NATURAL ENVIRONMENT RESEARCH COUNCIL

Wave & Tidal Consenting

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Impacts on Fish and Shellfish Ecology

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“Identifying the key potential impacts and the mechanisms underlying them for wave and tidal devices, and informed the priorities for research and the undertaking of Environmental Impact Assessment”

1 Background

The potential impacts arising from wave and tidal energy devices ('wave and tidal devices') on fish and shellfish have been described previously (e.g. Gill, 2005; OSPAR, 2006; Faber Maunsell and Metoc, 2007; ABPmer, 2010; Boehlert and Gill, 2010; ICES, 2011; Frid et al., 2012; Aquatera, 2012; Rusu and Soares, 2013; Slaski et al., 2013). These studies identify the key potential impacts and the mechanisms underlying them for wave and tidal devices, and informed the priorities for research and the undertaking of Environmental Impact Assessment ('EIA').

This paper builds on the existing literature and the experiences gained by those involved in the wave and tidal energy industry (obtained through telephone interviews with eleven stakeholders in the regulatory and development sectors). The consensus from those interviewed is that effects of wave and tidal technologies on fish and shellfish ecology are generally considered less of a priority than effects on fisheries. However, fisheries impacts are not within the scope of this position paper and are therefore not discussed further.

The aim of this paper is to highlight key fish and shellfish issues and potential impacts that have arisen during the development of wave and tidal technologies, and to provide a consolidated understanding of the wave and tidal industry, knowledge gaps and key experiences.

Table 1 summarises the number of full-scale devices installed or are currently operating in the UK where 3.4 MW are installed for wave and 5.2 MW for tidal projects.

TABLE 1. FULL SCALE DEVICES INSTALLED OR CURRENTLY OPERATING IN UK WATERS

DEVICE TYPE	OPERATOR	DEVICE	RATING (MW)	COMMISSIONED	LOCATION
TIDAL	Andritz Hydro Hammerfest	HS1000	1	2011	Fall of Warness, European Marine Energy Centre ('EMEC')
	Alstom	DeepGen 1MW	1	2013	Fall of Warness, EMEC
	Marine Current Turbines	SeaGen	1.2	2009	Strangford Lough, Northern Ireland ('NI')
	Minesto	Deep Green	0.5	2013	Strangford Lough, NI
	OpenHydro	Open Centre turbine	0.25	2008	Fall of Warness, EMEC
	Scotrenewables Tidal Power	SR250	0.25	2011	Fall of Warness, EMEC
	Voith Hydro Ocean Current Technologies	Hy Tide 1000-13	1	2013	Fall of Warness, EMEC
WAVE	Aquamarine Power	Oyster 800	0.8	2012	Billia Croo, EMEC
	Fred.Olsen	Bolt "Lifesaver"	0.25	2012	FaBTest, Cornwall
	Pelamis	Pelamis P2	0.75	2010	Billia Croo, EMEC
	Seatricity	Oceanus	1	2013	Billia Croo, EMEC
	Wello	Penguin	0.6	2013	Billia Croo, EMEC

2 Key Issues

In the last 5 years the wave and tidal industry has seen a period of rapid expansion. Much of this activity has been developer led and has focused on the provision of environmental information and assessments to gain consent, as well as the monitoring of environmental impacts in areas where devices have been installed (e.g. OpenHydro, Aquamarine Power, Marine Current Turbines ('MCT') and European Marine Energy Centre ('EMEC')).

"There is still uncertainty regarding the level of impact that may arise from the construction and operational phases of pre-commercial deployments and commercial scale arrays"

Deployment of wave and tidal technologies in the UK has been largely at the prototype/ demonstration site level, although the path for up-scaling to larger arrays was first recognised in 2011 when the Sound of Islay tidal stream project received consent (at the time the World's first consented array) and more recently the successful consent of MeyGen's Pentland Firth tidal array project. Therefore, the evidence-base for understanding the potential environmental impacts of these commercial scale deployments on fish and shellfish can only be extrapolated from existing knowledge. However, there is still uncertainty regarding the level of impact that may arise from the construction and operational phases of pre-commercial deployments and commercial scale arrays. For example, likely impacts at the population scale for diadromous fish are uncertain, as is the ability of hearing sensitive species to differentiate noise generated by the device from background in order to exhibit an avoidance response. This paper recommends that the consenting and development of arrays of around 10 megawatts ('MW') in size, or phased deployment of larger arrays, should be prioritised. These projects would then need to be monitored to advance the position of the industry as a whole.

