



Tidal Lagoon Swansea Bay

Alternative Fish Impact Assessment Results

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1 Introduction

1.1 Aims and Objectives

- 1.1.1 The purpose of this paper is to present the results of the alternative modelling methodologies used to provide a sensitivity test of the original predictions made of the impact of turbine operation of Tidal Lagoon Swansea Bay (the Project) on key fish species, within Swansea Bay and in the wider marine environment. The following scenarios have been undertaken to confirm the predicted impact on fish and identify a level of offsetting that will enable determination of the Marine Licence for the Project.
- 1.1.2 This paper presents the results of testing the alternative scenario methodologies and draws conclusions on the results of the modelling by species. Further papers will then provide details of how Tidal Lagoon Swansea Bay plc (TLSB) proposes to mitigate and offset, where required, for any impacts predicted.
- 1.1.3 In addition, this paper highlights several areas where assumptions, many of which are considered to be currently unquantifiable, have been made and where monitoring will potentially be required to validate the parameters used within the models. Details of the monitoring proposed by TLSB will also be reported in a separate paper.
- 1.1.4 The structure of the document provides the background to the Project and work completed to date, before giving a summary of the methods used in the modelling and the assumptions used. The document then presents and discusses the results of the modelling before sensitivity testing key parameters within the models and finally concluding with the next steps.

1.2 Background

- 1.2.1 An application was made to the Planning Inspectorate in February 2014 for a Development Consent Order (DCO) and a separate parallel application was made for a Marine Licence to Natural Resources Wales (NRW) Marine Licensing Team (MLT). The DCO for the Project was granted in June 2015, and this current submission is to support ongoing discussion through the Marine Licensing process.
- 1.2.2 Given the unique design of the Project, and lack of direct comparability with similar tidal lagoons or hydro-electrical energy generation structures throughout the world, bespoke modelling approaches were necessary. The original submissions for the DCO and Marine Licence therefore included an assessment of fish impacts, derived using Individual Based Modelling (IBM) to calculate fish encounter rates with the turbines and the STRIKERv.4 model to calculate fish injury rates. The principles behind both techniques are industry recognised with modification required for the unique nature of the Project.

- 1.2.3 Subsequent discussions with NRW Technical Experts (NRW(TE)) and advisors from the Centre for Environment, Fisheries and Aquaculture Science (Cefas) identified concerns with the use of IBM. In particular, regarding: the impact of fish residency in adjacent waters to the lagoon; perceived insufficient consideration of migratory fish movements upon approaching their natal rivers through migratory path tortuosity and delay; and impact on additional lifestages of certain fish species. In order to address these concerns further alternative modelling approaches have been developed.
- 1.2.4 Modelling work in relation to the Project has considered, probabilistically, both the elements of encounter with the Project (originally addressed through Individual Based Modelling (IBM)) and also injury having encountered the Project (through STRIKER v.4 modelling).

2 Basic Principles of Lagoon Operation

2.1 Lagoon Design

- 2.1.1 A number of design modifications have been made as detailed design work has progressed. These have been developed within the Rochdale Envelope specified within the DCO granted since the submission of the Environmental Statement (ES) and resulting in the latest design. The modifications have been made to improve operational performance and efficiency as well as mitigating potential environmental impacts, some of the latter having been made in response to concerns expressed by wider stakeholders, regulators and consultees.
- 2.1.2 For example, and of relevance to the topic discussed here, the bulb turbines themselves have passed through several design iterations originally being a 7.0m±0.2m diameter, fixed speed, then 7.35m diameter variable speed, and finally a 7.2m diameter, variable speed. A summary of the design iterations of relevance can be seen in Table 2.1 along with the final models which have been used to assess their impact on fish. A description of each of the modelling approaches which evolved during the assessment period is provided in Section 3.

Table 2.1 Summary of Design Iterations and Modelling Approach

	Original ES submission (2014)	DCO Examination process (Dec 2014)	Marine Licence Assessment (2015)	Alternative scenario testing (May 2016)		
Turbine blade diameter	7m±0.2m	7m±0.2m	7.35m	7.2m	7.2m	7.2m
Turbine type and revolutions per minute (RPM)	Fixed 67 RPM	Variable 90 RPM	Variable 73 RPM max	Variable 73 RPM max	Variable 73 RPM max	Variable 73 RPM max
Encounter and injury rate models used	IBM + STRIKER	IBM + STRIKER	IBM + STRIKER (inc. CFD)	Draw Zone + STRIKER (inc. CFD)	Alternative Draw Zone + STRIKER (inc. CFD)	IBM + STRIKER (inc. CFD)

- 2.1.3 The turbines have been improved to increase energy generation efficiency and to reduce impacts on fish. The move to variable speed rather than fixed speed, resulted in far lower pressure changes (below 10Nm²) and shear stresses within the turbine housing and consequently far higher predicted survival rates for fish passing through, particularly of sensitive pelagic species such as herring and shad. Table 2.2 sets out the shear stresses expected from the current turbines.

Table 2.2: Probability distributions of Computational Fluid Dynamic predictions of hydraulic shear stress compared for the STPG Reference design (McEwan and Scobie, 1992) and the Andritz 3-bladed variable speed design.

Shear Stress N/m ²	Fixed Speed 67 RPM Reference %	Andritz 3-Blade Variable Speed %
10	0	100
100	56.89	0
500	28.14	0
1000	6.21	0
2000	2.99	0
3000	2.4	0
4000	1.2	0
5000	2.1	0

- 2.1.4 The sixteen 7.2m diameter, 3 blade, bulb turbines are set in the central area of the turbine housing and fish will have to enter the 33m long draught tubes (either side of the blades) before encountering the turbines. Fish may enter the draught tubes under their own volition or, involuntarily, if they cannot escape from the flows of water being drawn past the turbines. The risk of unintended entry is considered as part of the assessment below.
- 2.1.5 In addition to the turbines there will be six rising sluice gates each measuring 13m wide by 14.35m in height. These will be situated in the centre of the sluice gate housing section with 45m long draught tubes leading towards them. Beyond the entrance to the draught tubes of both the turbines and sluices there will be a 10m concrete apron and further scour protection mattress on the sea bed, as shown in Figure 2.1.

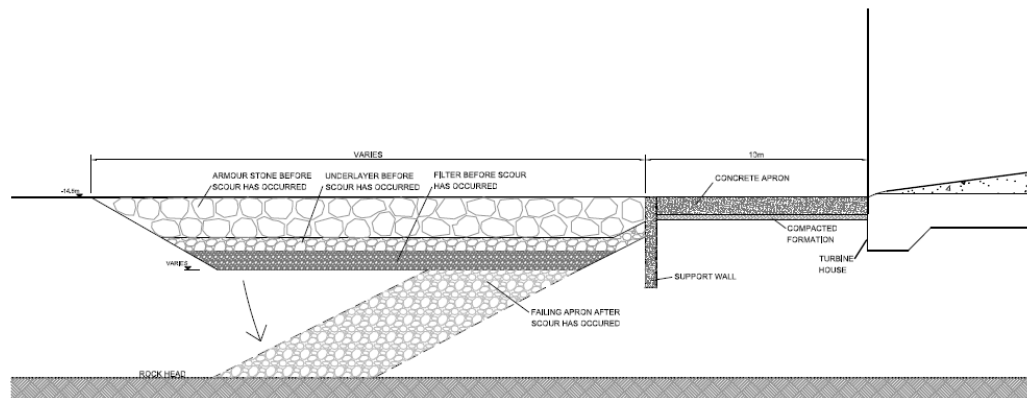


Figure 2.1: Cross-section of proposed scour protection in front of turbine and sluice housing.

2.2 Lagoon Operation

2.2.1 The Project, unlike run-of-river hydro-electric schemes, will generate electricity bi-directionally on both the flood and ebb tides. Thus there will be four generation windows during any 24 hour period. A basic outline of the lagoon operation is described below and shown in Figure 2.2:

- **Generation phase:** water passes through the turbine houses driving the turbines and generating electricity.
- **Sluicing phase:** sluice gates are raised allowing the free passage of water into or out of the lagoon. This occurs when the head difference between the lagoon and outer Bay is between 0 - 1.5m and is used to balance the water levels. During sluicing, water is also allowed to flow through the turbines but at a much lower speed than during generation (due to lower head difference).
- **Pumping phase:** upon cessation of generation and sluicing phases water may be pumped into or out of the lagoon using the turbines in order to create an increased head difference prior to the next generation phase.

2.2.2 Between each flood and ebb tide there will be a holding period (four hours in each 24 hour cycle) during which the sluices and turbines will be closed and water will be unable to pass between the sea and the lagoon.

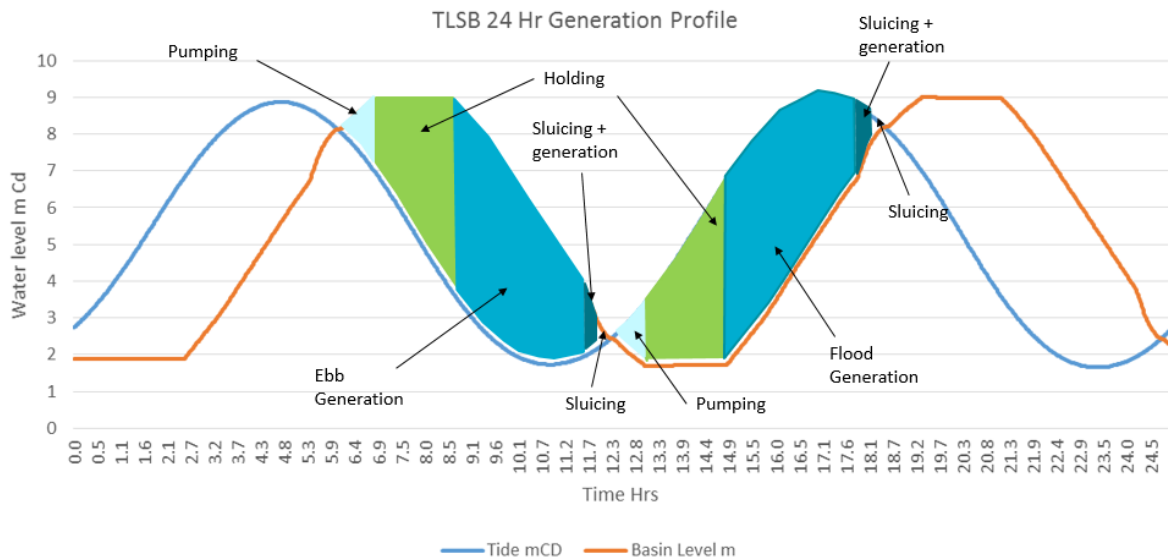
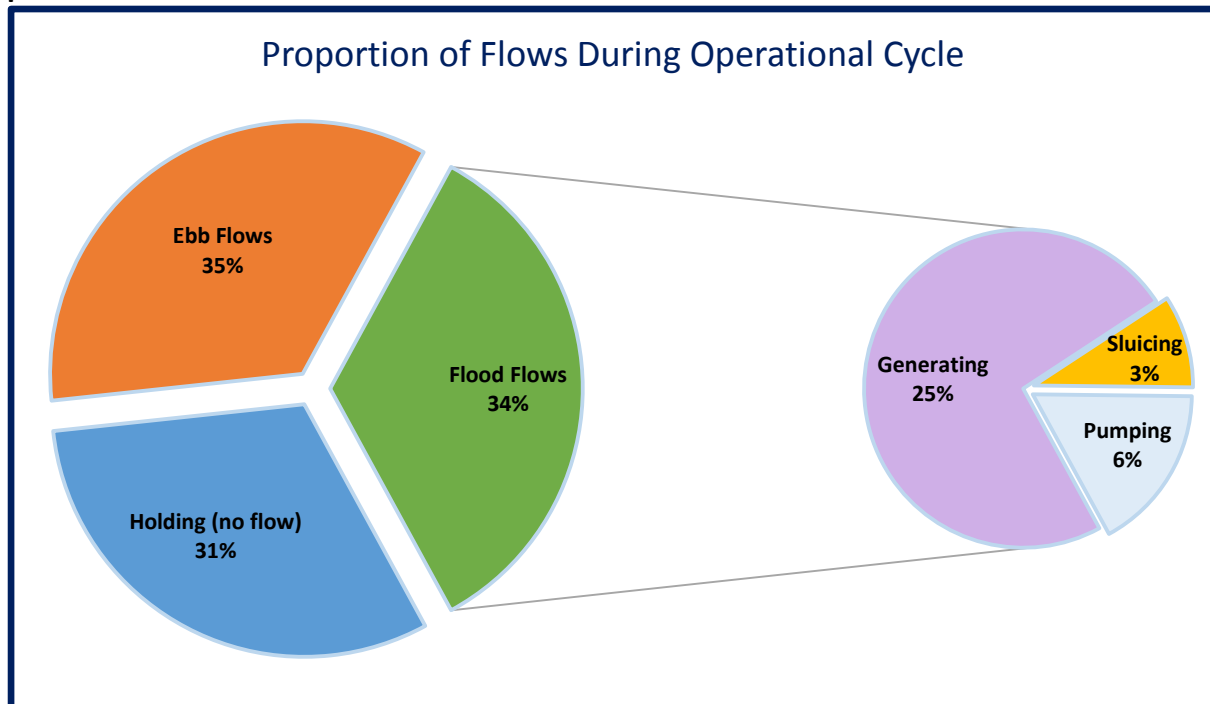


Figure 2.2: Illustrating the operation of the lagoon over two tidal cycles (approximately 24 hours) (mCD – mean Chart Datum)

2.3 Timing of generation

- 2.3.1 During every 24 hour cycle there are approximately two tidal cycles. This results in water flowing into the lagoon twice a day via the turbines and sluices, for a total over the two tidal cycles of 8.43 hours, equivalent to 34% of the day (see Chart 1 below).
- 2.3.2 At the start of each flood and ebb tidal cycle the lagoon is 'closed' and in its 'hold' position. In such a state no water is passed between the lagoon and the outer Bay and vice versa. This period lasts over 2 hours on each flood and ebb tide and represents 32% of the diurnal cycle. During this period no fish can enter or exit from the lagoon.
- 2.3.3 Thus, the only period during which fish can enter the lagoon is during the flood generation, pumping and sluicing phases and exiting can only occur on the corresponding ebb phases of operation. The only potential exception may be a very short period of time when flows through the sluices on the ebb tide are reduced as water levels approach equilibrium (zero head difference) between the lagoon and outer Swansea Bay, and so fish may be able to enter or exit through these flows.

Chart 1: Diagram showing the proportion of timing and direction of water flows into and out of the lagoon. Note that generating and sluicing may occur concurrently for a short period of time.



2.4 Flow Velocities

- 2.4.1 High flow velocities exiting the lagoon during ebb generation (up to 10 ms^{-1}), sluicing and pumping, will prevent fish from entering the lagoon during these phases as they will be unable to swim against such flows.
- 2.4.2 During sluicing, flows of up to 6 ms^{-1} will be encountered. As discussed in 2.3.3 these will however diminish as the head difference reduces prior to closure of the sluice gates.
- 2.4.3 The limited opportunity for fish to enter and exit the lagoon in each tidal cycle is considered in the calculations of the alternative assessment modelling through consideration of the actual operational time of each cycle.

3 Summary of Alternative Assessment Methodologies

3.1 Species Considered

3.1.1 A wide, and seasonably variable, range of fish species are present in Swansea Bay as evidenced in the Environmental Statement, including Appendix 9.1 (Fisheries Baseline) and Appendix 9.2 (Fish Fauna Characterisation Surveys). During the Environmental Impact Assessment (EIA) process, key fish species were identified on the basis of their environmental, commercial and recreational importance, these are referred to as Valued Ecological Receptors (VERs). The initial species considered as VERs (ES, Chapter 9, Tables 9.28 to Table 9.37) and assessed within the ES in relation to the Project were:

- Atlantic Salmon
- Sea Trout
- European Eel
- Shad (Allis and Twaite)
- River Lamprey
- Sea Lamprey
- Herring
- Common Sole
- Sandeel
- 'Other demersal and pelagic species'

3.1.2 Other species, such as bass, were considered under recreational species in Table 9.37 of ES, Chapter 9.

3.1.3 Following requests from NRW(TE) and Cefas advisors in Autumn 2015, the impact assessment was expanded to include:

- Cod/Whiting
- Plaice
- Bass

3.2 Evolution of Turbine Design and Associated Impact Assessments

3.2.1 The assessment of the potential impact of the lagoon on key fish populations was first presented in the Environmental Statement submitted in support of the DCO and Marine Licence applications in February 2014.

3.2.2 The initial assessments considered the risk of injury caused by turbine operation and utilised two computer models:

- **Fish Behaviour Modelling:** 'Individual Based Modelling' (IBM) was used to predict the frequency with which fish would encounter the turbines and the number of subsequent passes back and forth through them. Using hydrodynamic models over a full spring tide cycle, coupled with species specific 'rules' (such as olfactory trail following in salmonids) the model

aimed to calculate fish position based on hydrodynamic flows, swimming ability, reactions to different bathymetrical features (such as shallow water and beaches), navigational error (tortuosity) and direction.

- **Turbine Injury Modelling:** Having encountered the turbines the probability of fish being injured through blade strike or physical stresses including pressure change, shear stress and cavitation, during the passage, was assessed using the STRIKERv.4 model, an industry accepted tool for this purpose.

- 3.2.3 These models were combined and resampled to give a % Mean Mortality, with an associated standard error of the mean.
- 3.2.4 The above assessments were undertaken for different design turbine/slucice configurations necessitated as part of the design process starting initially with fixed speed 7.0m diameter turbines before progressing through other iterations to the current design of sixteen 7.2m variable speed turbines and six sluice gates.
- 3.2.5 The DCO for the Project was granted in June 2015 on the basis of this assessment however further queries have been raised during the Marine Licensing process. Consequently, alternative approaches have been developed as described in Appendix 1: *Alternative Fish Impact Assessment Methodologies*. Appendix 1 outlines three methods to calculate encounter rate with the turbines, and a method of combining with STRIKERv.4 injury rates throughout a year. These approaches, termed Volumetric, Draw Zone and Alternative Draw Zone, aim to address the issues it was felt were not addressed by the IBM+STRIKER approach.

3.3 Volumetric Approach

- 3.3.1 This method was initially developed following discussion between NRW(TE), Cefas and TLSB and used the known volume of water moving into, and then out of the lagoon during each tidal cycle. It assumed fish populations were evenly distributed and that the volume of water passing through the turbines represented an equivalent proportion of the fish population. The volume of water moving in and out of the lagoon was considered in relation to the overall volume of water within Swansea Bay.
- 3.3.2 In addition to the volume of water, other factors are also applied which estimate the proportion of fish within the volume of water that are drawn into the turbines and those which are likely to avoid entry.
- 3.3.3 The Volumetric Approach relied on a subjective assessment of the likely encounter avoidance rate of fish. The development of alternative models has therefore been undertaken and the further use of the Volumetric Approach suspended.

3.4 Draw Zone Approach

- 3.4.1 Given the reliance in the Volumetric Approach on a constant encounter rate between species for both entry and exit from the lagoon, and the application of

an avoidance rate, an additional method has been used which, rather than being based on water volumes passing into or out of the lagoon, calculates the risk of a fish entering the Draw Zone area around the turbine or sluice housing from which they would be unable to escape. This is based on the method described by Hammar et al. (2015) and again assumes an even distribution of fish.

- 3.4.2 The estimate of the Draw Zone area, for generating and sluicing phases separately, for each species is based on the peak intake water velocities at fixed distances during each of the ebb and flood, generation and sluicing cycles, and the maximum sustained swimming speed (MSSS) of each fish species. It is based on the premise that if a fish enters the zone it will be unable to avoid entry into the turbines or sluices.

3.5 Alternative Draw Zone Approach

- 3.5.1 Following further discussion with NRW(TE) and Cefas, an Alternative Draw Zone method has also been developed as a variation on the original Draw Zone method, which follows the same principles as the Draw Zone but applies a probability for fish, within a certain distance of the Draw Zone, entering the Draw Zone as a proportion of the direction choices that a fish could make.

3.6 Key Model Parameters/Factors

- 3.6.1 The new models as discussed above all considered the different lifestages of fish that may be at risk. For example, salmon will migrate past the lagoon as out-migrating smolts or kelts, and also as inward migrating 1-sea winter or multi-sea winter adults. In the case of sea trout there is far greater complexity, with seven sea-age classes used in calculations in addition to smolts, whitling and kelts. Consideration has also been given to the potential residency of sea trout, and other diadromous species, in the Bristol Channel and beyond.
- 3.6.2 For certain species (e.g. salmon and sea trout) the estimated survival and impact rates are used to determine the probability of the loss of adult fish and also the potential loss of subsequent egg production. These two values do differ because some species of fish (e.g. sea trout) have a greater proportion of females that are at risk of turbine strike mortality and impoundment within the lagoon and therefore a greater loss of eggs, and fecundity increases for older fish. Importantly, the approach used in the alternative methodologies enables the contribution of different age classes of fish, and their relative contribution to overall annual egg deposition, to be considered.
- 3.6.3 In developing the alternative methodologies, the following key factors, which have been raised by both the regulators and public stakeholders during wider consultation, have been incorporated into the assessments:
- Residency of certain migratory fish species (or particular lifestages thereof) in and around Swansea Bay. For example, it is assumed that, unlike salmon, an element of the sea trout stock remain within the Bristol Channel rather than migrating into the wider Celtic Sea and beyond;

- Replenishment of stocks on each tide if fish are removed from the population as a result of injury passing through the turbines or remaining within the lagoon;
- Impacts of fish being impounded and subsequently delayed past certain dates and thus failing to complete, their migration either into the adjacent rivers (e.g. adult salmon) or out to sea (e.g. salmon smolts);
- Consideration of additional lifestages of particular species (eg. Sea trout / resident eels) which may lead to repeated exposure to the lagoon as they migrate in/out past the lagoon.
- Seasonality of fish presence using monthly estimates of fish abundance;
- Exposure to lagoon entrainment over multiple tidal cycles;
- Variation in the probability of fish entering the lagoon compared to those exiting the lagoon;
- Mode of entry into and out of the lagoon using either the turbines and/or sluices;
- Consideration of the population range of the fish species with some being considered native to the Bristol Channel, Swansea Bay and adjacent rivers (e.g. salmon) whilst others are a sub-set of a far wider geographic population (e.g. cod and herring);
- The combined impact over multiple life stages in terms of both adult numbers of fish injured and egg production lost as a consequence.

3.6.4 The Draw Zone Alternative Draw Zone Model has been used to calculate the estimated % Annual Mortality and survival of each modelled life stage. This information has then been used to assess the impacts at a population level, from the Alternative Draw Zone model on a precautionary basis.

4 Modelling Assumptions

- 4.1.1 In order to produce modelled approaches a number of assumptions have been applied in relation to some of the model input parameters. In making such assumptions a conservative approach has been taken where necessary, thus creating a level of precaution within the assessment and giving confidence that any impacts that may be realised will be below those modelled.
- 4.1.2 The baseline population of fish present in the Bay will remain constant on each day per month of fish presence. Thus any fish lost due to turbine entrainment are assumed to be 'replenished' after each tidal cycle. A 60 tide (approximately one month) rolling average has been applied to the population figures in order to phase the transition in fish numbers between the last day of one month and the first day of the next. The 60 tide period has been reduced for particular lifestages of fish where they are believed to migrate through Swansea Bay over a shorter period of time. This applies to salmon and sea trout smolts, and silver eels, all of which are leaving the river systems and migrating to the sea, as well as inward migrating elvers.
- 4.1.3 Where fish are predicted to be injured passing through the turbines due to one, or more of; shear stress, pressure change, cavitation and blade strike, they are, for the purposes of the calculations, regarded as mortalities. This acknowledges that whilst a proportion of 'struck' fish may survive as fish are simply deflected, such fish may be at greater risk of fish predation whilst disorientated.
- 4.1.4 Peak water flow velocities have been used during flood and ebb tides in calculations of the Draw Zone rather than average flows, increasing the area of the Draw Zone and thus the likelihood that fish would encounter the Draw Zone. Appendix 1 provides further details of the definition of the Draw Zones.
- 4.1.5 For all species, the precise population of fish within the coastal area is unknown and varies seasonally and annually. The precise monthly populations, used in the assessments, will vary year on year and for several species little data exists upon which to base any estimates. Where evidence of proportions of the annual population are not available expert opinion has been used (see Appendix 2: *Fish Datasheets*). In such cases the proportion of the population at risk each month has been averaged across the months of expected presence. In addition, sensitivity tests have been applied to this data in order to demonstrate the effect of using differing distributions in the calculations.
- 4.1.6 In the case of salmon and sea trout, a large dataset of fish catch records was made available by NRW(TE) from Panteg Fish Trap on the River Tawe. This data, assumed to be representative of populations in the Bay, has provided a large sample size enabling interrogation of the data to determine potential monthly presence of fish, sex ratios and life stages present within the population of salmon and sea trout. Whilst there are some shortcomings with such data, in terms of its age, potential trap bias and delay between fish entering Swansea Bay and

eventually being caught in the trap 18km up river, it is nevertheless one of the most comprehensive data sets available. Alternative data available through the rod licence catch return system, whilst more contemporary, is fraught with issues such as a shorter sampling (fishing season) window, lack of data on individual fish, small samples of fish each year and inadvertent inaccuracies in reporting of catches at the end of the year by anglers.

- 4.1.7 When a fish has entered the Draw Zone, it is assumed that, despite having a burst speed above its maximum sustainable swimming speed (MSSS) it is unable to escape, and is drawn into the turbine housing. This entry and exit can occur through either the turbines or sluices on both flood and ebb tides.
- 4.1.8 It is assumed that fish present in the draw-zone when the turbines or sluices are first operated, during each cycle, do not exhibit an escape response, and are thus drawn into the turbines or sluices therefore increasing the risk of encounter.
- 4.1.9 It is assumed that all salmon smolts impounded within the lagoon after 1st July will not be able to undertake their natural migration and are therefore lost. Sea trout smolts are assumed to be able to reside in the Bay or lagoon and therefore are not subject to such losses although a cut-off scenario has been applied on a precautionary basis.
- 4.1.10 Adult salmon and sea trout calculated as being in the lagoon after 1st December are considered to be lost from the population of spawners. Whilst the precise delay time within the lagoon is not known (the models and sensitivity analysis have been used to predict this) salmon and sea trout are known to migrate into local rivers in December and thus a fish which leaves the lagoon in late November may still be able to spawn.
- 4.1.11 Certain species exhibit diel behaviour becoming dormant during the day (e.g. eel, lamprey) or night (e.g. shad) which has been incorporated in the models.
- 4.1.12 In addition to the above assumptions regarding what is included within the assessments, there are a number of factors which have not been included:
 - Fish are highly adapted to detect water flow velocities and exhibit behaviours such as positioning themselves in areas of low velocity when resting or using tidal flow streams to transport themselves from one location to another. Fish will therefore be able to detect the flow velocities created by the lagoon operation. This has to be considered in conjunction with the fact that the water will be flowing into, and out of, large concrete tunnels containing the turbine and sluice equipment. Given the uncertainties, no avoidance or attraction behaviours have been assumed within the Draw Zone or Alternative Draw Zone approaches related to water flows or chemistry, nor has the impact of turbine noise, vibration and degree of thigmophobic behaviour of each species been considered.

- The tidal movement of fish and their subsequent likely horizontal or vertical position relative to the turbine housing have not been considered. For example, fish moving in-shore, or into estuaries on the flush of the flood tide may have passed the turbines prior to the start of generation and sluicing, the sequence of which commences once the flood tide water levels have risen by approximately 2.5m above low water level. Given the location of the turbines in the lower half of the water column, fish swimming close to the surface may be able to avoid being drawn in to the turbines as sea trout, for example, generally occupy the upper sections of the water column (Sturlaugsson, 2016; Rikardsen et al., 2007).
- Seasonal dormancy is also undertaken by species, such as sandeel, which overwinter buried in the seabed thus reducing the likelihood of encounter with the lagoon during such periods.
- Beyond the entrance to the draught tubes of both the turbines and sluices there will be a 10m concrete apron and further scour protection mattress on the sea bed. This area is unlikely to prove attractive to fish as it will be scoured by both incoming (flood) and outgoing (ebb) tides four times a day and therefore fish density within this area is likely to be lower.

5 Modelling Results

5.1 Results

- 5.1.1 As previously discussed a number of approaches have been undertaken to assess the impact of turbine entrainment and injury on fish, all of which have used models and associated calculations. The results of the relevant model runs are provided in Table 5.1 overleaf and are illustrated in Chart 5.1.
- 5.1.2 The Draw Zone and Alternative Draw Zone models have considered the impacts on a greater number of lifestages for certain species, when compared with the IBM+STRIKER models which has combined certain lifestages. For example, pre and post spawning shad have been considered and numerous age classes of sea trout.
- 5.1.3 Table 5.2 below provides a key to the colour bandings used in Table 5.1 and within the original ES.

Table 5.2 Assessment criteria for annual mortality rate due to turbine passage

Impact Magnitude	Annual Mortality Rate Due to Turbine Passage Only
High	> 10 %
Medium	> 2.0 - ≤ 10 %
Low	> 1 - ≤ 2.0 %
Negligible	≤ 1 %

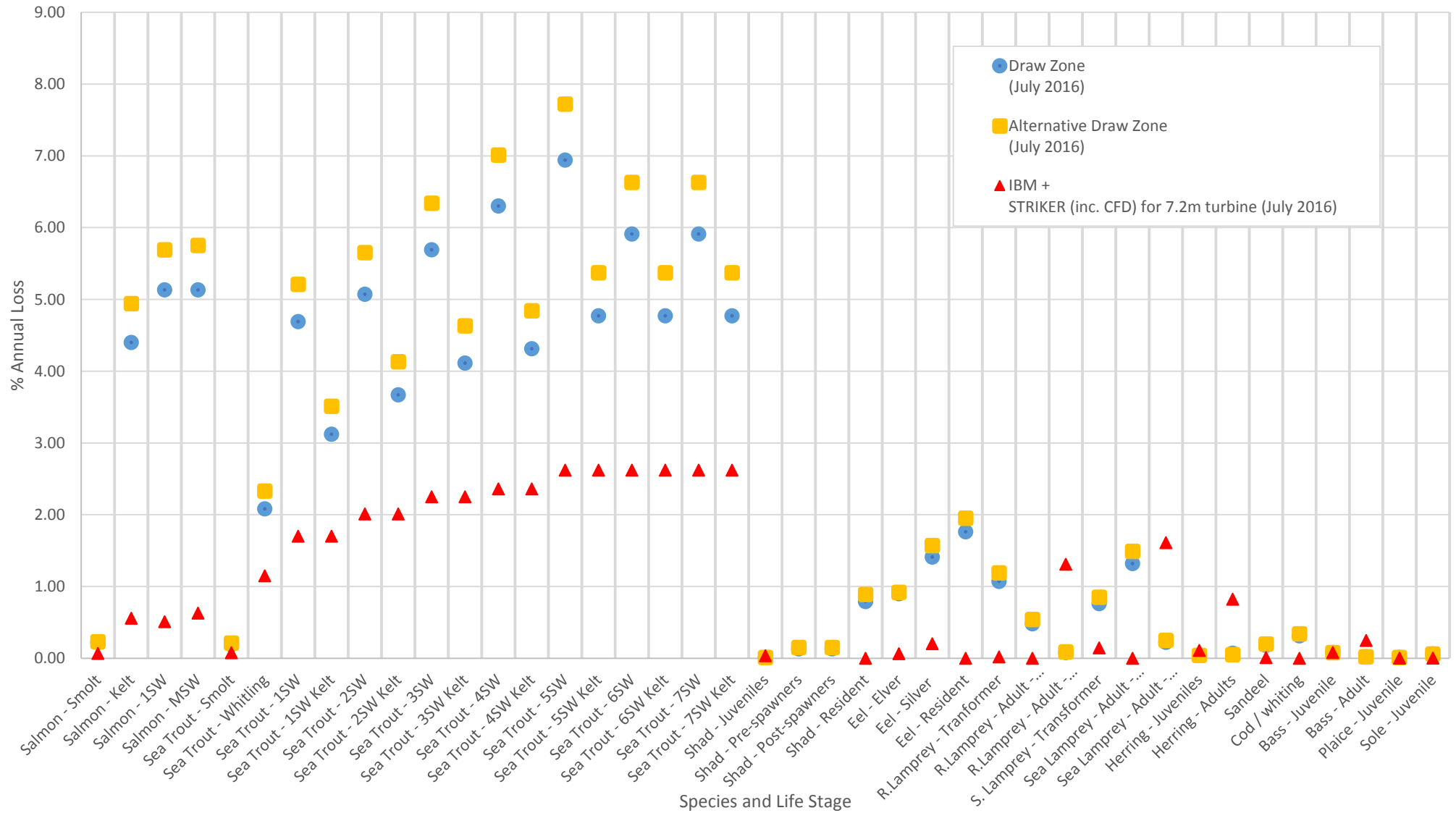
- 5.1.4 In general, as can be seen from Table 5.1 all of the updated IBM/Striker results (July 2016) are reduced when compared to the original ES results (2014). This is a direct consequence of the turbine improvements. In terms of the alternative scenario methods, the results of these are generally within the same magnitude (see Table 5.2) as that originally predicted within the ES, indicating broadly similar magnitudes of impact, except for salmon where the alternative assessment methods show an increased impact. A more detailed discussion of the results are provided in Section 6.

