Marine Scotland Science

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The Regulatory Context

The Scottish Government has ambitious targets for renewable energy production, to which offshore renewables could make a substantial contribution. However, the new marine energy industries must develop on a sustainable basis, ensuring that environmental impacts are assessed, and if necessary, minimised through appropriate mitigation. The likelihood of any impacts on Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*) or European eels (*Anguilla Anguilla*) will depend on interactions between (1) migratory routes and behaviour (2) the distribution of offshore developments (3) the technologies deployed (3) the dynamics of the relevant fish populations and (4) the occurrence of a negative interaction, such as strike or interactions with acoustic disturbance or electro-magnetic fields (EMF) (Figure 1). However, in many cases we have less than perfect knowledge of fish behaviour, migration, likely interactions or population status, leading to uncertainties in the information underlying licensing decisions. This paper identifies knowledge gaps, existing initiatives and future research needs where these are not currently being addressed.

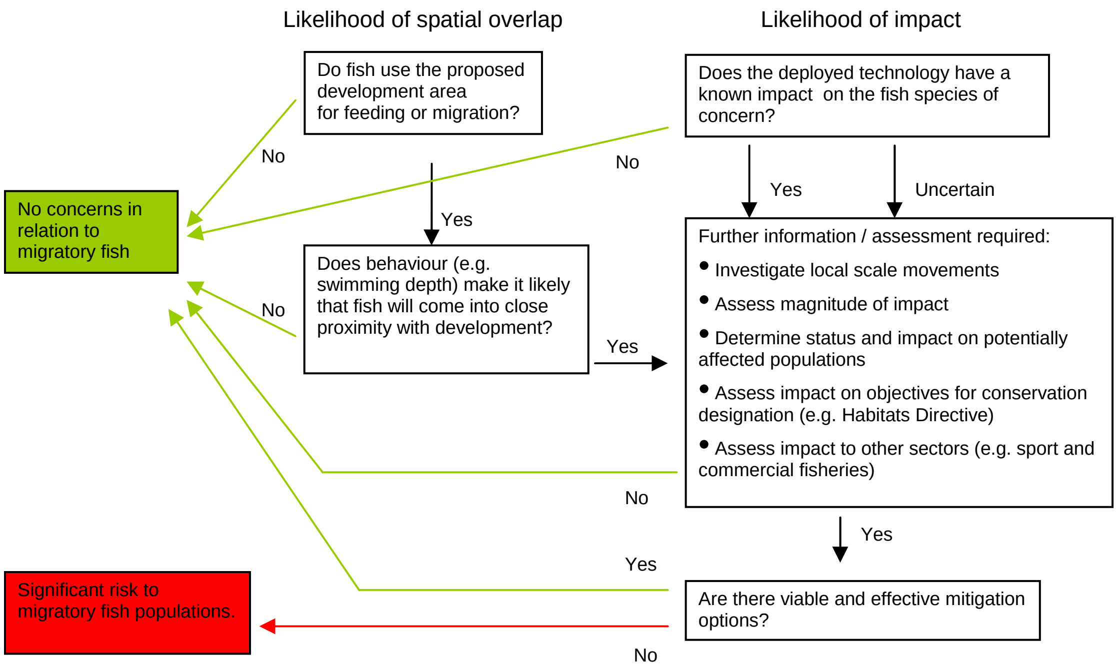

Figure 1 Schematic diagram showing the information required by advisors and decision makers to assess the likely impacts of offshore renewable developments on diadromous (migratory) fish.

Migratory Routes and Behaviour

Atlantic salmon lay their eggs (spawn) in fresh water. The freshwater life stage typically last between 1 and 3 years before individuals migrate to sea as smolts in spring having grown larger in length than approximately 9cm. Salmon return to fresh water throughout the year and spawn in autumn and winter, typically homing to their natal river. Sea trout are the marine migratory form of brown trout. In Scotland they follow a broader range of life history and migration strategies than salmon and may remain in coastal locations for extensive periods during their time at sea. Trout also spawn in autumn and winter in fresh water, again typically in their natal river. Eels probably spawn near, or in, the Sargasso Sea and then disperse as glass eels across Europe, with a fraction of the population entering Scottish fresh waters. Adults (silver eels) later migrate back to the marine spawning areas after many years (often decades), generally leaving Scottish rivers in summer and autumn.