The main priority identified by both industry and regulators is a better understanding of the population dynamics and habitats associated with diadromous fish (species which migrate between freshwater and seawater) in the context of large scale installations. Based on current knowledge of migration routes there is insufficient resolution to make the assessment of these site-specific risks meaningful. However, the necessary investment needed to strengthen the evidence-base for diadromous fish is a potential challenge, as addressing temporal and spatial trends in fish population dynamics is complex and considered too broad a scope for developers engaged in demonstration or small-scale arrays (i.e. up to 10MW commercial demonstrators). Closing the knowledge gap required to achieve this level of understanding would need a strategic approach and investment from a government-led programme of research. Reliance on investment from individual developer projects coming through consent would be considered disproportionate to the scale of these individual projects, although it is recognised that some research investment is being provisioned (e.g. Marine Scotland's Research Strategy, see Table 2).

A 'one-size-fits-all' approach to standardising impacts from wave and tidal devices may not be possible as technology designs are highly variable (i.e. floating to mid-water column devices will vary in the type and nature of moving parts compared to seabed mounted devices). From an environmental perspective, demersal fish that spend time near the seabed, for example, will not necessarily be affected by the moving parts of wave power generating devices on/near the water surface. By contrast, oscillating wave surge converter (e.g. Aquamarine's Oyster) do not generate Electromagnetic Fields ('EMF') as there is no subsea cabling and so no source or pathway exists to affect any electromagnetic sensitive species. It is, therefore, important to be clear about the degree to which the results of monitoring programmes can be extrapolated between technology types and locations. For example, the reaction of fish to noise is not necessarily a device specific response and data may be relevant to other technologies where the design of the monitoring studies permit such extrapolation.

The application of the source-pathway-receptor model within the EIA process identifies the potential impacts, but it is the quantification of the impacts that remains a key challenge. A degree of uncertainty will remain, regardless of ongoing research or monitoring of test devices, until monitoring results from larger installations become available. Although this uncertainty may be viewed negatively, ensuring that it is addressed in a constructive and co-ordinated fashion early in the development of the industry may avoid the issues that continue to hamper the development of offshore wind. It is also likely to prove to be a more cost effective solution in the medium to longer term by reducing regulatory burdens and reducing monitoring requirements in the future. This general position is common to both wave and tidal projects. However, it is acknowledged that there are fundamental differences between these two types of generation at the level of individual impacts.

> **"A 'one-size-fits-all' approach to standardising impacts from wave and tidal devices may not be possible as technology designs are highly variable"**

The monitoring of fish in the marine environment is expensive and any monitoring programmes need to be clearly targeted towards identifying and clarifying impacts. General monitoring of fish close to wave and tidal devices is unlikely to provide conclusive data on impacts, because at this scale it is unlikely to be able to address population level dynamics. Moreover, in some cases, monitoring programmes have been considered by the regulatory authorities and their advisors as inadequate with regard to fish movements as too few individuals, for example, have been sampled and/or equipment has failed. Therefore, testing of equipment/instruments should be undertaken in advance of deployment for field investigations to reduce risk and add certainty. In addition, survey and monitoring programmes should be designed to ensure the data they collect have sufficient statistical robustness to detect any changes they are designed to monitor.

Survey requirements to inform EIA should be proportional to the potential impacts posed by each individual project, although defining what is considered proportional needs agreement with regulators and advisers. In addition, the surveys undertaken should be focused on the particular technology type and be purposefully designed to reduce levels of uncertainty. Therefore, the benefits of engendering a strongly project-focused approach would be the delivery of robust EIA with lower levels of uncertainty regarding impact prediction. There would also be benefits in gathering specific data that would be useful in reducing uncertainty associated with the assessment of schemes that are similar in design. In this way, it could be envisaged that some level of standardisation could be reached that would make assessing future projects 'easier' from a regulatory perspective.

There is already a high degree of co-operation and shared interest in building knowledge between developers, the regulatory authorities and their advisors, and other stakeholders. In this regard, developers have led and funded field-based studies to provide sufficient environmental information to support consent applications. Yet very few Environmental Statements ('ES') identify any potential impacts as being greater than negligible[1], suggesting that when assessed, impacts on fish and shellfish ecology are deemed as being less of a priority than potential impacts on birds and marine mammals. However, the robustness of assessments needs continuous review by the industry to ensure improvements. Marine Scotland recently refused consent for GlaxoSmithKline's ('GSK') Montrose Tidal Array on the basis of potential impacts to diadromous fish species. Uncertainty over different life cycle stages, behaviour and interaction with the proposed turbines were the instrumental factors in the final decision. Moreover, field studies undertaken to help reduce uncertainty were considered to be not scientifically robust (see Marine Scotland consent decision, April 2013).