Table 5.1 Results of Modelling against range of turbine design configurations

Phase		Original ES (2014)	Examination (December 2014)	ML Assessment (2015)	Draw Zone (July 2016)	Alternative Draw Zone (July 2016)	IBM + STRIKER (inc. CFD) for 7.2m turbine (July 2016)
Turbine Size		7m	7m	7.35m	7.2m	7.2m	7.2m
RPM		67 Fixed	90 Variable	73 RPM max	73 RPM max	73 RPM max	73 RPM max
Models Used		IBM + STRIKER	IBM + STRIKER	IBM + STRIKER (inc. CFD)	Draw Zone + STRIKER (inc. CFD)	Alternative Draw Zone + STRIKER (inc. CFD)	IBM + STRIKER (inc. CFD)
VER	Life Stage Considered	% Mean Mortality*	% Mean Mortality*	% Mean Mortality*	% Annual Mortality	% Annual Mortality	% Mean Mortality*
Salmon	Salmon - Smolt	0.12	0.13	0.07	0.22	0.23	0.07
	Salmon - Kelt				4.40	4.94	0.56
	Salmon - 1SW	0.87	0.53	0.45	5.13	5.69	0.51
	Salmon - MSW				5.13	5.75	0.63
Sea Trout (resident and migrants)	Sea Trout - Smolt	0.16	0.13	0.08	0.19	0.21	0.08
	Sea Trout - Whiting				2.08	2.33	1.15
	Sea Trout - 1SW				4.69	5.21	1.70
	Sea Trout - 1SW Kelt				3.12	3.51	1.70
	Sea Trout - 2SW				5.07	5.65	2.01
	Sea Trout - 2SW Kelt				3.67	4.13	2.01
	Sea Trout - 3SW				5.69	6.34	2.25
	Sea Trout - 3SW Kelt				4.11	4.63	2.25
	Sea Trout - 4SW	3.40	2.18	1.86	6.30	7.01	2.36
	Sea Trout - 4SW Kelt				4.31	4.84	2.36
	Sea Trout - 5SW				6.94	7.72	2.62
	Sea Trout - 5SW Kelt				4.77	5.37	2.62
	Sea Trout - 6SW				5.91	6.63	2.62
	Sea Trout - 6SW Kelt				4.77	5.37	2.62
	Sea Trout - 7SW				5.91	6.63	2.62
	Sea Trout - 7SW Kelt				4.77	5.37	2.62
Shad	Shad - Juveniles				0.01	0.01	
	Shad - Pre-spawners	0.77	0.61	0.04	0.13	0.15	0.04
	Shad - Post-spawners				0.13	0.15	
	Shad - Resident	-	-	-	0.79	0.89	-
Eel	Eel - Elver	0.19	0.07	0.07	0.90	0.92	0.07
	Eel - Silver	0.07	0.19	0.19	1.41	1.57	0.20
	Eel - Resident	-	-	-	1.76	1.95	-
River Lamprey	R.Lamprey - Transform	0.02	0.02	0.02	1.07	1.19	0.02
	R.Lamprey - Adult - re	-	-	-	0.48	0.54	-
	R.Lamprey - Adult - m	1.35	1.35	1.35	0.08	0.09	1.31
Sea Lamprey	S. Lamprey - Transform	0.15	0.15	0.15	0.76	0.85	0.15
	Sea Lamprey - Adult -	-	-	-	1.32	1.49	-
	Sea Lamprey - Adult -	1.86	1.53	1.53	0.22	0.25	1.61
Herring	Herring - Juveniles	-	18.90	-	0.04	0.04	0.11
	Herring - Adults	26.69		0.85	0.07	0.05	0.82
Sandeel	Sandeel	0.01	0.01	0.01	0.18	0.20	0.01
Cod / Whiting	Cod / whiting	-	-	-	0.31	0.34	-
Bass	Bass - Juvenile	0.27	0.27	0.27	0.08	0.08	0.08
	Bass - Adult	0.27	0.73	0.27	0.02	0.02	0.25
Plaice	Plaice - Juvenile	0.69	0.00	0.00	0.01	0.01	0.003
Sole	Sole - Juvenile	-	0.00	-	0.06	0.06	0.003

*% Mean Mortality: The mean results are the predicted percentage of fish that are injured or killed during the combined model operation. The IBM encounter model is run with 10,000 individual model fish and each model fish history is then applied to the STRIKER™ likelihood of injury model. The process of coupling the IBM model out with the STRIKER™ predictions is resampled 1000 times to produce a mean and standard deviation of mortality probability.

Chart 5.1 : Summary of Modelling Results for All Species and Life Stages



5.2 Sensitivity Testing

- 5.2.1 The various modelling approaches used to assess fish impacts have, in many cases, used empirical data from a range of sources. However, where specific data has not been available then assumptions (as outlined in Section 4) and expert opinion have been used to inform the scenario testing.
- 5.2.2 Where assumptions have been made regarding the input data then this naturally creates an element of uncertainty in the outputs provided by each model. In order to reduce the levels of uncertainty alternative data inputs can be used through a sensitivity analysis in order to demonstrate the range of outcomes that would be produced.
- 5.2.3 In undertaking such analysis the models can be tested to:
- Assess their robustness;
 - Develop better understanding of relationships between input and output variables and the impacts of changes;
 - Reduce levels of uncertainty by focusing on removing those areas where uncertainty is greatest;
 - Identify data inaccuracies that can be corrected;
 - Simplify approaches as superfluous information can be removed;
 - Identify those input parameters that are most sensitive and have greatest impact on outputs and consequences; and
 - Improve confidence in the output of the models used.
- 5.2.4 Alternative assessment methodologies and assumptions can be explored to assess the impact on the output values. Table 5.3 below provides a summary of the various tests that have been completed. Only a selection of fish species and/or lifestages have been used for the tests, chosen to represent marine and diadromous species where appropriate.
- 5.2.5 Sensitivity tests have been undertaken on those parameters within the model where assumptions have been made around fish biology, behaviour and distribution, and also where there is possible variability within the operational regime of the project. The sensitivity tests undertaken are presented in Appendix 3 and summarized by species in Table 5.3.

Table 5.3 Summary of Species/Life Stages and Sensitivity Testing Undertaken

Species	Life Stage	Sensitivity Test						
		1. Population Range	2. Draw Zone + MSSS	3. 1SW:MSW salmon ratio	4. Seasonal Population distribution	5. Sex Ratio	6. Tide to tide non-replenishment	7. Retention time
Salmon	Smolts	x	x				x	x
	1SW	x		x		x	x	x
	Kelts	x					x	x
	MSW	x		x	x	x	x	x
Shad	Juveniles							
	Pre-spawners				x			
	Post-spawners							
	Residents	x						
Eel	Elver							
	Silver Eel							
	Residents	x						
River Lamprey	Transformers							
	Adults							
	Residents	x						
Sea Lamprey	Transformers							
	Adults		x					
	Resident	x						
Herring	Juveniles							
	Adults		x					
Sandeel			x					
Cod / Whiting					x			
Bass	Juveniles							
	Adults							
Plaice	Juveniles							
Sole	Juveniles							
Sea trout	Smolts							
	Whitling							
	Kelts							
	Adults	x						

6 Discussion of Results

6.1 Introduction

- 6.1.1 The Draw Zone and Alternative Draw Zone approaches ('alternative assessment' approaches) combined with the STRIKER model have generated the percentage annual mortality on each lifestage of each VER fish species. This combines the impact of entrainment and injury from the turbines, and provides an alternative scenario to the original IBM+STRIKER approach which calculated the percentage mean mortality for the VERs. The results are presented in Table 5.1 and the assumptions included within the models are discussed in Section 4 above with sources of information for the values chosen within each model provided in the datasheets in Appendix 2.
- 6.1.2 As any avoidance behaviour of fish encountering the flows and structure associated with the lagoon is unquantified and ultimately unknown at this stage. The Draw Zone and Alternative Draw Zone approaches have not attempted to quantify any avoidance factor to the models.
- 6.1.3 The results of the alternative assessment approaches presented in this paper, around the predicted impact of entrainment and injury from turbines from the IBM+STRIKER approach, have been used to update the Revised Appendix 7.7.1 '*Summary of Fisheries Impact Assessments for Valued Ecological Receptors V2*' (June, 2015). An overall impact judgement from the various individual impacts predicted, considering the revised IBM+STRIKER approach values and the sensitivity testing around this from the Draw Zone and Alternative Draw Zone approaches discussed below, is then provided in the Revised Appendix 7.7.1: '*Summary of Fisheries Impact Assessments for Valued Ecological Receptors V3: Turbine entrainment and injury sensitivity testing*' (TLSB, May 2016).
- 6.1.4 Consideration of impacts on compliance with the WFD will follow the agreed WFD methodology to be provided by NRW MLT.
- 6.1.5 Habitats Regulations Assessment Report submitted during the Examination concluded that there was no adverse effect on site integrity with respect to any of the fish species that are listed under the Habitats Directive and Ramsar designation, which are located from approximately ~60km (Severn Estuary Special Area of Conservation (SAC), Ramsar) to ~100km (River Wye SAC) upstream of the Project. Effects on the fish populations of the Carmarthen Bay and Estuaries SAC, Cleddau Rivers SAC and Pembrokeshire Marine SAC were screened out of further assessment at the Screening Stage.
- 6.1.6 The assessment using alternative modelling methodologies is considered to validate these conclusions i.e. that for each of the SAC species assessed, there will be no adverse effect on site integrity of the Severn Estuary, the River Usk or the River Wye fish populations as a result of the Project. This is discussed further below:

- The alternative assessment methodologies for sea lamprey has specifically considered the potential impact on fish leaving Swansea Bay rivers, then residing within the Bristol Channel and returning to freshwater to spawn. As sea lamprey do not show natal homing behavior they may not return to the Swansea Bay rivers to spawn, but may spawn in other rivers. The predicted annual mortality levels for sea lamprey in this instance are low, but notwithstanding this the impact on sea lamprey that leave the SAC rivers and reside within the Bristol Channel before returning to the SAC rivers will be markedly lower as they are some distance from the Project. It is not known what proportion of sea lamprey from the SAC rivers inhabit Swansea Bay whilst resident at sea, but due to the distance upstream of the SAC rivers and the limited records of occurrence within Swansea Bay, it is considered to be very low. As such it is concluded that there will be no adverse effect on any of the SACs integrity as a result of the Project.
- For river lamprey, the alternative assessment methodologies again considered the potential impact on fish leaving Swansea Bay rivers, then residing within the Bristol Channel and returning to freshwater to spawn. As river lamprey do not show natal homing behavior they also may not return to the Swansea Bay rivers to spawn, but may return to other rivers. The predicted annual mortality levels for river lamprey in this instance are low, but notwithstanding this the impact on river lamprey that leave the SAC rivers and reside within the Bristol Channel before returning to the SAC rivers will be markedly lower, as the SACs are some distance from the Project. In addition, the numbers of river lamprey that actually leave freshwater or the estuaries as a proportion of the whole population is very low, as they are understood to primarily reside close to the shore or in the estuaries. Therefore, the numbers of river lamprey from the SAC rivers that enter Swansea Bay are considered to be limited. As such it is concluded that there will be no adverse effect on any of the SACs integrity as a result of the Project.
- For shad, the alternative assessment methodologies considered fish leaving the rivers in the Bristol Channel, before residing within the Bristol Channel then returning to freshwater to spawn. Annual mortalities are predicted to be very low and whilst currently it is assumed in the models that there is an even distribution of the species across the Bristol Channel, there have been limited records of this species within Swansea Bay and so there are likely to be fewer shad in Swansea Bay than other areas in the Bristol Channel. As such it is concluded that there will be no adverse effect on any of the SACs integrity as a result of the Project.
- For salmon, the alternative assessment methodologies consider fish leaving the Swansea Bay rivers before migrating to the Arctic to mature, then returning to Swansea Bay rivers. As salmon show natal homing behavior, the majority of salmon within Swansea Bay are likely to be destined for Swansea Bay rivers. For salmon destined for the River Wye SAC, they could

potentially pass through Swansea Bay on their upstream or downstream migrations but they could also pass further offshore in the Bristol Channel and thereby avoid the lagoon altogether. With the large width of the Bristol Channel at the point it flows past Swansea Bay and the off-line nature of Swansea Bay 'hydrodynamically', means the use of selective tidal transport is likely to take this species past Swansea Bay upstream. As such the annual mortalities on salmon destined for the River Wye SAC are considered to be very small, and will not affect the integrity of the SAC.

- 6.1.7 For the purposes of the impact assessment, the fish species assessed fall into two broad categories, diadromous migrants (salmon, sea trout, river lamprey, sea lamprey, European eel and shad) and marine (sole, plaice, bass, cod/whiting, sandeel and herring) species. For the migrant species, where appropriate, resident lifestages have also been considered within the alternative assessment approaches.
- 6.1.8 From the results presented in Section 5, the Alternative Draw Zone approach produces the highest % mortality values for most species and lifestages and is closely matched (albeit with lower impacts) by the Draw Zone Approach. This result is reflective of similar input parameters in both models, the lack of any avoidance factor applied to either mode, as well as incorporating residency and delay factors. Conversely, the IBM+STRIKER model produces lower values for most species.
- 6.1.9 When reviewed together, the results of all the assessments indicate that the juveniles of all species suffer generally lower mortalities largely as a consequence of their lower injury (STRIKER) rates when passing through the turbines.
- 6.1.10 Marine species, are also predicted to have lower annual mortality percentages compared to migratory species. This reflects both the larger population ranges of the marine species and the use, by several species, of the Bristol Channel as a nursery/spawning ground for juveniles, rather than a residential area for mature adults. Therefore, the smaller, younger marine fish are more prevalent and whilst more likely to be exposed to the turbines and sluices have lower injury rates predicted by STRIKER IV. The migrant adult phases of marine species will be present for a shorter duration than the residential diadromous or marine counterparts.
- 6.1.11 In terms of herring, although the original ES IBM+STRIKER modelling predicted a 'High' level of impact, this was due to high shear stress levels in the original fixed speed turbine. The original IBM model for herring also parameterised the fish returning to a potential spawning site within the lagoon. Three such potential sites are purported to exist within Swansea Bay (two outside the lagoon) however, to date, survey work has not produced any evidence of herring spawning in the Bay. Redesign of the turbine to a variable speed design has also reduced the shear stress levels to extremely low levels, resulting in overall mortality predictions in the range of 0.04% - 0.82%.

- 6.1.12 The following sections provide a discussion of the results by species, of the IBM+STRIKER and alternative assessment models for turbine entrainment and injury.

6.2 Atlantic Salmon

Smolts

- 6.2.1 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.07% for salmon smolts that are leaving Swansea Bay having been born in Swansea Bay rivers at least two years earlier.
- 6.2.2 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 0.22% and 0.23%. The alternative approaches consider the presence of salmon smolts that are in Swansea Bay after leaving the rivers Tawe, Neath and Afan to migrate to their north Atlantic feeding grounds and their likelihood of encountering the turbines and being injured.
- 6.2.3 In order to try and address uncertainty around the retention of smolts within the lagoon a cut-off date of 1st July was used. After this date, any salmon smolts still residing in the lagoon were deemed to have been lost from the population and added to the total loss (mortality) figures. Alternative cut-off dates have been considered as part of our sensitivity analysis with earlier cut-off, run-timing and duration being considered.
- 6.2.4 Sensitivity analysis demonstrated that smolts that were exposed to, and entered the lagoon on one tide, had all left the lagoon within 97 tides (49 days) of entry with 50% leaving within 10 tides (5 days) and 95% within 40 tides (20 days). This suggests that the majority of smolts leaving the river at any point during April will have entered, and exited, the lagoon by 1st June.

Adults

- 6.2.5 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of between 0.51% and 0.63% for salmon one sea-winter (1SW), multi sea-winter (MSW) and kelt adults that are either leaving Swansea Bay as kelts having spawned, or as in-migrating adults to Swansea Bay rivers.
- 6.2.6 The Draw Zone and Alternative Draw Zone approaches have also separated the different lifestages of adult salmon into kelts, 1SW individuals and MSW individuals and generated % Annual Mortalities of between:
- Kelts – 4.40% and 4.94%
 - 1SW – 5.13% and 5.69%
 - MSW – 5.13% and 5.75%
- 6.2.7 As the annual mortality rate from turbine entrainment and injury for this species is >2%, based on Table 5.2 above, and Table 9.5 of the TLSB Environmental

Statement (TLSB), mitigation is required for this species. This mitigation will be in the form of offsetting for the egg losses from lost inward migrating fish each year.

- 6.2.8 Appropriate offsetting to provide additional spawning opportunities (by removing barriers to migration and implementing measures to improve existing habitat), sufficient to provide an increase in egg production to offset for the annual loss of 3.71% of adults, would reduce the predicted impact on salmon from 5.70% (Alternative Draw Zone weighted average) to below 2%.
- 6.2.9 The resultant annual egg loss as a consequence of fewer adults returning has been calculated. This estimates an annual egg loss, scaled to the Panteg distribution of 1SW and MSW salmon, of:
- 5.13% using the Draw Zone Approach
 - 5.70% using the Alternative Draw Zone Approach
- 6.2.10 Further details of the calculations of offsetting requirements are provided within the Mitigation, Monitoring and Offsetting Framework (TLSB, July 2016). Offsetting will be provided, on a precautionary basis, for the cohort level impacts as discussed in Section 6.14, rather than the annual egg losses shown above.

Summary

- 6.2.11 All the approaches for calculating impacts from turbine entrainment and injury on salmon adults and smolts consider the potential effects on the specific Swansea Bay population of salmon, as they leave (smolts and kelts) or home (1SW and MSW adults) to their natal rivers in order to spawn. The population area has been taken to be Swansea Bay for the Draw Zone and Alternative Draw Zone models.
- 6.2.12 This range of % Annual Mortality values is based solely on the population of salmon in Swansea Bay and is assumed, in the absence of data to the contrary, to comprise of fish destined for the Tawe, Neath and Afan. IBM modelling considered salmon and sea trout orientated towards the River Neath in order to assess the relative encounter rates with the River Tawe. Results indicated that for the Tawe, 603 adult salmon would encounter the turbines (with 997 passes) whilst only one Neath salmon would do likewise (making 3 passes). When combined with the STRIKER model the Mean Mortalities were 0.87% and 0.002% for the Tawe and Neath respectively. The Neath was modelled to also represent a worst-case scenario for the Afan and therefore, it is considered that the majority of any impact would be incurred in the Tawe.

6.3 Sea Trout

Smolts

- 6.3.1 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.08% for sea trout smolts that are leaving Swansea Bay having been born in Swansea Bay rivers at least two years earlier.

- 6.3.2 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 0.19% and 0.21%. The alternative assessment approaches consider the presence of sea trout smolts that are in Swansea Bay after leaving the Tawe, Neath and Afan rivers to migrate to their marine foraging areas. These fish then enter the whitling or resident adult component of the sea trout stock.

Whitling

- 6.3.3 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generated encounter rates for a combined adult lifestage of sea trout. This has been broken down into lifestages by applying different STRIKERv.4 injury rates (based on the length-frequency distributions) to generate predicted % Mean Mortality values for whitling and up to 7SW lifestages of sea trout. A predicted % Mean Mortality value of 1.15% for sea trout whitling has been generated.
- 6.3.4 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 2.08% and 2.33%. The alternative approaches consider the presence of sea trout whitling that have left Swansea Bay rivers (the Tawe, Neath and Afan) and then returned to the rivers in the same year.

Adults

- 6.3.5 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates predicted % Mean Mortality values of between 1.70% and 2.62% for sea trout adults that are either leaving Swansea Bay as kelts having spawned, or as in-migrating adults to Swansea Bay rivers, depending on their age.
- 6.3.6 The Draw Zone and Alternative Draw Zone approaches have separated the different lifestages of adult sea trout into sea-winter spawning migrants and kelts and generated % Annual Mortalities of between:
- 1SW Migrant – 4.69 and 5.21%
 - 1SW Kelt – 3.12 and 3.51%
 - 2SW Migrant – 5.07 and 5.65%
 - 2SW Kelt – 3.67 and 4.13%
 - 3SW Migrant – 5.69 and 6.34%
 - 3SW Kelt – 4.11 and 4.63%
 - 4SW Migrant – 6.30 and 7.01%
 - 4SW Kelt – 4.31 and 4.84%
 - 5SW Migrant – 6.94 and 7.72%
 - 5SW Kelt – 4.77 and 5.37%
 - 6SW Migrant – 5.91 and 6.63%
 - 6SW Kelt – 4.77 and 5.37%
 - 7SW Migrant – 5.91 and 6.63%
 - 7SW Kelt – 4.77 and 5.37%
- 6.3.7 Age classes of adult sea trout up to 7 sea winters have been chosen based on the age of fish caught in the Panteg Trap data, provided by NRW. The models show

that as fish age increases, % mortality rates increase, which is reflective of older fish being larger and therefore having increased STRIKERv.4 injury rate values. Individual STRIKERv.4 injury rates have been calculated for each age class for the purpose of the sensitivity testing approaches. Whilst the impacts on older fish will be greater, relatively few fish survive to these age classes as shown in the Panteg Trap data.

- 6.3.8 As the annual mortality rate from turbine entrainment and injury for this species is >2%, based on Table 5.2 above, and Table 9.5 of the TLSB Environmental Statement (TLSB), mitigation is required for this species. This mitigation will be in the form of offsetting for the egg losses from lost inward migrating fish each year.
- 6.3.9 Appropriate offsetting to provide additional spawning opportunities (by removing barriers to migration and implementing measures to improve existing habitat), sufficient to provide an increase in egg production to offset for the annual loss of 3.05% of adults, would reduce the predicted impact on sea trout from 5.04% (Alternative Draw Zone weighted average) to below 2%.
- 6.3.10 The resultant annual egg loss as a consequence of fewer adults returning has been calculated, scaled to the distribution of lifestages shown by data from Panteg Trap. This estimates an annual egg loss of:
- 4.78% using the Draw Zone Approach
 - 5.33% using the Alternative Draw Zone Approach
- 6.3.11 Further details of the calculations of offsetting requirements are provided within the Mitigation, Monitoring and Offsetting Framework (TLSB, July 2016). Offsetting will be provided, on a precautionary basis, for the cohort level impacts as discussed in Section 6.14, rather than the annual egg losses shown above.

Summary

- 6.3.12 All the approaches for calculating impacts from turbine entrainment and injury on sea trout adults and smolts consider the potential effects on the specific Swansea Bay population of sea trout, as they home to their natal rivers to spawn.
- 6.3.13 The impacts also consider that during their lives each sea trout can follow various life-history strategies with some fish remaining as residents within coastal waters for long periods before returning to spawn. Conversely, others opt to return to spawn either sooner, or more frequently. Each strategy adopted will result in different mortality assessments as each fish is exposed to the turbines at different stages (each time they migrate into/out of the rivers) and risk of injury changes as the fish age.
- 6.3.14 Sea trout that are regarded as 'resident' are those living in coastal waters (Bristol Channel) where they are foraging and growing. Migrants are those individuals that then leave the resident population migrate towards the Swansea Bay rivers thus increasing their risk of encounter and subsequent injury.

- 6.3.15 Sea trout do not undertake migrations on the same scale as Atlantic salmon, and are believed to remain comparatively closer to home waters (10-100km) but with some exceptional 200km+ tracks, as discussed in Appendix 4. Given the lack of information on the location of sea trout in coastal waters their distribution has been assumed to be random within the Bristol Channel for the purpose of the alternative modelling.
- 6.3.16 This range of % Annual Mortality values is solely on the Swansea Bay population of sea trout. The impact on the wider sea trout populations from other rivers in the Bristol Channel will be much smaller with sea trout bound for other rivers only being present in Swansea Bay occasionally.

6.4 Shad

- 6.4.1 Shad have been considered in our assessments despite the fact that they are not known to spawn in Swansea Bay rivers. For the purposes of this assessment we have not differentiated between Allis and Twaite shad as they are of a similar biology particularly in early years. However their geographic distribution and occurrence are different, with Allis shad rarely recorded in the UK.
- 6.4.2 A key difference between the two species is the survival of spawning by Twaite shad (which we have modelled) compared to Allis shad which all die after spawning. It is therefore reasonable to assume that our assessment for Twaite shad, which allows for repeat pre and post-spawning passage past the lagoon, would provide a higher impact assessment than could be expected for Allis shad if they were present.

Juveniles

- 6.4.3 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.04% for shad juveniles within Swansea Bay.
- 6.4.4 The Draw Zone and Alternative Draw Zone approaches have generated % Annual Mortality values of 0.01% for juvenile shad. The Draw Zone and Alternative Draw Zone (0.02%) approaches consider the presence of shad within their population range, defined as the Bristol Channel, and their likelihood of encountering the turbines whilst migrating out of the Bristol Channel rivers. This population range has been chosen as it encompasses the four principal spawning rivers for shad: Wye, Usk, Severn and Tywi. There is limited evidence of any shad spawning in the rivers entering Swansea Bay.

Migrating Adults

- 6.4.5 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.04% for shad adults within Swansea Bay.

6.4.6 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality for both pre-spawning and post-spawning adults separately of between:

- Pre-spawners – 0.13% and 0.15%
- Post-spawners – 0.13% and 0.15%

6.4.7 Both ranges for pre-spawners and post-spawners are the same, which as the so values are similar pre-spawners and post-spawners have the same STRIKERv.4 values. The Draw Zone and Alternative Draw Zone (0.13 to 0.15%) approaches consider the presence of pre-spawning and post-spawning shad within their population range, defined as the Bristol Channel, and their likelihood of encountering the turbines whilst migrating into the Bristol Channel rivers. The Bristol Channel population range has been chosen as it encompasses the four principal spawning rivers for shad of the Wye, Usk, Severn and Tywi. Shad do not spawn in the rivers entering Swansea Bay and there is limited evidence of shad presence within Swansea Bay itself.

Resident

6.4.8 Resident shad are defined as those adults that may remain in the Bristol Channel for all months other than those when they migrate into their natal rivers as pre-spawners and out as post-spawners. . The population ranges for the alternative assessment approaches consider the Bristol Channel as the population range for resident shad. This would be considered to be a conservative approach as the range of shad may be far larger, for example stretching into the Celtic Sea and Atlantic.

6.4.9 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 0.79% and 0.89% for resident shad. These values consider the likelihood of a resident shad that spends the whole year swimming through its population range of the Bristol Channel with no affinity to any particular area of its population range, encountering the turbines and being injured by them. This is therefore considered to be a precautionary value as some level of avoidance may be expected and there is likely to be some exchange between the population in the Bristol Channel and the wider population range in the Celtic Sea. As discussed in Section 4.1.12, the diurnal nature of this species has been considered within the assessment, by assuming that the resident fish are only active during the day. Shad tend to be diurnal in their migratory habits and have been found to enter and pass upstream passage structures primarily during the day (Fisher 1997; Haro and Kynard 1997; Sullivan 2004), while falling back to lower-velocity zones at night (Theiss 1997).

Summary

6.4.10 The IBM+STRIKER approach and the alternative approaches for shad have generated % Annual/Mean Mortality figures of <1%.

6.5 Eel

Elver

- 6.5.1 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.07% for elvers within Swansea Bay.
- 6.5.2 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 0.9% and 0.92% for elvers. The Draw Zone and Alternative Approaches (0.9-0.92%) consider the wider population of elvers that arrive from the mid-Atlantic and then migrate through Swansea Bay to reach the rivers Tawe, Neath, Afan.

Silver

- 6.5.3 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.20% for silver eels within Swansea Bay.
- 6.5.4 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 1.41% and 1.57% for silver eels. The Draw Zone and Alternative Draw Zone approaches consider the population of silver eels as they migrate out and head towards the Sargasso Sea. The population range is assumed to be Swansea Bay for the silver eels migrating outwards.

Resident

- 6.5.5 Resident eel are those developed from elvers that remain in the Bristol Channel and its estuaries all year round, without migrating into the rivers. Resident eels are believed to remain within the Bristol Channel until migrating to the Sargasso Sea to spawn with other silver eels. Data from studies in the Gironde (Davarate & Tomas, 2006) suggest that European eel populations are split between coastal, estuarine and freshwater environments.
- 6.5.6 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine has not generated a predicted % Mean Mortality value for resident eel. The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 1.76% and 1.95% for resident eels.
- 6.5.7 The alternative assessment approaches have considered the Bristol Channel population range of this lifestage and these model the likelihood of a resident eel that spends the whole year swimming through its population range of the Bristol Channel with no affinity to any particular area of its population range, encountering the turbines and being injured by them. This is therefore considered to be a precautionary value as some level of avoidance may be expected and there is likely to be some exchange between the population in the Bristol Channel and the wider population ranges in the Celtic Sea and Bay of Biscay. As discussed in Section 4.1.12, the diurnal nature of this species has been considered within the assessment, by assuming that resident eel are only active in the night.

Summary

- 6.5.8 The IBM+STRIKER approach and the alternative assessment approaches for elver have generated low % Annual Mortality figures of <1%. Resident eels, which have been assumed to have a discrete population within the Bristol Channel that are present year-round and which show no avoidance behaviour to the lagoon, have impacts below 2% and similarly impacts on silver eel leaving Swansea Bay rivers are <2%.

