MARINE RENEWABLES
Consideration of Atlantic Salmon Collision Modelling – Meygen – Inner Sound; Pentland Firth.

The purpose of this paper is to review the encounter rate assumptions and conclusions in the modelling carried out by Xodus for Phase 1 of the MeyGen project. It was carried out by a working group consisting of Ian Davies (MSS), Chris Eastham (SNH), Ross Gardiner (MSS) and Erica Knott (SNH). Other colleagues also input comments, in particular Colin Bean and (at an early stage) Julia Stubbs Partridge (SNH). In addition to the 20 and 86 turbine arrays considered by Xodus, arrays of 6 and 61 turbines have also been considered to reflect an initial deployment and the total number of turbines for MeyGen Phase 1.

In the Xodus report

1. Only salmon were considered.
2. Both salmon smolts and returning adults are considered.
3. Figures of 309,305 and 230,647 were used for the numbers of 1 sea winter (SW) and multi sea winter (MSW) adult salmon returning to Scotland
4. 90% of adult salmon returning to Scotland was assumed to migrate through the Pentland Firth
5. It was assumed that returning adult salmon are uniformly distributed across the Pentland Firth cross-sectional area
6. The rotational plane of one turbine was calculated as 0.0945% of the cross sectional area of the Pentland Firth and equivalent figures for arrays of 20 and 86 turbines were given as 0.00945 and 0.0208%
7. It was stated that turbines operate 72.7% of the time
8. It was assumed that 95% of adult salmon which would otherwise pass through the rotational plane will be able to avoid doing so.
9. It was calculated using an adapted Band model that 0.282 of 1SW and 0.330 of MSW salmon passing through the turbines rotational plane would be expected to collide with the rotor blades

1. Only salmon were considered by Xodus

No information is available on the extent to which sea trout, eel and lamprey are likely to be present in the Pentland Firth and therefore no assessment of potential impacts could be provided by Xodus.

2. Both salmon smolts and returning adults are considered in the Xodus report

There are no strong indicators that a high proportion of Scottish smolts are likely to migrate through the Pentland Firth, and the small size of the fish will greatly reduce the number of smolts which pass through the turbine rotational plane which would be expected to collide with the turbine. In addition the small size of smolts should reduce the likelihood that smolts which would be expected to collide with the turbine blades will get injured or be killed. We therefore concentrated our review on the adult salmon element as the risk to smolts was considered to be much lower.

3. Figures of 309,305 and 230,647 were used in the Xodus report for the numbers of 1 SW and MSW adult salmon returning to Scotland

The Xodus Estimating encounter rate for Atlantic salmon for the MeyGen Tidal Energy Project, Phase 1 and potential population effects (file dated 21/5/12, takes estimates (Sections 2.3 and 3.1) from ICES (2011) ICES for the numbers of 1 SW and MSW salmon of 309,305 and 230,647 for the number of adult salmon returning to home waters (i.e. prehomewater fishery abundance) in 2010. Although the ICES report cited is no longer the latest report (the ICES 2012 report is now available), the figures used would look a suitable basis.

The report looks at the partitioning of total salmon rod catch between north, west, and east coasts and partitions the estimated homewater returns of salmon on this basis as 88% to the east coast. This appears a reasonable assumption if catch rates are similar.

4. 90% of adult salmon returning to Scotland was assumed to migrate through the Pentland Firth in the Xodus report

Based on currently available information (see Malcolm et al, 2010), the Xodus report assumes that

- 90% of salmon returning to the Scottish east coast does so through the Pentland Firth. This appears to be a reasonable assumption of the basis of the limited available information
- no salmon returning to the Scottish north and west coasts do so through the Pentland Firth. This appears to be a reasonable assumption for overall modelling.

So, at this stage, the assumption would appear to be that 90% of 88% = 79.2% of the adult salmon returning to Scottish homewaters does through the Pentland Firth.

What is actually used as a precautionary figure is 90%, this is agreed to be reasonable.

5. It was assumed in the Xodus report that returning adult salmon are uniformly distributed across the Pentland Firth cross-sectional area

This equates to an even spread of fish across the width of the Pentland Firth after correction for varying depth, and an even distribution of fish with depth.

5.1. Assumption of even spread of fish across the width of the Pentland Firth

Although, there is some evidence that in some conditions salmon move along the coasts, until better information becomes available, our assessment has been based on this assumption.

5.2. Assumption of even distribution of fish with depth

The swimming depth is an important element in the collision risk modelling for salmon for subsurface tidal turbines as proposed by the MeyGen development. The choice of distribution of swimming depth will determine the proportion of the fish passing the turbines that would be within the depth zone where the turbines are located.

In the case of MeyGen, the water depth at the site is typically around 35 m. The turbine blades are up to 10m long, and occupy approximately 57% of the water column. The MeyGen risk assessment assumes that the salmon are evenly distributed through the water column, and so 57% would be estimated to be within the zone occupied by the turbines. This will be an over-estimate, as it does not take account of the disk-shape of the turbine swept area, but can be taken forward in this discussion.