A distinction needs to be drawn between perceived, but negligible impacts and those which need further consideration. In this regard, studies on fish behaviour being undertaken by MeyGen Ltd ('MeyGen') will be very helpful in better understanding population level dynamics and responses. For example, MeyGen are currently undertaking field studies to develop encounter rate models for migratory salmonids using active sonar to track adult fish. As previously stated, with the exception of diadromous fish population dynamics, fish and shellfish are considered to be a low priority and offer the greatest potential to scope out issues compared to birds and marine mammals. Moreover, any potential impact will vary depending on device and array design, site location and scale and seasonality of the construction activities (see Shields et al., 2009). Generally, the environmental effects of decommissioning are considered to be similar to, or less, than those occurring as a result of construction activity (Wilhelmsson et al., 2010).

[1] The significance of an impact is graded as negligible, low, minor, moderate or major, where typically impacts greater than moderate require some form of mitigation measure.

A key message from those interviewed for this position paper was the need to consider the positive effects to fish and shellfish (e.g. lobster may benefit from increased habitat availability around devices), or to wider society (such as through increasing security of supply and reducing dependencies on fossil fuel generated electricity). However, societal or community related benefits are not the focus of this paper.

In summary, the key issues considered important for ensuring the future consenting success of the wave and tidal industry are:

- *Identifying the challenges with assessing complex population dynamics of diadromous fish species to the presence of large scale arrays;*
- *Validating collision risks assumptions;*
- *Migration and displacement effects of diadromous fish;*
- *Ensuring that uncertainty is highlighted and that consideration is given to how it should be dealt with in the impact assessment process;*
- *Standardising impacts from wave and tidal devices should be discouraged as technology designs are highly variable, although it is recognised that where technologies are similar in nature opportunities to inform impact assessments, strategic planning and cumulative impact assessment will be beneficial;*
- *Undertaking further research to reduce uncertainties and provide tools for developers to use within the assessment process i.e. EIA and Habitats Regulations Assessment ('HRA') (undertaken under The Conservation of Habitats and Species Regulations 2010 (as amended) in England and Wales and The Conservation (Natural Habitats, etc.) Regulations 1994 (as amended) in Scotland);*
- *Acknowledging that at the current scale of projects impacts on fish and shellfish ecology are less of a priority than those associated with birds and marine mammals;*
- *Acknowledging the positive effects to fish and shellfish associated with habitat creation/artificial reefs;*
- *Understanding how the potential assessment of cumulative impacts can be undertaken as the number and size of projects increases; and*
- *Improving the ability of equipment to undertake observations at the most appropriate resolution and with sufficient reliability, given the harsh environment in which wave and tidal devices are deployed.*

> "This section describes the current state of knowledge on the key impacts from wave and tidal technologies to fish and shellfish ecology."

3 Key Impacts

This section describes the current state of knowledge on the key impacts from wave and tidal technologies to fish and shellfish ecology. These were determined from a combination of reviewing available research and monitoring studies, review of project specific scoping and EIA documents and information gathered during telephone interviews.

3.1. Barrier Effects on Movement and Migration *Wave and Tidal Devices*

Barrier effects associated with the blade length of tidal turbines, width and number, the spacing of devices and the clearance distance between blade tip and sea bed, and blade tip and sea surface (see ABPmer, 2010). Fish may pass over or under the turbine blades to avoid collision (see the MeyGen ES for their Pentland Firth site). For wave technologies and some non-seabed based tidal devices, barrier effects may be primarily caused by their physical presence, although to date no barrier effects have yet been observed for fish. Indirectly, barrier effects on the movement and migration routes of diadromous fish such as *Atlantic salmon Salmo salar, Brown trout Salmo trutta* and *European eel Anguilla anguilla* are a concern in Scottish waters. Given the nature of the hydrodynamic environments in which wave and tidal devices are sited, similar issues are likely to occur in other UK locations when wider deployment occurs. This may be most prominent impact for migratory species or species that cover large areas during foraging.

Areas for spawning, resting and nursing may be also be at risk, but there is little known about corridors used by migrating fish. Currently, only broad-scale patterns of migration are known for Atlantic salmon, and even less is known for Brown trout, although their migration is likely to be within shallow coastal waters as they migrate back to natal rivers (see Malcolm et al., 2010). The greatest uncertainty regarding the effects from wave and tidal devices is associated with European eel (especially with respect to information on behaviour and swimming depths). This is primarily because of differences in the life stages (e.g. glass eels arriving or adults leaving) and local geography. No information currently exists relating to juvenile migration routes for any of these diadromous species.