A review of available information on migratory routes and behaviour of Atlantic salmon, sea trout and eels was carried out by Marine Scotland (MS) in 2009-10 and published in 2010 (Malcolm et al., 2010). The following bullets re-iterate the findings of this review. Additional information identifies progress made since then, research that remains unfunded to the knowledge of Marine Scotland Science (MSS), and options for taking such work forward. Detailed planning and costing of each such option is beyond the scope of this report and should be an initial component of each project that subsequently addresses the issues. However, provisional scoping is provided for research that commenced within Marine Scotland Science as priorities in 2011-2012.

Atlantic Salmon

• *There is no information on the behaviour (including swimming depths, speeds and nearshore/offshore movement) of post-smolts in the Scottish context. This is a particular issue for east coast rivers and coastal areas which differ markedly in their geography from Norwegian systems.*

Improved information on swimming depths and onshore / offshore habitat use would be valuable in assessing the likely interactions between post smolts and electricity generating structures. A specific example of where detailed spatial information is required is in the development of models to determine likelihood of fish being struck or seriously disoriented by tidal turbines.

Since the Malcolm et al. review was published in 2010, there has been no additional research on this topic for east coast salmon populations. However, recent work conducted in Loch Linnhe on the west coast of Scotland (Middlemas S J unpublished data) provides additional information on salmon smolt migration speeds between fixed points and on inshore habitat use. Such information is not directly transferable to the East coast given marked differences in geography.

It is logistically challenging to obtain detailed information on salmon smolt movements and swimming depths due to the small size of fish which significantly constrains the sizes and types of transmitter tags that may be used. However, data could potentially be obtained through the deployment of depth sensitive acoustic tags on appropriate sized (large) smolts leaving east coast Scottish rivers. Triangulating acoustic receivers mounted on fixed moorings might be used to determine precise routes. Trawled receivers and single moored receivers could be used to determine approximate fish locations, with a precision in the order 100-1000m corresponding to the detection ranges of the tags. Salmon smolts could be captured at existing fixed trap sites, for example on the rivers North Esk and Conon, or using rotary screw traps, which may be moored in most rivers. In each case, the specific logistical constraints and costs of deploying traps would have to be investigated as would the size of emigrating smolts and hence the size, range and lifespan of tags that could be deployed. Triangulated receivers could provide near-continuous information on fish movements and swimming depths over a relatively constrained geographical extent and may be highly appropriate in examining priority localised sites identified for installation of generating structures. Trawled receivers could provide instantaneous data on fish locations over a potentially larger area, but with associated loss of geographical detail. For spatial coverage at larger spatial scales alternative trawling approaches are likely to be required (see below), unless a large scale regional acoustic receiver network could be set up around the Scottish coast (e.g. http://vemco.com/join-the-collaboration/).

• *There are currently no data on the migratory routes or geographical distribution of post-smolts in the North Sea.*

If most of the migration takes place through spatially constrained routes, it may be possible to discount interaction with some offshore renewable developments and thereby reduce the scope of Environmental Statements. Recent work under SALSEA (Mork et al., 2012; SALSEA-MERGE, 2012) has improved understanding of the distribution and origin of post-smolts in the Northeast Atlantic and Norwegian Sea. Post-smolts have been successfully captured using near surface trawls after which the region/

river of origin of the fish can, in some cases, be determined using genetic assignment techniques. However, there has been no similar work undertaken in the North Sea to improve understanding of smolt migration routes from the major Scottish east coast salmon rivers, nor in most of the more geographically complex west coast. Similarly, there has been no near-shore trawling work to investigate this potentially important geographical region for migrating smolts and also deployment of marine renewables structures.

A combination of near-surface trawling and genetic assignment could improve understanding of post-smolt distribution from specific rivers and regions of origin at points in their migration in the North Sea. An alternative approach would be to deploy a network of acoustic listening devices in Scottish waters (see above), potentially utilising deployed Marine Renewable Energy (MRE) structures along with existing moorings and infrastructure that has been developed for cetacean monitoring (Passive Acoustic Monitoring - PAM network).