The turbine blades will be required to maintain a minimum clearance below the water surface of approximately 10 m (8 m is the absolute minimum clearance required), i.e. the rotor swept area would be between 10 and 30 m depth. The foundations would be found below 30 m, and the zone from 0 – 10 m would not be used.

We considered the evidence that the salmon may not be evenly distributed through the water column, resulting in an increase or decrease in the predicted risk.

We have evidence from tagging that salmon at sea predominantly occupy near surface waters, rather than are evenly distributed through the water column. The most helpful evidence currently available is derived from a report by Holm *et al* (2006, http://www.ices.dk/products/CMdocs/2006/Q/Q1206.pdf) who captured and tagged 406 fish with data storage tags (DSTs) in the Norwegian Sea between 2002 and 2004. Only five tagged fish were recaptured from which to recover data. The recaptured fish all showed limited activity for 10-14 days following tagging, after which there was substantial variation in behaviour. Generally fish resided within 5-10 m of the surface, although dives were also observed ranging from ca. 85-280 m. The number and depth of dives varied widely between fish. It was suggested that fish were travelling to the coast and feeding at the same time.

The behaviour of the five recovered fish (depth distribution) can be summarised as:

Depth m	% of records
0 – 5	58.2
5 – 10	14.5
10 – 15	6.1
15 – 20	4.2
20 – 25	3.7
25 – 30	2.6
30 - 35	2.4
35 - 40	1.6
40 +	6.93

Starlaugsson (1995, http://star-oddi.com/Home/Aquatic-Fisheries-Research/Fish-and-Marine-Animal-Tagging/migration-study-of-homing-of-atlantic-salmon-in-coastal-waters-w-iceland/) tagged 60 salmon returning to the coast of Iceland and relocated them 25-95 km offshore, eventually recapturing them in the fjord where they were first captured. Most of the salmon spent most of their time within 4 m of the surface. However, frequent diving was also observed in these fish to depths ranging from 10 to 123 m, suggesting that diving behaviour is not exclusively an offshore phenomenon. The majority of the salmon spent most of their time in the uppermost 3 m, which is not inconsistent with the data of Holm *et al* (2006). We understand that Sturlaugsson has a large amount of unpublished data.

Audun Rikardsen of the University of Tromso has some information on depths of tagged adult salmon but this is mainly not published, either grey or peer-reviewed literature. In summary, his data indicate (pers comm.) that adult salmon spend 70-80% of the time at depth 0-5 m, particularly at 1-2 m, but they sometimes dive (0.5 h to several h), and this can be from only modest dives (tens of metres) right down to 900 m in one case. The deeper the dive, the longer they tended to stay at depth. If there was a thermocline present, dives were often limited to that depth. Rikardsen suspects that this behaviour is associated with feeding activity in at least some cases. Again, these observations are not inconsistent with the data of Holm *et al* (2006), which indicate that salmon spend 73% of their time in the top 10 m.

In the meantime, Holm *et al* (2006) provides the best summary of quantitative data on the uneven distribution of salmon swimming depths. These data would suggest that:

72.7% of the time would be spent at 0 – 10 m	Above the turbines
16.6% at 10 – 30 m	At turbine depth
10.7% below 30 m	Below turbine depth

These estimates do not take account of the total water column depth at the locations of the measurements. This will introduce some uncertainty, for example there may be less than 10.7% of the fish below 30 m if the total depth is only 35 m.

The preference shown by the fish for near surface waters is a consistent feature across all the studies. This is also consistent with typical Scottish fishing practices for Atlantic salmon, such as the historical drift net fishery, which targeted near-surface waters. Such a preference would have the effect of reducing the estimated proportion of fish at risk of collision. The reduction would be proportional to the change in the proportion of fish in the turbine depth zone, i.e. a reduction in risk by a factor of 57.1/16.6, i.e. a factor of 3.4

This estimate is based on a relatively small data set. MSS is making efforts to increase the size of the data set by gathering information from other sources (Sturlaugsson, Rikardsen, La Croix). While the data will be from coastal and open sea sites, it is unlikely if any can be linked directly with behaviour in very strong tidal stream velocities. This remains a clear research target.

A more detailed description of swimming depths might allow the variation in collision risk across the surface of the turbine swept to be taken into account. Higher proportions of fish in the upper parts of the swept area would also tend to reduce the collision risk.

Although the currently available information does not include fast, reversing tidal streams as in the Pentland Firth where fish behaviour could be different, and may not reflect similar mammalian predator or feeding activity levels, the information in Holm et al (2006) is currently the best available and this has therefore been used in the revisions to the risk modelling carried out by MSS / SNH. It is anticipated that adult salmon tagged with popup tags on the north coast of Scotland in the summer of 2013 will also contribute useful information on swimming depth.