6.6 River Lamprey

Transformer

- 6.6.1 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.02% for river lamprey transformers within Swansea Bay.
- 6.6.2 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 1.07% and 1.19% for river lamprey transformers leaving Swansea Bay rivers.

Adult – migrant

- 6.6.3 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 1.31% for river lamprey adult migrants within Swansea Bay.
- 6.6.4 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 0.08% and 0.09% for river lamprey adult migrants. The Draw Zone and Alternative Draw Zone approaches consider the wider population of river lamprey transformers across their Bristol Channel population range as they do not show natal homing behavior and therefore having left the Swansea Bay rivers as a transformer could migrate to any of a number of rivers to spawn after maturing.

Adult – resident

- 6.6.5 Resident river lamprey have been taken as those adults that remain in the Bristol Channel year round, having left the Swansea Bay rivers as a transformer, without migrating into the rivers to spawn at any point. The impact on the returning population to spawn is considered at the migrant lifestage above. It is acknowledged that river lamprey, after leaving the river as transformers, generally reside in the estuarine environment (with some having been known to reside wholly within the freshwater environment). Therefore, the numbers of river lamprey that actually leave the rivers and enter Swansea Bay out as far as the turbines and sluices, or go into the Bristol Channel are likely to be very small. Therefore, the impacts predicted on resident river lamprey will be on a very small proportion of the population of residents, the majority of which will remain in the estuaries.

- 6.6.6 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine has not generated a predicted % Mean Mortality value for resident river lamprey as the IBM was only run for migratory lifestages. The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 0.48% and 0.54% for resident river lamprey.
- 6.6.7 These values consider the likelihood of a resident river lamprey that spends the whole year swimming through its population range of the Bristol Channel, with no affinity to any particular area of its population range, encountering the turbines and being injured by them. This is therefore considered to be a precautionary value as some level of avoidance may be expected and there is likely to be some exchange between the population in the Bristol Channel and the wider population range in the Celtic Sea.
- 6.6.8 The diurnal nature of this species has been considered within the models for this lifestage with lamprey understood to be active at night and dormant during daylight.

Summary

- 6.6.9 The IBM+STRIKER approach and the alternative approaches for lamprey have generated low % Annual Mortality figures of <1.2%.

6.7 Sea Lamprey

Transformer

- 6.7.1 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.15% for sea lamprey transformers within Swansea Bay.
- 6.7.2 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 0.76% and 0.85% for sea lamprey transformers leaving Swansea Bay rivers.

Adult – migrant

- 6.7.3 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 1.61% for sea lamprey adult migrants within Swansea Bay.
- 6.7.4 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 0.22% and 0.25% for sea lamprey adult migrants. The Draw Zone and Alternative Draw Zone approaches (0.22 – 0.25%) consider the wider population of sea lamprey transformers across their Bristol Channel population as they do not show natal homing behavior and therefore having left the Swansea Bay rivers as a transformer could migrate to any of a number of rivers to spawn after maturing. Therefore, only a small proportion of the population of migrants will encounter the lagoon turbines and sluices.

Adult – resident

- 6.7.5 Resident sea lamprey have been taken as those adults that remain in the Bristol Channel year round, without migrating into the rivers to spawn at any point. The impact on the returning population to spawn is considered at the migrant lifestage above.
- 6.7.6 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine has not generated a predicted % Mean Mortality value for resident sea lamprey as the IBM was run for migratory lifestages only. The, Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 1.32% and 1.49% for resident sea lamprey.
- 6.7.7 These values consider the likelihood of a resident sea lamprey that spends the whole year swimming through its population range of the Bristol Channel with no affinity to any particular area of its population range, encountering the turbines and being injured by them. This is therefore considered to be a precautionary value as some level of avoidance may be expected and there is likely to be some exchange between the population in the Bristol Channel and the wider population range in the Celtic Sea.

Summary

- 6.7.8 Catches and recordings of sea lamprey within Swansea Bay are rare and whilst the IBM+STRIKER approach has generated a figure of 1.61% Mean Mortality for sea lamprey adult migrants within Swansea Bay, the population range of sea lamprey is much wider, and they do not show homing behaviour to their natal rivers. Therefore, the presence of sea lamprey in Swansea Bay will likely be on an occasional basis as they migrate to their SAC populations in the Severn and Carmarthen Bay. Swansea Bay only makes up approximately 2.2% of the wider Bristol Channel population range of this species and therefore, impacts will be imperceptible on the wider population. The alternative assessment approaches for sea lamprey have generated low % Annual Mortality figures of <2%.

6.8 Herring

Juvenile

- 6.8.1 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.11% for juvenile herring within Swansea Bay.
- 6.8.2 The, Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of 0.04%. The Draw Zone and Alternative Draw Zone approaches consider the impact on juvenile herring present within the wider population and their likelihood of encountering the turbines and being injured.

Adults

- 6.8.3 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Annual Mean Mortality value of 0.82% for adult herring within Swansea Bay.
- 6.8.4 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 0.05% and 0.07%. The Draw Zone and Alternative Draw Zone approaches (0.05% and 0.07% respectively) consider the impact on adult herring present within the wider Bristol Channel population and their likelihood of encountering the turbines and being injured.

Summary

- 6.8.5 The IBM+STRIKER approach and the alternative assessment approaches for herring have generated low % Annual Mortality figures of <1%.
- 6.8.6 Early modelling of herring (for ES) produced higher % Annual Mortality values for herring. These were based upon higher encounter rates due to the IBM modelling herring returning to a spawning position within the proposed lagoon and increased injury rates inflicted by an older turbine design with significantly higher shear stress levels (see 2.1.3 above).

6.9 Sandeel

- 6.9.1 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.01% for sandeel within Swansea Bay.
- 6.9.2 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 0.18% and 0.20%. The Draw Zone and Alternative Draw Zone approaches consider the impact on sandeel present within the wider Bristol Channel population and their likelihood of encountering the turbines and being injured.

Summary

- 6.9.3 The IBM+STRIKER approach and the sensitivity testing approaches for sandeel have generated low % Annual Mortality figures of <1%.

6.10 Cod / Whiting

- 6.10.1 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine has not generated a predicted % Mean Mortality value for cod/whiting within Swansea Bay.
- 6.10.2 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of between 0.31% and 0.34%. The Draw Zone and Alternative Draw Zone approaches consider the impact on cod/whiting present within the wider Bristol Channel population and their likelihood of encountering the turbines and being injured.

Summary

- 6.10.3 The IBM+STRIKER approach and the alternative approaches for cod/whiting have generated small % Annual Mortality figures of <1%.

6.11 Bass

Juvenile

- 6.11.1 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.08% for juvenile bass within Swansea Bay.
- 6.11.2 The, Draw Zone and Alternative Draw Zone approaches have also generated a % Annual Mortality of 0.08%. The Draw Zone and Alternative Draw Zone approaches consider the impact on juvenile bass present within the wider Bristol Channel population and their likelihood of encountering the turbines and being injured.

Adult

- 6.11.3 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.25% for adult bass within Swansea Bay.
- 6.11.4 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of 0.02%. The Draw Zone and Alternative Draw Zone approaches consider the impact on adult bass present within the wider Bristol Channel population and their likelihood of encountering the turbines and being injured.

Summary

- 6.11.5 The IBM+STRIKER approach and the alternative assessment approaches for bass have generated low % Annual Mortality figures of <1%.

6.12 Plaice

- 6.12.1 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.003% for juvenile plaice within Swansea Bay.
- 6.12.2 The Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of 0.01%. The Draw Zone and Alternative Draw Zone approaches (0.01%) consider the impact on juvenile plaice present within the wider Celtic Sea population and their likelihood of encountering the turbines and being injured.

Summary

- 6.12.3 The IBM+STRIKER approach and the alternative approaches for plaice have generated low % Annual Mortality figures of <1%.

6.13 Sole

- 6.13.1 The IBM+STRIKER approach for the Andritz 7.2m variable speed turbine generates a predicted % Mean Mortality value of 0.003% for juvenile sole within Swansea Bay.
- 6.13.2 The Volumetric, Draw Zone and Alternative Draw Zone approaches have generated a % Annual Mortality of 0.06%. The Draw Zone and Alternative Draw Zone approaches consider the impact on juvenile sole present within the wider Bristol Channel population and their likelihood of encountering the turbines and being injured.

Summary

- 6.13.3 The IBM+STRIKER approach and the alternative approaches for sole have generated low % Annual Mortality figures of <1%.

6.14 Population Level impacts

- 6.14.1 The following section presents the assumptions, methods and results of an assessment of the levels of potential population impact for migratory and marine fish. The assessment is based on the results of the Alternative Draw Zone method of calculating annual mortality rates for turbine entrainment and injury as these were the highest figures generated.
- 6.14.2 The Environmental Statement (ES) prepared to inform the DCO and Marine Licence applications expressed impacts from turbine entrainment and injury, modelled using IBM and STRIKER v.4, as a percentage annual mortality at different lifestages. For example the impact on outward migrating salmon smolts or inward migrating salmon adults was given as a percentage annual mortality for each lifestage. This was then compared with the magnitude criteria as shown in Table 5.2, extracted from the ES, to provide expected magnitudes of impact. Table 5.1 above presents comparative percentage annual mortality figures to those modelled for the ES and applies magnitudes of impact to them in the same way. In terms of offsetting, where a potential significant impact is predicted (greater than the 2% annual mortality threshold) for any species lifestage, the weighted average impact on that species has been calculated based on relevant age structure data, such as from the Panteg fish trap. This method of calculation for offsetting remains an appropriate format to present the results as mitigation by offsetting will be provided such that it will offset impacts every year once implemented. Therefore, it is considered appropriate to offset for those impacts experienced annually and offsetting requirements have been calculated on this basis within the Mitigation, Monitoring and Offsetting Framework (TLSB, July 2016).
- 6.14.3 When considering impacts for species across all of their lifestages, this has been expanded to include the impact over multiple years in order to further understand the potential consequences at the population level. It should be noted that for

some species there is no existing data on the age structure, or how many individuals reach the various lifestages, for example for eels, river lamprey, sea lamprey or shad, or the marine species in Swansea Bay or the Bristol Channel. Some evidence can be drawn from studies from the River Severn, South West England, and the UK or from further afield, and assumptions of life histories have been made on that basis. However, the definitive proportion of different ages of these species that may be present in a given cohort is unknown. Notwithstanding this data exists for salmon and sea trout from trapping at Panteg (1991-2002), and therefore it has been possible to develop an age structure for these species and impacts are correspondingly related to that age structure.

- 6.14.4 Steps have been taken to develop life cycle models for salmon within the River Tawe, and for shad more widely, to explore longer-term effects of the Project without the application of mitigation by offsetting. Significant uncertainties remain, however, with a large number of the parameters within these models, such as marine survival, in-river survival, angler exploitation and post-angling survival rates.
- 6.14.5 Data requirements for life cycle models are substantial and the availability of the required data limits their application to well-studied populations. Therefore, it is considered at this stage, that the life cycle models for the Tawe are not able to be appropriately calibrated to the various parameter values as there is not sufficient baseline data available to parameterise these models within an acceptable level of certainty. Further work is proceeding to understand and address the uncertainties inherent within the models, with the aim of improving their future effectiveness.

Salmon and Sea Trout

- 6.14.6 As discussed above, for salmon and sea trout, the age structure of returning fish is better understood from the data collected at the Panteg Trap on the River Tawe between 1991 and 2002. Therefore, consideration is given to the impact on a cohort of fish returning to spawn, over the whole period that that cohort is present. This is achieved through calculating the survival rates for each lifestage as the product of the survival rates for all the previous lifestages that the fish has been through. This, for multiple spawners such as sea trout, considers the potential for a fish to leave the river as a smolt, then return to spawn multiple times passing the lagoon as both an inward migrant and an outward migrant (kelt) over a series of years.
- 6.14.7 For salmon in any given year, the fish returning comprise individuals derived from multiple brood years (i.e. year classes) because the fish of a single year class may leave the river as smolts aged 1, 2 or 3 years and each of these smolt groups may return after 1,2 or (rarely) 3 or more sea winters. In addition, a small number of adults may survive spawning, leave the river as kelts and return to spawn after one more sea winter. For sea trout the same pattern of returning fish applies, with two exceptions: (1) fish may return from sea in their smolting year, before their first sea winter, (2) many more survive spawning than do salmon, and thus return

from sea more than once and are multiple spawners. Therefore sea trout adult runs are much more diverse in their individual life histories. This, coupled with the complexity and uncertainty of the process of partial migration (Chapman et al., 2012; Dodson et al., 2013) by which brown trout become anadromous (i.e. turn into sea trout), have meant that full life cycle modelling for sea trout was not practicable with available knowledge and data.

- 6.14.8 Subsequently, levels of egg losses have been derived based on the egg losses of the cohort over their life history, as any offsetting would also be provided to increase egg production. However, providing offsetting to the level of the losses of the cohort over their life history, but in each year, is over and above the requirements of the impacts predicted and is done to address the uncertainty within the turbine entrainment and injury modelling. Th
- 6.14.9 The cohort egg losses calculation takes into consideration the potential for the increased risk to older and multiple spawning fish that have had to pass by the lagoon on multiple occasions to spawn in their natal river, or who are present in the bay for longer periods of time as resident. Tables 6.1 and 6.2 provides the calculations of egg losses for salmon and sea trout for the cohort.

Table 6.1: Salmon cohort egg losses. This impact is on the returning cohort over two years (1SW returning spawners, and MSW returning spawners)

	Probability of survival to stage (as the product of survival rates of all previous lifestages)	Egg/Female (2015 EDR assessment, NRW)	Baseline population based on management target. 1SW:MSW Age structure based on 1991-2002 Panteg data.	Proportion of Females (2015 EDR assessment, NRW)	Baseline egg production	Egg production with Project in place	Egg production lost	% impact on egg deposition
Smolts	0.9977							
1SW	0.9409	4546	947	0.49	2,109,300	1,984,685	124,615	5.91%
Kelts	0.8941							
MSW	0.9403	6293	99	0.42	260,700	245,138	15,562	5.97%
				Total egg production of the cohort	2,370,000	Total egg production lost from the cohort	140,177	5.915%

Table 6.2: Sea trout cohort egg losses. This impact is on the returning cohort over seven years (1SW returning spawners through to 7SW returning spawners)

Lifestage history	Probability of survival to lifestage	Lifestage structure from River Tawe Fisheries Performance: Annual Report 2002, Environment Agency. No. of fish from assumed management target for River Tawe.	Egg/Female (based on UK fecundity equation; Review of Sea Trout Fecundity R&D Technical Report W60, Solomon, 1997; and length data from Panteg Trap 1991-2002)	Proportion of Females (Panteg Trap data 1991-2002)	Baseline egg production	Egg production with Project in place	Egg Production lost	
Smolt and Whitling	0.9746	142	1,158	0.83	135,814	132,366	3,448	
Smolt, Whitling and 1SW	0.9239	129	2,670	0.73	251,023	231,913	19,110	
Smolt, Whitling, 1SW + 1 spawning mark	0.8410	41	3,850	0.60	95,804	80,575	15,229	
Smolt, Whitling, 1SW + 2 spawning marks	0.7552	12	5,000	0.59	35,268	26,635	8,633	
Smolt, Whitling, 1SW + 3 spawning marks	0.6698	4	5,560	0.68	16,365	10,961	5,404	
Smolt, whitling, 1SW + 4 spawning marks	0.5882	0	6,618	0.71	2,267	1,334	934	
Smolt, whitling, 1SW + 5 spawning marks	0.5197	0	7,936	0.60	2,284	1,187	1,097	
Smolt and 1SW only	0.9459	577	2,670	0.73	1,121,671	1,061,012	60,660	
Smolt, 1SW + 1 spawning mark	0.8611	124	3,850	0.60	287,412	247,494	39,917	
Smolt, 1SW + 2 spawning mark	0.7732	38	5,000	0.59	111,447	86,175	25,271	
Smolt, 1SW + 3 spawning mark	0.6858	18	5,560	0.68	69,095	47,384	21,711	
Smolt, 1SW + 4 spawning mark	0.6022	6	6,618	0.71	27,208	16,384	10,824	
Smolt, 1SW + 5 spawning mark	0.5321	2	7,936	0.60	9,135	4,861	4,275	
Smolt, 1SW + 6 spawning mark	0.4701	0	7,179	1.00	3,443	1,619	1,825	
Smolt and 2SW only	0.9414	25	3,850	0.60	59,042	55,585	3,457	
Smolt, 2SW + 1 spawning mark	0.8454	8	5,000	0.59	22,571	19,081	3,490	
Smolt, 2SW + 2 spawning marks	0.7498	2	5,560	0.68	9,091	6,816	2,275	
Smolt, 2SW + 3 spawning marks	0.6584	1	6,618	0.71	6,802	4,478	2,324	
	Total No. of fish	1131					Total No. of eggs	2,265,743
							Total egg production lost	229,881
							% egg production lost	10.15%

Shad, eel, river lamprey and sea lamprey

- 6.14.10 As with salmon and sea trout, for the other diadromous species considered within the assessment; shad, eel, river lamprey and sea lamprey; consideration of impacts at the population level also requires an understanding of the age structure of the population and the life history of each species. This includes number of times that shad, river lamprey and sea lamprey may return to spawn needs to be understood, as well as the duration and area of residency in between spawning or before migrating to spawn in the case of eels.
- 6.14.11 Table 6.3 provides a review of existing literature on the life history of these species. It presents the assumptions made in considering the population level impacts on shad, eel, river lamprey and sea lamprey through generation of a life history which is used for the cohorts of these species.

Table 6.3: Assumptions of life history made for shad, eel, river lamprey and sea lamprey population impact consideration.

Species	Life history literature review	Modelled life history
Shad	Migrates from freshwater to coastal waters as a juvenile. Remains resident for a period of 2-4 years to mature (Kottelat, M. and J. Freyhof, 2007), before returning to spawn, potentially on multiple occasions (Hillman, 2003). Spent adults return to the sea and may spawn for 3-4 seasons throughout their lifetime (Kottelat, M. and J. Freyhof, 2007), though most Twaite shad caught from around the coast of south-west England were found to have spawned either once or twice before and most female Twaite shad first spawned in their fourth year (Hillman, 2003). The maximum ages of males and females in the Severn were 10 and 12 years, respectively. Shad are distributed around the north east Atlantic: from the British Isles and southern Norway to Morocco, including the Baltic, Mediterranean and Black Seas (Whitehead, 1985). Female Twaite shad have been estimated to lay between 25,942 and 675,000 eggs per year (Maitland and Hatton-Ellis, 2003). The relative fecundity has been reported to range from 42,540 to 302,358 eggs per kg; and at 139,479 in the River Severn (Aprahamian, unpublished). Annual instantaneous mortality at sea of Twaite shad has been approximated at 0.67 year⁻¹ (Aprahamian et al., 2010) A sex ratio of 1:11 male:female was found by Hillman (2003) in South West England, however noting that sexual dimorphism (females are larger) could explain the apparent scarcity of males in the population: their smaller size would reduce the chance of being caught in nets. Also, smaller body size made sexing the fish more difficult, making males more likely to be among the fish that were too small to sex.	Leaves river as juvenile. Resident for 2 years, split between Bristol Channel and Celtic Sea, then spawns in three subsequent years, with residency in between.
Eel	Migrates as a glass eel/elver from the Sargasso Sea. Matures either in freshwater or estuarine/coastal waters for a number of years. The growth phase lasts from 3 to 15 yr or more (Dávalos and Tomas (2006)) before returning to the Sargasso Sea to spawn as a silver eel.	Enters Swansea Bay rivers as glass eel/elver. 27% remain resident in coastal waters (19% marine resident plus

Species	Life history literature review	Modelled life history																														
	Eel residency distribution following Davelal and Tomas (2006): <table><tr><th></th><th colspan="3">Capture location</th><th></th></tr><tr><th></th><th>Coastal (n=45)</th><th>Estuarine (n=162)</th><th>River (n=63)</th><th>Overall proportion</th></tr><tr><td>Freshwater resident</td><td>0%</td><td>15%</td><td>97%</td><td>37%</td></tr><tr><td>Estuarine resident</td><td>16%</td><td>44%</td><td>3%</td><td>21%</td></tr><tr><td>Marine resident</td><td>57%</td><td>0%</td><td>0%</td><td>19%</td></tr><tr><td>Nomad</td><td>27%</td><td>41%</td><td>0%</td><td>23%</td></tr></table> In the Severn, eels less than 150 mm tend to be 3 years old or younger sexually undifferentiated eels. Those 150 mm to 450 mm are young sexually undifferentiated eels, immature males and females and mature males. Eels longer than 450 mm are almost all female. In the lower reaches of the Severn, eels aged from 7 to 8 years were generally the most abundant (Aprahamian, 1988). Younger, shorter eels also tend to be found in estuaries or the lower reaches of rivers, and Naismith and Knights (1992) found that in the Thames estuary, 82% of eels caught within the estuary sample sites were between 250-300mm in length. Moriarty & Dekker (1997) suggest natural mortality to be in the order of 75% over the total continental life span, but Dekker (2000) showed this assumption to lead to incongruous results and used 75% mortality over the pre-exploited yellow eel stage instead, conforming to an instantaneous mortality rate of 13.8%. The existence of 3 genetically distinct sub-populations of eel is suggested: a Northern European subpopulation (consisting mainly of the Icelandic stocks); a Western European subpopulation (including the Baltic, the Mediterranean and Black Sea); a Southern sub-population (including stocks of Morocco) (Wirth and Bernatchez, 2001).		Capture location					Coastal (n=45)	Estuarine (n=162)	River (n=63)	Overall proportion	Freshwater resident	0%	15%	97%	37%	Estuarine resident	16%	44%	3%	21%	Marine resident	57%	0%	0%	19%	Nomad	27%	41%	0%	23%	23% nomads one-third of the time) for 8 years of maturation, split between Bristol Channel and Celtic Sea. Then leaves Swansea Bay river for Sargasso Sea as silver eel. Swansea Bay impacts considered as proportion of the wider Western Wales RBD
	Capture location																															
	Coastal (n=45)	Estuarine (n=162)	River (n=63)	Overall proportion																												
Freshwater resident	0%	15%	97%	37%																												
Estuarine resident	16%	44%	3%	21%																												
Marine resident	57%	0%	0%	19%																												
Nomad	27%	41%	0%	23%																												
River lamprey	Migrates from freshwater to coastal waters as a juvenile, though a proportion are permanent freshwater residents (Renaud, 2011). Remains resident for a period of years before returning to spawn. Adults die after spawning. Juveniles live within the substratum for 3–5 years until metamorphosis, when they migrate to estuaries. After spending one to two years in estuaries (Kottelat and Freyhof, 2007), maturing adults cease feeding in autumn and move back upriver to spawn. Fecundity in river lamprey is highly variable and ranges from 650 to 42,500 eggs/female; however an average of 16,000 eggs per female was found by Maitland (1980). In the absence of specific mortality rates of river lamprey available within the literature, values of annual instantaneous mortality has been assumed from sea lamprey models by Robinson et al. (2013) of between 9.2 and 14.4%. Hardisty & Potter (1971) noted that sex ratios in <i>Lampetra</i> vary from near-equality to as much as five males to one female, and suggest that the annual fluctuations are due to environmental factors such as	Leaves river as juvenile. Resident for 2 years, split between estuarine and coastal environment, before returning to rivers to spawn. Presence of river lamprey around the turbine and sluice gate housing is considered to be unlikely due to their preference for residing within estuaries and coastal waters, therefore, it has been assumed that 75% of the population is resident within estuaries and																														

Species	Life history literature review	Modelled life history
	temperature or water levels, and that these factors vary from one river system (and one year) to another.	therefore not at risk of turbine entrainment and injury.
Sea lamprey	Migrates from freshwater to coastal waters as a juvenile. Remains resident for a period of years before returning to spawn. Species is not a repeat spawner. Sea Lamprey ammocoetes (larvae) inhabit burrows in muddy/sandy substrata for their first 5–6 years. Spends its adult life in the sea for 20-36 months (Kottelat and Freyhof, 2007). Sea lamprey are distributed around the north east Atlantic, from Norway including Iceland and the Barents Sea, south to northern Africa and throughout the western and central Mediterranean (Kottelat and Freyhof, 2007). Female sea lamprey have been estimated to lay on average, 172,000 eggs (Maitland, 1980). Annual instantaneous mortality of sea lamprey was estimated by Robinson et al, (2013) of between 9.2 and 14.4%. Hardisty & Potter (1971) noted that sex ratios in Lampetra vary from near-equality to as much as five males to one female, and suggest that the annual fluctuations are due to environmental factors such as temperature or water levels, and that these factors vary from one river system (and one year) to another.	Leaves river as juvenile. Resident for 3 years, split between Bristol Channel and Celtic Sea, before returning to rivers to spawn once.

6.14.12 Tables 6.4 to 6.7 present the application of the annual mortality rates from the Alternative Draw Zone approach across cohorts of eel, river lamprey, sea lamprey and shad. As for salmon and sea trout, this considers the impact over a number of years.

Table 6.4: Eel cohort age structure changes.

Year	Lifestage (marine/freshwater split follows Dával and Tomas, 2006).	Baseline Population distribution (indicative starting population with distribution based on 13.8% annual instantaneous mortality; Dekker, 2000)	Survival at stage	Predicted Population distribution
1	Elver/glass eel (inward migrant to Swansea Bay)	1000	0.9908	990.76
2	Resident (27% marine, 73% estuarine/freshwater; marine residency split between Bristol Channel and Celtic Sea)	862	0.9968	851.32
3	Resident (27% marine, 73% estuarine/freshwater; marine residency split between Bristol Channel and Celtic Sea)	743.04	0.9968	731.50
4	Resident (27% marine, 73% estuarine/freshwater; marine residency split between Bristol Channel and Celtic Sea)	640.50	0.9968	628.54
5	Resident (27% marine, 73% estuarine/freshwater; marine residency split between Bristol Channel and Celtic Sea)	552.11	0.9968	540.08
6	Resident (27% marine, 73% estuarine/freshwater; marine residency split between Bristol Channel and Celtic Sea)	475.92	0.9968	464.06
7	Resident (27% marine, 73% estuarine/freshwater; marine residency split between Bristol Channel and Celtic Sea)	410.25	0.9968	398.75
8	Resident (27% marine, 73% estuarine/freshwater; marine residency split between Bristol Channel and Celtic Sea)	353.63	0.9968	342.63
9	Resident (27% marine, 73% estuarine/freshwater; marine residency split between Bristol Channel and Celtic Sea)	304.83	0.9968	294.40
10	Silver Eel (escapement from Swansea Bay)	262.76	0.9843	249.78
% Impact on Silver Eel escapement numbers (Swansea Bay)				4.94
Area of Swansea Bay (12,814ha), Neath, Tawe and Afan estuaries (334.1ha) as proportion of RBD coastal and transitional waters (446,628.8ha)				0.029
% Impact on Silver Eel escapement numbers (Western Wales RBD)				0.15

Table 6.5: River lamprey cohort egg losses.

Year	Lifestage	Baseline Population distribution (indicative starting population with distribution based on 50:50 1SW:2SW returning split, and 11.8% annual instantaneous mortality; Robinson <i>et al.</i> , 2013)	Survival to stage	Fecundity (eggs per female; Maitland, 1980)	Sex Ratio (Female to Male ratio; Hardisty and Potter, 1971)	Baseline egg production	Egg production with Project
1	Transformer	1000	0.9881				
2	1SW Migrant (including 1 year of residency)	441	0.9859	16000	0.17	1,199,520	1,182,623
3	2SW Migrant (including 2 years of residency)	388.962	0.9846	16000	0.17	1,057,977	1,041,682
Totals						2,257,497	2,224,304
						% egg loss	1.47

Table 6.6: Sea lamprey cohort egg losses.

Year	Lifestage	Baseline Population distribution (indicative starting population with distribution based on 1/3 of the population returning at each of 1SW, 2SW and 3SW, and 11.8% annual instantaneous mortality; Robinson et al., 2013)	Survival to stage	Fecundity (eggs per female; Maitland, 1980)	Sex Ratio (Female to Male ratio; Hardisty and Potter, 1971)	Baseline egg production	Egg production with Project
1	Transformer	1000	0.9915				
2	1SW Migrant (including 1 year of residency split between Bristol Channel and Celtic Sea)	294	0.9801	172000	0.17	8,596,560	8,425,362
3	2SW Migrant (including 2 years of residency split between Bristol Channel and Celtic Sea)	259.308	0.9713	172000	0.17	7,582,166	7,364,403
4	3SW Migrant (including 3 years of residency split between Bristol Channel and Celtic Sea)	228.709656	0.9626	172000	0.17	6,687,470	6,437,044
Totals						22,866,196	22,226,809
						% egg loss	2.80

Table 6.7: Shad cohort egg losses.

Year	Lifestage	Baseline Population distribution (indicative starting population with distribution based on 67% annual instantaneous mortality; Aprahamian, 2010)	Survival to stage (including residency in between spawning)	Fecundity (eggs per female; based on average of 600g, 800g and 1kg fish weight (assumption) and 139,379 eggs/kg from Aprahamian, unpublished)	Sex Ratio (Female to Male ratio; Hillman, 2003)	Baseline egg production	Egg production with Project
1	Juvenile	1000	0.9999				
2	1SW resident (residency split between Bristol Channel and Celtic Sea)	330	0.9945				
3	2SW resident (residency split between Bristol Channel and Celtic Sea)	108.9	0.9892				
5	1st spawning	35.937	0.9877	83627.4	0.083	249,441	246,376
6	2nd spawning	11.85921	0.9808	111503.2	0.083	109,754	107,649
7	3rd spawning	3.9135393	0.9740	139379	0.083	45,274	44,096
Totals						404,469	398,121
						% egg loss	1.57

Marine fish species

- 6.14.13 Resident marine species have widely dispersed populations and do not migrate into freshwater to spawn, therefore are not exposed to the same risk of lagoon encounter as diadromous fish species. Whilst knowledge of the age structure of the populations of these species is available on a wide geographic basis (e.g. ICES rectangles) local site specific scale data is limited. As such in order to calculate the potential maximum population impact, the percentage annual mortality rates from the Alternative Draw Zone approach (as the highest figures generated), have been applied to individuals of these species across the juvenile phase and across multiple adult phases, based on existing knowledge of the likely maximum age of fish, if data exists for them, within the Bristol Channel or, if not, more generally as the likely maximum age of fish. This is precautionary as it assumes the individuals inhabit the same area (Bristol Channel/Celtic Sea) for their entire life and considers every fish to reach the maximum reported age of that species. Many individuals are likely to inhabit a wider area at some point of their life cycle, or will not live to the maximum reported species age, and as such would be subject to lower impacts. Table 6.8 provides the calculations of mortality over all life stages of the marine species considered.