Additional information on large scale movements of smolts could be obtained by linking hydrographic and particle tracking models with field observations from tagging and fish capture programmes (for calibration / validation). This process would upscale and generalise observations from more spatially constrained programmes of work (Mork et al., 2012) to the larger spatial scales required for Marine Spatial Planning and to provide the strategic background in support of marine energy development licensing considerations. An example of this type of work is currently being funded by Crown Estates at a regional level (Pentland Firth and Moray Firth), see below.

Although less well developed and proven than the options discussed above, it is possible that scale or otolith micro-chemistry or isotope analysis (Dempson et al., 2009; Mackenzie et al., 2012) could also provide insights into fish migration and feeding areas. This would involve the collation and analysis of scale samples from different rivers and stocks and the matching of chemical signatures to similar marine signatures. However, it seems unlikely that these techniques could provide sufficient spatial resolution to be of great utility in the context of sectoral planning and licensing requirements.

Finally, there is the option of highly localised sampling, using video and/or acoustic camera systems, in the areas of proposed wind, wave and tidal energy development. In this case, there would be no information on the origins of detected post-smolts, but the method may rule out the possibility of significant damage if the numbers of fish are low. Such work would require careful pilot studies to determine the limitations and potential of detection systems.

• *It is uncertain whether adults or post-smolts migrate through the area around Orkney and Shetland or if the Pentland Firth is the preferred or only route used.*

There is a significant challenge to determine the precise migration routes used by juvenile and adult salmon in the Pentland, Orkney and Shetland regions of Scotland. Nevertheless, this is an important knowledge gap given that so much development (particularly wave and tidal) is planned for this area, and there is a need to fulfil the requirements of Habitats Regulations Assessment (HRA) and Appropriate Assessment (AA) for Natura 2000 sites as part of the licensing process.

Work recently carried out by The University of Highlands and Islands, Environmental Research Institute (ERI), Thurso and funded by The Crown Estates will attempt to combine hydrographic and particle tracking models (with a behavioural component) with historical and contemporary tagging data (see section below on swimming depths) to identify likely migratory routes in the Pentland and Moray area for juvenile and adult salmon. It is possible that this work could be extended to consider Scotland as a whole. Such work may be somewhat speculative because of limitations in understanding of the behaviour of migrating salmon, especially in areas where swimming speeds greatly exceed tidal current speeds. Nevertheless, there may be opportunities to test model predictions using tagged smolts and the acoustic receiver methods mentioned earlier in the text.

In the case of larger adult fish, it is possible to use a range of tags and it may be possible to satellite tag multi-sea winter (MSW) fish on the Scottish west coast to determine their migratory return routes around Scotland on return to the east coast. The chances of success of this approach would be greatly improved if the final destination of fish were determined from genetic assignment to river of origin so that a sample of appropriate fish was selected and the chance of recovering useful data was maximised. Work is currently underway at MSS to determine whether this may be possible. However, this approach would not necessarily identify all potential routes if salmon were also to return directly to the east of Scotland without migrating around the coast. Furthermore, it would require the re-instatement of a net fishery at historically active locations on the west coast to capture fish for tagging and this would likely to be associated with a high risk of failure.

An indirect approach to determining the migratory routes used by adult fish to return to different rivers would involve genetic sampling of remaining coastal netting stations and determining whether there was a gross mis-match between the expected number of adults returning to rivers and the proportions caught in the coastal netting stations. It would be expected that local rivers would dominate catches, but more distant rivers should be sampled approximately equally if they were all to use the same migratory routes. This approach depends on selection of a set of appropriate genetic markers and the levels of assignment (regional or river level) that can be made.

In order to look at adult fish migration specifically through the Pentland area, MS have recently instigated a programme of work to capture adult fish on the north coast and attach satellite pop-off tags. This work programme will provide information on fish capture location, the location of the fish at the time the tag was released and information on swimming depths throughout the time between tagging and tag release (see below). By staggering the release times it will be possible to determine patterns and consistency of migration routes, if indeed such patterns exist. It is intended that if development of genetic tools progresses as hoped, then fish will also be assigned to river of origin using genetic methods, in which case it would be possible to determine whether salmon heading for different rivers used grossly different migratory routes.

