats related to wave, tidal and hydrokinetic turbines and offshore wind. An observational study at a wave energy test farm by **Langhamer (2010)** considered the impacts on benthic habitats due to changes in hydrodynamic and sediment patterns of ORE systems. The findings indicated a slight increase in abundance of soft-bottom macrofaunal species, mostly polychaetes, with changes in physical seabed structure due to reduced hydrodynamic forces and an accumulation of organic matter.	Changes in Organism Health, Survival & Reproductive Success Burying or Transport of Eggs, Larvae, Benthos & In-Fauna
Change in coastal/ shoreline habitat	<u>**Affected Ecosystem Component: Invertebrates & Plants (B)**</u> <u>**All Organisms (B)**</u> (See Change in Community Structure & Function) Little research is available on this issue. **Defeo *et al.* (2011)** predicted the potential for effects on coastal and shoreline habitats due to changes to wave patterns caused by: ▪ Wave energy extraction; or ▪ Modified current flows due to tidal/current devices deployed in enclosed sites, such as bays, inlets and rivers.	Changes in Organism Health, Survival & Reproductive Success Burying or Transport of Eggs, Larvae, Benthos & In-Fauna
Change in movement patterns **Change in predator/prey/mate detection**	<u>**Affected Ecosystem Component: All Organisms (A)**</u> Laboratory experiments suggest movement patterns of fish may be affected by flow velocities upstream, along the sides, and downstream of the turbine. **Castros-Santos and Haro (2011)** experiments with an operating 4-blade Encurrent 5KW vertical axis turbine found: ▪ Slight behavioural response in juvenile Atlantic salmon related to movement patterns and orientation, but no evidence of avoidance response; ▪ Active avoidance response in American shad, including reluctance to pass through or by the turbines.	Changes in Organism Health, Survival & Reproductive Success Change in Community Structure & Function

	Alden Laboratory (2011) observed some active avoidance response in rainbow trout (facing and active swimming against current, moving along walls and floor) in response to a single vertical cross-flow turbine and a ducted axial flow turbine. The few available monitoring reports have not identified any significant changes in movement patterns, detection abilities or behaviours in any species in relation to operational-induced changes in sediment and/or hydrodynamic conditions.	
Changes in plankton & macrophyte productivity	**Affected Ecosystem Component: Invertebrates & Plants (A & B)** **All Organisms (B)** (See Change in Community Structure & Function) There has yet to be any published research examining this issue or its possible implications.	Change in Community Structure & Function
Burying or transport of eggs, larvae, benthos & in-fauna	**Affected Ecosystem Component: Invertebrates & Plants (A)** **Fish (A)** **Shields *et al.* (2011)** provides an overview of the potential implications of hydrodynamic changes on settlement cues and egg/larvae dispersal and fertilization due to ORE.	Changes in Organism Health, Survival & Reproductive Success
Change in community structure & function	**Affected Ecosystem Component: All Organisms (B)** See **Table 8: Change in Surface & Sub-surface Habitat Structure & Function: Habitat Attraction** This is a very complex issue dependant on a number of variables. Research and monitoring related to the operation of ORE have yet to tackle long-term changes in community structure or ecological processes.	Changes in Organism Health, Survival & Reproductive Success
Changes in species health, survival an reproductive success **Population-scale effects**	**Affected Ecosystem Component: Fish** There is some evidence of potential physiological and behavioural responses in some fish species due to noises, EMFs, changes in flow velocities and patterns and changes in habitat structure related to ORE devices, particularly tidal and hydrokinetic turbines (see above). Potential population-scale and cumulative impacts of ORE operation-related stressors on fish communities have been identified in **Langhamer and Wilhelmsson (2009); Langhamer *et al.* (2009, 2010); Kadiri *et al.* (2011); Polagye et al. 2011; Shields *et al.* (2011) and Frid *et al.* (2012)**. Long-term systematic studies, and specific mechanisms to understand population scale effects, are lacking. **Affected Ecosystem Component: Marine / aquatic mammals & turtles** There has yet to be any systematic research published indicating an effect of ORE operations on the health, fitness and long-term survival of any marine/aquatic mammals or turtles during the operation of ORE	Change in Community Structure & Function

	developments. Potential population-scale and cumulative impacts of ORE operation-related stressors on fish communities have been identified in **Polagye et al. 2011 and Frid *et al.* (2012)**. Long-term systematic studies, and specific mechanisms to understand population scale effects, are lacking. **<u>Affected Ecosystem Component: Invertebrates & plants</u>** Potential population-scale and cumulative impacts of ORE operation-related stressors on marine invertebrate communities, particularly in relation to the colonization of epibenthic communities on and around ORE structures, have been identified in **Sundberg and Langhamer (2005); Wilhelmsson and Malm (2008); Langhamer and Wilhelmsson (2009); Langhamer *et al.* (2009, 2010); Kadiri *et al.* (2011); Polagye et al. 2011; Shields *et al.* (2011) and Frid *et al.* (2012)**. There is some evidence of potential physiological and behavioural responses in some invertebrate species due to noises, EMFs, changes in flow velocities and patterns and changes in habitat structure related to ORE devices, particularly tidal and hydrokinetic turbines. Long-term systematic studies, and specific mechanisms to understand population scale effects, are lacking. **<u>Affected Ecosystem Component: Marine / aquatic birds</u>** **Grecian et al (2010) and Langton *et al.* (2011)** summarized the potential impacts of tidal and wave-powered marine renewable energy devices on marine birds, deriving most of their information from studies of offshore wind farms. Potential cumulative effects on fish and birds have been identified by **Hunter and Mitchell (1968); Bulleri and Airoldi (2005); Sundberg and Langhamer (2005); Wilhelmsson and Malm (2008); Langhamer and Wilhelmsson (2009); and Langhamer *et al.* (2009, 2010)**. Experience with responses of marine birds to anthropogenic structures in coastal environments is well developed, and several survey protocols have been introduced (e.g. **Desholm and Kahlert 2005; Desholm *et al.* 2006; Stewart *et al.* 2007; see also Hill *et al.* 1997**).	

*All effects are relevant for Wave, Instream tidal, In-river hydrokinetic and Offshore wind technology categories

**Type of Effects Linkage: A – Direct effect on ecosystem components; B - Effect on the habitat/ecosystem, with indirect effects on ecosystem component