Table 6.8: Impacts for marine species over their entire life, using the maximum reported age for each species

Species	Life history	Annual Mortality	Mortality over whole life history
Bass	Sexual maturity occurs between 4 and 8 years of age. Maximum reported age of this species is 30 years (Kottelat, M. and J. Freyhof, 2007).	Juvenile: 0.0008 Adult: 0.0002	0.96% (1-0.0008) ⁶ x (1-0.0002) ²⁴
Sole	Maximum reported age of this species is 26 years (Deniel, C., 1990). Juveniles live in coastal areas for 2-3 years before migrating to deeper water (ICES, 2012).	Juvenile: 0.0006	0.0018% (1-0.0006) ³
Cod/Whiting	Maximum reported age of cod is 25 years (Muus and Dahlstrom, 1974). Maximum reported age of Whiting is 20 years (Muus and Nielsen, 1999). Parker-Humphreys (2004) indicates a maximum length of 80cm for cod within the Bristol Channel. ICES (2006) suggests a age-growth curve for Atlantic cod that shows an 80cm cod is approximately 6 years of age. Brander (1994) also suggests Celtic Sea cod reach a weight of 15kg by age 7, but with no further data on cod older than this age.	0.0034	2.36% (1-0.0034) ⁷
Herring	Sexual maturity occurs between 2 and 9 years of age (ICES, 2009). Max reported age of this species is 25 years (Corten, 2002).	Juvenile: 0.0004 Adult: 0.0005	1.18% (1-0.0004) ⁶ x (1-0.0005) ¹⁹

Plaice	Maximum reported age of this species is 50 years (Muus and Dahlström, 1974). Maturity generally occurs after three years (Pawson, 1995). Dunn and Pawson (2002) suggests that the majority of plaice at ages 1-2 years remained within 20km of the nursery ground.	Juvenile: 0.0001	0.03% (1-0.0001) ³
Sandeel	Maximum reported age of this species is 7 years (Reay, 1973).	0.0019	1.39% (1-0.0020) ⁷

6.15 Consideration of age structure impacts

- 6.15.1 For multiple spawners, such as sea trout, with a known population distribution (from Panteg trap data, 1991-2002), it is possible to consider how the potential annual mortality effect of the lagoon may affect the age structure of the population without the implementation of any mitigation by offsetting.
- 6.15.2 The age structure of sea trout present within the River Tawe from 1991 to 2002, from River Tawe Fisheries Performance: Annual Report (Environment Agency, 2002) is shown in Table 6.9.

Table 6.9: Population structure of sea trout from Environment Agency (2002)

Lifestage history	Number of individuals (River Tawe Fisheries Performance: Annual Report, Environment Agency, 2002)
Smolt and Whitling	296
Smolt, Whitling and 1SW	269
Smolt, Whitling, 1SW + 1 spawning mark	86
Smolt, Whitling, 1SW + 2 spawning marks	25
Smolt, Whitling, 1SW + 3 spawning marks	9
Smolt, whitling, 1SW + 4 spawning marks	1
Smolt, whitling, 1SW + 5 spawning marks	1
Smolt and 1SW only	1202
Smolt, 1SW + 1 spawning mark	258
Smolt, 1SW + 2 spawning marks	79
Smolt, 1SW + 3 spawning marks	38
Smolt, 1SW + 4 spawning marks	12
Smolt, 1SW + 5 spawning marks	4
Smolt, 1SW + 6 spawning marks	1
Smolt and 2SW only	53
Smolt, 2SW + 1 spawning mark	16
Smolt, 2SW + 2 spawning marks	5
Smolt, 2SW + 3 spawning marks	3

- 6.15.3 There are three key strands present within the age structure: those fish that return as whitling to spawn and then spawn each year thereafter; those fish that return after one winter at sea and each year thereafter to spawn; and those fish that return after two winters at sea and each year thereafter to spawn. For each

of these strands, it is possible to identify a baseline loss between lifestages without the lagoon in place, as shown in Table 6.10, and then include a loss between lifestages as a result of the Project and combine them to explore potential age structure changes.

- 6.15.4 The likelihood of mortality at each lifestage is calculated, both from the Project and considering the wider pressures on the fish in between the lifestages, which are inferred from the losses between lifestages shown by the existing age structure. The assessment assumes that TLSB has an impact on the lifestage prior to any other pressures, and is therefore on all the individuals at that lifestage.
- 6.15.5 In reality, other pressures will be experienced by the fish between entering the river as migrants and leaving as a kelt, whereas the assessment assumes that they face no other pressures until they have passed the lagoon as both a migrant and a kelt at that lifestage. Therefore, the assessment assumes the lagoon presents the first impact on that lifestage. If other pressures were applied at an earlier point, the contribution of impact from the Project would be reduced and correspondingly would provide a reduced contribution to the overall losses between lifestages.

Table 6.10: Calculation of potential future age structure of multiple spawning sea trout considering age structure shown by River Tawe Fisheries Performance: Annual Report (Environment Agency, 2002) and application of mortalities by lifestage from the Project using the Alternative Draw Zone approach.

Returning as Whitling						
Lifestage history	No. of individuals given by assumed Management Target. Age structure given by River Tawe Fisheries Performance: Annual Report, Environment Agency, 2002	% Loss from previous lifestage due to other pressures (e.g. predation, pollution).	Notes	% Loss from previous lifestage due to TLSB	% loss from previous lifestage combining TLSB and other pressures	Age structure incorporating % loss from previous lifestage combining TLSB and other pressures (No. of individuals)
Eggs	567898.22					567898.21882952
Smolts	2839.49	99.50%	Assumed eggs to smolt survival of 0.5%		99.50%	2839.49
Smolt and Whitling	141.97	95.00%	Assumed smolt to adult survival rate of 5%	0.21%	95.01%	141.68
Smolt, Whitling and 1SW	129.02	9.12%	Whitling to 1SW losses	2.33%	11.24%	125.75
Smolt, Whitling, 1SW + 1 spawning mark	41.25	68.03%	1SW to 2SW losses	8.54%	70.76%	36.77
Smolt, Whitling, 1SW + 2 spawning marks	11.99	70.93%	2SW to 3SW losses	9.55%	73.71%	9.67
Smolt, Whitling, 1SW + 3 spawning marks	4.32	64.00%	3SW to 4SW losses	10.68%	67.84%	3.11
Smolt, whitling, 1SW + 4 spawning marks	0.48	88.89%	4SW to 5SW losses	11.51%	90.17%	0.31
Smolt, whitling, 1SW + 5 spawning marks	0.48	0.00%	5SW to 6SW losses	12.68%	12.68%	0.27

Returning as 1SW adults						
Lifestage history	No. of individuals given by assumed Management Target. Age structure given by River Tawe Fisheries Performance: Annual Report, Environment Agency, 2002	% Loss from previous lifestage due to other pressures (e.g. predation, pollution).	Notes	% Loss from previous lifestage due to TLSB	% loss from previous lifestage combining TLSB and other pressures	Age structure incorporating % loss from previous lifestage combining TLSB and other pressures
Eggs	2306127.23					2306127.23
Smolt	11530.64	99.50%	<i>Assumed eggs to smolt survival of 0.5%</i>		99.50%	11530.64
Smolt and 1SW only	576.53	95.00%	<i>Assumed smolt to adult survival rate of 5%</i>	0.21%	95.01%	575.32
Smolt, 1SW + 1 spawning mark	123.75	78.54%	<i>1SW to 2SW losses</i>	8.54%	80.37%	112.95
Smolt, 1SW + 2 spawning mark	37.89	69.38%	<i>2SW to 3SW losses</i>	9.55%	72.30%	31.28
Smolt, 1SW + 3 spawning mark	18.23	51.90%	<i>3SW to 4SW losses</i>	10.68%	57.03%	13.44
Smolt, 1SW + 4 spawning mark	5.76	68.42%	<i>4SW to 5SW losses</i>	11.51%	72.06%	3.76
Smolt, 1SW + 5 spawning mark	1.92	66.67%	<i>5SW to 6SW losses</i>	12.68%	70.89%	1.09
Smolt, 1SW + 6 spawning mark	0.48	75.00%	<i>6SW to 7SW losses</i>	11.64%	77.91%	0.24

Returning as 2SW adults						
Lifestage history	No. of individuals given by assumed Management Target. Age structure given by River Tawe Fisheries Performance: Annual Report, Environment Agency, 2002	% Loss from previous lifestage due to other pressures (e.g. predation, pollution).	Notes	% Loss from previous lifestage due to TLSB	% loss from previous lifestage combining TLSB and other pressures	Age structure incorporating % loss from previous lifestage combining TLSB and other pressures
Eggs	101684.48					101684.48
Smolt	508.42	99.50%	Assumed eggs to smolt survival of 0.5%		99.50%	508.42
Smolt and 2SW only	25.42	95.00%	Assumed smolt to adult survival rate of 5%	0.21%	95.01%	25.37
Smolt, 2SW + 1 spawning mark	7.67	69.81%	2SW to 3SW losses	9.55%	72.69%	6.93
Smolt, 2SW + 2 spawning marks	2.40	68.75%	3SW to 4SW losses	10.68%	72.09%	1.93
Smolt, 2SW + 3 spawning marks	1.44	40.00%	4SW to 5SW losses	11.51%	46.91%	1.03

* lifestage % loss from previous lifestage due to TLSB. This is calculated as follows:

$1 - ((1 - \text{lifestage migrant mortality}) * (1 - \text{lifestage kelt mortality}))$

** This assumes that when smolts leave the river, they encounter TLSB before incurring any other losses and therefore TLSB has a 0.21% impact on the whole population, before the 95% loss from other pressures manifests on the remaining population. This is calculated as follows:

$((1 * \% \text{ loss due to TLSB}) + ((1 - 1 * \% \text{ loss due to TLSB}) * \% \text{ loss due to other pressures}) * 100$

***This assumes that whitling returning to the rivers will encounter TLSB before spawning, and before incurring any other losses between the whitling and 1SW migrant lifestage. Therefore, TLSB has a 2.33% impact on the whole population, before the 9.12% loss from other pressures manifests. This is calculated as follows:

$((1 * \% \text{ loss due to TLSB}) + ((1 - 1 * \% \text{ loss due to TLSB}) * \% \text{ loss due to other pressures}) * 100$

****As an XSW migrants returns to spawn, it encounters the lagoon on its way into the rivers and then on the way out as a kelt. Therefore, the % loss due to TLSB is applied to the whole population of inward migrants. Then the % loss due to other pressures is applied to the remaining population of XSW fish as they spend the rest of the year at sea, before they become X+1SW fish. This is calculated as follows:

$((1 * \% \text{ loss due to TLSB}) + ((1 - 1 * \% \text{ loss due to TLSB}) * \% \text{ loss due to other pressures}) * 100$

7 Conclusions / Next Steps

- 7.1.1 Having initially developed three alternative assessment methodologies for modelling fish encounter rates for the Project two; the Draw Zone Approach and the Alternative Draw Zone Approach have been used to provide comparative assessment with the original IBM+STRIKER modelling. The results of these models have been combined with the STRIKERv.4 injury model to generate figures of % Annual Mortality for the various fish species considered.
- 7.1.2 TLSB maintain that the use of an IBM and the STRIKERv.4 combination provides the best available scientific method for the calculation of turbine entrainment and injury rates, whilst acknowledging that there is some uncertainty, largely due to limitations with input parameters and use of professional judgement inherent within the approach. The alternative assessment methodologies have bound the uncertainty within the IBM model, using different methods to calculate the encounter rate and also addressing issues such as marine residency and delay of diadromous species.
- 7.1.3 In general, it can be seen that potential annual mortalities predicted on marine species are low (all <1%), when using either the IBM+STRIKER combination or the alternative assessment methodologies. This is likely to be as a consequence of larger population ranges used in the Draw Zone and Alternative Draw Zone models and the greater propensity towards juvenile life stages of marine species being present in Swansea Bay and the Bristol Channel.
- 7.1.4 The predicted impacts for natal migrants (salmon and sea trout) that are migrating into the Tawe, Neath and Afan are higher, as the whole population must come into closer proximity to the turbines as they migrate, and so have a higher probability of encounter (factored into alternative models through smaller population ranges at the migrant lifestages). These natal migrants are the only species that have an annual mortality % of greater than 2%. IBM+STRIKER values for salmon are predicted of between 0.07 and 0.63% Mean Mortality, with the alternative assessment methods generating values of between 4.40 and 5.75%. For sea trout, IBM+STRIKER values are between 0.08 and 2.62% Mean Mortality, with the alternative approaches generating values of between 0.21 and 7.72% Annual Mortality across the range of age classes. The higher values are generally for the larger fish, which naturally decrease in number between each age class with for example, significantly fewer MSW compared to 1SW salmon. However, recognising this uncertainty, as a responsible developer, TLSB proposes to use the higher values predicted for salmon and sea trout as values used for offsetting, as set out within the Mitigation, Monitoring and Offsetting Framework (TLSB, July 2016).
- 7.1.5 The other diadromous migrants (sea lamprey, river lamprey, shad and eel) have generally lower predicted impacts than salmon and sea trout (IBM+STRIKER between 0.02 and 1.61% Mean Mortality; alternative assessment methodologies between 0.01 and 1.95% Annual Mortality) by virtue of their non-natal behaviour

and therefore a larger population range is applied as they may return to a number of potential rivers while migrating to spawn (or mature in the case of eel). For these species, there is limited evidence of their presence in Swansea Bay in significant numbers.

- 7.1.6 Resident lifestages of the migratory species generally have slightly higher predicted impacts from turbine entrainment and injury, as their presence is assumed year-round and so they are potentially vulnerable at all times.
- 7.1.7 Revised Appendix 7.7.1 *Summary of Fisheries Impact Assessments for Valued Ecological Receptors V3: Turbine entrainment and injury assessment* (TLSB, May 2016) has been produced to draw conclusions from the alternative scenario testing and present the results in the context of the EIA and original assessment. This considers the range of figures generated by the alternative assessment approaches and the updated IBM and STRIKERv.4 figures for the latest turbine design (Andritz 7.2m, three blade, variable-speed). A variety of embedded mitigation is inherent within the Project design, as described in the *Fisheries Assessment: Mitigation, Monitoring and Offsetting Framework* (TLSB, May, 2016). The embedded mitigation has been considered within the alternative scenarios modelling, as well as the Revised Appendix 7.7.1 (TLSB, May 2016).
- 7.1.8 It is acknowledged that some uncertainties remain within the IBM and STRIKER v.4 models used for the Project, and also regarding the fish populations in this geographical area. There are also uncertainties within the alternative assessment methodologies developed as demonstrated by the sensitivity testing (such as behavioural traits, fish biology and distributions). Notable key uncertainties within both approaches include migratory fish path tortuosity and use of olfactory trails, fish residency within Swansea Bay, fish densities and behavioural responses to the structure itself, turbine noise and high flows. The Draw Zone and Alternative Draw Zone approaches do not parameterise these issues, assuming random fish distribution and swimming direction and no behavioural response upon encountering the Draw Zone and turbines. Also, these approaches do not take into account predicted hydrodynamic flows, with encounter rate primarily driven by the MSSS of the species being considered. Residency in the bay is considered however. This may explain why these approaches result in higher percentage Annual Mortality figures than the IBM/STRIKER approach.
- 7.1.9 It is the intention of the Project to monitor a number of elements of fish behaviour, through the Adaptive Environmental Management Plan (AEMP) to validate, where possible, the predictions made by the IBM and parameters used within the alternative encounter rate methods. Also to reduce the uncertainties present in this approach around fish migratory path tortuosity and fish behaviour around the turbines and lagoon wall. This will make it possible to more accurately parameterise these elements within any future model or assessment and to further understand these fish behavioural characteristics. A monitoring framework is provided in the *Fisheries Assessment: Mitigation, Monitoring and Offsetting Framework* (TLSB, May, 2016) and it is the intention for this framework to be developed further, to finalise a detailed monitoring programme that

considers the best available research and techniques, post-determination of the Marine Licence.

- 7.1.10 For salmon and sea trout, the alternative assessment approaches have shown that there may be greater uncertainty around potential turbine entrainment and injury rates than for other species. It is therefore proposed to offset for this uncertainty, and further details of the offsetting framework to be followed is provided in the *Fisheries Assessment: Mitigation, Monitoring and Offsetting Framework* (TLSB, May, 2016). A range of offsetting measures are presented within this document, from which a suite can be developed, with the intention being to develop and refine these to quantify their various potential benefits to fish through increases in egg deposition and ultimately numbers of adults.

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9 Appendices

Appendix 1: Alternative Fish Impact Assessment Methodology



Tidal Lagoon Swansea Bay

Alternative Fish Impact Assessment Methodology

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1 Introduction

1.1 Aims and Objectives

- 1.1.1 The purpose of this paper is to outline the alternative modelling methodologies used to provide a comparative assessment to the original method of impact predictions of turbine entrainment and injury from Tidal Lagoon Swansea Bay (the Project) on key fish species, within Swansea Bay and in the wider marine environment. Alternative methods have been used to test whether similar results are generated from conducting the assessment. This paper explains how, and why, these methods have been developed and details the consultation with regulators and statutory advisors held in the development of these approaches.
- 1.1.2 The results obtained from these methods are presented in Alternative Fish Impact Scenarios Results (TLSB, July 2016) alongside those results from the original assessments and predictions, from previously submitted Individual-based Model (IBM) for encounter rates and STRIKER Model for blade strike probability. The 'Alternative Fish Impact Scenarios Results' paper (TLSB, July 2016) also provides a sensitivity test of the different input data for the alternative scenarios, to test the assumptions used in the modelling and to reduce uncertainty where such assumptions have necessarily been made. Such sensitivity testing provides a range of possible outcomes to of changing model parameters used.
- 1.1.3 The key objective of this paper is to discuss the methodology used within the alternative modelling approaches tested. It is also intended to provide reassurance that key factors, such as fish residency within Swansea Bay and the associated repeat risk of exposure to the lagoon on numerous tides, and their influence on fish populations have been considered.
- 1.1.4 The information obtained will, when assessed with previous results, assist in reaching agreement on the potential level of impact of the operation of the Project for individual fish species. This in turn will inform the assessment of the significance of those impacts, the requirement for any mitigation or offsetting and the appropriate level of off-setting, if required.

1.2 Background

- 1.2.1 Predicting potential fish impacts at this stage is critical in that it will influence:
- the Adaptive Environmental Management Plan (AEMP);
 - the need for further potential mitigation measures;
 - the need for and feasibility of off-setting proposals for certain species at an appropriate level;



- consideration of the Project under the Habitats Regulations and the Water Framework Directive;
- consideration of the Project under the Eels Regulations and the Salmon and Freshwater Fisheries Act.

1.2.2 Assessment of injury caused by turbines has been studied in many locations although historically, such work has tended to focus on run-of-river turbines. Comparatively little research has been undertaken in relation to tidal turbines, which although based on run-of-river turbine design can be bi-directional and as such are a relatively new concept. Past studies have also focused on the injury element of fish passage rather than considering this in combination with an encounter model which predicts the numbers of fish likely to be placed at risk of injury.

1.2.3 Modelling work in relation to the Project has considered, probabilistically, both the elements of encounter with the Project (originally through an Individual Based Modelling (IBM)) and also injury having encountered the Project (through STRIKER modelling). A third, and more subjective element, the avoidance and attraction behaviour of fish towards the Project, is recognised as important, though more difficult to quantify and apply to the models. This is recognised as a limitation of the modelling work and in such cases it may be necessary to rely on expert opinion, which was used during the original submissions.

Species Considered

1.2.4 A wide, and seasonably variable, range of fish species are present in Swansea Bay as evidenced in the Environmental Statement (ES), including Appendix 9.1 (Fisheries Baseline) and Appendix 9.2 (Fish Fauna Characterisation Surveys). During the Environmental Impact Assessment (EIA) process, key fish species were identified on the basis of their environmental, commercial and recreational importance, these are referred to as Valued Ecological Receptors (VERs). The initial species considered as VERs (ES, Chapter 9, Tables 9.28 to Table 9.37) and assessed within the ES in relation to the Project were :

- Atlantic Salmon
- Sea Trout
- Freshwater Eel
- Shad (Allis and Twaite)
- River Lamprey
- Sea Lamprey
- Herring
- Common Sole
- Sandeel
- Other demersal and pelagic species of local and regional value



- 1.2.5 Other species, such as bass, were considered under recreational species in Table 9.47 of ES, Chapter 9.
- 1.2.6 Following requests from the Centre for Environment, Fisheries and Aquaculture Science (Cefas) and Natural Resources Wales (NRW) in Autumn 2015, the impact on the following species has been expanded upon:
- Cod/Whiting
 - Plaice
 - Bass

2 Fish Impact Methodology

2.1 Summary of the Methods Previously Reported

- 2.1.1 As documented within the ES submission in 2014, modelling work was undertaken to consider the impact of the Project, on key VERs identified, from turbine entrainment and injury. This was undertaken using the most advanced modelling methodologies available at the time and the aim of the assessment was to calculate:

Probability of fish loss = probability of fish encountering the turbines x probability of injury

- 2.1.2 Two models were therefore used and these are referred to as IBM and STRIKER.

Individual Behaviour Modelling (IBM)

- 2.1.3 IBM is a recognised and accepted technique for predicting the movement of animals and people. It requires the identification of key parameters which influence migration of individuals within a population of the species of interest and then the replication of the model run for each individual with their own pre-programmed characteristics such as swimming speed. The modelling for the Project using IBM involved 10,000 model runs in order to ascertain the likely movement patterns of each species and their risk of turbine encounter.
- 2.1.4 Whilst this method was considered as part of the Examination during the ES process for the Development Consent Order (DCO) for the Project, and subsequently resulted in the granting of the DCO by the Secretary of State (SoS), concern was expressed through the marine licensing process around other potential scenarios for fish movements and behaviours that were considered necessary to assess and were not factored into the original IBM model, as well as impacts only being considered by lifestage. Consequently, and following discussions with NRW (Advisory) (NRW(A)) and Cefas, three additional alternative methods of calculating fish encounter probabilities have been considered to enable a comparative assessment with the predictions made through IBM.
- 2.1.5 TLSB maintain that the IBM modelling approach presented within the ES follows the best available scientific knowledge and methodology and therefore best represents the potential predicted impacts of the Project. The following three alternative encounter rate calculations have been provided to compare against the original predictions made within the ES and DCO process and provide reassurance to NRW's Marine Licensing Team (MLT) that the concerns raised with the IBM model, when addressed, do not fundamentally change the predicted impact magnitudes. It should be recognised however, that due to the concerns raised by NRW(A) and Cefas regarding the IBM model and its ability to predict fish

distributions, behaviour and response to migratory/other cues, it has been necessary to apply a series of assumptions and statistical theory to the alternative encounter rate models. This is in lieu of some of the original assumptions of fish movement and distribution that were included in the IBM.

- 2.1.6 Through discussion with NRW(A) and Cefas, a number of initial Alternative Encounter Scenarios were developed in late 2015, based broadly on the IBM and STRIKER model combinations and these were presented. During subsequent discussions between NRW(A), Cefas and TLSB, a further alternative method to calculate the probability of fish encountering the Project during operation was suggested by Cefas, and termed the 'Volumetric Approach'. It should be noted that this new approach required a significant element of expert judgement to be applied, particularly in relation to the likelihood of fish encountering the turbines.
- 2.1.7 A second alternative method of quantifying the probability of encounters with hydro-turbines was identified from the scientific literature (Hammar et al., 2015) and was developed into the model referred to as the 'Draw Zone Approach'. This method, using known parameters relating to the fish populations (such as population range), reduces the need to use values based on expert judgement and has been used in order to reduce uncertainties within the Volumetric Approach relating to the vulnerability values.
- 2.1.8 A third method adapted from the Draw Zone Approach was also then suggested at a meeting with TLSB, NRW(A) and Cefas on 28th April 2016.
- 2.1.9 Details of the Volumetric Approach, Draw Zone Approach and Alternative Draw Zone Approach methods for calculating the probability of fish encountering the turbines are presented below.
- 2.1.10 Subsequently, it was agreed with NRW(A) and Cefas at a meeting on the 20th June 2016 that it would be appropriate to no longer include the Volumetric Approach method for calculating encounter rates.

STRIKER Injury Model

- 2.1.11 The STRIKER model was developed to assess the probability of injury caused by fish passage through the turbines themselves. STRIKER was originally developed to assess fish injury from blade strike in hydropower projects in the US. It is widely accepted as the most appropriate modeling tool having been developed and evolved from studies which commenced in the 1960s. Four key elements, each of which can cause injury, are factored into the STRIKER model:
- Cavitation – the formation of bubbles by the rotating turbine. The bubbles are 'explosive' and capable of harming fish and damaging the turbine blades.



- Pressure Change – this is most significant when there is a large water-head difference either side of the lagoon. Sudden changes can cause barometric trauma within fish.
- Shear Stress – caused by planes of water moving against one another at high speed. Certain species of fish, such as herring and shad are more susceptible to damage in such circumstances.
- Blade Strike – fish being struck by the any part of the turbine blade.

2.1.12 Thus, IBM, as well as the alternative turbine encounter rate models, provide a probability that a fish would firstly encounter the turbines and the STRIKER model then determines the probability that a fish entering the turbines would be injured while passing through. The combination of these encounter and injury probabilities is a recognised method of estimating the losses of fish due to tidal turbines (Hammar et al, 2015, Wilson et al, 2007).

2.1.13 The above approach was used to support the application for, and subsequent granting of the DCO for the Project. However, further assessment has been requested by NRW MLT in order to satisfy their requirements in granting a Marine Licence for the development.

2.2 Alternative Scenarios

2.2.1 As discussed above, three new probabilistic approaches to estimating the turbine encounter probability of key fish species on the Project's operation species have been developed and these are termed:

- the Volumetric Approach
- the Draw Zone Approach
- the Alternative Draw Zone Approach

2.2.2 These methods provide alternative approaches to calculating the encounter rate, to compare with the previous impact predictions which used an IBM to calculate encounter rates and STRIKER modelling to assess turbine injury.

2.2.3 In developing the alternative scenarios certain assumptions have been made. Where this is the case these have been noted and subsequent monitoring programmes will be designed, in consultation with relevant stakeholders, with the intention of validating such assumptions, to improve understanding of such projects and to reduce levels of uncertainty for any future projects.

2.2.4 Factual information to quantify impacts has been used wherever possible whilst an element of expert opinion has been required in order to determine information relating to some fish behaviours.

Key Parameters/Factors

2.2.5 In developing the alternative scenarios, the following key factors, which have been raised by both the regulators and public stakeholders during wider consultation, have been incorporated into the assessment:

- Residency of certain migratory fish species (or particular life-stages thereof) in and around Swansea Bay. For example, it is assumed that, unlike salmon, an element of the sea trout stock remain within the Bristol Channel rather than migrating into the wider Celtic Sea and beyond. Resident life-stages have been modelled for sea trout, river lamprey, sea lamprey, shad and eel assuming presence within the models year-round;
- Replenishment of stocks if fish are removed from the population through injury or impoundment. The fish population is distributed through the year in the model based on when they are likely to be present, and the fish is then present in the model on each tide throughout the month. Of the fish present on tide 1 of the month, as a proportion passes into the lagoon and out again, losses are incurred due to turbine strike. However, on tide 2 of the month, it is taken that the same number of fish as tide 1 are present with those lost having been replenished;
- Impacts of fish being impounded and subsequently delayed in, or failing to complete, their migration. For salmon smolts and migrant adults, if the migration of an individual is delayed beyond July 1st (due to likely increased predation upon leaving the lagoon having missed the out-migrating smolt shoals) or December 1st (due to mortality from being unable to spawn) respectively then it is assumed that this fish is lost;
- Consideration of additional life-stages of particular species (eg. Sea trout / resident eels) which may lead to repeated exposure to the lagoon;
- Seasonality of fish presence using monthly estimates of fish abundance. The fish population is distributed through the year in the model and then the impact taken over the full year (704 tides);
- Exposure to lagoon entrainment over multiple tidal cycles. Each fish is present in the model for a full month of tides;
- Variation in the probability of fish entering compared to those exiting the lagoon;
- Mode of entry into and out of the lagoon using either the turbines and/or sluices;
- Consideration of the population range of the fish species with some being considered native to the Bristol Channel, Swansea Bay and adjacent rivers (e.g. salmon) whilst others are considered as a sub-set of a far wider geographic population (e.g. cod and herring). The population range is used to define the area that a fish could theoretically occupy and therefore

encounter the lagoon from – for example salmon smolts migrate from their natal rivers in Swansea Bay to mature in the N.Atlantic and then return as adults to spawn. As they home to their natal rivers in Swansea Bay, they must pass through Swansea Bay to spawn and so their population range is Swansea Bay as smolts and migrants. As they are resident in the N.Atlantic, the resident life-stage has not been considered. For sea trout, they also migrate from their natal rivers as smolts and return as adults, so for these life-stages Swansea Bay has been used as the population range. However, it is believed that sea trout remain resident within the Bristol Channel or wider Celtic Sea after out-migrating as smolts or kelts. Therefore, as the fish is resident within the Bristol Channel, this population range has been used.

- The combined impact over several life stages in terms of both adult numbers of fish injured and egg production lost as a consequence.

Alternative Scenario Methods

- 2.2.6 All the alternative methods use the same population data for each species and fish life-stages, and model losses over a full calendar year from the first fish entering the conceptual model and consequently, at least 704 tidal cycles. This approach therefore exposes fish to numerous lagoon operational cycles and repeated risk of entrainment addressing a key concern of local fishery interests.
- 2.2.7 The limited opportunity for fish to enter and exit the lagoon in each tidal cycle is considered in the calculations of all the methods (based on either limited volumes of water entering during an operational cycle, or the actual operation time. The operating cycle of the lagoon provides an approximate 8.5 hour window, during flood tides, in each 24 hour period during which fish can enter the lagoon. Entry will not be possible during the remaining 14 hours because the lagoon sluices and turbines will be closed or, water will be flowing out of the lagoon at velocities, within the turbine housing, greater than the fastest fish swimming speeds.
- 2.2.8 In the methods, the proportion of fish impacted is calculated, which means that the starting nominal population (given as 100,000 in the current models) is not a dependent factor. The 100,000 nominal population chosen does not represent an actual population estimate for any given species but instead provides a means of calculating a percentage mortality which could then be applied to a given population.
- 2.2.9 For certain species (such as salmon and sea trout), the estimated survival and impact rates, are used in order to determine the probability of the loss of adult fish and also the potential loss of subsequent egg production. These two values do differ because some species of fish (e.g. sea trout) have a greater proportion of females that are at risk of impoundment within the lagoon and therefore a greater loss of eggs. Importantly, the methodology used enables the contribution of



different age classes of fish, and their relative contribution to overall annual egg deposition, to be assessed.

- 2.2.10 All the models have considered the different life-stages of fish that may be at risk. For example, salmon will migrate past the lagoon as out-migrating smolts or kelts, and also as inward migrating 1-sea winter (1SW) or multi-sea winter (MSW) adults. In the case of sea trout there is far greater complexity with seven sea-age classes used in calculations in addition to smolts, whitling and kelts. In addition, consideration has been given to the potential residency of sea trout in the Bristol Channel and Swansea Bay area and it has been assumed that there are resident and migrant elements of the sea trout population.
- 2.2.11 Once the level of loss has been calculated, for species, such as salmon and sea trout the level of potential off-setting that would be required to achieve an equivalent gain, and how this might be achieved, can be considered and this will be reported separately.

Volumetric Approach

- 2.2.12 This method was developed following discussion between NRW(A), Cefas and TLSB and uses the known volume of water moving into, and then out of the lagoon during each tidal cycle, as a contributory factor to estimate the proportion of fish that will be lost through injury (caused by turbine passage) and/or impoundment (those trapped in lagoon after a certain date and assumed to be lost, e.g. from the spawning or out-migrating populations). The volume of water moving in and out of the lagoon is considered in relation to the overall volume of water within Swansea Bay waterbody.
- 2.2.13 In addition to the volume of water and the even distribution of fish across this volume, factors are also applied which estimate the proportion of fish within the volume of water that are vulnerable and the proportion that are then drawn into the turbines and those which are able to avoid entry.
- 2.2.14 Whilst these water volume values are constant for all species, and assuming an even distribution the proportion of fish in this water volume is constant, variations in predicted impacts are caused by varied population distributions across the year and from delays to migration (either in or out of the rivers) and the different STRIKER (turbine injury) values applicable to each species.
- 2.2.15 During the meeting with NRW(A) and Cefas on 20th June 2016, it was agreed to no longer use the Volumetric Approach method of calculating encounter rates and therefore no further detail is provided on the methodology within this paper.