• *There is currently no information on the swimming depths utilised by adult fish in Scottish coastal waters.*

Swimming depth is a critical parameter in strike risk and particle tracking models (for estimating migratory routes). There are greater opportunities for establishing swimming depths for adult fish than there are for juveniles given their greater size, although even adult salmon are at the lower size limit for the deployment of large satellite tags. Recent work funded by MS (see above) will aim to deploy satellite tags on large adult fish in the Pentland Firth region. These tags will record depth data between the time of tagging and time of release and convey this back through a satellite network thereby providing detailed and regular depth data with a known probability of data recovery.

An alternative approach would involve the deployment of smaller and cheaper data storage tags (DST) (Sturlaugsson, J. 1995) on fish caught on the north coast. But these would be associated with a lower probability of data recovery given the need to recapture the fish to download the data. Fish would again need to be captured in commercial fisheries on the north coast and genetically typed to determine their target river. A sub-set of fish could then be tagged which were bound for home rivers where a high probability of recapture was likely e.g. N. Esk, Conon, Dee, Tay. Radio tags would also be attached to these fish to allow for re-location within river systems. When the fish were re-located they would have to be captured using sweep netting or electrofishing approaches. Previous attempts to use DST's have experienced very varying success and have often suffered from very low rates of recovery (Holm et al., 2005). However, this has generally occurred where researchers have relied on passive recovery through commercial and recreational fisheries rather than actively seeking out fish using radio tag signals. An MSS report detailing success rates of detecting and recapturing fish radio-tagged at sea is anticipated by the end of February 2013.

• *There is substantial uncertainty as to the mechanisms and routes by which adult salmon home to and around the Scottish coast to the proximity of their natal rivers.*

Migration by salmon is believed to comprise several distinct phases, which are likely to involve different sensory systems and behavioural strategies. A large gap in our understanding relates to how the fish locate home rivers having reached the Scottish shores. This phase of migration is likely to use olfaction and involve elaborate behaviours for searching through the water column and sampling different river systems. Establishing the detailed nature of this coastal phase is particularly important for understanding how the fish are likely to interact with coastal wind, wave and tidal energy (MRE) installation and operation. The application of acoustic telemetry using networks of receivers to map fine-scale movements of salmon in response to patterns of mixing of river and sea water is a good starting point for such investigations, with subsequent extension to more open coastal areas where renewables developments are more likely.

• *There is limited information on the timing of migration for both juvenile and adult fish for specific locations on the Scottish coast.*

The timing of fish migration could be an important consideration in the installation phase of MRE. If the timing of migration of both adult and juvenile fish is well understood and is temporally constrained then this presents opportunities for mitigation in terms of the timing of construction, which is often considered to be the period of highest risk associated with additional disturbance from installation and potentially high levels of impulsive noise through activities such as pile driving.

A number of potential options exist for (1) establishing the time that smolts leave rivers and (2) assessing the timing of migration of fish from particular rivers in Scottish coastal waters. In the case of the former it may be possible to establish the timing of migration through the deployment of rotary screw traps near the mouth of major rivers or to use acoustic cameras, however, neither of these approaches have been commonly used in a Scottish context, so work would be required to assess feasibility and limitations. If it were possible to capture fish in smolt wheels, then there would be an opportunity to apply acoustic tags to these fish and monitor progress in the near-coastal zone using acoustic receivers deployed as part of a regional network.

An alternative approach would involve the use of temporally stratified trawl surveys, with captured juveniles being assigned back to region or river of origin using genetic approaches. However, it should be noted that geographical detail of the information obtained would be highly dependent on the reliability of genetic assignments, which in turn is strongly affected by the breadth of the baseline rivers dataset. This is something that is currently the focus of research at MSS.

Diadromous Brown Trout (Sea Trout)

• *There is currently no detailed information on post-smolt habitat use on the east coast of Scotland where the geography is significantly different from previous studies.*

The opportunities for obtaining new data would involve similar approaches to those identified for assessing salmon smolt movements and behaviour above, specifically, trawling, genetic analysis, acoustic tagging and tracking with fixed or mobile receivers. However, because sea trout have generally been less well studied than salmon, any attempt to use combinations of fish capture and genetic assignment would first require substantial genetic method development and validation. Because sea trout are thought to exhibit greater variability in life history strategies than salmon and make greater use of estuarine and nearshore habitats, they may be more liable to impacts from MRE developments than salmon.