3.2.Underwater Collision *Primarily Tidal Devices*

ABPmer (2010) undertook a desk-top study to review the potential collision risks to fish from wave and tidal devices. The key risk was avoidance behaviour and potential disruption to migration pathways due the following factors:

- *Source levels of underwater noise. Current evidence suggests that hearing sensitive fish (such as herring Clupea harengus) may be able to detect and avoid operational tidal devices at distances between 120 and 300 metres ('m') (depending on the depth of the water) even when background noise levels are comparatively high. For wave devices, the risks of collision are generally much lower than for tidal devices and hearing sensitive fish may be able to detect and avoid operational devices anywhere between 35 to 200m depending on water depth. For hearing insensitive fish species, noise levels from either wave or tidal devices are likely to be below that required to trigger an avoidance reaction;*
- *Design components such as foil/rotor length, speed and pressure fields, location and position of the device in the water column relative to fish routes (largely tidal devices), and joints or oscillating components (largely wave devices). For example, the speed of rotation of most tidal turbines towards the terminal end of the blades poses the greatest risk of damage in the event of a collision (see Turnpenny et al., 2000). That said, evidence from underwater cameras show that the hydrodynamics and design of some technologies such as OpenHydro*

prevent fish making contact with the device when in operation and so for pelagic fish collision risks may not exist; and

» *Visibility of the devices and close-range evasion by fish species. The visual acuity and maximum swimming speeds of different species and their near-field behavioural responses play a role in evasion success. In relatively shallow water with low turbidity, devices are likely to be visible in the day time at distances of ~ 5 – 10m.*

Potential risks of collision by basking shark *Cetorhinus maximus* at some tidal sites have been raised due to the difficulties in counting basking sharks, no abundance estimates currently exist for north-east Atlantic waters (Drewery, 2012). Basking sharks may be more analogous to marine mammals and perhaps better investigated on this basis.

3.3. Habitat Creation *Wave and Tidal Devices*

Wave and tidal devices have the potential to create habitats by providing a suitable surface and structural complexity for typically hard bottom species, which tend to colonise foundations with vertical surfaces rather than horizontal ones (see Langhamer et al., 2009). This creates 'artificial reefs' and/or where floating structures are deployed act as fish aggregating devices ('FADs'). Thereby, increasing food availability and providing shelter for fish and shellfish (see Ibrahim et al., 1996; Langhamer et al., 2009; Langhamer and Wilhelmsson, 2009). However, this could have the effect of increasing predation and increasing collision risk as a result of attracting fish towards the devices. For shellfish such as lobster and crab increased structural complexity/habitat could have beneficial effects.

Devices with the highest FAD potential are those with large elements (e.g. mooring points). Structures placed in areas with high flow rates would be predicted to attract and aggregate fewer fish. Impacts of habitat removal upon decommissioning must be taken into account if the devices do act as habitats (Gill, 2005). Tidal devices will only have FAD potential out of the current on the sheltered side of the device, which will also reduce collision risk for fish. Moreover, axis turbine devices will have a small footprint and so their FAD potential will be low. By contrast, wave devices that form large surface structures such as Pelamis have the highest potential to act as FADs.

There have been a small number of field-based studies undertaken to date, in most cases they have been by-products of more engineering focussed investigations e.g. use of underwater cameras to observe technology performance, and so only provide brief insights into species behaviour relative to the device under observation. Only recently have dedicated fish and shellfish research programmes come on line (see Key Research, Section 12 below). To date, there is insufficient knowledge to predict the potential impacts with any certainty.

3.4. Underwater Noise *Primarily Tidal Devices*

Underwater noise and vibrations are detected by fish using their inner ear and lateral line (Thomsen et al., 2006). The inner ear is sensitive to sound pressure whereas the lateral line detects vibration. Some fish species (e.g. sprat *Sprattus sprattus*) have connections from their inner ear to the swim bladder making them more sensitive to noise. However, the majority of fish species do not have these connections or have no swim bladders (e.g. flatfish and elasmobranchs) and so are less susceptible to injury (Goertner et al., 1994).

Shellfish are considered to be insensitive to underwater noise but sensitive to vibration as it allows them to detect potential predators, prey and even sense the activity of tides and currents (see Normandeau Associates, 2012). However, the lack of a swim bladder, such as those possessed in fish, means that shellfish are unlikely to be susceptible or at risk from underwater noise impacts associated with tidal devices.

The primary source of underwater noise and vibration is expected during construction where drilling activities are used (e.g. drilling to install structures on the seabed rather than piling). Subsea noise associated with these construction activities have the potential to affect the physiology, behaviour and so indirectly the spawning, feeding and migration of diadromous fish (see Popper and Hastings, 2009). However, noise from drilling activities is considered unlikely to cause mortality or injury to fish.

