Investigating displacement of marine animals as a potential effect of marine renewable energy development

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I. Introduction

MARINE renewable energy (MRE) developments, such as those harvesting wave or tidal energy, will need to grow towards large-scale arrays for the sector to successfully contribute toward the portfolio of sustainable energy alternatives and fight global climate change. However, this growth must be accompanied by the investigation of potential environmental effects at larger scales, and will require investigations of stressor-receptor interactions that may not be relevant at the scale of small numbers of devices, such as changes in oceanographic systems and displacement of marine animals [1]. In the MRE context, stressors are (parts of) a device that can produce stress, harm, or injury to receptors such as marine animals or habitats, and oceanographic or ecosystem processes [2].

Whether large arrays of MRE devices (i.e., 10-30 devices) will displace marine animals from their preferred or essential habitats remains to be examined [3]. Many marine animals undertake annual migrations, during which they could encounter MRE arrays, potentially altering their course and lengthening their routes to avoid the devices. Resident animals may be displaced locally if a complete or partial loss of critical habitats occurs due to the installation and operation of arrays. However, research around mechanisms and effects of displacement has been precluded by the lack of large-scale deployed arrays [4]. In addition, there is a lack of common understanding within the international MRE community about the definition of displacement, the mechanisms that cause displacement, as well as the consequences, species of concern, and methods to investigate the outcomes.

Displacement of marine animals is not specific to the MRE sector and lessons may be learned from other marine, or even terrestrial, human activities. These activities should be identified, as well as the relevant knowledge to transfer. Remaining knowledge gaps will need to be filled through targeted research studies, involving field-based approaches and/or numerical modeling.

A literature review on displacement of marine animals was undertaken across three offshore energy sectors: MRE, offshore wind, and oil and gas, and a workshop was organized with international subject matter experts to gather feedback and attempt to reach a consensus around the definition and mechanisms of displacement. This study aims to establish a definition of this stressor-receptor interaction, explore which groups of marine animals may be affected and how, and identifies pathways for investigating displacement through modeling and monitoring in the MRE context.

II. Displacement: definitions and process

Definitions of displacement that are relevant to MRE development are found in a limited number of recent references but are not consistent, nor do the authors agree on which organisms to consider, and/or the processes and consequences of displacement. These earlier definitions are listed first, then we provide our own understanding of displacement.

A. *Definitions of displacement from the scientific literature*

Displacement has only been defined by a few studies in the context of MRE, mainly related to marine mammals or fish. For example, Long [5] defined displacement as the "potential for the loss of habitat due to disturbance or barrier effects. This may be in the form of redistribution from an area or complete avoidance of an area".

Sparling et al. [6] defined displacement as "the movement of animals away from the area within or immediately adjacent to an area in which an anthropogenic activity is occurring or has occurred". The authors highlighted that displacement may be the result of habitat loss (i.e., "the habitat held for the animal is no longer present. Therefore, animals must go elsewhere for a resource that they previously found there") or of disturbance (i.e., "the anthropogenic activity creates a response in an animal that results in a behavioral change").

Copping et al. [3] defined displacement of fish as the result of a partial or complete loss of preferred or essential habitat or because "an array of MRE devices placed in a line or large installation might cause a disturbance that acts as a barrier, causing resident fish to move away from the area and/or migratory fish to modify their routes". Moreover, the authors add that "displacement of fish from their preferred habitats is likely to occur across much greater spatial and temporal scales than the avoidance behavior of individual fish or schools of fish when faced with an instream tidal or river turbine".

Buenau et al. [4] argued that "MRE arrays may displace animals, fully or partially, from foraging or breeding habitats if the arrays are located in those areas or are perceived as barriers to access. Displacement could also lengthen migration routes, thereby increasing energetic costs and changing access to prey; all of these factors could lead to population-level effects. Under this definition, displacement is caused by the presence of an array of devices as distinguished from related noise, electromagnetic fields, or other stressors".

Displacement is also an interaction used by the wind industry (land-based and offshore) mainly in relation to birds and bats. Marques et al. [7] contrasted displacement and attraction based on habitat availability: "We consider displacement as the reduced density of birds occurring near wind turbines, due to long-term disturbance leading to functional habitat loss […]. Conversely, we define attraction as an increase in bird density within or near the wind farm." Similarly, SEER [8] distinguished displacement from avoidance and a barrier effect, defining displacement as "limiting the normal use of an area within or adjacent to a wind farm, such as resting, roosting, or foraging habitat"; avoidance as "an action taken by a bird to prevent interaction with the infrastructure of a wind farm"; and a barrier effect as the alteration of a bird's flight behavior that "prevents it from accessing an area".