• *In the case of both the east and west coast adult sea trout there is very limited information on migration and feeding areas.*

Given that adult sea trout are often considered to migrate locally and do not appear to show clear and consistent long-distance migrations, there are not such clear opportunities to capture adult fish on homeward migrations. Furthermore, because of their limited size, there is not the same opportunity to deploy larger tags such as satellite tags. However, smolts can be captured on leaving rivers (fixed traps or smolt wheels) and older fish can also be captured in the near-shore environment using sweep nets. These capture opportunities mean that it is at least theoretically possible to track sea trout in near and offshore areas using acoustic tags and fixed or mobile (trawling) receivers. Furthermore near-surface trawls may be able to capture post-smolts, with potential opportunities for assignment back to river or region following appropriate method development.

Two sea trout initiatives are underway in Scotland that include sea trout migration within their remit, these are (1) the Living North Sea project and (2) The Celtic sea trout project. The Living North Sea project in Scotland is focussed around the Tweed and on in-river migration. Promotional material suggests the possibility of marine tracking but no details are currently available. The Celtic sea trout project is orientated around understanding sea trout in the Irish sea. In Scotland the project focuses on the southwest Solway area.

Promotional material suggests that attempts to understand migratory routes are focussed around the use of scale micro-chemistry.

• *There is currently no information on the swimming depths used by sea trout post-smolts or adults.*

The opportunities to obtain data on the swimming depths used by juvenile and adult sea trout are similar to those available for salmon, specifically through the use of depth sensing acoustic tags and fixed receivers. Because of the relatively smaller size of adult sea trout compared to salmon there are currently no options for the deployment of satellite tags which are considered only to be suitable for larger fish (ca. 0.75m length) given currently available tag sizes. As far as MSS are aware there are currently no published data on depth use by juvenile or adult sea trout, although the information would be valuable in assessing strike risk and interaction with various designs of MRE.

• *There is limited information on the timing of migration for both juvenile and adult fish for specific locations on the Scottish coast*

In common with salmon there are opportunities to investigate the timing of sea trout migrations, specifically through the use of smolt traps, acoustic tags, mobile and fixed receivers. However, sea trout are known to exhibit a high degree of variability and plasticity in their behaviour (Middlemas et al., 2009; Shearer, 1990), as such it may be hard to determine common patterns of behaviour. At present there are no plans to obtain information on the timing of sea trout migration across Scotland.

European Eel

- *Glass eel migratory routes into Scottish waters and past Scotland into the North Sea can at present only be inferred. No direct evidence is available.*

Previous work on the marine migration of glass eels has relied on unstructured observations and hydrographic and particle tracking models. At present, no direct observations are available. Such information could in theory be obtained through trawls designed to catch glass eels (Hagstrom & Wickstrom, 1990; Schmidt, 1923) where sampling could be repeated at different locations throughout the year and catch per unit effort (CPUE) used to infer migratory routes and timing.

- *Migration routes of adult silver eels leaving northern continental Europe and the British Isles are unknown. These may pass through northern and/or western Scottish waters.*

At present, the best opportunity to establish the migratory routes of silver eels is through the use of pop-off satellite tags (PSATS) (Aarestrup et al., 2009). However, it should be noted that there are growing concerns over the effects of PSATS on the behaviour of eels due to the additional energetic costs and drag associated with deployment (Burgerhout et al. 2011; Methling et al. 2011). Acoustic tags could also be used depending on the availability of receivers around the Scottish coast and in Scottish waters more generally.

- *The timing of peak migration for both glass eel and silver eel stages is poorly known in Scottish waters*

The timing of glass migration could most readily be established through a combination of trawls at sea and estuarine areas (Schmidt, 1923; Aarestrup et al., 2009), while that of silver eels could be established using a combination fixed traps and fyke nets in lower catchments or alternatively radio tracking of eels first captured in upper catchments to determine their time of departure, or acoustic tagging to determine their arrival in the coastal zone.