Robinson and Lepper (2013) suggest that operational noise from some tidal devices are rarely as high as those quoted for a 'modest' vessel, and the evidence suggests behavioural effects are unlikely. However, there is evidence of operational noise for some technologies above background and so may cause behavioural responses in fish. MeyGen devices, for example, are predicted to elicit mild behavioural responses in hearing specialist fish up to 68m from the array and a strong behavioural avoidance within 18m of the array. However, if fish aggregate during the operational phase, then this may be a good indication that noise is unlikely to be considered an issue (supported by anecdotal underwater camera video footage).

By contrast, underwater noise and vibration from operational wave technologies is not considered a critical issue (see Natural Environmental Research Council ('NERC')/University of Exeter, Table 2 below) and for some devices not greater than background levels (see Robinson and Lepper, 2013). For example, avoidance behaviour of fish to the Oyster devices is predicted not to occur unless fish are within 1m of the device. However, generally the behavioural response of fish to the noise will be species specific and vary depending on the location of the device relative to sensitive habitats, constrained passages or in open waters (see Kastelein et al., 2008).

There is uncertainty over the potential effects of noise (both construction and operation) of larger commercial scale arrays. For this reason, validation of noise impacts at smaller arrays and even single devices is considered important in predicting any potential noise effects of future large-scale deployments. Modelling specific hearing thresholds for sensitive fish species could use these data to understand the implications of scaling up. Where fish are considered at risk, model

"Underwater noise and vibrations are detected by fish using their inner ear and lateral line ...the inner ear is sensitive to sound pressure whereas the lateral line detects vibration"

predictions could be validated through monitoring.

3.5. EMF Emissions
Primarily Tidal Devices

There is sufficient information to allow inferences to be drawn about potential impacts to species (e.g. elasmobranchs and diadromous fish) that use the Earth's magnetic field for orientation, homing and navigation over long or short-range migrations (see Gill and Bartlett, 2010; Tricas and Gill, 2011; Gill et al., 2012). The general consensus from those interviewed for this paper is the risks of exposure to EMF emissions are considered to be greatly reduced because undersea power cables for wave and tidal projects are limited spatially and armoured to help insulate these emissions.

Cables suspended in the mid-water column (e.g. those associated with Pelamis Wave Power technology) potentially create larger EMF emissions than devices which have buried cables (given that no distance separation occurs between a cable and a receptor). However, the effect, if any, could range from a relatively trivial temporary change in swimming direction to a potentially more serious avoidance response or delay to migration (see Gill and Bartlett, 2010). By contrast, wave such as Oyster do not have any EMF issues given they have no subsea cabling associated with this technology. Feedback from the interview process suggested that regulators already acknowledge EMF impacts on Atlantic salmon and European eel, for example, are not a major issue.

3.6. Cumulative Impacts

As the number of projects entering the planning system increases, the potential for an increase in uncertainty within the assessment process and a greater focus on cumulative impacts has been recognised and described by RenewableUK (2013) and MacArthur Green (2013). The development of the offshore wind industry has been hampered by a lack of clarity and agreement regarding how to undertake a robust Cumulative Impact Assessment ('CIA'); with uncertainty resulting in the provision of qualitative and overly precautionary assessments. This means that the quantification of impacts at the individual project level is often highly conservative and based on worst-case scenarios making the addition of effects across projects unrealistic. This is often compounded when wide Rochdale Envelopes are used which, whilst useful for engineering design, inevitably inflate the level of risk above that likely to be realised.

At present there is a lack of connectivity between project sites/arrays suggests that effects on fish and shellfish ecology are generally not seen as a major issue. However, the deployment of more numerous or larger scale wave and tidal devices/arrays may result in cumulative effects with other marine developments. The following points were raised during interviews as needing further consideration:

- *The potential cumulative effects from habitat creation, although not all wave and tidal devices create the same effects (e.g. the Oyster device is different to other wave and tidal devices and interacts with the environment in a completely different way to other technologies). However, identifying any cumulative effects from habitat creation may not always be clear; and*
- *Potential cumulative effects associated with collision risks to migrating species are likely as single devices are added to and become arrays. Therefore, opportunities exist to better understand the scale and location of these developments in relation to potential cumulative effects*

4 Impact Mitigation

There is a limited range of possible mitigation measures for fish and shellfish given the current lack of information on impacts and clarity on whether such measures are required. On the whole, mitigation is device and location specific. For fish, the possible measures to mitigate potential collision risks and barrier effects include acoustic deterrents, visibility of rotating blades and increased spacing between devices, which is often adventitious to prevent 'shadowing' effects (e.g. achieved with Aquamarine Power).