Draw Zone Approach



- 2.2.16 Given the use in the Volumetric Approach on a constant encounter (or vulnerability) probability factor for both entry and exit from the lagoon, an additional method is proposed which, rather than being based on water volumes passing into or out of the lagoon, uses a calculated probability of a fish entering the draw zone around the turbine or sluice housing from which they would be unable to escape. This is based on a method described by Hammar et al, 2015.
- 2.2.17 The estimate of the draw zone area for each species is based on the intake water velocities at fixed distances, the maximum sustained swimming speed (MSSS) of each fish species, to apply a level of precaution and, where appropriate, life stage. It is based on the premise that if a fish enters the zone it will be unable to avoid entry into the turbines or sluices.
- 2.2.18 By calculating the time it would take for a fish to swim across a draw-zone sized unit, and with knowledge of the area of the population of that species, and the length of turbine/sluice operation during a tidal cycle, the probability of a fish entering or exiting the lagoon in a single tidal cycle can be determined. The area of this flow velocity contour ('draw zone') divided by the geographic range of the species being considered (or the lagoon itself for impounded fish) is taken as the probability that a fish will be drawn into the sluice or turbine.
- 2.2.19 Draw Zones for the various flow velocity bands have been determined by identifying the relevant velocity contour. Figure 1 below illustrates the flow velocity contours for Peak Flood Generation and give a visual indication of the Draw Zone area outside the lagoon. Appendix 1 provides further detail on the definition of the Draw Zone areas during each sluicing and generation phase.

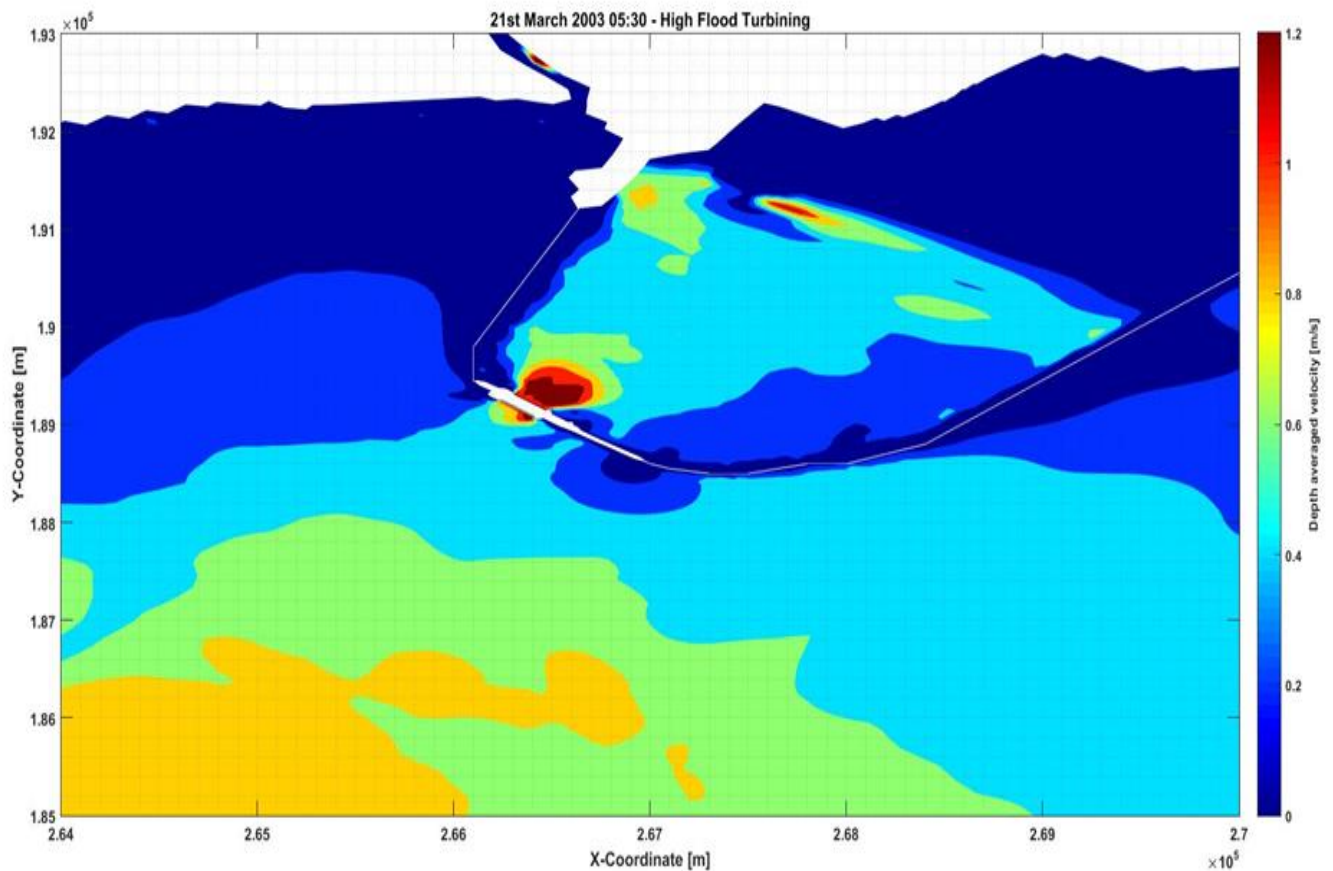


Figure 1: Close up of contours showing flow speeds around the turbine house during peak flow flood generation when water is passing through the turbines

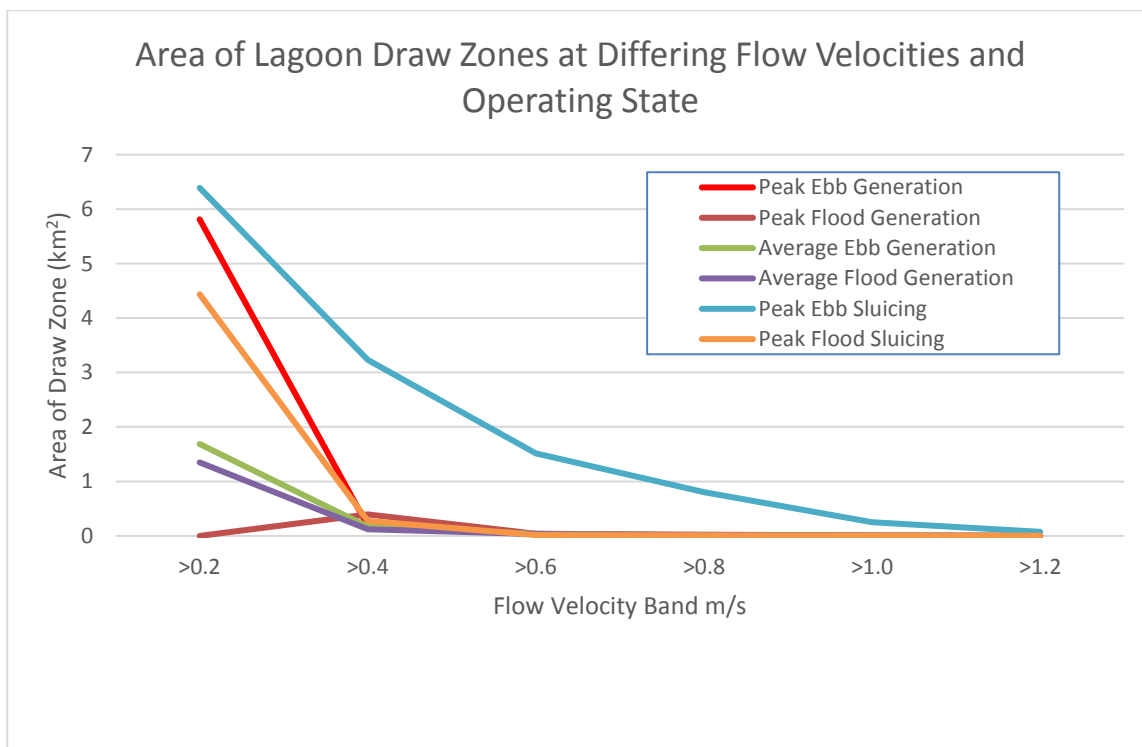
2.2.20 Draw Zones, reported in km^2 , based on specific velocity bands, have been calculated during the most extreme water velocity periods for generation and sluicing with Average Velocities provided for comparison and presented in Table 1 and Chart 1 below.

Table 1: Modelled Draw Zone Areas

Flow Speed	Area of Draw Zone (km ²)					
	Peak Velocities		Average Velocities		Peak Velocities	
	Ebb Generation	Flood Generation	Ebb Generation	Flood Generation	Ebb Sluicing	Flood Sluicing
>0.2	5.811	NULL #	1.687	1.349	6.39	4.436
>0.4	0.179	0.394	0.166	0.121	3.231	0.273
>0.6	0.033	0.042	0.04	0.033	1.515	0.014
>0.8	0.003	0.022	0.012	0.01	0.806	0.008
>1.0	0.001	0.009	0.005	0.003	0.254	0.005
>1.2	<0.001	0.003	0	0	0.075	0.004

- this value was unable to be obtained due to inability to distinguish draw zone velocity area from wider Swansea Bay current speeds.

Chart 1: Lagoon Draw Zones During Flood and Ebb Flows



Alternative Draw Zone Approach

- 2.2.21 At the meeting of 28th April 2016 between TLSB, NRW(A) and Cefas, an alternative method to calculating the encounter risk based on the draw zone was discussed. This uses a random distribution of fish and an element of probability of movement in certain directions when encountering the Draw Zone in each second over the generating period and this approach is discussed further in Section 3 below.

2.3 Assumptions

- 2.3.1 In order to produce the Draw Zone and Alternative Draw Zone Scenarios a number of assumptions have necessarily been applied. In making such assumptions a conservative approach is taken in each case, thus creating a level of precaution within the assessment and increasing the likelihood that any impacts that may be realised will be below those modelled. These key assumptions include:

- The baseline population of fish present in the Bay will remain constant on each day per month of fish presence. Thus any fish lost due to turbine entrainment are assumed to be 'replenished' after each tidal cycle.
- Where fish are predicted to be injured passing through the turbines due to one, or more of; shear stress, pressure change, cavitation and blade strike, they are, for the purposes of the calculations, regarded as mortalities. This acknowledges that whilst a proportion of 'struck' fish may survive as fish are simply deflected, such fish may be at greater risk of fish predation whilst disorientated.
- Peak water flow velocities have been used in calculations of the Draw Zone, rather than average flows increasing the probability that fish would swim into the Draw Zone.
- For certain species and life-stages thereof, the precise monthly populations will vary year on year. In such cases the proportion of population has been averaged across the months of expected presence.
- Where a fish has entered the draw zone, it is assumed that it is unable to escape (despite having a burst speed above its MSSS and is drawn into the turbine housing. This entry and exit can occur through the turbines or sluices on both flood and ebb tides.
- Whilst the MSSS has been assumed, fish in general will swim at speeds below this and therefore will be less likely to encounter any draw zone.
- It is assumed that fish present in the draw-zone when the turbines or sluices are first operated, during each cycle, do not exhibit an escape response, and are thus drawn into the turbines.

- It is assumed that all salmon and sea trout smolts impounded after 1st July will not be able to undertake their natural migration and are therefore lost.
- Adult salmon and sea trout calculated as being in the lagoon after 1st December are considered to be lost from the population of spawners. Whilst the precise delay time within the lagoon is not known, salmon and sea trout are known to migrate into local rivers in December (THA trapping on R. Afan in 2015) and thus a fish which leaves the lagoon in late November may still be able to spawn.
- No avoidance or attraction behaviours related to water flows, chemistry or turbine noise and vibration are assumed.
- The tidal movement of fish and their subsequent likely horizontal or vertical position relative to the turbine housing is not considered. For example, fish moving in-shore, or into estuaries on the flush of the flood tide may have passed the turbines prior to the start of generation and sluicing, or may be swimming close to the surface above the turbine entrances. Some of such factors were considered within the IBM model.

2.3.2 Table 2 below sets out the various input parameters and assumptions used within all four of the turbine encounter models, and identifies the common parameters and assumptions used across the models.

Table 2: List of input parameters and assumptions used within turbine encounter models

Input parameter or assumption	Turbine encounter model input parameter or assumption applied to.		
	IBM	Draw Zone	Alternative Draw Zone
Swim Speed (ms ⁻¹) of fish	x	x	x
Directedness (radians) of fish swimming	X		
Navigational period	x		
Max/min depths (m)	X		
Sensitivity to tide state	X		
Random / even distribution of fish		x	x
Tide-to-tide replenishment of fish		x	x
Resident lifestages of fish		x	x
Population range of fish		x	X
Seasonal population distribution of fish		x	X
Avoidance behaviour of fish (e.g. noise, vibration, water chemistry, increased			

flows, temperature, scent, predation)			
Attraction behaviour of fish (e.g. noise, vibration, water chemistry, increased flows, temperature, scent, predation)			
Exposure of fish to lagoon through multiple tidal cycles		x	x
Delay and failed migration due to impoundment		x	X
Likely horizontal or vertical position of fish when encountering lagoon			
Separate lifestages of salmon and sea trout (kelt, multiple spawners)		x	x
Variation in the probability of turbine encounter when entering or exiting	x	X	x
Mode of entry into and out of the lagoon (turbines or sluices)		x	x
Increased or decreased risk of encounter at different periods of the year			
Diurnal activity of fish		x	x
Volume of water entering lagoon			
Velocity of water entering lagoon		x	x
Proportion of water passing turbines and sluices			
Operational periods of generating and sluicing		x	x

3 Model Rationale

3.1 Introduction

- 3.1.1 Presented below is a summary of the model principles for each of the encounter rate models used for the alternative scenarios, and how they have been combined with the injury rate model to generate the overall impact percentages. Results have been presented in Alternative Fish Impact Scenarios Results (TLSB, July 2016) for the application of each of the IBM, Draw Zone and Alternative Draw Zone methods of calculating the encounter rate of a fish with the lagoon turbines/sluices, combined with the STRIKER method of calculating the likelihood of injury of a fish encountering the turbines. As outlined previously, on a precautionary basis it is assumed that each injury predicted results in the mortality of that fish. The combination of encounter rate and likelihood of injury has been calculated for the latest turbine and sluice arrangement (16 turbines and 8 sluices) and turbine design (7.2m variable speed) for the Project.
- 3.1.2 A detailed description of the Draw Zone and Alternative Draw Zone encounter models, including descriptions of the process followed in building each of the models, is provided in Section 4 below. A summary of the methodology for calculating the Annual Mortality for the alternative modelling approaches is also provided. Summaries of the Individual Based-Modelling (IBM) encounter model and STRIKER v.4 collision risk model are also provided above, with further descriptions provided within the ES for the Project (TLSB, 2014).

3.2 STRIKER injury rate

- 3.2.1 As noted above, Appendix 9.4 of the TLSB Environmental Statement (TLSB, 2014) provides a detailed description of the STRIKER v.4 injury rate model and approach. Further information on subsequent amendments to the STRIKER v.4 model for the Andritz 7.2m variable speed turbines to be used for the Project is provided in *Swansea Tidal Turbines: STRIKER IV Fish Injury Assessment for 7.2 m Diameter Turbines* (THA Aquatic, July 2016).

3.3 Individual-Based Modelling (IBM) encounter rate

- 3.3.1 As noted above, Appendix 9.3 of the TLSB Environmental Statement (TLSB, 2014) provides a detailed description of the IBM encounter rate approach.

3.4 Draw Zone approach encounter rate

- 3.4.1 Acknowledging the uncertainty associated with the Volumetric Approach and the application of the 95% avoidance rate of fish that are exposed, an alternative method of calculating the encounter rate (without applying an avoidance factor) has been developed, adapted from Hammar *et al.* (2015).

3.4.2 The premise of this approach is that a fish encountering a certain area of the faster flowing currents/water in front of the turbines (the 'Draw Zone') will encounter the turbines. The area of the Draw Zone is defined as the area in which the speed of the water/currents exceeds that of the MSSS of that species and life-stage of fish. The approach assumes a random/even distribution of fish across the area of their population and that they swim in random directions but always across new areas.

3.4.3 Upon commencement of the generating phase, it is assumed that all fish already within the Draw Zone will be unable to escape and will therefore encounter the turbines. For the remainder of the generating phase, it is assumed that fish can cover a maximum proportion of their population range, split into equivalent 'Draw Zone' sized units, swimming at their MSSS. A schematic of this is shown in Figure 4. Therefore having assumed a random distribution and swimming direction, the risk of encountering the Draw Zone is calculated by:

$$\text{Risk of encountering the Draw Zone} = \frac{\text{Number of Draw Zone units covered in a generating phase at MSSS}}{\text{Number of Draw Zone units in Population Range}}$$

3.4.4 The proportion of fish encountering the turbines at the commencement of the generating phase (i.e. that are already in the Draw Zone when the turbines start to operate) and the proportion of fish that are at risk of encountering the Draw Zone are summed to give the total encounter rate.

Simplified example:

3.4.5 The Draw Zone method calculates the maximum proportion of a fish's population area that the fish can cover in a generating cycle assuming it is constantly swimming at its MSSS. If a fish can cover X% of its population area, being randomly distributed, swimming in a random direction (but always across areas it has not crossed previously), then the likelihood that it encounters the 'Draw Zone' for the turbines and thus goes through the turbines is X%.

Given:

- Draw Zone = 1m²,
- Population area = 10m²
- Fish MSSS = 1ms⁻¹
- Generating period = 5 seconds

3.4.6 A fish swimming at 1m/s for 5 seconds covers 5 different 1m² areas (assuming it does not swim over ground covered in previous seconds), which is 50% of its population area. The likelihood of the Draw Zone being within this area and therefore being crossed is 50% (0.5).

- 3.4.7 In this example, if the population area was 5m^2 , a fish swimming at 1ms^{-1} for 5 seconds will cover 100% of its population area. Therefore, the likelihood of the Draw Zone being within this area and therefore being crossed is 100% (1)
- 3.4.8 If the population area was smaller than a fish could cover over the generating period swimming at its MSSS, a fish could cover its whole population area and more in the generating period. For this example if the population area is 4m^2 , a fish swimming at 1ms^{-1} for 5 seconds will cover 4m^2 or 100% of its population area in 4 seconds and then cover a further 1m^2 or 25% in the 5th second, for a second time. However, as the approach assumes that as soon as a fish encounters the Draw Zone it is lost, with the Draw Zone acting as a 'point of no return', a fish can only cover a maximum of 100% of its population area before encountering the Draw Zone and therefore will encounter the Draw Zone part way through the generating cycle before starting to cover its population area a second time.

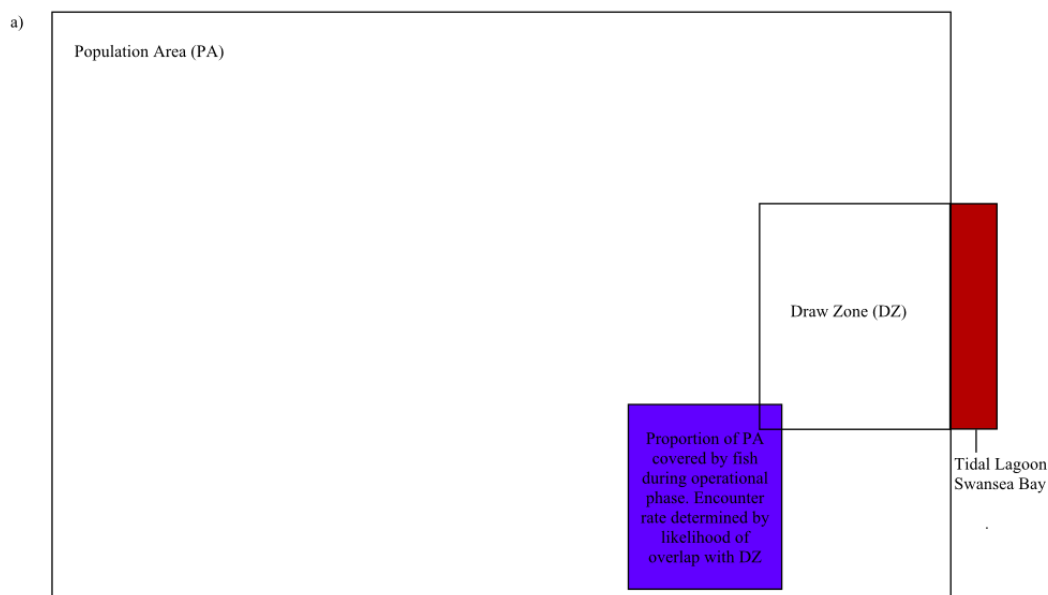


Figure 4: Schematic of the Alternative Draw Zone approach

3.5 Alternative Draw Zone approach encounter rate

- 3.5.1 The Draw Zone approach was discussed at a meeting between TLSB, NRW and Cefas on 28th April 2016. During the meeting an alternative approach to calculating the risk of encountering the Draw Zone was developed, termed here the



‘Alternative Draw Zone’ approach, to address any potential confusion associated with the scenario described in Section 3.5.8.

- 3.5.2 This again assumes a random distribution of fish, but follows a probability of encounter at each second of the generating phase. As for the original Draw Zone method, all fish within the Draw Zone at the commencement of the generating phase are assumed to pass through the turbines. Then, a Vulnerable Zone (in this instance 1m wide) is defined around the edge of the Draw Zone, as shown in Figure 3. The probability that any fish would go into the Draw Zone from the Vulnerable Zone during the generating phase is then calculated. The proportion of fish within the Vulnerable Zone at any one time is the area of the Vulnerable Zone as a proportion of the wider population range area of that species.

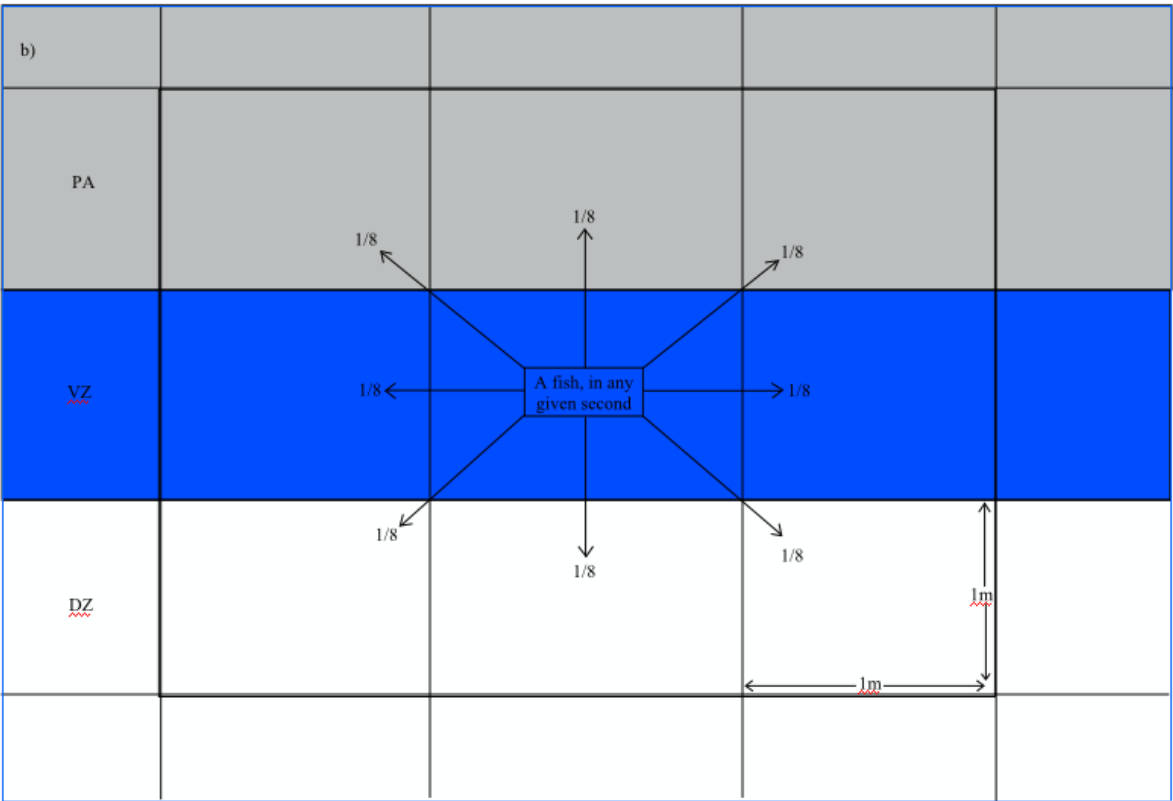
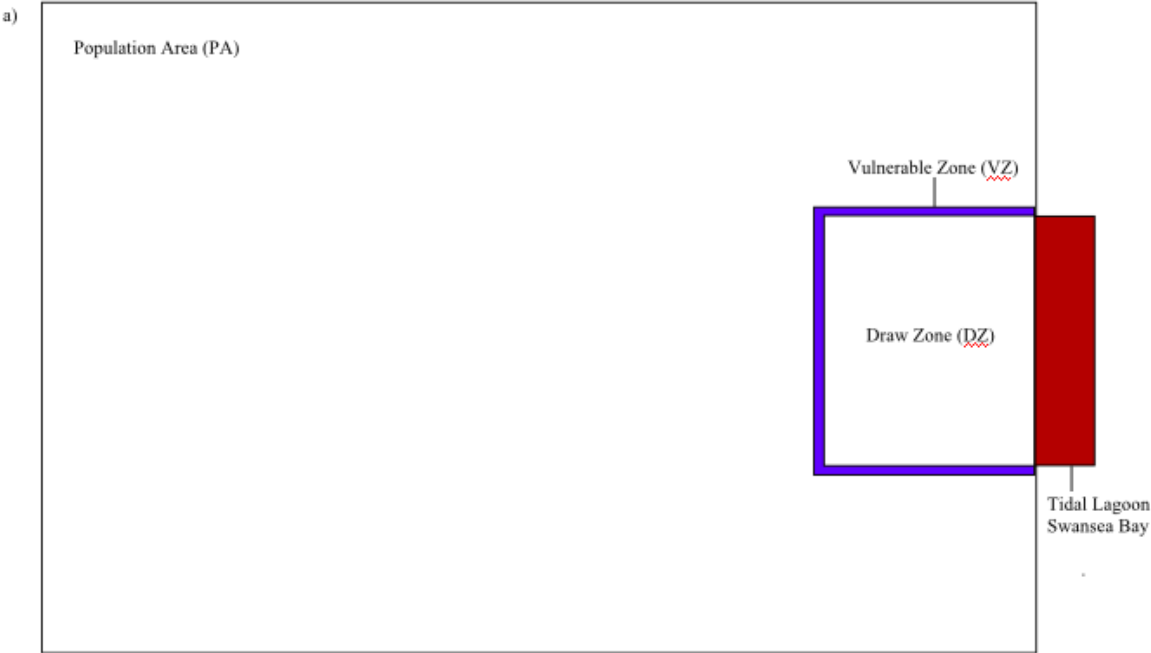


Figure 3: Schematic of the Alternative Draw Zone approach showing: a) the Vulnerable Zone (VZ) within the wider Population Area (PA), Draw Zone (DZ) and TLSB; and b) the probability that any fish that is within the Vulnerable Zone (VZ) will then go on to enter the Draw Zone (DZ) in any given second.

3.5.3 Presented below is the method for calculating the encounter probability using the Alternative Draw Zone approach, where:

- $DZ = \text{Area of the Draw Zone (m}^2\text{)}$
- $cDZ = \text{Circumference of the Draw Zone (m)}$
- $VZ = \text{Area of the Vulnerable Zone (m}^2\text{)}$
- $wVZ = \text{Width of the Vulnerable Zone (m)} - \text{assumed to be 1m wide}$
- $PA = \text{Population Area (m}^2\text{)}$
- $Sp = \text{Swimming Speed of fish (ms}^{-1}\text{)} - \text{in this case taken to be the MSSS}$
- $Tp = \text{Generating Period (seconds)}$

3.5.4 The area of the Vulnerable Zone is calculated by:

$$VZ = wVZ \cdot cDZ$$

3.5.5 Where wVZ has been taken as 1m in this case.

3.5.6 The time (in seconds) a fish takes to cross the Vulnerable Zone is given by:

$$\frac{wVZ}{Sp}$$

3.5.7 The proportion of fish present within the Draw Zone at the commencement of generation, and thus encountering the lagoon immediately, is given by:

$$\text{Proportion of fish within Draw Zone at commencement of generation} = \frac{DZ}{PA}$$

3.5.8 At each second time-step, the probability of a fish being present in the Vulnerable Zone is given by:

$$P(\text{presence in Vulnerable Zone}) = \frac{VZ}{PA}$$

3.5.9 At each second time-step, for a fish present within the Vulnerable Zone, the probability of a fish entering the Draw Zone from the Vulnerable Zone is given by:

$$P(\text{Encountering Draw Zone in any given second}) = \frac{VZ}{PA} \cdot \frac{3}{8}$$

3.5.10 In statistical theory, if this event has probability $\frac{VZ}{PA} \cdot \frac{3}{8}$ of occurring in any given second, then in any given second it has probability $1 - \left(\frac{VZ}{PA} \cdot \frac{3}{8}\right)$ of not occurring.

3.5.11 To calculate the probability of the event occurring over a number of seconds (the Generating Period, Tp), first the probability of the event not occurring:

$1 - \left(\frac{VZ}{PA} \cdot \frac{3}{8}\right)$, is raised to the power of Tp , moderated to the number of seconds it takes a fish to cross the Vulnerable Zone, $\frac{wVZ}{Sp}$.

The below equation therefore gives the probability of the event not occurring over Tp :

$$P(\text{Not encountering Draw Zone over the Generating Period}) = \left(1 - \left(\frac{VZ}{PA} \cdot \frac{3}{8}\right)\right)^{\left(\frac{Tp}{\frac{wVZ}{Sp}}\right)}$$

- 3.5.12 Over the Generating Period (in seconds), the probability of a fish encountering the Draw Zone is therefore given by:

$$P(\text{Encountering Draw Zone over the Generating Period}) = \left(1 - \left(1 - \left(\frac{VZ}{PA} \cdot \frac{3}{8}\right)\right)^{\left(\frac{Tp}{\frac{wVZ}{Sp}}\right)}\right)$$

3.6 Annual Mortality model

- 3.6.1 For the IBM and STRIKER combination, the results are presented to provide a comparison between previous IBM and STRIKER combinations for earlier arrangements and turbine designs.
- 3.6.2 For the Draw Zone and Alternative Draw Zone methods combined with STRIKER, the encounter rates and STRIKER values have been calculated for a range of additional life-stages of certain species. For each species life-stage, the Draw Zone and Alternative Draw Zone encounter rates and STRIKER rates are applied to a population of that species life-stage over a full year of tides (704 tides) in an annual mortality model. This model is run for 704 tides from time that the first fish enters the model to ensure a full year of potential exposure of fish is captured.
- 3.6.3 The presence of fish within the model is defined by the population distribution throughout the year, which distributes the nominal 100,000 fish population across each of the 704 tides. For resident life-stages, the population is distributed evenly across the year and thus a constant number of fish are present on each tide. For migratory life-stages, the population is distributed using best available knowledge on migratory timings for each species, and so is concentrated within a number of months through the year.
- 3.6.4 On applying the population distribution to the model, fish numbers are averaged over approximately a month of tides (60 tides) to account for potential early or late migrating individuals and to acknowledge uncertainties when defining precise timings of migration. Defining the population distribution on a monthly basis, and averaging fish numbers over a month of tides, whilst running the model on each



tide means that fish can be exposed to the turbines on multiple occasions whilst they are resident or migrating. The model therefore accounts for fish that do not make a direct migration past the lagoon into the rivers within Swansea Bay or out of Swansea Bay over a single tide.