- *The migratory behaviour of silver eels is not well-established. In particular swimming depths and the use of tidal transport is poorly understood, and entirely unknown for Scottish waters.*

Recent research has begun to provide insights on the swimming behaviour and depths used by European silver eels during migration (Aarestrup, 2009). This data suggests that eels use a wide range of depths depending on availability, and that depth use appears to vary with time of day. Further details of habitat use in Scottish waters including swimming depths and use of currents is most likely to be obtained using PSATS. However, it should be noted that only large females would be big enough to tag and therefore uncertainty would remain over the transferability of findings to smaller male eels. Furthermore it would again be important to note concerns over the affects of tagging on behaviour and energetics (Methling et al., 2011).

Interaction Between MRE Developments and Diadromous Fish

EMF

A review of the potential impacts of EMF on diadromous fish was recently commissioned by SNH (Gill & Bartlett, 2010) and subsequently published in the peer reviewed literature (Gill et al., 2012). In these reviews, Gill *et al.* conclude that diadromous species can use the Earth's magnetic field for direction and orientation during migration and that EMF from subsea cables may interact with migrating fish especially in the case of European eel and especially in shallow waters. However, it is also noted that this will not necessarily lead to biologically significant effects.

Marine Scotland commissioned work to investigate the effects of EMF from AC cables on salmon, sea trout and eels. An EMF generating system based on Helmholtz coils was developed as a tool for investigating the behavioural responses of migratory fishes to magnetic fields associated with alternating currents. It consisted of four pairs of Helmholtz coils used to create four channels through which fish can swim in a toroidal tank. The strength of the generated EMF emitted by the coils was varied by altering the input between 1/16 V AC and 8 V AC, generating an EMF strength which can range from <1 µT to nearly 100 µT. Fish behaviour was recorded using underwater and overhead video cameras. The system was tested in 2011 with a small number of European eels *Anguilla Anguilla.* In 2012 further trials have been conducted on Atlantic salmon *Salmo salar* smolts, with further eel research to follow in the coming year. In future, it should be possible also to test the behaviour of sea trout, adult salmon and other diadromous species to EMF using the similar approaches.

The current work at MSS specifically tests the response to AC fields, which might startle fish. However, it should be noted that AC fields would not be expected to have the same effects as DC fields, which might disorientate fish. Experiments with EMFs from DC cables would probably require *in situ* field observations using tagged migrating fish.

Noise

The same recent reviews (Gill & Bartlett, 2010; Gill et al., 2012) that considered the potential interaction effects of EMF on salmon, sea trout and eels, also considered issues of underwater noise. These reviews indentified that (1) there was a paucity of data on noise generated by MRE developments and modelling of its propagation is more difficult in coastal waters than in the open sea (2) that construction noise (particularly if pile driving is used) is likely to be the most substantial affect and (3) that there is uncertainty over the response of diadromous species to underwater noise.

Given the development of various MRE projects, there is the opportunity to monitor background noise and the noise associated with various construction and operational activities using fixed hydrophones deployed at various distances from the activity. This work could most usefully be undertaken by industry during device testing and early stages of development. However, there remains a need to improve understanding of the hearing characteristics of the diadromous fish of interest. The hearing sensitivity (audiogram) of fish is typically determined by laboratory experiments, where sounds at different levels and frequencies are presented to test subjects. Recognition of noise is usually determined through behavioural responses (movement or changes in heart rate) or through direct assessment of electrical impulses from auditory nerves. At present, audiograms are not available for European eel, although some data are available for Atlantic salmon (Hawkins & Johnstone, 1978) and sea trout (Nedwell et al., 2006). In addition to considering thresholds for behavioural responses, there is also potential for noise from pile-driving to damage fish directly, particularly their swim bladders. Recent research suggests that species with physostomous (open) swimbladders (e.g Atlantic cod) are more at risk than species with physoclist (closed) swimbladders (including salmonids and eels), but that the latter may nevertheless be subject to damage (Halvorsen et al., 2012). Therefore, further understanding of these thresholds would also be desirable.