Once effective mitigation methods are developed for wave and tidal devices, the need for novel mitigation is considered unlikely in the short to medium term as the technology has largely converged – for example, tidal devices have converged around horizontal axis designs. However, rotor diameters are expected to increase over time. The more likely changes are in wave devices undergoing development with new concepts emerging. The potential for novel mitigation methods may be needed for such technologies.

5 Key Research

It is recognised there is a lack of quantitative data on fish and shellfish and that these pose a potential risk to future consent of large scale arrays. Field-based observations and measurements of fish and shellfish (e.g. using underwater camera and acoustic tagging) may be considered helpful in clarifying the priorities for further research as they might also be used to inform/develop mitigation measures.

Opportunities for research through projects undertaking EIA are generally limited because potential impacts to fish and shellfish are not considered to be significant issues. Moreover, resolving the complexities of fish and shellfish population dynamics, for example, is unlikely within the timescales and budgets of current development programmes. This therefore suggests that a more strategic approach should be adopted by regulators and developers, such as the proposed Wave and Tidal Joint Industry Project being led by The Crown Estate, which is one example of a strategic initiative to identify key consenting-related research priorities and progress potential research projects. It is hoped that the recommendations presented here can form a starting point for the development of specific projects that will be funded through this initiative.

A number of research initiatives have been undertaken by academia (e.g. funded through NERC), Government (e.g. funded by Marine Scotland Science ('MSS'), Department for Environment Food and Rural Affairs ('Defra') and Welsh Assembly Government ('WAG')), and developers (e.g. OpenHydro and EMEC). Much of the focus has been on quantifying the potential effects of wave and tidal devices on fish behaviour including physiological responses to underwater noise and risk of collision with devices. During this time, regulators have been primarily focused on the development of policy and guidance, and steering the focus of academic research.

Research conducted in other countries where similar and/or the same technology used is being deployed can add to the evidence-base by providing further insight into the research priorities for the UK. For example, in Canada the potential risk of fish interactions with OpenHydro turbines using underwater acoustic telemetry receivers to track fish movements is being investigated (see Redden et al., 2011). Other countries that have deployed wave and tidal technologies that may provide further insights into fish and shellfish interactions include Denmark (WaveDragon), Norway (Hammerfest Strom), New Zealand (OpenHydro). Moreover, opportunities to adapt current modelling techniques for different applications could yield benefits to the wave and tidal industry such as the Band et al. (2005) model, which was developed to assess bird collision risks, but recently used to assess fish collision risks and accepted by Scottish Natural Heritage ('SNH').

Knowledge transfer is another opportunity, where work currently being undertaken by E.On Climate and Renewables Limited ('E.On') at the Robin Rigg Offshore Wind Farm ('Robin Rigg') project, for example, on the effects of the project on fish behaviour may also prove applicable for the wave and tidal industry. The Environmental Interactions of Marine Renewable Energy (EIMR) Technologies International Conference (Orkney, Scotland 2012) provided another knowledge transfer opportunity across different disciplines to share studies regarding ecological interactions relating to fish and shellfish with marine renewable energy devices (see table 2).

Current research programmes for fish and shellfish ecology will provide vital information, but to ensure momentum is not lost, further funding initiatives that focus on the quantification of environmental impacts will be critical during the coming three to five years. In return, these initiatives need to provide statistically robust monitoring with scientific and regulatory oversight to advance the industry position as a whole. Accordingly, research outputs will be key in providing comfort to regulators by reducing uncertainty.

As the industry moves toward installing large commercial scale arrays, they will be provided with the opportunity to reduce consenting risks by ensuring that uncertainty can be reduced sufficiently to avoid the prolonged precautionary approach adopted by regulators during the deployment of offshore wind (an approach most associated with HRA). The key to the success of this will be to ensure that the design of the monitoring strategies are focused on answering specific questions and do not simply repeat the surveys undertaken to inform the consenting process.

Research priorities identified over the next three to five years include:

- *Tracking behavioural changes of key species to the presence of wave and tidal devices and the collision risk posed by those devices (i.e. to better understand if species hug the coastline when migrating, to determine how they interact with tidal areas and to what depths in the water column they move). For example, using active sonar to track the wider movement patterns of adult fish to see if they avoid arrays;*
- *Closing the significant knowledge gaps that remain for migration routes for diadromous fish;*
- *Understanding the effects (direct and indirect) of fish and shellfish aggregations associated with devices and cables. For example, the EMEC is open to exploring*

The key research identified during the telephone interviews is outlined in Table 2.