- 3.6.5 In addition, on each tide, it is assumed that there is replenishment of the population within the model, so that any fish lost on the previous tide are not taken into account in the next tide's population.
- 3.6.6 The Annual Mortality model provides for fish being able to enter or exit the lagoon either through the turbines or sluices, reflecting the generating cycle where turbines are opened first at high head and then sluices are opened when the head is low after the turbines cease operation. Encounter rates are applied for the turbine generating cycle first, then for the remaining fish for the sluicing cycle.
- 3.6.7 The encounter rates used on entry and exit have been calculated separately for the Draw Zone and Alternative Draw Zone methods and are considered independently within the Annual Mortality model. It therefore reflects the potential for a fish to enter the lagoon on one tide but not leave on the immediately subsequent tide, and remain within the lagoon for a period of time, thereby allowing for fish to accumulate within the lagoon. The length of time that fish spend within the lagoon is different for different species and life-stages depending on their encounter rate and STRIKER values.
- 3.6.8 Cumulative losses for each species and life-stage (from entry and exit of the lagoon/passing through the turbines - and also from delayed migration) are calculated to give an Annual Percentage Mortality for that species life-stage. Where data is available, the predicted Annual Percentage Mortality has been converted to the loss of eggs from spawning across all life-stages.
- 3.6.9 For Salmon, it has been assumed that the delayed out-migration of smolts, or the delayed in-migration of adults for spawning, through entry into the lagoon results in mortality if the delay is beyond specified dates. This is based on the assumption of delayed smolt out-migration resulting in the delayed smolts missing the wider shoals of out-migrating smolts from the rivers and being subject to increased predation when they leave the lagoon to migrate. For in-migrating adults, it is assumed that the delay results in missed spawning and thus mortality.

4 Guide to Individual Worksheets

4.1 Introduction

4.1.1 For each species a model has been created within Microsoft Excel, which contains a series of worksheets as follows:

- Index
- Introduction
- Explanation of Worksheets
- Assumptions
- Population Data
- Tides per Month
- Draw Zone Probability Calculations
- Alternative Draw Zone Probability Calculations
- Draw Zone (one per each relevant life-stage and repeated for migrant and resident sea trout).
- Alternative Draw (one per each relevant life-stage and repeated for migrant and resident sea trout).
- Survival and Impact Calculations

4.1.2 The approach to developing each worksheet, parameters, assumption and explanation and rationale are provided in the following sections:

4.2 'Assumptions' Worksheet

Key Features

4.2.1 For each species an Assumptions worksheet has been developed to present the necessary facts and assumptions used in calculating fish and, where appropriate, egg losses. These are linked to formulae in subsequent tables and calculations. Each species' Assumptions worksheet includes the following key information and Table 2 provides the assumptions headings and explanation / rationale for each element :

- A brief explanation of each value and its source.
- The values for the different input parameters are shown as being 'variable' or 'fixed'.
- Those parameters with 'variable' values (green background) can be adjusted by the user to test different scenarios.
- An indication of the range of scenarios that can be used for sensitivity testing.
- As agreement is reached on the range of scenarios and modelled impacts, then the potential monitoring and survey methods by which they will be validated and tested can be recorded to ensure linkage with the AEMP and off-setting plans.

Table 2: Assumptions worksheet parameters and explanation/rationale

Heading in Worksheet	Explanation/Rationale
Starting Population	This value can be set by the user. Whilst the resultant calculations will produce the same proportionate impact assessment, a larger starting population value makes other figures more intuitive.
STRIKER v.4 Values	These values have been calculated for each species and each relevant life stage.
Draw Zone Based Encounter Probability	Taken from the Draw Zone Probability Calculation worksheet.
Fecundity	Where egg losses are estimated the fecundity of females is provided.
Sex Ratios	Where egg losses are estimated the ratio of male:female is provided. This can be significant for certain species where a 50:50 ratio is not appropriate.
Life Stages Considered	For certain species more than one life-stage has been considered. For example for salmon, smolts and kelts have been included in addition to returning 1 sea-winter and multi-sea winter adult fish.
Other Assumptions	Where appropriate to a particular species other assumptions have been included.

Sensitivity Testing Within Assumptions Worksheet

- 4.2.2 Values relating to the vulnerability of the fish either entering or exiting the lagoon can be adjusted to increase/decrease vulnerability to entry or exit from the lagoon.

4.3 'Population Data' Worksheet

Key Features

- 4.3.1 For each species a population data worksheet has been developed which provides a breakdown of the temporal distribution of each reported life-stage on a month by month basis. Where detailed data is unavailable an estimated distribution has been provided based upon expert opinion and recorded in Fish Datasheets.
- 4.3.2 Given the seasonal nature of the presence of some species or their life-stages these tables can span more than a twelve month period or in some cases, run from July to June rather than January to December, to allow for overwintering fish in the vicinity of the lagoon.

- 4.3.3 As indicated above, where possible, key life-stages have been included in the tables in order to allow for a more comprehensive assessment of impact over the whole population.

Sensitivity Testing

- 4.3.4 Adjustments to the proportion of fish within the population in each month can be made to provide for sensitivity testing. Further sensitivity testing is presented in the Alternative Fish Impact Scenarios Results paper (TLSB, July 2016).

4.4 ‘Tides Per Month’ Worksheet

- 4.4.1 The tides per month worksheet, based on 704 tides per annum, is provided for reference to aid the interpretation of graphical information provided in the individual impact assessments and the tabulated results in the Draw Zone and Alternative Draw Zone worksheets.
- 4.4.2 For the purpose of the assessments, we have not factored in changes due to tidal cycles (springs to neaps) however, this is taken into account within the STRIKER modelling.

4.5 ‘Draw Zone Probability Calculations’ Worksheet

- 4.5.1 This worksheet is used to calculate probability values for each life-stage and tidal state. The results are then transferred to the Assumptions worksheet before being used in the final Impact Calculations.

Key Features

- 4.5.2 For each species a Draw Zone Probability Calculations worksheet has been developed as outlined in section 1.2 above. Table 4 provides the key features of the draw zone probability calculations and an explanation / rationale of each stage of calculations:

Table 4 Draw zone probability calculations worksheet key features

Heading in Worksheet	Explanation
Population Ranges	For each species an appropriate population range has been selected from one of four geographic areas : Swansea Bay, Bristol Channel, Celtic Sea, Atlantic – Bay of Biscay. The area of each of these ranges has been measured to provide an approximate area in hectares.
Swimming Speed	Following a review by fisheries consultants at THA and APEM, the MSSS for each species (where available) at 10°C has been selected for the purpose of this assessment. This is a conservative estimate given that fish have burst speeds in excess of their sustained swimming speeds and do not swim constantly at the MSSS.

Area of Draw Zone at defined swimming speed (km ²)	Flows in and out of the lagoon have been modelled by TLSB under varying operating conditions. A conservative approach has been taken into consideration and the peak flood and ebb generation cycles and peak flood and ebb sluicing cycles have been used. These models enable the area (in km ²) to be measured in water flow velocity bands. Where the swimming speed of the fish falls between flow bands, again, the conservative approach of using the next flow band below the swimming speed has been applied.
Area of Draw Zone at defined swimming speed (ha)	The area in km ² is converted to Ha. by a multiplication factor of x100.
Width of Draw Zone at defined swimming speed (m) (√ of Area of Draw Zone, given a random distribution of fish swimming in random direction)	The Draw Zone is 'converted' into a square with the length of one side presented in metres.
Area of Fish Population (ha) (Bristol Channel)	This is the selected population range of the species being modelled.
Number of Draw Zones in Fish Population (Bristol Channel)	The number of potential 'Draw Zone' boxes throughout the species' population range is calculated by dividing the Area of Fish Population by the Area of the Draw Zone.
Operating Time (seconds)	This represents the number of seconds in this part of the tidal cycle (14400 secs = 4 hours, 1800secs = 30 mins).
Average number of Draw Zones crossed by a fish over an operating period (assuming a random distribution of fish swimming in random directions at its MSSS). Where the number of Draw Zones crossed over the operating period is greater than the number of drawzones in the population area, this assumes the fish could cross every Draw Zone within its population range and so the risk of encounter is 1.	The swimming speed of the fish is divided by the Width of Draw Zone in order to determine how many Draw Zones a fish could cross in one second swimming at its MSSS and always covering new ground.
Z = Draw Zones crossed by a fish as a proportion of the total number of Draw Zones in their population area. Giving risk that a randomly distributed fish swimming in a random direction in its population area will encounter the Lagoon Draw Zone during generation phase.	This represents the number of Draw Zones that the fish species could cross in the operational cycle (eg. in 14400 secs).
Y = Proportion of population within lagoon Draw Zone at	A conservative assumption has been made that any fish within the draw zone at the time of the operational cycle (eg. flood generation) will be drawn into (or out of) the lagoon.

commencement of generation phase	
$1-Y$ = Fish remaining in wider population outside lagoon Draw Zone	Given that the proportion of fish (Y) above has been lost from the wider population then the wider population is $1-Y$.
Encounter Risk (P) $= [(1-Y)*Z]+Y$	This equation uses the previously calculated figures to provide a probability of fish encountering the Draw Zone and, as a consequence, it is assumed that the fish has been drawn into the turbine housing. This does not consider any avoidance/attraction behaviours by the fish.
Avoidance Risk $= 1-P$	Any fish not entering the Draw Zone must, by default avoid it.
Flood Generation	This is the operation of the turbines on an incoming tide.
Flood Sluicing	Sluices are used to balance the water levels in the lagoon and outer Bay towards the end of the generation cycle.
Ebb Generation	This represents the operation of the turbines on an outgoing tide.
Ebb Sluicing	Sluices are used to release water from the lagoon into the wider Bay following ebb generation in order to drop the levels within the lagoon in preparation for the next flood generation.

4.5.3 The above calculations and steps are used to assess the probability of an individual fish, swimming within its population range, encountering an area of water around the turbine or sluice housing where the velocity is such that the fish is unable (due to insufficient swimming speed) to escape.

4.5.4 In making the calculations it is assumed that :

- Water currents within the channel do not increase/decrease likelihood of encounter (except within the Draw Zone).
- Fish swim at their MSSS.
- Fish do not actively seek to enter the lagoon.
- Fish do not show avoidance behaviours when they encounter increased flows.
- When a fish enters the Draw Zone it enters the turbine even though it may still have the capability to use its burst speed to escape.

4.5.5 Where possible, the MSSS has been used at 10°C. It is acknowledged that swimming speed can vary according to fish size and water temperature. However, in using the selected figures a draw-zone below the MSSS (and even lower than the Burst Speed) has been identified and thus the approach is conservative. Furthermore, any lower swimming speeds by the fish will reduce the risk of encounter with the draw zone. Further details of the swimming speeds used and sources of information are provided within Appendix 4: Fish Datasheets of the Alternative Fish Impact Assessment Results paper (TLSB, July 2016).

Table 5. Swimming Speeds Used for Draw Zone and Alternative Draw Zone Encounter Rate calculation methods

Species	Life Stage	Max. Sustainable Swimming Speed (m/sec)	Draw Zone Band Selected
Salmon	Smolt	1.2	>1.2
	Kelt	3.4	>1.2
	Adult	3.4	>1.2
Sea Trout	Smolt	1.6	>1.2
	Whitling	2.2	>1.2
	Kelt	3.2	>1.2
	Adult	3.2	>1.2
Shad	Juveniles	0.025	>0.2
	Pre-spawners	0.5	>0.4
	Post-spawners	0.5	>0.4
Eel	Elver/Glass Eel	0.13	>0.2
	Silver Eel	0.61-0.68	>0.6
	Resident adult	0.43-0.62	>0.4
River Lamprey	Transformer	0.56-0.94	>0.6
	Adult	0.56-0.94	>0.6
Sea Lamprey	Transformer	0.56-0.94	>0.8
	Adult	0.56-0.94	>0.8
Herring	Juvenile	0.3	>0.2
	Adult	1.02	>1.0
Sandeel		0.4	>0.4
Cod/ Whiting		0.5	>0.4

Bass	Juvenile	0.29	>0.2
	Adult	0.48	>0.4
Plaice	Juvenile	0.01	>0.2
Sole	Juvenile	0.005-0.03bl/s	>0.2

4.6 'Alternative Draw Zone Probability Calculations' Worksheet

4.6.1 This worksheet is used to calculate probability values for each life-stage and tidal state for the Alternative Draw Zone approach. The results are then transferred to the Assumptions worksheet before being used in the final Impact Calculations.

Key Features

4.6.2 For each species an Alternative Draw Zone Probability Calculations worksheet has been developed as outlined in section 1.2 above. Table 6 provides the key features of the draw zone probability calculations and an explanation and rationale of each stage of calculations:

Table 6 Alternative Draw Zone probability calculations worksheet key features

Heading in Worksheet	Explanation
Population Range	For each species an appropriate population range has been selected from one of four geographic areas: Swansea Bay, Bristol Channel, Celtic Sea, Atlantic – Bay of Biscay. The area of each of these ranges has been measured to provide an approximate area in hectares.
Swimming Speed	Following a review by fisheries consultants THA and APEM, the MSSS speed for each species (where available) at 10°C has been selected for the purpose of this assessment. This is a conservative estimate given that fish have burst speeds in excess of their SSS.
Area of Draw Zone at defined swimming speed (km ²)	Flows in and out of the lagoon have been modelled by TLSB under varying operating conditions. A conservative approach has been taken into consideration and the peak flood and ebb generation cycles and peak flood and ebb sluicing cycles have been used. These models enable the area (in km ²) to be measured in water flow velocity bands. Where the swimming speed of the fish falls between flow bands, again, the conservative approach of using the next flow band below the swimming speed has been applied.
Area of DZ at defined swimming speed (m ²)	The area in km ² is converted to m ² by a multiplication factor of 1,000,000.
Width of DZ at defined swimming speed (m)	The Draw Zone is 'converted' into a square with the length of a side provided in metres.

(Square root of draw zone area in metres, given a random distribution of fish swimming in random direction)	
Vulnerable Zone (VZ) (m ²) (Perimeter of DZ x 1m ² (1m ² chosen as mandatory unit for consideration as swim speed in ms ⁻¹))	An area, 1m wide, has been applied around the three sides of the draw zone that fish could encounter and this cell gives the areas of this zone, the Vulnerable Zone.
Population Area (PA) (m ²)	This is the selected population range of the species being modelled in m ²
Time taken to cross VZ (1/Sp)	This is the amount of time, in seconds, it takes for a fish to cross the 1m wide vulnerable zone.
Operating Time (secs)	This represents the number of seconds in this part of the tidal cycle (14,400 secs = 4 hours, 1,800 secs = 30 mins).
Y = Proportion of population that enters lagoon from draw-zone initially	A conservative assumption has been made that any fish within the draw zone at the time of the operational cycle (eg. flood generation) will be drawn into (or out of) the lagoon.
Z = Proportion of population that enters lagoon from draw-zone during operating phase	This represents the likelihood of a fish entering the Draw Zones over the operational cycle (eg. in 14,400 or 1,800 seconds).
1-Y = Fish remaining in wider population outside draw-zone	Given that the proportion of fish (Y) above has been lost from the wider population then the wider population is 1-Y.
Encounter Probability (P) = [(1-Y)*Z]+Y	This equation uses the previously calculated figures to provide a probability of fish encountering the Draw Zone and, as a consequence, it is assumed that the fish has been drawn into the turbine housing. This does not consider any avoidance/attraction behaviours by the fish at this stage.
Avoidance Probability = 1-P	Any fish not entering the Draw Zone must, by default avoid it.
Flood Generation	This is the operation of the turbines on an incoming tide.
Flood Sluicing	Sluices are used to balance the water levels in the lagoon and outer Bay towards the end of the generation cycle.
Ebb Generation	This represents the operation of the turbines on an outgoing tide.
Ebb Sluicing	Sluices are used to release water from the lagoon into the wider Bay following ebb generation in order to drop the levels within the lagoon in preparation for the next flood generation.

4.6.3 The above calculations and steps are used to assess the probability of an individual fish, swimming within its population range, encountering an area of water around the turbine or sluice housing where the velocity is such that the fish is unable (due to insufficient swimming speed) to escape.

4.6.4 In making the calculations it is assumed that:

- Water currents within the channel do not increase/decrease likelihood of encounter (except within the Draw Zone).
- Fish swim at their MSSS.
- Fish do not actively seek to enter the lagoon.
- Fish do not show avoidance behaviours when they encounter increased flows.
- When a fish enters the Draw Zone it enters the turbine even though it may still have the capability to use its burst speed to escape.

4.7 'Draw Zone' Worksheet (one per life-stage)

4.7.1 The worksheet is split into four key areas :

- The Input Parameter values – the avoidance value and volume entering/exiting the lagoon values used in the Volumetric Assessment have been removed as they are replaced by Draw Zone probability values in this method;
- The results which are displayed in a summary 'Results' table;
- Key data relating to the numbers of fish and the calculated impacts of the lagoon are displayed on three charts;
- A table showing the calculated impact on each tide throughout the year. In some cases the table has been extended beyond a calendar year in order to provide an impact on a full 12 month cycle of 704 tides from the first tide a fish enters the model.

Key Features

4.7.2 For each species the Draw Zone method uses the probability of a fish swimming within its normal population range, encountering the draw zone area around the turbines and sluices and assumes that if the fish enters the draw zone, it will pass through the turbine or sluice - depending on operation mode at the time of encounter.

4.7.3 Table 11 provides a detailed breakdown of the 'Impact Shown by Tide' and an explanation/rationale to the development of each element.

Table 11 'Impact Shown by Tide' section of Worksheet.

Heading in Worksheet	Explanation
Tide	The model has been repeated for all 704 tides in a calendar year from the first tide a fish enters the model.
Population in the Bay	This is based on the proportion of fish assumed to be present in each month multiplied by a fictitious population. The size of this population does not affect the outcome but use of a larger population does assist in making a results more meaningful and easier to interpret.

Average Population In the Bay	In order to smooth out the transition from one month to the next a rolling average population across 60 tides has been provided.
No. of fish entering the lagoon via the Turbines	The average number of fish in the Bay is multiplied by the probability of a fish entering via the turbines (as calculated in the Draw Zone Probability worksheet).
No. of fish Entering the Lagoon via the sluices	The average number of fish in the Bay is multiplied by the probability of a fish entering via the sluices (as calculated in the Draw Zone Probability worksheet).
Total No. of fish Entering the Lagoon	The number of fish predicted to enter the lagoon via the turbines and sluices is combined to provide a total number entering.
No. of fish injured on way in	The relevant STRIKER value is applied to the number of fish entering the lagoon via the turbines.
No. of fish Surviving Passage	The number of fish that enter the lagoon uninjured having passed through the turbines and sluices.
No. of fish alive in the lagoon between tides	This is a cumulative value that increases (or decreases) as more fish are added (or removed) from the lagoon population.
No. of fish exiting via the turbines	The average number of fish in the Bay is multiplied by the probability of a fish entering via the turbines (as calculated in the Draw Zone Probability worksheet).
No of fish Exiting via the sluices	The average number of fish in the Bay is multiplied by the probability of a fish entering via the sluices (as calculated in the Draw Zone Probability worksheet).
Total No. of fish Exiting the lagoon	The number of fish predicted to enter the lagoon via the turbines and sluices is combined to provide a total number entering.
No. of fish injured on the way out	The relevant STRIKER value is applied to the number of fish exiting the lagoon via the turbines.
Total No. of fish injured (in/out)	This is the sum of the number of fish predicted to be injured (using STRIKER) both entering and exiting the lagoon on each tide.
Cumulative Losses	This is the sum of all injuries (and therefore losses) on all tides.
No of fish re-entering the Bay	This represents the number of fish exiting the lagoon having subtracted those fish that were injured (and presumed lost).
No. of fish Added to Lagoon Popn	This is equivalent to the number of fish entering the lagoon with those exiting subtracted from it.
No. of fish left alive in lagoon (cumulative)	The number of fish added to the lagoon population on each tide is added to provide a running total (cumulative) and overall estimate of the lagoon population.
Date	The 1 st day of each month has been provided as a reference point to aid interpretation of the data.

4.8 ‘Survival and Impact Assessment’ Worksheet

Key Features

4.8.1 Using the data produced within the Draw Zone and Alternative Draw Zone methods outlined methods above, a summary table is produced for each of the VER species to show the impact over the different life-stages in terms of adult fish losses and where possible, egg production loss. Table 12 presents the headings and explanation / rationale for the impact summary tables.

4.8.2 The calculations are based on the survival rate from one life-stage to another.

Table 12 Survival and Impact Assessment Impact summary table

Heading in Worksheet	Explanation
Life Stage	For several species of fish more than one life-stage is assessed for example for salmon smolts, 1 sea winter (1SW), kelts and multi-sea winter fish (MSW) are included.
No. of Fish Impounded	This figure is taken from the Results section of the worksheet for the Draw Zone calculations worksheet.
No. of Fish Lost	This figure is taken from the Results section of the worksheet for the Draw Zone calculations worksheet.
Total No. of fish Combined	The proportion of fish impounded and lost are added to provide a combined proportion of impact.
Survival at life stage	This represents the proportion of fish surviving at each life stage.
Probability of survival to life stage	This is calculated as the product of a particular life-stage and, where appropriate, the other earlier life-stages.
Eggs/Female	Where applicable, the fecundity of the species is indicated and this is used to calculate overall impacts in the subsequent calculations.
Baseline Population / Age Structure	Where information is available on the species population and the proportion in each life-stage, an estimate of the baseline population against which impacts can be assessed is provided.
Proportion of females	Certain fish species do not have a 50:50 ratio of male:females and therefore the relevant proportions are provided where these are known.
Baseline egg production	This is the product of the proportion of females x population x egg production without the lagoon in operation (eg. natural state).
Egg production with Project in place	This represents the number of eggs produced having taken into consideration the impact of the lagoon.
Egg Production Lost	The ‘Impacted No. Eggs’ subtracted from the ‘Baseline egg production’ provides a figure for the estimated potential loss of eggs as a result of lagoon construction.
% Impact on egg deposition	The Loss of Eggs is represented as a proportion of the baseline egg production.

Avoidance / Attraction Behaviours

4.8.3 As indicated by many studies, including Wilson et al (2007) in a report to the Scottish Office, the models do not include key elements of fish behaviour which would encompass attraction and avoidance characteristics. These would include, for example, fish avoiding areas of increasingly high flows due to their awareness of potential danger, or fish taking advantage of high flows to attack prey species. Other factors influencing fish behaviour but are not included in the new assessments include:

- Seasonality – whilst we have included the seasonal presence of fish (by providing monthly proportions of the annual population) fish may be more, or less, at risk during different times of the year. For example there may be a strong urge by salmonids to exit the lagoon in the autumn in order to spawn or, in the case of sandeels, for example, periods of time are spent dormant, buried in the substrate.
- Deterrent effect of turbine noise and vibration.
- Water chemistry
 - Salinity gradients may attract or deter fish.
 - Turbidity caused by the turbine/slucice operation may lead to greater/fewer encounters with turbines.
 - Temperature – some species e.g. eels become dormant below certain temperatures and this may lead to lower encounter rates.
- Olfactory trail – used by migrating salmon and sea trout to return to their natal rivers. Given that there are no freshwater inputs into the Swansea Lagoon then the water within the lagoon will have far less of an olfactory attraction than the water to the east (Neath) and west (Tawe).
- Tidal movements
- Predator/prey relationships
- Some fish species may be attracted to or actively avoid the high flow, or the exiting plume may alter the migratory path of a fish.

4.8.4 Given the unique nature of the lagoon, whilst expert advice can be obtained in relation to the above, the application of such advice, in the absence of evidence from the site, is largely speculative.

Appendix 1: Technical Note: Fish “Draw Zone” Areas as a proxy for encounter probabilities

Background

As part of the ongoing Marine Licence application, additional work is required around potential fish mortality. Concerns have been expressed around the parameterisation of the Individual-Based Model (“IBM”) used within the EIA. This model calculates the probability that a fish will be close enough to the turbine or sluice to be drawn into it (and also models whether fish are repeatedly drawn into the turbines).

Concerns have been expressed regarding some of the input parameters within the IBM model (e.g. allowing for resident fish). Accordingly, TLSB have constructed a model in order to supply this detail. This works on the assumption that fish are evenly distributed across the bay, and will only be drawn into the turbine or sluice if they are within their “event horizon” (Draw Zone). This is the velocity contour which represents the limit of their maximum sustained swimming speed.

The area of this velocity contour divided by the geographic range of the species being considered (or the lagoon itself for impounded fish) is taken as the probability that a fish will be drawn into the turbines or sluices.

This document supplies snapshots of the following moments in time:

1. Peak velocities (spring) for ebb and flood generation
2. Peak velocities at start of sluicing (ebb and flood).

It was found that area changes due to the ebb and flow of the tide were not distinguishable due to the resolution of the 2D Delft model used, nor was the wetting and drying inside the lagoon.

The area of Swansea Bay (“Exterior Area”) was thus taken as a constant 95.0 km², and the area inside the basin as a constant 11.9 km² (“Interior Area”).

Given the other first order assumptions made in this fish modelling, these approximate areas are not considered to be a significant issue.

Peak Velocities Ebb Generation

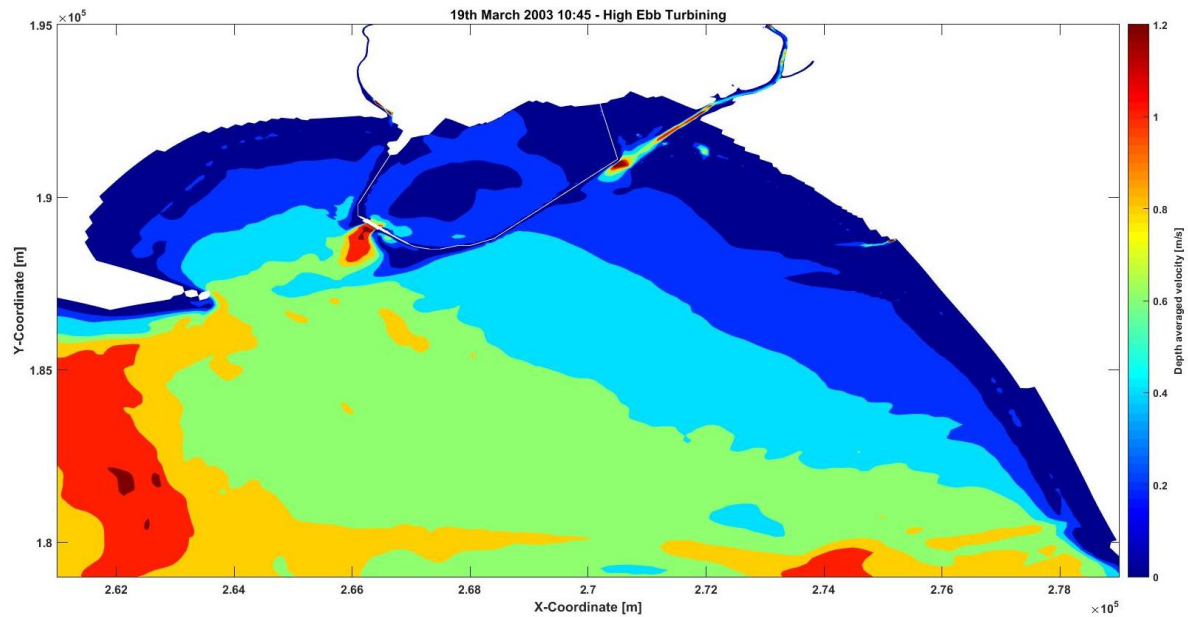


Figure 1. Contours showing flow speeds around the turbine house with the whole of Swansea bay during high flow ebb turbinning

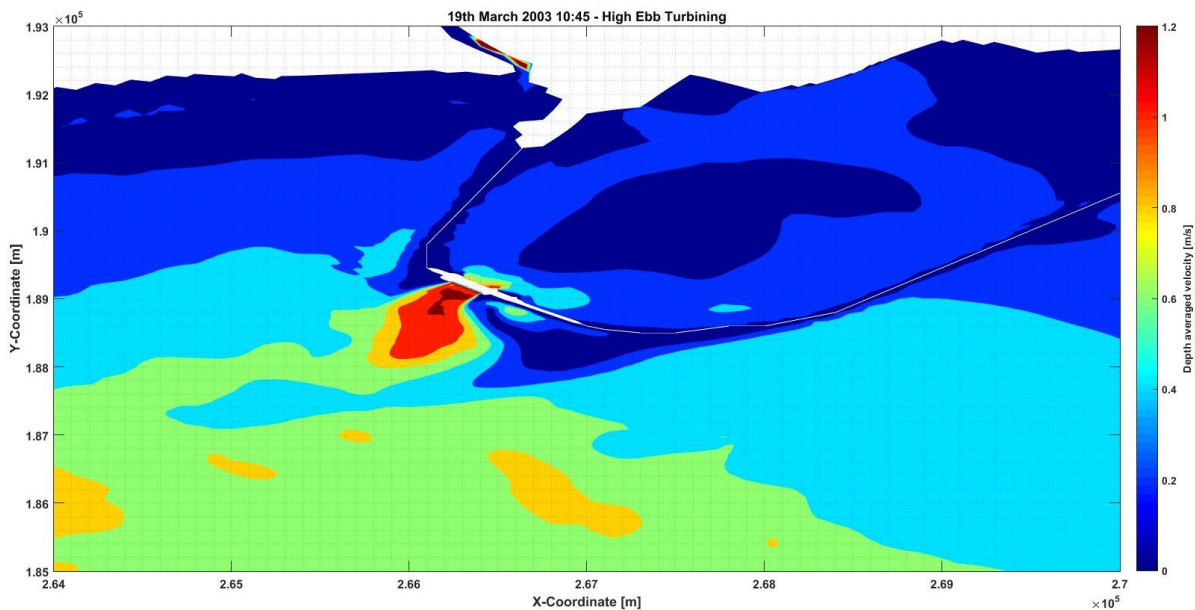


Figure 2. Close up of contours showing flow speeds around the turbine house during high flow ebb turbinning

Flow Speed [m/s]	Total Area [km ²]	Percentage of Interior Area [%]
> 0.2	5.811	48.766
> 0.4	0.179	1.505
> 0.6	0.033	0.274
> 0.8	0.003	0.026
> 1.0	0.001	0.007
> 1.2	<0.001	<0.001