In response to the Gill reviews, MS has commissioned a series of projects to fill the identified knowledge gaps. Specifically MS has commissioned studies to (1) measure audiograms for salmon, sea trout and eels (amongst other species) to improve understanding of the hearing characteristics of these species (2) model the consequences of salmon exposure to piling and operational noise using information on the hearing range of diadromous fish and noise associated with MRE construction and operation. Future work may include assessment of behavioural responses to pile driving (and other acoustic signals) through observations of the behaviour of caged fish. Taken together, it is considered that these projects will provide sufficient information to inform Enironmental Statements (ES) of the potential impacts of MRE noise on diadromous fish.

Strike

One of the greatest concerns associated with the development of MRE is the risk of mortality, either directly or indirectly (e.g. disorientation and predation), particularly in association with the deployment of tidal turbines. To date, developers have attempted to assess the risk of strike using strike risk models, variably adapted from early hydropower risk models or more recently strike models for birds in relation wind farms. In order to parameterise the models, there is the need for biological information in relation to the number of fish passing the installation, the size of fish, range of swimming speeds, range of swimming depths (see above) and avoidance rates (Amaral et al., 2011). There is also a requirement for information on the number and size of blades and the velocity at which they turn. The physical data on the structures is readily obtained by the manufacturer, but the biological data is less easily obtained.

The options for obtaining data on swimming depths and migration routes to give approximate fish numbers of fish near structures was discussed above. Information on swimming and burst speeds can be approximated from existing studies reported in the literature. However, avoidance rates are far more difficult to estimate and are likely to be affected by water clarity and local hydraulic characteristics associated with the structure and its deployment location. Avoidance rates can therefore either be assessed using down-scaled models in large flume systems or through direct *in-situ* observation of fish passage either side of tidal devices, for example using Didson acoustic cameras. Neither of these approaches has been tested in the UK at present, although flume based experiments using scaled down model versions of potential devices have been carried out in the USA (Amaral et al., 2011). The Didson approach is potentially more achievable given the lack of large scale flume facilities in the UK where scaled model testing could take place.

Assessing Unexpected Consequences?

Research into the processes by which salmon may interact with MRE installations can be expected to clarify the significance of the impact pathways predicted from existing knowledge in the relatively few locations at which research can feasibly be undertaken. Extrapolating such knowledge to predict overall impacts on fish populations will introduce additional uncertainties. In large part, this is because biological systems are complex, and it may be difficult to identify and quantify the cumulative impacts of installations at a range of locations. Furthermore, secondary or indirect impact pathways, for example, if installations act as fish aggregating devices, may also become hotspots for salmon predators at certain locations, with subsequent deleterious effects on populations that are currently difficult to assess.

It would be highly advantageous to devise monitoring systems to establish whether there are clear effects of MRE development on salmonids at population levels and if so, then investigate the detailed causes to evaluate options for post-deployment mitigation measures. At present, there are very few fish-counting systems in Scotland for assessing emigrating smolt or returning adult numbers, yet direct counts are the most useful data for assessing population strength. A network of counters in SAC rivers, important salmon rivers and major tributaries is required to derive a large scale salmonid stock monitoring system. Such a system would mesh with existing rod-catch data sets and vastly increase the value of those data. The requirement for population status assessment is discussed further below.

Population Status

To determine whether impacts can be tolerated by a particular salmon population or groups of salmon populations it is necessary to understand (1) which populations will be affected (2) the likely level of impact (see above) (3) the status of salmon populations in relation to a target threshold (MSY, maximum smolt output or other biologically relevant protection thresholds) derived from appropriate stock-recruitment relationships (4) likely future status given a range of naturally observed marine mortality conditions beyond management intervention. In this regard, SAC rivers are likely to have particularly demanding regulatory needs as they will be subject to HRA and AA during the application process. However, fisheries management and conservation interests will apply to a larger range of rivers that have the potential to be affected by development.