TABLE 2. KEY FISH AND SHELLFISH RESEARCH

PROJECT TITLE/PUBLICATION	BRIEF DESCRIPTION	REPORTING
SEAGEN ENVIRONMENTAL MONITORING PROGRAMME	The objectives for the SeaGen mitigation programme was to determine that the presence of the turbine did not have a significant detrimental impact on the integrity of the breeding harbour seal population, the abundance, diversity, integrity and extent of the benthic biological, and communities associated with the submerged rocky reefs, and the population of breeding seabirds.	Final report issued January 2011.
AQUAMARINE POWER. UNDERWATER NOISE IMPACT STUDY IN SUPPORT OF THE OYSTER WAVE ENERGY PROJECT, ISLE OF LEWIS	Noise study on the effects of drilling and operational noise on hearing sensitivity of Atlantic salmon, European eel, Atlantic herring and sea trout, and other fish considered hearing generalist and specialists.	Final report issued by Kongsberg Maritime Ltd, 2012.
AQUAMARINE POWER	Operational noise monitoring projects planned.	Studies may start latter part of 2013 (weather permitting).
OPENHYDRO RESEARCH AND DEVELOPMENT ('R&D')	R&D platform deployed since 2006 and PhD research ongoing. In particular, pollock Pollachius pollachius show seasonal aggregations associated with the OpenHydro R&D device in Alderney waters. Real-time deployment of monitoring equipment.	A draft scientific paper to be submitted for peer review.
MEYGEN	Field studies to develop encounter rate models for migratory salmonids using active sonar to track adult fish (i.e. looking for detection rates in relation to devices). Wider movement patterns of fish also being explored to see if avoid the array. FLOWBEC project at EMEC has had some success with active sonar and fish. Results are not available yet.	On-going.
EMEC	Undertook a workshop that included issues surrounding EMF on elasmobranches, although no specific study conducted.	Completed in 2012
	Lobster study at the Billia Croo wave site. Studied lobster distribution around a 'scientific monitoring zone', with EMEC working closely with commercial fishermen and others to establish lobster number and distribution.	Billia Croo Fisheries Project – Final Report to Scottish Government 2012.
	EMEC is discussing funding options for developing a project to study scallops Chlamys opercularis, their habitat and distribution at its EMEC Fall of Warness tidal test site.	No date.
MARINE SCOTLAND SCIENCE (MSS) MIGRATORY FISH 1	Measurements of audiograms for key fish species – salmon, sea trout, eels, herring, cod Gadus morhua and sand eel Ammodytes marinus (Work Package A1 Migratory Fish)	Completed January 2013.
MSS MIGRATORY FISH 2	Modelling the consequences for salmonids of exposure to piling and operational noise (Work Package A2 Migratory Fish). Proposed project to model effects and potential impacts of construction methods and operational noise to salmon in Scottish waters.	Completed March 2013.
MSS PROJECT NO. AP5	Collation of data on salmonid populations in the Solway region to assess the potential influence of the Robin Rigg offshore wind farm development	Commissioning Specification and Final Report (November 2012).
MSS PROJECT NO. AP6	The potential influence of Robin Rigg wind farm on the abundance of adult and juvenile Atlantic salmon. The project also carried out power analysis on the available data to determine its ability to have detected any change, thereby informing the design of future monitoring programmes.	Final report issued by Poisson Consulting Ltd. for Marine Scotland Science (2013).
SNH: MARINE ENERGY SPATIAL PLANNING GROUP RESEARCH ACTIVITIES ON THE DIRECT IMPACT ON FISH	Literature review of the effects of EMF and noise on Atlantic salmon, sea trout and European Eel.	No date.