Peak Velocities Flood Generation

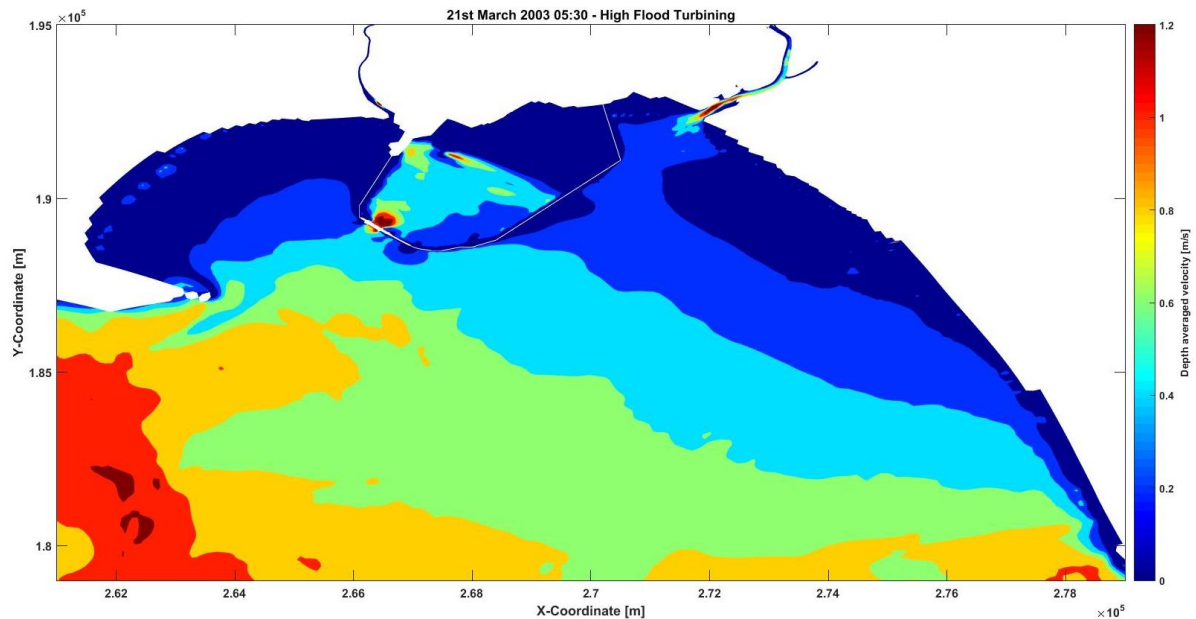


Figure 3. Contours showing flow speeds around the turbine house with the whole of Swansea bay during high flow flood turbinning

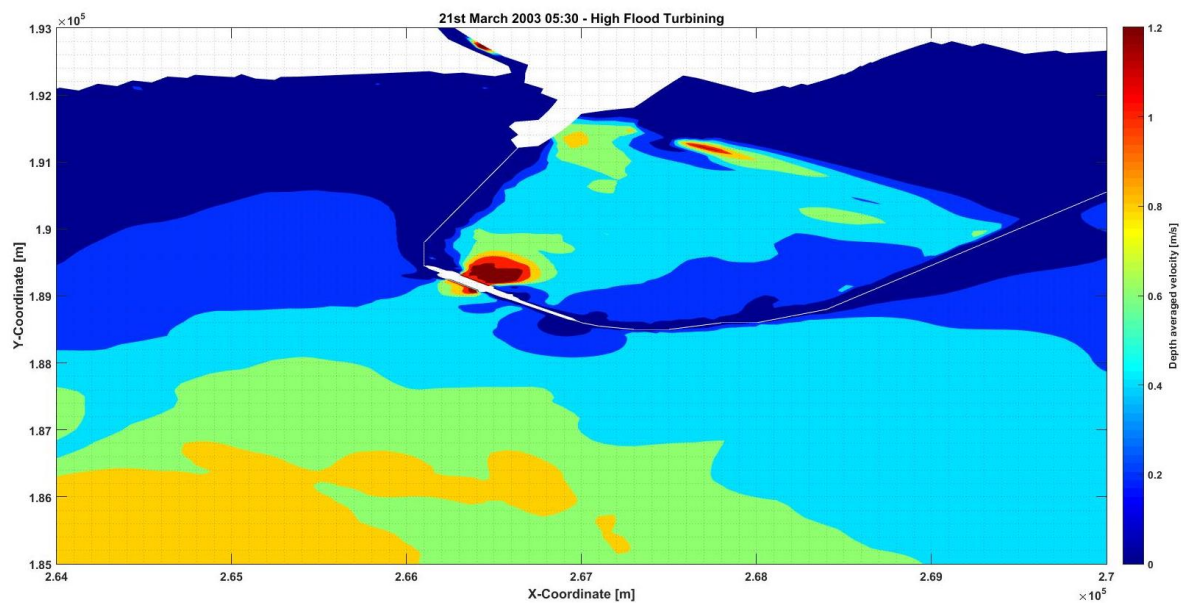


Figure 4. Close up of contours showing flow speeds around the turbine house during high flow flood turbinning

Flow Speed [m/s]	Total Area [km ²]	Percentage of Exterior Area [%]
> 0.2	-	-
> 0.4	0.394	0.415
> 0.6	0.042	0.044
> 0.8	0.022	0.023
> 1.0	0.009	0.009
> 1.2	0.003	0.002

Peak Velocities Ebb Sluicing

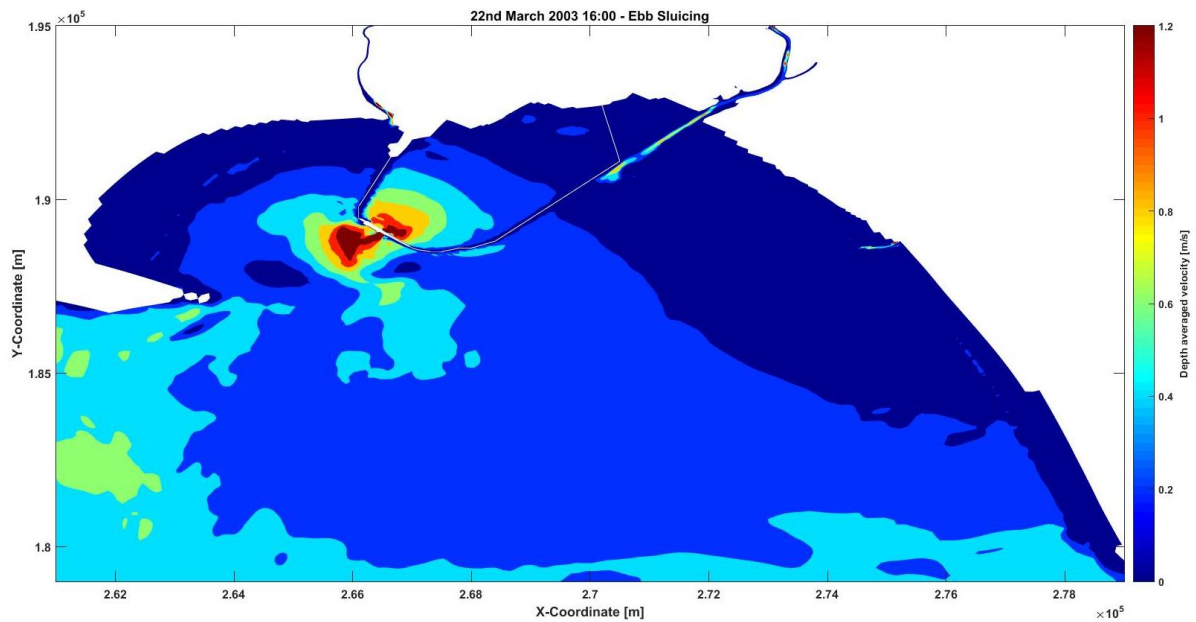


Figure 5. Contours showing flow speeds around the turbine house with the whole of Swansea bay during ebb sluicing

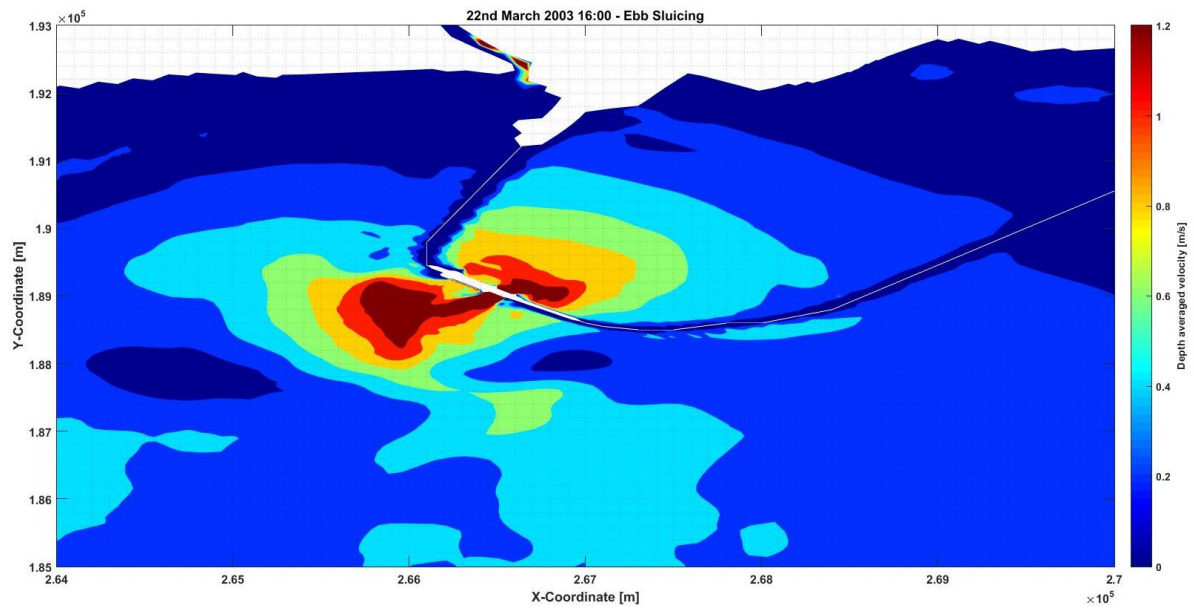


Figure 6. Close up of contours showing flow speeds around the turbine house during ebb sluicing

Flow Speed [m/s]	Total Area [km ²]	Percentage of Interior Area [%]
> 0.2	6.390	53.626
> 0.4	3.231	27.118
> 0.6	1.515	12.718
> 0.8	0.806	6.763
> 1.0	0.254	2.129
> 1.2	0.075	0.629

Peak Velocities Flood Sluicing

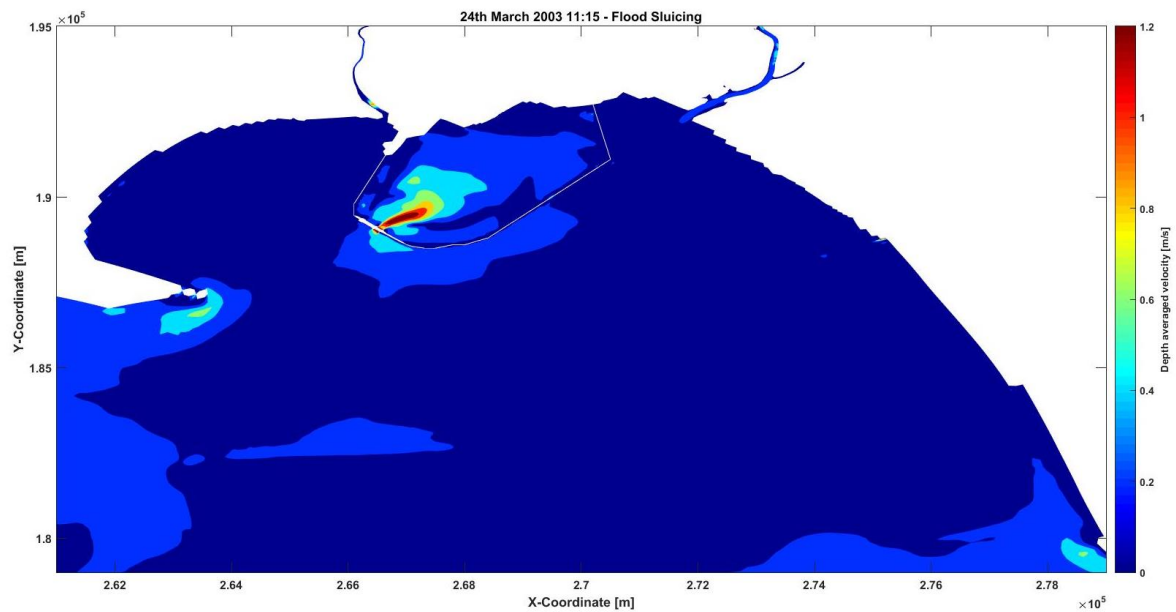


Figure 7. Contours showing flow speeds around the turbine house with the whole of Swansea bay during flood sluicing

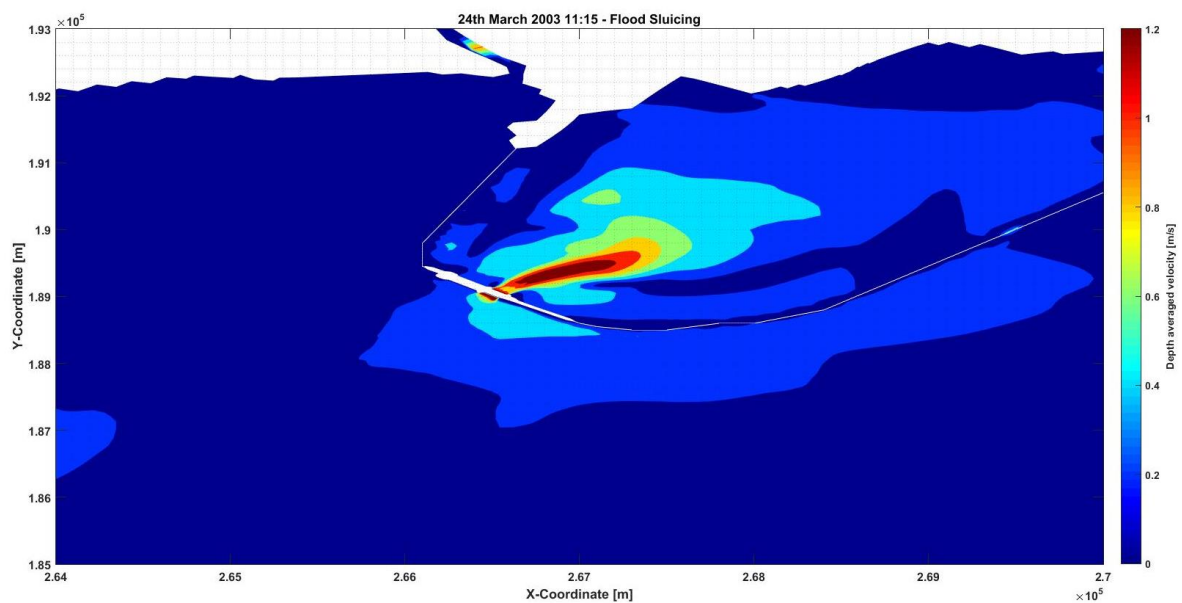


Figure 5. Close up of contours showing flow speeds around the turbine house during flood sluicing

Flow Speed [m/s]	Total Area [km ²]	Percentage of Exterior Area [%]
> 0.2	4.436	4.666
> 0.4	0.273	0.287
> 0.6	0.014	0.015
> 0.8	0.008	0.009
> 1.0	0.005	0.006
> 1.2	0.004	0.003

5 References

Expert advice received from APEM and THA consultants both verbally and in the form of Fish Datasheets which in turn cite references used.

Fishbase.org

Fish Datasheets prepared by THA / APEM consultants including M.Aprahamian, N. Teague, R. Perez, N.Milner, T.Harding, A.Turnpenny

Hammar L. Eggertsen L. Andersson S. Ehnberg J. Arvidsson R. Gulltrom M et al (2015) A Probabilistic Model for Hydrokinetic Turbine Collision Risks: Exploring Impacts on Fish. PLoS ONE 10(3)

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Tidal Lagoon Swansea Bay PLC (2014) Environmental Statement.

Appendix 2: Fish Datasheets

Tidal Lagoon Swansea Bay

FISH SPECIES DATASHEET

Species	European seabass <i>Dicentrarchus labrax</i>
Life stages at risk	Juvenile and Adult
Offsetting Units e.g. eggs , ammocoetes	

Seasonality

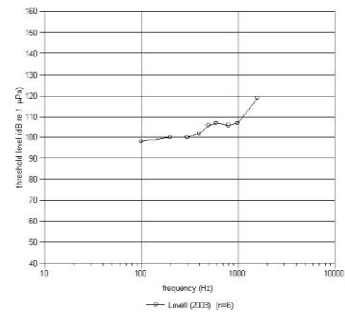
Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan		2 group basis		
Feb		aim for head of tide over June		
Mar		September		
Apr		(Kelley, 1988)		
May		From October		
Jun		They head		
Jul		downstream for		
Aug		Deeper water		
Sept	Peak abundance	(Colclough et al., 2002)		
Oct		Henderson &		
Nov				
Dec				

	Comment	Supporting Evidence
Possible seasonal behavioural changes	European sea bass display predominantly nocturnal self-feeding patterns in winter and early spring. During winter, sea bass go offshore where the temperature is higher. Postlarvae arrive in May-June, a month or two after spawning takes place offshore. They concentrate initially at the head of the 'salt-wedge' before spreading back through the estuary. In their first summer they favour shallow creeks, channels, marsh pools and tributary streams; Spartina marshes are especially favoured in some areas. In October they move to deeper parts of the estuary, the largest individuals moving first as in all such changes of habitat.	Azzaydi <i>et al.</i> (2000); Claridge & Potter (1983); Kelley (1988)
Migrant species - likely time spent in Bay - e.g. no. of tidal cycles		
Resident Species / Stages : Preferred location in Bay (if residential)	The Severn Estuary and Inner Bristol Channel is an important nursery area for juvenile bass. Juvenile bass occupy defined nursery areas whilst adults return to the same offshore spawning sites each year.	Claridge & Potter (1983); Ares (2016)
Hearing Sensitivity	0.1-1 kHz linear sweep (150 dBrms re 1µPa) produced a significant increase in motility in sea bass. 58.5% of bass will avoid sounds of 56 dBHT.	Buscaino <i>et al.</i> (2010); Nedwell <i>et al.</i> (2007);
Known attraction behaviour to flows / structures	The larval transport mechanism into estuaries is initially passive, becoming active through selective behavioural strategies such as selective tidal stream transport. Based on this it can be hypothesised that juvenile bass attempt to hold station in channel margins and in the lee of piers, jetties and other structures on the ebb tide.	Jennings & Pawson (1992); A. Turnpenny pers comm.
Known avoidance behaviour to flows / structures		
Position in tide e.g. on flush of flood tide	Probably varies with tidal state, seeking low velocity refuges on the ebb tide and high velocities on the flood. Fish sample horizontal and vertical velocity profile, selecting low velocities in resting phase and high velocities during active migration.	A. Turnpenny pers comm.
Diurnal variations (e.g. inactive/active at night)	Juvenile individuals school by day and disaggregate at night.	Aaras <i>et al.</i> (1997)
Likelihood of presence at turbines during flood generation e.g. two hours after low water.		
Feeding/foraging behaviour	Juvenile seabass feed primarily on macroplankton. Adults feed of a wide variety of prey ranging from smaller fish to crustaceans. Sea bass are active predators that capture prey by pursuit, as part of a shoal when they are juveniles.	Ferrari & Chieregato (1981); Laffaille <i>et al.</i> (2001); Claireaux <i>et al.</i> (2006)
Avoidance Ability		
Ability to Avoid : Burst swimming speed	Burst= 12 bl/s	Turnpenny (1981)
Ability to Avoid : Sustained swimming speed	MS55±0.15 /7.2 bl/s @ 12°C (median/90%ile)	Turnpenny (1981)
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area		
Random distribution across Bay	Postlarvae concentrate initially at the head of the 'salt-wedge' before spreading back through the estuary. In their first summer they favour shallow creeks, channels, marsh pools and tributary streams; Spartina marshes are especially favoured in some areas. In October they move to deeper parts of the estuary, the largest individuals moving first as in all such changes of habitat.	Kelley (1988)
Concentration in surf-zone/littoral zone		
Proportion of Fish impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	No	
Wider Population unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Bristol Channel	House of Commons, 2016
Motivational Drivers		

Audiogram from figure supplied by J. Lovell. Threshold levels in dB re 1 μ Pa. 6 specimens.

Frequency (Hz)	100	200	300	400	500	600	800	1000	1600
Mean	98	100	100	102	106	107	106	107	119

(F₂, ref: Base01)

Audiogram for bass

Motivation to enter lagoon		
Chasing prey	Adult bass are active predators that have potential to chase prey in the lagoon.	Claireaux et al. (2006)
Being chased by predators	Juvenile bass are predated on by larger fish, including gadoids and bass.	Henderson & Corps (1997)
Seeking new habitat	Bass (of all ages) are euryhaline; they can tolerate freshwater and will freely move to it. This species migrates between different habitats during its lifecycle. Although postlarvae gather near the salt/freshwater interface in estuaries, it is questioned whether bass are attracted to lower salinities or if the influence of temperature or the availability of food is a greater draw.	Varsamos et al. (2001); Dando & Demir (1985)
Protected environment	On the Britain Atlantic coast, sea bass spawn between February and April. Young of the year migrate towards estuaries.	Claridge & Potter (1983)
Spawning	No	
Other	N/A	
Motivation to exit lagoon		
Chasing prey	Adult bass are active predators that have potential to chase prey out of the lagoon.	Claireaux et al. (2006)
Being chased by predators		
Spawning drive	Adult bass spawn offshore.	Ares (2016)
Lack of niches/refuges to occupy	Not anticipated	
Lack of food availability	Subsequently, bass disperse back downstream to utilise productive intertidal feeding areas along the estuarine margins and tidal creeks. By late autumn bass return to deeper water and back to the lower estuary. In autumn, O-group bass leave marginal estuarine habitat for deeper, warmer water, often being seen on power station screens at this time.	Coklough et al. (2002); Pickett & Pawson (1994)
Spawning	See spawning above	
Other	In these, the young bass remain largely within the estuary for their first four or five years, including usually the winters (except in periods of heavy flood or prolonged cold, when the older juveniles may move out temporarily).	Kelley (1988)

Other Factors

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Tidal Lagoon Swansea Bay FISH SPECIES DATASHEET

Species	Cod and Whiting
Life stages at risk	All
Offsetting Units e.g. eggs, ammocoetes	

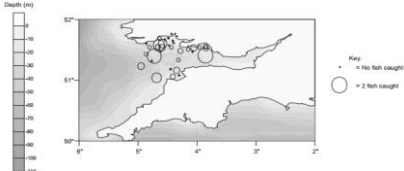
Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan				
Feb		Summer and winter		
Mar		temperatures		
Apr		are critical		
May		determinants of		
Jun		the relative		
Jul		abundance of		
Aug		dominant		
Sept	Peak abundance	estuarine		
Oct	Peak abundance	species, Power		
Nov	Peak abundance	et al. (2002)		
Dec				

	Comment	Supporting Evidence
Possible seasonal behavioural changes		
Migrant species: likely time spent in Bay: e.g. no. of tidal cycles		
Resident Species / Stages: Preferred location in Bay if residential	the occurrence or peak numbers or very young whiting in the Bristol Channel in mid-April and of the 0+ stages of Oldbury during September and October of 1974	Claridge & Potter (1984); Henderson & Holmes (1989); Brander (1994)
Hearing Sensitivity	Cod are sensitive to pure tones in the frequency range from 30 to 470 Hz with greatest sensitivity in the range 60 to 310 Hz.	Chapman & Hawkins (1973)
Known attraction behaviour: to flows / structures	Fish tracking and mistraler trawling experiments have shown that cod use the tidal streams to migrate in the southern North Sea and that large numbers of plaice move through the Dover	DFR (1994)
Known avoidance behaviour: to flows / structures		
Position in tide: e.g. on flush of flood tide		
Diurnal variations (e.g. inactive/active at night)	Cod have a diurnal rhythm of swimming activity with a slightly lower swimming speed during a 5-h period at night, indicating that they search more actively for food during the day.	Løkkeborg (1998)
Likelihood of presence at turbines during flood generation: e.g. two hours after low water.		
Feeding/foraging behaviour	Cod have a generalized feeding pattern. whiting were viewed as generalist feeders. High percent occurrence of Crangon in the stomachs of sampled whiting indicate	Løkkeborg (1998); Henderson et al. (2006)
Avoidance Ability		
Ability to Avoid: Burst swimming speed	Atlantic cod individuals can maintain speeds exceeding 1.1 m/s for less than one minute.	Winger et al. (1997)
Ability to Avoid: Sustained swimming speed	Speeds between 0.8 and 0.8 m/s in which endurance exceeded 200 minutes have been recorded for Atlantic cod. The maximum sustained speed of a 35-cm cod is about 50 cm/s.	Winger et al. (1997); He (1993); He & Wardle (1988); Breen et al. (2004)
Fish concentrated in drawdown zone area		
Random distribution across Bay		
Concentration in surf-zone/littoral zone		
Proportion of Fish Impacted as part of wider population		
Is species / life-stage: part of a discrete Swansea Bay population?		
Wider Population unit (eg. Bristol Channel / Celtic Sea/ Atlantic)		
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey		
Being chased by predators		
Seeking new habitat	Five of the seven most numerous species of Gadidae found in the Severn entered the shallows of the inner estuary in the occurrence of the winter months in the late autumn and early winter. Cod utilises estuarine habitats and other coastal waters as nursery grounds.	Claridge & Potter (1984)
Protected environment		Power et al. (2002); Wheeler (1978); Rogers et al. (1998)
Spawning		
Other	High percent occurrence of Crangon in the stomachs of sampled whiting indicate predator-prey relationship.	Henderson et al. (2006)
Motivation to exit lagoon		

Cod (Parker-Humphreys, 2004):



Whiting (Parker-Humphreys, 2004):

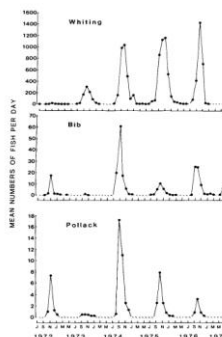
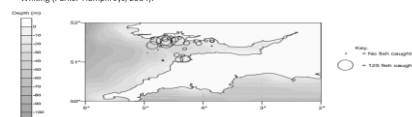


Fig. 2. The mean daily number of whiting (*Merlangius merlangus*), h.b. (*Trisopterus luscus*) and pollack (*Pollachius pollachius*) collected from Oldbury in each month between July 1975 and June 1977. In this and the subsequent two figures an open circle denotes a zero value, i.e. no fish were caught in any of the samples taken that month.

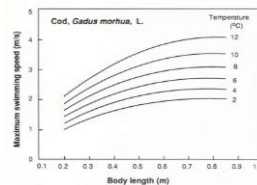


Figure 5. The maximum swimming speed of cod, *Gadus morhua*, in relation to body length and temperature as predicted from the measured muscle contraction time. Drawn from data given in Videler and Wardle (1991) with a stride length of 0.60 L.

Chasing prey		
Being chased by predators		
Spawning drive		
Lack of riches/refuges to occupy		
Lack of food availability		
Spawning	Cod spawn off the north coast of Cornwall from late winter to early spring.	Ellis <i>et al.</i> (2012)
Other	Temperature fluctuations act as a stimulus to movement within the estuary as individuals seek a preferred thermal range.	Power <i>et al.</i> (2002)

Other Factors

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Species	Eel
Life stages at risk	Glass eel
Offsetting Units e.g. eggs , ammocoetes	

Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan			5	Cefas 2012-2013
Feb			25	
Mar			55	
Apr			15	
May				
Jun				
Jul				
Aug				
Sept				
Oct				
Nov				
Dec				

Life History Characteristics

	Comment	Supporting Evidence
Possible seasonal behavioural changes	An increased time at a constant temperature (high or low) may reduce the migratory urge (preference for FW) in active eels - becoming resident.	Edeline et al 2005
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Glass eel utilise a combination of STST and active swimming behaviours. During the flood tide, glass eels are spread throughout the water column and passively migrate upstream utilising the flood tide current. During the slack and early ebb tide, glass eels move to the margins and actively swim upstream for a short period until the current speed exceeds their sustained swimming capability. During the full ebb tide, glass eels move to the bottom and remain on or in the substrate in order to maintain their position in the estuary and avoid being carried back downstream by the ebb tide current and river flow. When the water temperature reaches 10-12 °C, the glass eels swim actively upstream in the estuary.	Gascuel, 1986; Creutzberg, 1958. McCleave, & Kleckner, 1982; Harrison et al, 2014
Resident Species / Stages : Preferred location in Bay if residential		
Hearing Sensitivity		
Known attraction behaviour to flows / structures	Attracted to flood tide	
Known avoidance behaviour to flows / structures	Avoidance of ebb tide	
Position in tide e.g. on flush of flood tide	Surface, majority of glass eels migrate on the flood tide at night, some do enter the water column during the ebb tide - eel densities are greater at the surface than at deeper depths; particularly than at depths of 7m and at lower salinities.	Cefas study 2012-2013; Elie 1979; McCleave and Kleckner 1982; Sheldon and McCleave 1985
Diurnal variations (e.g. inactive/active at night)	An increase in activity during the first hours of darkness , during which time they also distribute closer to the surface and during the new moon phase, but not the full moon.	Bardonnet et al. 2003; Bureau Du Colombier et al. 2007; Adam et al., 2008
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	High	
Feeding/foraging behaviour	Not feeding	
Avoidance Ability		
Ability to Avoid : Burst swimming speed		
Ability to Avoid : Sustained swimming speed	Mean critical swimming speeds of 11.7–13.3 cms-1 (A.rostrata); 2 bls-1	For A. rostrata glass eels over a temperature range of 14–24.5 C (Wuenschel and Able 2008). Clough & Turnpenny (2001).