All these studies described displacement as some combination of habitat loss and a barrier to access, more often due to the physical presence of MRE devices or wind turbines. However, displacement may be a more complex interaction, as described in the following sections.

B. New proposed definition

Displacement is "the moving of something from its place or position" (Oxford Dictionary). In the MRE context, we propose to define displacement as the outcome of one of three mechanisms (i.e., attraction, avoidance, and exclusion) triggered by a receptor's response to one or more stressors acting as disturbance, with various consequences at the individual through population levels (Figure 1).

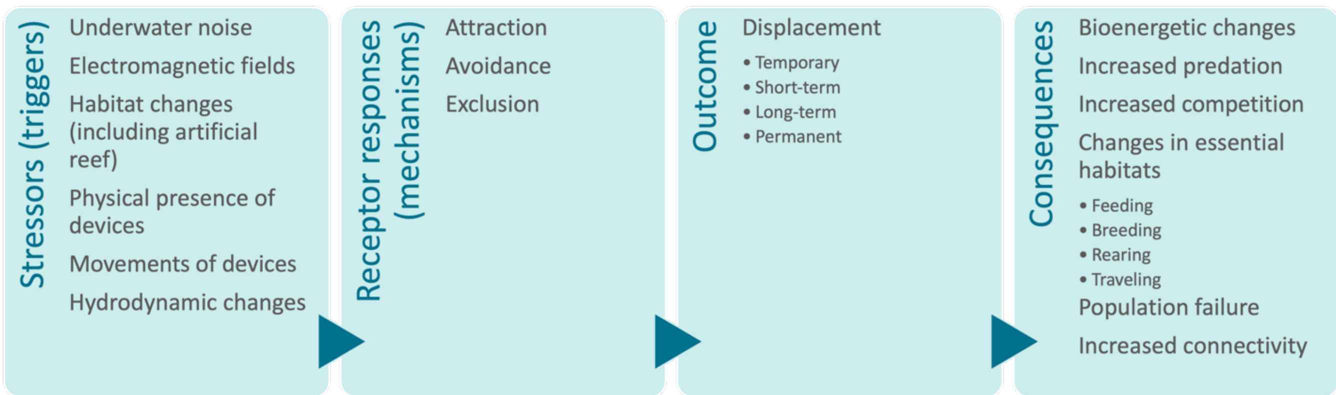

Fig. 1. Displacement flow chart: displacement is the outcome of one of three mechanisms triggered by a receptor's response to stressors, with the potential for a range of consequences on marine animals that span from effects on the individual to effects on populations.

Stressors that are most likely to trigger a response from marine animals are the physical presence of MRE devices in their natural environment, underwater noise and electromagnetic fields emitted by the devices and/or associated equipment, changes in habitats including the creation of artificial reefs, the movements of (parts of) devices including the rotation of turbine blades, and hydrodynamic changes due to the operation of large numbers of devices. Various combinations and/or cumulative effects of these stressors may also be responsible for triggering a response, depending on species and individuals.

Responses to these stressors may include attraction, avoidance, or exclusion (Figure 2), or an animal may have no response to the stressor at all. These responses are expected to be species specific and may vary across different life stages and/or populations, as well as location specific to some extent, perhaps driven by physical factors such as seascape or hydrodynamics. The ability (or decision) to respond may also vary through time, based on the behavior state of an animal. Attraction can be defined as the movement of animals toward an area within or immediately adjacent to an MRE array (i.e., going toward); avoidance is the intentional bypassing of an area with MRE devices in order to go in the same general direction (i.e., going around); and exclusion is the departure or movement away from the area, bailing on going toward the initial direction (i.e., going away). Exclusion can result in a barrier effect, preventing animals from passing through an array of MRE devices and/or associated equipment. These mechanisms can apply to migratory species along their travel route (e.g., grey whales migrating between Mexico and Alaska), as well as to mobile animals that move within small home ranges (e.g., rockfish navigating between a few rocky reefs), or sessile animals that disperse through a pelagic larval phase (e.g., biofouling animals like sea anemones and tunicates).