TABLE 2. KEY FISH AND SHELLFISH RESEARCH

PROJECT TITLE/PUBLICATION	BRIEF DESCRIPTION	REPORTING
WELSH ASSEMBLY GOVERNMENT (WAG): MARINE RENEWABLE ENERGY STRATEGIC FRAMEWORK FOR WALES	Collision Risk of Fish with Wave and Tidal Devices. A review of all wave and tidal devices and development of a risk-based model for assessing collision.	Final report issued by ABPmer, 2010.
THE CROWN ESTATE	Enabling Actions work to support development of the Pentland Firth and Orkney waters ('PFOW') wave and tidal projects. This work aimed to accelerate and de-risk the development process, looking at a range of key issues.	The Crown Estate (commissioned Epsilon Resource Management Limited). Final report July 2013.
DEPARTMENT FOR ENVIRONMENT FOOD AND RURAL AFFAIRS (DEFRA)	The impact of anthropogenic noise on fish and invertebrates at the individual, population and community level.	No date.
DEFRA AND MARINE MANAGEMENT ORGANISATION (MMO)	Spawning and nursery areas of fish of commercial and conservation importance.	No date.
DEFRA	Experiments to obtain data on the direct effects of human-generated noise on a number of commercially important fish and crustacean stocks, including trying to define harm/disturbance and the sources and sound levels.	Final Report ME5205: September 2010 - August 2013.
SNH AND THE UNIVERSITY OF EXETER	Research currently underway on tagging basking sharks Cetorhinus maximus. The project aims to improve understanding of how basking sharks use sea areas within the Inner Hebrides and further afield in Scottish waters.	On going. [Also see wave and tidal position paper 3: marine mammals]
NATURAL ENVIRONMENT RESEARCH COUNCIL (NERC) AND UNIVERSITY OF EXETER	Knowledge Transfer Partnership ('KTP') between HR Wallingford and the University of Exeter to investigate the behavioural and physiological responses of marine fish to underwater noise using the knowledge to predict the response of fish to noise for EIA.	Ongoing (Aug 2013 - Aug 2016)
NERC AND DEFRA FUNDED PROJECT: FLOWBEC (FLOW AND BENTHIC ECOLOGY 4D)	FLOWBEC is a three-year £1.2 million project to improve the understanding of how the physical behaviour of the water such as currents, waves and turbulence at tide and wave energy sites influences the behaviour of marine wildlife, and how tide and wave energy devices might alter the behaviour of such wildlife. It is investigating the effects of such devices by monitoring environment and wildlife behaviour at UK test sites, the first of which is the tidal energy test area of the EMEC in Orkney.	FLOWBEC is a consortium of Universities of Aberdeen, Bath, Edinburgh, Exeter, Plymouth, Queens University Belfast, Plymouth Marine Laboratory, Marine Scotland Science, the British Oceanographic Data Centre, EMEC, and OpenHydro Ltd.

field-based studies at its sites to provide information on such aggregation around typical wave and tidal mooring structures;

- *Modelling noise and fish hearing thresholds (in relation to construction noise issues), which is in fact an industry wide issue applicable to other offshore renewable technologies, and so the scope and cost must be proportionate to the actual wave and tidal development activity;*
- *Adapting and improving current modelling techniques such as the Band et al. (2005) model for use in assessing collision risks of fish;*
- *Transferring knowledge across the offshore wind energy sector/overseas about potentially generic impacts in common with wave and tidal projects, and for these to be agreed with stakeholders; and*
- *Breeding and nursery grounds for key fish species need to be identified which are an ecologically important species for predators such as sea birds and seals.*

6 Recommendations

There is currently a high degree of uncertainty regarding how best to assess and monitor the interaction of fish and shellfish species with wave and tidal devices. There are considerable gaps in knowledge regarding how fish behaviour and migration routes may be affected by these devices, especially given that the development of commercial scale arrays have yet to provide sufficient experience. For Small and Medium Enterprises ('SME'), the experience and investment needed to consent their projects within UK waters is challenging. Test facilities and academic-led research (e.g. EMEC/NERC/universities) provide a viable opportunity to de-risk the consenting process.

As many of the key fish-related issues are manifested on migratory species, there is concern that the onus is on the developer to resolve the complexities of these issues. This may be impractical and disproportionate to the scale of deployment currently underway.

This paper makes the following recommendations:

- *To fast-track the consenting and development of arrays of around 10MW in size or phased deployment of larger arrays. These projects would then need to be monitored (using statistically robust methodologies) to advance the position of the industry as a whole;*
- *To consider non-diadromous fish and shellfish ecology as a low priority consenting issue by regulators and therefore minimal baseline survey required for small sites by regulators (generally desk based). Industry would welcome this approach but will continue to monitor interactions when possible to help inform larger scale deployments;*
- *To encourage the treatment of wave and tidal devices as separate technologies with differences in fish and shellfish impacts;*
- *To improve the continuity of advice being provided to the regulated industry and ensure the continued collation of available monitoring reports remains co-ordinated centrally;*
- *To support research that provides greater certainty over the migration routes of diadromous species and provides tools to inform decisions on the effectiveness of impact assessments;*
- *To ensure scientific investigations on the back of licensing requirements remain proportionate to the risk posed by the devices in question;*
- *To ensure a risked based approach to assessment is maintained across all technologies, regardless of technology type or scale;*
- *To encourage testing of equipment/instruments being deployed in harsh marine environments by encouraging collaborative projects with EMEC and other facilities that may come on line in the future (e.g. WaveHub, the Perpetuus Tidal Energy Centre ('PTEC')); and*
- *To link more spatial planning and co-operative initiatives with fishing industry/local stakeholder groups.*

"There is currently a high degree of uncertainty regarding how best to assess and monitor the interaction of fish and shellfish species with wave and tidal devices"

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