To estimate 3 and 4 above, would ideally require information on the timing of adult returns, returning adult numbers, the age distribution of returning fish, the size of returning fish, local fecundity relationships (number of eggs for a given fish size / mass) and an estimate of smolt output and ages and understanding of the spatial distribution and relatedness of populations in catchments. This would allow development of stock-recruitment relationships for independent stocks in each of the affected rivers and to identify a threshold beyond which mortality of adults would be deemed acceptable. The uncertainty in the stock-recruitment relationship should also be considered, with 95% plausibility or confidence limits to allow for a margin of safety in the estimated threshold. Such relationships can be estimated for heavily monitored rivers such as the North Esk, but unfortunately not for other Scottish rivers. In the absence of detailed monitoring data for all (or even a reasonable sub-set) of Scottish rivers, it has been necessary to use rod catch data as a proxy for fish abundance (Youngson et al., 2002; Thorley et al., 2005), where downward trends are generally viewed as unfavourable. However, such trend analysis is an extremely blunt tool in the absence of any clear understanding of how numbers of returning fish relate via rod catch to conservation limits for management.

Moving forward, decision making could be improved by obtaining greater information on fish populations in other Scottish rivers (specifically numbers and timing of adult returns and smolt output) which would allow the development of stock-recruitment relationships and biological thresholds for conservation. With additional geographically spread stock-recruitment relationships developed it should then be possible to develop scientifically defensible methods of transferring relationships to catchments without such information (MacLean, 2007). The data required for this work could be obtained using hydro-acoustic counting equipment and smolt wheels operated towards the tidal limit of mainstem rivers and on key tributaries. However, substantial technical difficulties remain and significant scientific work would be required to develop the methods and protocols to underpin such a monitoring network. Given the geographical scale of the problem it would also be necessarily for co-operation between local managers in the Salmon Fisheries Boards or their representatives in the Scottish Fisheries Coordination Centre (SFCC)or Rivers and Fisheries Trusts Scotland (RAFTS).

Summary and Discussion

The potential impact of MRE development on salmon, sea trout and eels will be related to the migratory routes and behaviour of fish, the location, construction techniques and technology deployed and the health of the fish populations that are being considered.

Potential impacts could come from disorientating effects of EMF and noise or directly damaging effects of noise or strike, and estimation of the likelihood and extent of damage through such pathways is an element of the licence application process for developments in areas where interactions with migratory fish are likely.

A wide range of continually evolving technologies is available for improving our understanding of these areas. However, all approaches have their own strengths and weaknesses and it is important that proper scoping is carried out with clear aims and objectives where the equipment and data requirements can be clearly specified prior to the initiation of any full scale studies. Furthermore, it should be recognised that due to their differences in size and ecology, specifically designed projects will often be required for different life stages and species.

Of the knowledge gaps that have been identified, internally commissioned work is underway to identify the migratory routes and behaviour of adult salmon in the Pentland / Moray area of northern Scotland and to provide information on the behaviour of salmon and eels in relation to EMF. Externally commissioned projects should provide valuable information on salmon, sea trout and eel behaviour in relation to noise. Nevertheless, a number of knowledge gaps remain which have been identified in this and previous documents. In some cases strategic level investment, for example in relation to acoustic receivers positioned in curtains around the Scottish coast, with local higher density deployments could provide valuable information for several species and life stages. However, in other cases specific laboratory or field experiments will be required.

Much of the research needed to address questions relating to MRE is highly novel and hence an iterative scoping process is required. For example, Marine Scotland Science has prioritised assessment of depth distribution of salmon returning home through the Pentland Firth as a key information need; the reason being that if salmon are mainly close to the surface, then collision with turbines relatively close to the sea bed in deep water can be dismissed outright as a concern. The research concept is that salmon can be captured in nets on the northern coast of Scotland and tagged with satellite transmitters before being released.

If genetics can be used to determine the home river, then there would be an additional option of deploying data storage tags together with radio tags to enable recovery of fish when they reach the home river. Although the home river would not be known until after release of the fish, it would allow for informed targeting of destination rivers for recovery, based on the likely number of fish returning to each river.

Despite considerable progress, the uncertainties that remain for this project are:

- whether existing net fisheries can and will provide salmon of an appropriate (large) size for tagging (negotiations are currently underway with netsman)

- whether reliable satellite transmitters can be constructed of an appropriate size (equipment has been purchased from 2 manufacturers, but these represent new technology with associated risks)

- whether genetic methods can be developed to give a reliable indicator of the river of origin of salmon (current work aims to determine to what level assignments can be made);

- what proportion of tagged fish arrive at their home river.

These issues are currently being considered as part of a research programme within Marine Scotland Science.

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