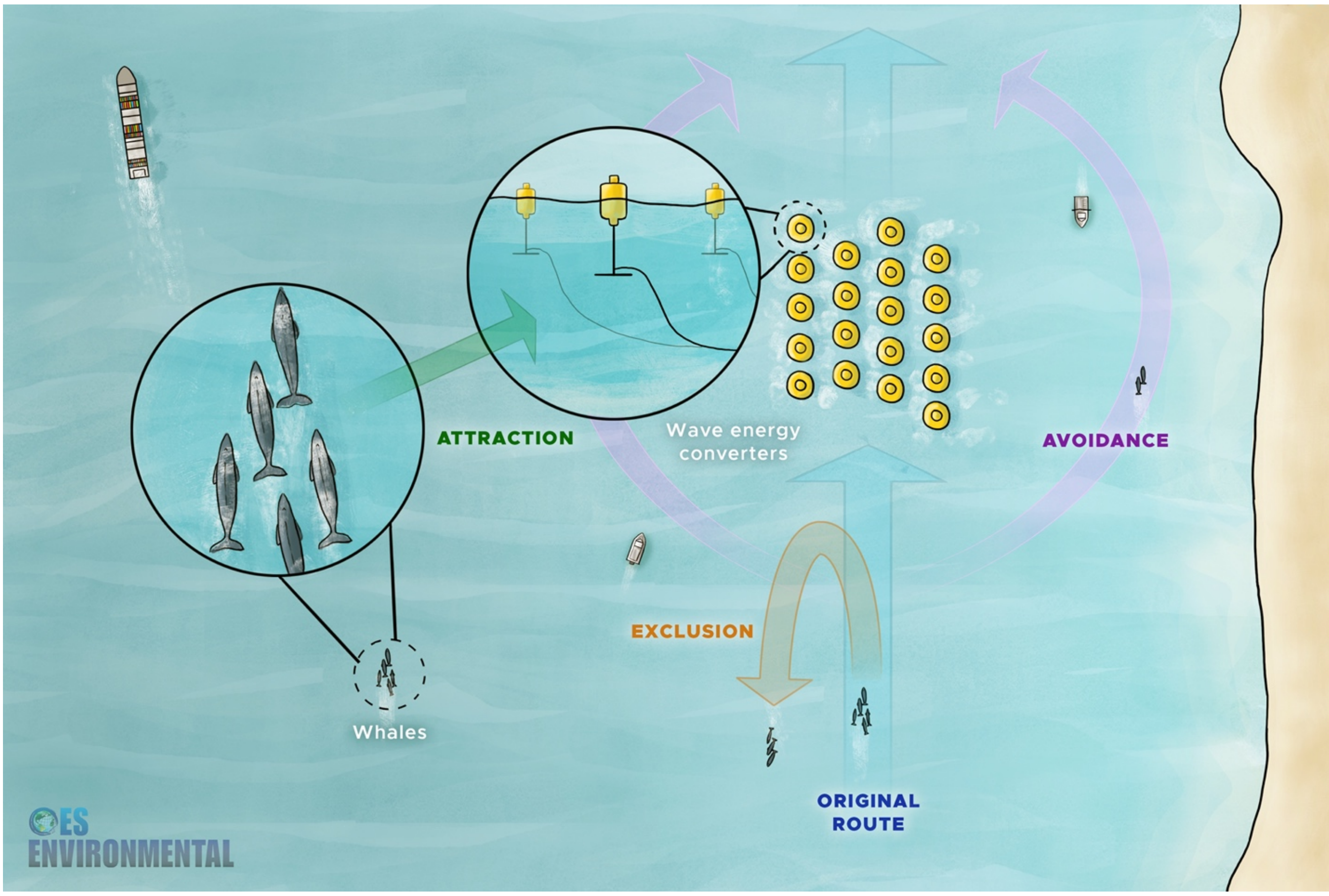

Fig. 2. Mechanisms of displacement. After encountering an array of wave energy converters, marine animals may exhibit an attraction, avoidance, or exclusion response (or no response at all), which may result in their displacement from key foraging or breeding grounds. (Illustration by Stephanie King, Pacific Northwest National Laboratory).