6. The rotational plane of one turbine was calculated in the Xodus report as 0.0945% of the cross sectional area of the Pentland Firth and equivalent figures for the effective rotational plane (cross sectional area) for arrays of 20 and 86 turbines were given as 0.00945 and 0.0208%

We accept the figures for the cross sectional area of the Pentland Firth and for the rotational plane of one turbine.

We do not accept, on advice from Bill Band, the cross-sectional area of the arrays. Following Bill Band's advice, the area for the 20 turbine layout should be 20 times that of a single turbine i.e. increased by a factor of 2 over what Xodus used, and for the 86 turbine layout 86 times that of a single turbine i.e. increased by a factor of 3.91.

Our revised collision risk calculations have taken this into account.

7. It was stated in the Xodus report that turbines operate 72.7% of the time

We accepted this figure for the purposes of present modelling.

8. The Xodus report assumes that 95% of adult salmon which would otherwise pass through the rotational plane will be able to avoid doing so.

There is evidence from field studies in various locations, including East River New York (Verdant Power 2010), Cobscook Bay (http://www.orpc.co), EMEC Falls of Warness (Broadhurst and Barr 2012) that fish generally avoid areas around turbines when tidal currents are flowing strongly. This would suggest a high avoidance rate. However, the fish involved in these observations are not actively migrating and may be familiar with the local environment, which would not generally be the case for actively migrating fish.

There is evidence from tank experiments that fish can avoid open hydrokinetic turbines at very short range, and that fish that pass through the area swept by the turbines can show survival rates (98%+) that are not different from control fish. However, these trials involve smaller fish than adult salmon in clear water in well-lit situations, with much smaller turbines with lower blade speeds and lower water current velocities. In addition, in the Pentland Firth, salmon may be migrating down current which will increase the approach speed. Therefore while these experiments offer the best observational data currently available, it is likely that avoidance by adult salmon and / or survival of adult salmon may be lower in the MeyGen situation

Because of the step change between the conditions that apply between the existing field studies and the MeyGen situation we concluded that an option with 0% avoidance should at least for the present be included in the modelling.

9. It was calculated in the Xodus report using a Band model that 0.282 of 1SW and 0.330 of MSW salmon passing through the turbines rotational plane would be expected to collide with the rotor blades

We accepted these figures, which averaged about 0.3, for the purposes of present modelling. There would therefore be a minimum figure of 0.7 for the proportion of adult salmon passing through the turbines rotational plane which would be expected to survive. It includes no allowance for slipstream effects or any active close range avoidance or as in our view there is currently no information clearly transferable to the MeyGen situation to justify this. Nor does it include any allowance for fish predicted to collide which survive impact.

10. Pulling the various threads together

For the purposes of illustration as to how varying avoidance rates and survival rates of fish predicted to pass through the turbines rotational plane would affect the outcomes, a spreadsheet is attached. The 0.7 survival column corresponds to the 0.3 Band value. The spreadsheet also includes estimates for the number of salmon predicted to be lost from an annual harvest of 40,000, assuming harvest is linearly related to population size, and that all fish that collide die.

For 6 turbines, this gives 171 adult salmon as the number predicted to collide for an assumed adult population of 540,000, with no avoidance assumed, and the survival of adult salmon passing through the turbines rotational plane = 0.7 (70%). The number of salmon predicted to be lost from an annual harvest of 40,000 would be 13 salmon, assuming harvest is linearly related to population size, and that all fish that collide die.

11. Additional notes

As noted above mortalities may directly impact on rod and net fisheries. They will also impact on spawning stock levels. The effect of this will vary from river to river depending on the position on where the stock lies on the stock-recruitment curve, and the size of the perturbation. As a result any mortalities may or may not have an adverse effect on the next generation. And in addition because of the variation in numbers arising from other causes small perturbations will not result in any detectable difference.

MSS continues to develop life history models on three systems (North Esk and two Dee tributaries) with good information on both adults and juveniles. Some of the output is already informative – the North Esk system overall appears to operate at something like peak productivity and as such taken overall should be fairly robust to losses as regards effects on the next generation. Work looking at separate components of the North Esk population is in progress. The two Dee tributaries that are being studied have in recent years operated closer to the origin on the stock recruitment curve so would be less robust.

Some of the differences between rivers and in different parts of rivers have a genetic basis. Rivers may contain different genetic components some of which will be less resilient than others. Maintenance of genetic types is a conservation objective of all Atlantic salmon SACs and salmon populations also support other qualifying interests – like freshwater pearl mussel.

There are several other tidal and wave developments planned for the Pentland Firth and there will therefore be cumulative impacts to consider in due course.

12. References

Section 3
1. ICES 2011 Report of the Working Group on North Atlantic Salmon (WGNAS), 22-31 March 2011, Copenhagen, Denmark. ICES 2011/ACOM:09. 286 pp.

Section 5
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Section 8
4. Broadhurst, M. and Barr, S. (2012). Short Term Temporal Behavioural Responses in Pollack, *Pollachius pollachius* to Marine Tidal Turbine Devices; a Combined Video and ADCP Doppler Approach. EIMR International Conference 2012.

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