As an outcome of these receptor responses, displacement can be temporary, short-term, long-term, or permanent on a temporal scale. A temporary displacement may occur during the installation of devices, resulting in affected animals returning to using the area once construction activities are completed. Temporary displacement may also occur if animals are sometimes disrupted from their day-to-day activities around an MRE array. Some animals may take more time to adjust to a new baseline but may resume their activities in the MRE development area within their lifespan. This can be considered as short-term displacement. For others, it may take several generations to reuse the area, which can be considered a long-term displacement. In some instances, animals may never come back to an area, in which case they would be permanently displaced. On a spatial scale, the outcome of displacement can occur at short or long distance, depending on the animals or sites specificities.

A diversity of consequences is expected to occur from the individual to the population level. A displaced animal may experience bioenergetic losses due to the extra time and effort spent travelling around (avoidance), to (attraction), or away from (exclusion) an MRE array, if food sources are not available along the way. Attraction may also result in bioenergetic benefits for individuals upon arrival. Displaced animals may also face increased predation and/or competition in the area they moved into, or increased risk of harm or injury from human activities in the new area, impacting their fitness and population survival. Displacement may also lead to the loss of essential habitat sustaining vital functions such as feeding, breeding, spawning, rearing young, or traveling between other critical habitats. When multiple individuals within a population are affected, displacement could result in failure of the whole population, which would become a serious concern for endangered species with small populations, like the southern resident killer whales in the Puget Sound (northwest of the United States) and adjacent waters. In contrast, animals displaced by attraction may thrive in their new environment, gaining new essential habitat and increasing their population, like predators attracted to artificial reefs and the numerous preys they harbor.

In summary, displacement of aquatic animals due to the presence and/or operation of MRE devices is defined as the result of mechanisms that cause animals to depart from or not enter their preferred or critical habitats, or to move into new areas.

III. Remaining knowledge gaps

Much remains to be understood about the mechanisms and significance of animal displacement around MRE sites to fully understand, and when necessary, mitigate, these interactions. Knowledge gaps remain on the animals themselves, the MRE technologies, the monitoring of animal-technology interactions, and the related regulations.

On the animal side, questions that must be raised to investigate displacement pertain to:

- species that are most likely to be affected by displacement;
- species' natural behavior and fluctuations in habitat use;
- main triggers, mechanisms, and consequences of displacement for each species;
- potential differences in vital rates and behaviors observed among life stages, individuals, or populations within a species;
- spatiotemporal scales of displacement relevant to each species and life stage, and
- individual consequences to the population or species levels.

On the technology side, questions that must be raised to investigate displacement pertain to:

- array configurations (e.g., size, geometry, spatial coverage, cable route) and/or device types most likely to cause displacement and in which type of environment, and
- surrogate marine and/or terrestrial activities that may inform this interaction.

On the monitoring side, questions that must be raised to investigate displacement pertain to:

- the most suitable commercial-off-the-shelf monitoring technologies for each species and their adaptation to different sites and MRE technologies;
- the modification of existing observation technologies or development of new ones;
- the spatiotemporal scales that monitoring surveys should cover for each species and MRE technology; and
- the monitoring and understanding of displacement in the context of climate change and other cumulative effects.

On the regulatory side, questions that must be raised to investigate displacement pertain to:

- the existence of specific national or international regulations or statutes that apply to displacement of marine animals (related to MRE and/or other sectors);
- common regulations that already protect species and populations that these interactions could fall into; and
- the identification of any actions that are required by law versus those recommended.

Investigating any or all of these questions will greatly enhance our understanding of displacement around MRE arrays and its consequences for marine animals.

IV. Conclusion

To move forward with investigating and understanding the risk of displacement for marine animals around MRE arrays, the MRE community must first agree on the definitions, mechanisms, and consequences of displacement. Leveraging definitions laid out in previous MRE studies as well as those related to offshore wind, we defined displacement as the outcome of one of three mechanisms (i.e., attraction, avoidance, and exclusion) triggered by a receptor's response to one or more stressors acting as disturbance, with various consequences at the individual through population levels. Although this stressor-receptor interaction is less likely to be a concern around single or small numbers of devices, it is important to understand its mechanisms, possible consequences, and how to monitor them before any large-scale arrays are in the water. The knowledge gaps highlighted in this study will help the regulatory and scientific communities prepare themselves for mitigating, observing, measuring, and characterizing displacement of various animals around MRE arrays in order to prevent irreversible consequences.

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