Population Impacted

	Comment	Supporting Evidence
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area		
Random distribution across Bay	No - Preference for shallow, inshore sites on the southern and northern sides of the Estuary.	Cefas study 20012-2013
Concentration in surf-zone/littoral zone or elsewhere		
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	No	
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Atlantic	

Motivation to enter/exit Lagoon

Motivational Drivers		
Motivation to enter lagoon		
Chasing prey		
Being chased by predators		
Seeking new habitat		
Protected environment	Avoid displacement on ebb tide	
Spawning		
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators		
Spawning drive		
Lack of niches/refuges to occupy		
Lack of food availability	On route to FW feeding arreas	At least for part of the population
Spawning		
Other		

Burst and sustained speeds (cm.s⁻¹) of eel (*Anguilla anguilla*) in relation to size and water temperature, with median and 90th percentile values (from SWIMIT v3.3)

Turnpenny, A.W.H., Richard Horsfield, Jacobs UK Ltd

Fish Length	Test Type	Swimming Speed (cms ⁻¹)			
		Spring		Summer/Autumn	
		Median	90%ile	Median	90%ile
8 cm	Sustained	8.3	7.9	2.5	2.2
	Burst	50	25	12	8

Migration Routes / Behaviours

	Comment	Supporting Evidence
Known Migration Routes /Behaviours Within Bristol Channel		
Adults		
Juveniles	Glass eels use the full width of the Channel to migrate upriver, the greatest abundance of eels was consistently found in shallow, inshore sites on the southern and northern sides of the Channel and eel densities are greater at the surface than at deeper depths; particularly than at depths of 7m. Low temperatures (less than 6 C) have been demonstrated to reduce glass eel activity, cease their vertical migration.	Cefas study 2012-2013. Deelder 1958; Elie 1979; Cantrelle 1981; Lecomte-Finiger and Razouls 1981; Gascuel 1986; De’saunay et al. 1987; Elie and Rochard 1994
Influenced by river spate Conditions		

	Comment	Supporting Evidence
Known Migration Routes /Behaviours Within River Estuaries		
Adults		
Juveniles	In estuaries, glass eels show a sharp reduction in the migratory propensity below a threshold temperature of about 11–12 oC. Lower water temperature (10 oC) significantly decreased both locomotor activity and preference for FW in glass eels as compared to higher temperature (18 oC).	Edeline et al 2005; Gascuel, 1986; McGovern and McCarthy, 1992; Jessop, 2003; Harrison et al 2014.
Influenced by river spate Conditions	In estuaries, delay in upstream migration due to high discharge	Elie, 1979; De Casamajor et al., 2000

Species	Eel
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Life stages at risk	Yellow
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Offsetting Units e.g. eggs , ammocoetes	
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Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan			100%	I.e - present all year round - though active May-October - Generally there is little activity below about 10oC, with increasing activity with rising temperature up to well over 20oC.
Feb			100%	
Mar			100%	
Apr			100%	
May			100%	
Jun			100%	
Jul			100%	
Aug			100%	
Sept			100%	
Oct			100%	
Nov			100%	
Dec			100%	

Life History Characteristics

	Comment	Supporting Evidence
Possible seasonal behavioural changes	Resident as opposed to migratory - may remain in the bay for up to 16 years - majority leaving after 12 years - females dominate (~80%)	Aprahamian (1984) - extrapolated from Severn Estuary data
Migrant species : likely time spent in Bay e.g. no. of tidal cycles		
Resident Species / Stages : Preferred location in Bay if residential	Preference for "sheltered habitat" - with depths <2.5m, with smaller yellow eels preferring shallower habitats, compared with larger individuals. Home range of ~150m - movements up to 3.5k.	Data from Poole harbour (ICES,2009) & Severn Estuary, Chadwick et al (2007).
Hearing Sensitivity	Audiogram measurements have shown that eels are sensitive to sound pressure at frequencies centring on 90Hz and to vibrations of around 40Hz.	Jerkø et al, 1989.
Known attraction behaviour to flows / structures		
Known avoidance behaviour to flows / structures	Avoid being exposed to high current velocities	
Position in tide e.g. on flush of flood tide	Bottom	
Diurnal variations (e.g. inactive/active at night)	Active at night	
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Low	
Feeding/foraging behaviour	At night - mysids small fish and gammarids	
Avoidance Ability		
Ability to Avoid : Burst swimming speed	1.75–2.12 m s–1.	Russon & Kemp, 2011
Ability to Avoid : Sustained swimming speed		

Population Impacted

	Comment	Supporting Evidence
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area		
Random distribution across Bay		
Concentration in surf-zone/littoral zone or elsewhere		
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	No	
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Atlantic	

Motivation to enter/exit Lagoon

Motivational Drivers		
Motivation to enter lagoon		
Chasing prey		
Being chased by predators		
Seeking new habitat		
Protected environment		
Spawning		
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators		

Spawning drive		
Lack of niches/refuges to occupy		
Lack of food availability		
Spawning		
Other		

Migration Routes / Behaviours

	Comment	Supporting Evidence
Known Migration Routes /Behaviours Within Bristol Channel		
Adults		
Juveniles		
Influenced by river spate Conditions		

	Comment	Supporting Evidence
Known Migration Routes /Behaviours Within River Estuaries		
Adults		
Juveniles		
Influenced by river spate Conditions		

Burst and sustained speeds (cm.s⁻¹) of eel (Anguilla anguilla) in relation to size and water temperature, with median and 90th percentile values (from SWIMIT v3.3)
 Tumpenny, A.W.H., Richard Horsfield, Jacobs UK Ltd

Water Temp. °C	Parameter	Body Length (cm)							
		10 cm		30 cm		50 cm		70 cm	
		Sust.	Burst	Sust.	Burst	Sust.	Burst	Sust.	Burst
<10	Mean	9	101	19	109	38	119	58	126
	90%ile	<5	80	6	88	18	98	31	105
10-15	Mean	13	104	23	112	43	123	62	129
	90%ile	<5	83	9	91	22	102	35	108
>15	Mean	18	107	27	115	47	125	66	132
	90%ile	6	86	13	94	26	104	38	111

Species	Eel
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Life stages at risk	Silver
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Offsetting Units e.g. eggs , ammocoetes	
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Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan			1%	Frost (1950); Matthews
Feb				
Mar				
Apr				
May				
Jun			1%	
Jul			2%	et al 2001
Aug			10%	
Sept			30%	
Oct			45%	
Nov			10%	
Dec			1%	

Life History Characteristics

	Comment	Supporting Evidence
Possible seasonal behavioural changes		
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Net migration speed ranged between 4.0 to 16.5 km d−1 in the Mediterranean, between 8.7 and 9.7 km d−1 in the Atlantic abd ~16kmd-1 in the Baltic. Progression rates in the outer part of the Randers Fjord (mean 0.78 ± 0.66 km h−1, range 0.04 to 2.5 km h−1, or mean 0.34 ± 0.30 body lengths s−1, range 0.2 to 1.22 body lengths s−1),	http://www.nature.com/articles/srep21817#t1 ; http://www.int-res.com/articles/ab_oa/b009p263.pdf ; Westerberg et al 2007
Resident Species / Stages : Preferred location in Bay if residential		
Hearing Sensitivity	Audiogram measurements have shown that eels are sensitive to sound pressure at frequencies centring on 90Hz and to vibrations of around 40Hz.	Jerkø et al, 1989.
Known attraction behaviour to flows / structures	Attracted to follow the main flow - major movements of silver eels correlated with elevated discharge, and associated increased turbidity.	Frost 1950, Tesch 1977, Moriarty 1978, Matthews et al 2001
Known avoidance behaviour to flows / structures		
Position in tide e.g. on flush of flood tide	If the run was small most fish were close to the bed, but when a major run was occurring the fish were distributed throughout the water column (Ardnacrusha dam, River Shannon). In the Baltic, on	Moriarty (1978); Westerberg et al 2007
Diurnal variations (e.g. inactive/active at night)	Very little migration takes place during daytime and movement is greatest on dark nights. Lunar cycle has a significant effect, with most movement being recorded in the first and last quarter of the moon. Eels show a specific diurnal activity pattern: passively resting on the sea floor during daylight, then swimming at or just beneath the surface at night.	Frost, 1950; Haraldstad and Vøllestad 1985; Tesch 1977; Todd, 1981; Westerberg et al 2007
Likelihood of presence at turbines during flood generation e.g. two hours after low water.		
Feeding/foraging behaviour	Not feeding	
Avoidance Ability		
Ability to Avoid : Burst swimming speed	1.75–2.12 m s−1.	Russon & Kemp, 2011
Ability to Avoid : Sustained swimming speed	0.61-0.68 m s-1	Palstra et al 2008

Population Impacted

	Comment	Supporting Evidence
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area		
Random distribution across Bay		
Concentration in surf-zone/littoral zone or elsewhere		

Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	No	
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Atlantic	

Motivation to enter/exit Lagoon

Motivational Drivers		
Motivation to enter lagoon		
Chasing prey		
Being chased by predators		
Seeking new habitat		
Protected environment	Avoid displacementon flood tide	
Spawning		
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators		
Spawning drive		
Lack of niches/refuges to occupy		
Lack of food availability		
Spawning	On route to Sargasso	
Other		

Migration Routes / Behaviours

	Comment	Supporting Evidence
Known Migration Routes /Behaviours Within Bristol Channel		
Adults		
Juveniles		
Influenced by river spate Conditions		

	Comment	Supporting Evidence
Known Migration Routes /Behaviours Within River Estuaries		
Adults		
Juveniles		
Influenced by river spate Conditions		

Species	<i>Herring, <i>Clupea harengus</i></i>
Life stages at risk	Juvenile and Adult
Offsetting Units e.g. eggs, ammocoetes	

Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

Month	Current	Basis	Alternative Summation	Basis
Jan				
Feb				
Mar				
Apr				
May				
Jun				
Jul				
Aug				
Sep				
Oct				
Nov				
Dec				

Comment	Supporting Evidence
Possible seasonal behavioural changes	
Migrant species : likely time spent in Bay e.g. no. of total cycles	
Resident Species / Stages : Preferred location in Bay if residential	o-group herring move into estuaries which serve as nursery grounds; herring are a marine migrant opportunist (MMO). Titmus et al. (1978); Henderson & Bird (2010)
Hearing Sensitivity	Herring is a hearing specialist and is able to detect frequencies up to at least 4000 Hz due to a gas filled channel that connects the swimbladder to the otolith organs. Herring has a uniformly low threshold of ~20 to ~25 dB for frequencies of 30-1200 c/s, with a sharp increase in threshold to >20 dB for 3000 c/s, >35 dB for 4000 c/s. Enger (1967); Mann et al., (2001); Nedwell et al. (2004)
Known attraction behaviour : to flows / structures	Juveniles hide in crevices and under rocks throughout estuaries and along coasts. Adult herring explore complex lagoons and shorelines for potential spawning sites. Rettingen (1990); Eggers et al. (2015)
Known avoidance : behaviour to flows / structures	Herring are pelagic in nature and as such are considered to be thigmophobic, due to their delicate decussate scales. No published data has been found, but personal observations by A. Turnpenny of herring held in tanks is that they avoid contact with tank surfaces which may be detected as a shear stress (or visual or reflected pressure waves) Turnpenny
Position in tide : e.g. on flush of flood tide	As a pelagic species, movements of herring are strongly influenced by tides. Turnpenny
Diurnal variations (e.g. inactive/active at night)	Schools are generally more compressed during daylight and form looser aggregations at night. In shallow waters (0 to at least 60 m) herring swim horizontally. At intermediate depths (around 100-200 m) herring swim horizontally during the period with sufficient light and at lower light levels swim with an upward tilt, or alternate between swimming upwards and gliding. In deep water (300-400 m) herring always either swim with an upward tilt or alternate between swimming upwards and gliding. In general, herring larvae are found near the surface at dawn and dusk and at a depth of 20 to 40 m during the day. In shallow waters spawning herring may stay in touch with the bottom at all hours and without dispersing closer to the surface during darkness. Munk et al. (1989); Huse & Ora (1996); Batty (1987) (Nathstad et al. 1996; Avelsen et al. 2003) (Woodhead & Woodhead 1955; Blaxter & Parrish 1965; Eggers et al. 2015) (Dietze 1998; Eggers et al. 2015).
Likelihood of presence at turbines during flood generation : e.g. two hours after low water.	
Feeding/foraging : behaviour	o-group clupeids feed throughout the year, whereas older clupeids feed seasonally, the majority tending to feed from late spring to late summer. Two peaks of feeding have been observed in o-group clupeids, one in the summer and the other in early spring after their first winter. The diet feeding behaviour of clupeids as o-group and older fish was studied, and it was found that, except for older spots, there were two peaks of feeding activity in a 24-h period. Tidal-induced turbidity in this environment reduces the effective water depth available for visual feeding by herring larvae by up to 50%. De Silva (1979)
Avoidance Ability	
Ability to Avoid : Burst swimming speed	Critical swimming speed of juvenile herring was measured at 10-12 h.p. at 16-19°C, and did not vary with salinity over the range 18 to 33. The burst speeds measured in experiments was of approximately 8-16 L s ⁻¹ . Turnpenny (1983); Batty & Blaxter (1992)
Ability to Avoid : Sustained swimming speed	0.25-0.35 m s ⁻¹ for an average length between 26-36 cm. Newly hatched herring larvae swim at 80-150 mm s ⁻¹ and the older herring at 100-160 mm s ⁻¹ depending on temperature. The maximum sustained speed measured was 4.06 B.L.S ⁻¹ or 1.02 m s ⁻¹ . Huse and Ora (1996); Batty (1987); Batty and Blaxter (1992); He and Wardle (1988)
Distribution of population in Swansea Bay	
Fish concentrated in drawdown zone area	Not known
Random distribution across Bay	Not known
Concentration in surf zone/littoral zone	Not known
Proportion of Fish Impacted as part of wider population	
Is species / stock a part of a discrete Swansea Bay population?	No
Wider Population unit (e.g. Bristol Channel / Celtic Sea / Atlantic)	English/Bristol Channel ICES VHF. Spring spawned stock in comparison to other west coast stocks. (ICES (2015); Titmus et al. (1978)
Motivational Drivers	
Motivation to enter lagoon	
Chasing prey	No
Being chased by predators	When in the juvenile stage, it's been observed individuals form small shoals, or that they hide in crevices and under rocks throughout estuaries and along coasts in order to hide themselves from predators. Rettingen (1990)
Seeking new habitat	
Protected environment	While young herrings may remain in marine environments during the first year of life, these and other o-group fishes migrate into estuaries during winter which then serve as nursery grounds. Titmus et al. (1978); Mass & Olivier (2000); Power et al. (2000)

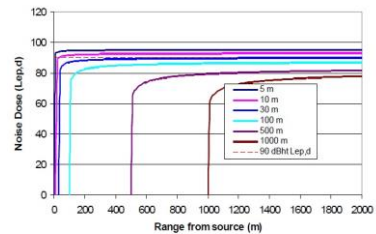


Figure 43. Herring cumulative Noise Dose with range from a 6.5 m diameter impact piling operation. Data are presented for animals at ranges from 5 m to 1000 m at the start of piling (and 1 m s⁻¹).

Fish and Marine Mammal Audiogram: A summary of available information

Audiogram from Fig. 6. Threshold levels in dB re 1 µPa. The figure presents a narrative audiogram for this fish, in the wet the author states that this is conservative, and the frequency range may be wider and the threshold may be lower.

Frequency (Hz)	Threshold level in dB re 1 µPa
10	100
20	100
30	100
40	100
50	100
60	100
70	100
80	100
90	100
100	100
120	100
150	100
200	100
300	100
400	100
500	100
600	100
700	100
800	100
900	100
1000	100
1200	100
1500	100
2000	100
3000	100
4000	100
5000	100
6000	100
7000	100
8000	100
9000	100
10000	100

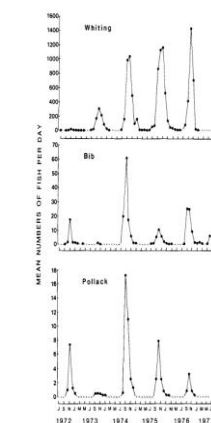
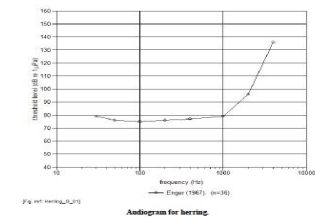


Fig. 45. The mean daily number of whiting (*Merlangius merlangus*), hsb (*Trigloporus luscus*) and pollack (*Pollachius pollachius*) collected from Oldbury in each month between July 1972 and June 1977. In this and the subsequent two figures an open circle denotes a zero value, i.e. no fish were caught in any of the samples taken that month.

Spawning	When herring reach 5cm they school, and grow and mature in estuaries for six months to a year. O-group herring are recorded from July to January in the Severn Estuary, peaking in late summer. O-group herring took approximately 22 weeks to pass from their spawning grounds to the middle of the lower estuary. During February and March herring are thought to spawn within Swansea Bay. Recent accounts indicate that herring spawning occurs closer to the shore, in proximity to the entrance of the River Tawe. In an area called 'Isorrasa Rough'. Herring spawning in this region must likely use the Sabellaria reef (63 ha) and shore defences found fronting the AWP owned land. Some fish are also reported to spawn in proximity to Blackpill, a section of shoreline called 'The Buldy'. There is also evidence to suggest that the sea defences at the entrance of Port Talbot Dock are used by spawning herring. Herring lay benthic eggs on shells, gravel, coarse sand and small stones at depths down to 250 m. Nevertheless, intertidal spawn are viable and there are mixed reports of relative survival which depends on predators, gas exchange and other factors. Intertidal spawn is transferred to terrestrial ecosystems and may represent an important resource.	Rattingen (1990), Claridge et al. (1986), Tidal Lagoon Swansea Bay Plc (2013), Horsfall, I., pers. comm. (2013), Thomas, B., pers. comm. (2013), Wisby, I., pers. comm. (2013), Thomas, B., pers. comm. (2013) (Eggers et al. 2015), (Horn et al. 1998).
Other	N/A	
Motivation to exit lagoon		
Chasing prey	No	
Being chased by predators	Increased size-related predation at sea or temperature and salinity tolerance limits may cause exponential increase or decrease in abundance. Further confidence for exponential migration rates was given by the fact that large increases of juvenile herring and gurd during winter months have been observed in other North Sea estuaries.	Mues & Oliveira (2000)
Spawning drive	Not anticipated	
Lack of niches/refuges to occupy	Not anticipated	
Lack of food availability	After a juvenile growth and maturing period herring migrate to feeding grounds in large shoals at depths of up to 250m.	Rattingen (1990)
Spawning	Not anticipated	
Other	N/A	

Other Factors

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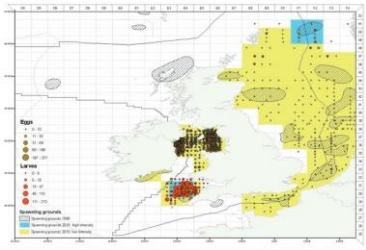
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Species	Plaice <i>Pleuronectes platessa</i>
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Life stages at risk	Juvenile
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Offsetting Units e.g. eggs , ammocoetes	
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Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan		Plaice are most abundant during the summer and can be absent from shallow waters during cold winters. (Henderson & Bird, 2010)		
Feb				
Mar				
Apr				
May				
Jun				
Jul	Peak abundance			
Aug	Peak abundance			
Sept				
Oct				
Nov				
Dec				

	Comment	Supporting Evidence
Possible seasonal behavioural changes	Juvenile plaice move offshore during the winter months and return to the nursery ground in the spring. Spawning occurs in shallow waters from December to March.	Rogers (1993); Pawson (1995)
Migrant species : likely time spent in Bay e.g. no. of tidal cycles		
Resident Species / Stages : Preferred location in Bay if residential	Frequent visitor.	Henderson & Holmes (1991)
Hearing Sensitivity	Plaice are sensitive to sounds in the frequency range from 30 to 250 Hz with greatest sensitivity around 110–160 Hz. Overall they have low sensitivity to sound.	Chapman & Sand (1974); Nedwell <i>et al.</i> (2004)
Known attraction behaviour to flows / structures	Plaice are able to migrate in a fixed direction over fairly long distances by swimming in midwater at a particular tidal phase and remaining stationary at the bottom when the current flows in the opposite direction.	De Veen (1978)
Known avoidance behaviour to flows / structures		
Position in tide e.g. on flush of flood tide	Juvenile plaice select flood tides to facilitate their entry into estuaries.	Claridge <i>et al.</i> (1986)
Diurnal variations (e.g. inactive/active at night)	During periods of activity plaice may lose contact with the bottom and shows pelagic swimming behaviour, generally during the hours of darkness. Plaice appear to adopt local diel vertical movements at approximately 24 h as opposed to 12 h intervals.	Videler (2012)

Likelihood of presence at turbines during flood generation e.g. two hours after low water.		
Feeding/foraging behaviour	Plaice are diurnal, feeding on crustaceans, molluscs and small fish. It relies on both vision and chemoreception.	Batty & Hoyt (1995)
Avoidance Ability		
Ability to Avoid : Burst swimming speed		
Ability to Avoid : Sustained swimming speed	Ground tracks suggest that plaice moving by selective tidal stream transport orientate down tide and swim at a speed of 0.5^{-1} BL/ S. Plaice larvae have stride lengths of 0.3 L during steady swimming.	DFR (1994); Videler (2012)
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area		
Random distribution across Bay		
Concentration in surf-zone/littoral zone		
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	No	
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Bristol Channel/ Irish Sea	Dunn & Pawson (2002)
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey	Not anticipated	
Being chased by predators	Not anticipated	
Seeking new habitat	See below	
Protected environment	Juvenile plaice select flood tides to facilitate their entry into estuaries. Abundance is greatest at less than 15m depth.	Claridge <i>et al.</i> (1986); Riley <i>et al.</i> (1981)
Spawning	No	
Other	N/A	
Motivation to exit lagoon		
Chasing prey	Not anticipated	
Being chased by predators	Not anticipated	
Spawning drive	Spawning in shallow, but still 20 to 40m depth, so outside of the lagoon / inner bay.	Dipper (1987)

Lack of niches/refuges to occupy	Not anticipated	
Lack of food availability	Movement away from the coast may be caused by the search for larger prey items as well as lowering temperatures in winter.	Claridge <i>et al.</i> (1986)
Spawning	See spawning above	
Other	N/A	

Other Factors

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Species	River lamprey - Lampetra fluviatilis
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Life stages at risk	Adults
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Offsetting Units e.g. eggs , ammocoetes	ammocoetes in line with condition assessment monitoring
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Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan	Year-round presence	Adults grow and mature in coastal waters for 1 to 2 years (Maitland, 2003)	Peak	Abundance peaks in Severn
Feb	Year-round presence		Peak	Estuary during migration to freshwaters between
Mar	Year-round presence		Peak	October and March (Abou-Seedo & Potter, 1979)
Apr	Year-round presence		Lower resident levels	
May	Year-round presence		Lower resident levels	
Jun	Year-round presence		Lower resident levels	
Jul	Year-round presence		Lower resident levels	
Aug	Year-round presence		Lower resident levels	
Sept	Year-round presence		Lower resident levels	
Oct	Year-round presence		Peak	
Nov	Year-round presence		Peak	
Dec	Year-round presence		Peak	

	Comment	Supporting Evidence
Possible seasonal behavioural changes	Likely to spend between 1 & 2 years in estuarine/coastal waters and then move into freshwater between October & March. Two forms in the Severn Estuary/Bristol Channel - typical and smaller praecox form. Typical form peak migration in November and praecox form February. Could be resident in Bay throughout the year but no direct evidence to support this. If so, their behaviour would change when commencing their spawning migration.	(Abou-Seedo & Potter, 1979)
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Unknown - grow and mature in sea/coastal waters and also migrate through coastal areas to reach freshwater habitats to spawn but residency times in the bay are unknown. Majority of local data is from Olbury and Hinkley power stations in the Severn Estuary. No data or information for the Bay. Could be present in the Bay throughout the year for up to 2 years.	
Resident Species / Stages : Preferred location in Bay if residential	Unknown - grow and mature in coastal habitats but preferred locations in general unknown. Herring and sprat are likely to be preferred prey species so may congregate in areas of high prey abundance.	(Webb et al., 2010, Hardisty, 2006)
Hearing Sensitivity	No direct information available for river lamprey. Lamprey have limited hearing phsiology and detection is likely to be limited to infrasound.	
Known attraction behaviour to flows / structures	Move upstream with tidal surge. Attracted to move towards freshwaters through olfactory response to juvenile scent. Likely to move in high flow zones.	
Known avoidance behaviour to flows / structures	Poor swimming ability likely means river lampray are unable to escape rapid attraction flows. Show a strong avoidance of light.	
Position in tide e.g. on flush of flood tide	Poor swimming ability probably means they move towards freshwaters with flooding tide & move out of the flow during ebb tides however, no direct supporting evidence.	
Diurnal variations (e.g. inactive/active at night)	Migratory movement restricted to dark nights. Active avoidance of light including full moons.	(Hardisty & Potter, 1971, Hardisty, 2006)
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Most upstream movement occurs with tidal currents so potential to be present at turbines during flooding tide when actively migrating. This is likely to be restricted to flod tides at night however. Resident species likely to be moving with prey populations e.g. herring & sprat.	
Feeding/foraging behaviour	Parasitic feeding on a wide range of fish species while in coastal habitats, especially herring & sprat & migratory species such as salmonids and shad	(Bird, 2008, Hardisty, 2006)
Avoidance Ability		
Ability to Avoid : Burst swimming speed	Unknown - undulating swimming means poor swimmers compared to many other fish. Closest-related species for which burst swimming speed is known is American sea lamprey (390 cm s-1) but comparability is questionable	(Hunn & Youngs, 1980)
Ability to Avoid : Sustained swimming speed	Unknown - undulating swimming means poor swimmers compared to many other fish. Closest-related species for which sustained swimming speed is known is Pacific lamprey (56-94 cm/s) but comparability is questionable	(Dauble et al., 2006)
Distribution of population in Swansea Bay		

Fish concentrated in drawdown zone area	Resident individuals likely to be associated with prey abundance. Migrating individuals will be moving towards the Tawe and may therefore pass the drawdown zone.	
Random distribution across Bay	Unknown. Resident individuals likely to be associated with prey, migratory individuals likely to have a bias towards the freshwater plume of the Tawe but may search across the Bay and approach from either direction.	
Concentration in surf-zone/littoral zone	Unknown but resident presence likely to be dependent upon prey presence and habitat type. Could happen with migratory individuals if FW plumes track the shoreline.	
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	Unlikely, they don't natally home but are attracted to larval pheromones.	Maitland, 2000, Gaudron & Lucas, 2006.
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Unknown - widely distributed across north-western Europe but unknown whether discrete populations exist or whether they are broadly mixing. Depending on coastal movement likely to at least represent a Bristol channel/Severn Estuary population.	Maitland, 2000
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey	Potential motivation for resident species.	
Being chased by predators		
Seeking new habitat		
Protected environment	Potential given their relatively poor swimming ability if prey species are present.	
Spawning	Unlikely as will spawn in freshwater & unlikely to be larval pheromone cue exiting lagoon.	
Other		
Motivation to exit lagoon		
Chasing prey	Potential motivation for resident species.	
Being chased by predators	Potential if significant avian predators present, especially at reduced water levels.	
Spawning drive	Drive to migrate in to freshwater to spawn in autumn/spring.	
Lack of niches/refuges to occupy		
Lack of food availability	If prey absent likely to seek to leave lagoon.	
Spawning		
Other	Potential to passively drift with downstream currents and tidal movements as juveniles	

Other Factors

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Species	River lamprey - Lampetra fluviatilis
Life stages at risk	Transformers
Offsetting Units e.g. eggs , ammocoetes	ammocoetes in line with condition assessment monitoring

Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan		(Claridge et al., 1996)	Commencement of downstream migration	(Potter & Huggins, 1973 , Maitland, 2003)
Feb			Commencement of downstream migration	
Mar			Peak abundance in the Severn Estuary	
Apr			Peak abundance in the Severn Estuary	
May			Peak abundance in the Severn Estuary	
Jun			Continued growth in coastal habitats year-round	
Jul			Continued growth in coastal habitats year-round	
Aug			Continued growth in coastal habitats year-round	
Sept			Continued growth in coastal habitats year-round	
Oct	Peak abundance of transformers moving downstream from estuaries		Continued growth in coastal habitats year-round	
Nov	Peak abundance of transformers moving downstream from estuaries		Continued growth in coastal habitats year-round	
Dec	Peak abundance of transformers moving downstream from estuaries		Continued growth in coastal habitats year-round	

	Comment	Supporting Evidence
Possible seasonal behavioural changes	Transformers move downstream from later winter peaking in the Severn Estuary between March and May. May then reside in the Bay & coastal waters for between 1 & 2 years.	(Potter & Huggins, 1973; Maitland, 2003)
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Unknown - grow and mature in sea/coastal waters and also migrate through coastal areas to reach freshwater habitats to spawn but residency times in the bay are unknown. Majority of local data is from Olbury and Hinkley power stations in the Severn Estuary. No data or information for the Bay. Could be present in the Bay throughout the year for up to 2 years.	(Claridge et al., 1986; Maitland, 2003)
Resident Species / Stages : Preferred location in Bay if residential	Transformers most likely to be found near estuary mouths as they complete metamorphosis quickly upon reaching sea. Continue to grow and mature in coastal habitats but preferred locations in Swansea Bay unknown	
Hearing Sensitivity	No direct information available for river lamprey. Lamprey have limited hearing physiology and detection is likely to be limited to infrasound. Hearing sensitivity likely to be less advanced than adults.	(Lenhardt & Sismour, 1995)
Known attraction behaviour to flows / structures	Tend to passively drift downstream in fastest, deepest currents.	
Known avoidance behaviour to flows / structures	Relatively weak swimming behaviour suggests unlikely to be able to escape rapid attraction flows. Move mainly at night suggesting that they move out of strong flows during daylight.	
Position in tide e.g. on flush of flood tide	Poor swimming ability probably means they likely move seawards passively with out-going tides	
Diurnal variations (e.g. inactive/active at night)	Downstream migration of transformers occurs predominantly at night (19:00-07:00)	(Potter & Huggins, 1973)
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Migration movements poorly known but poor swimming ability suggests they migrate passively with currents. Their restriction of movement at night however, suggests that they have the ability to move out of flow lines during daylight. Active downstream migrants likely to be out of flow paths during the flooding tide.	(Lucas et al., 2006)
Feeding/foraging behaviour	Parasitic feeding on fish once transformed, especially herring & sprat & migratory species such as salmonids and shad.	(Bird, 2008, Hardisty, 2006)
Avoidance Ability		
Ability to Avoid : Burst swimming speed	Unknown - undulating swimming means poor swimmers compared to many other fish. Closest-related species for which burst swimming speed is known is American sea lamprey (390 cm s-1) but comparability is questionable	(Hunn & Youngs, 1980)
Ability to Avoid : Sustained swimming speed	Unknown - undulating swimming means poor swimmers compared to many other fish. Closest-related species for which sustained swimming speed is known is Pacific lamprey (56-94 cm/s) but comparability is questionable	(Dauble et al., 2006)

Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	Resident inidividuals likely to be associated with prey abundance. Migrating inidividuals will be moving away from predominantly the Tawe and may therefore pass the drawdown zone during the ebbing tide.	
Random distribution across Bay	Unknown. Resident individuals likely to be associated with prey, migratory individuals likely to be biased towards areas of flow from the Tawe.	
Concentration in surf-zone/littoral zone	Unknown movement in coastal environments but resident individual presence likely to be dependent upon prey species. Potential for use of marginal habitat such as saltmarsh/creeks as nursery areas but no evidence to support this.	
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	Unlikely as don't natally home.	Maitland, 2000, Guadron & Lucas, 2006.
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Unknown - widely distributed across north-western Europe but unknown whether discrete populations exist or whether they are broadly mixing. Depending on coastal movement likely to at least represent a Bristol channel/Severn Estuary population.	Maitland, 2000
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey	Potential motivation but limited swimming ability.	
Being chased by predators	Potential.	
Seeking new habitat	Migrate downstream from river habitats to grow and mature in coastal habitats. Habitat utilisation unknown but potential for use of marginal habitat as nursery areas.	
Protected environment	Potential.	
Spawning		
Other		
Motivation to exit lagoon		
Chasing prey	Potential.	
Being chased by predators	Potential, especially if significant avian predators present.	
Spawning drive	Not until the adult stage.	
Lack of niches/refuges to occupy		
Lack of food availability	If prey absent likely to seek to leave lagoon.	
Spawning		
Other	Poor swimming ability and tendency to move in high flow zones could result in passive transport out of the lagoon.	

Other Factors

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Species	Sandeel (<i>Ammodytes</i> sp.)
Life stages at risk	All
Offsetting Units e.g. eggs , ammocoetes	

Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan				
Feb				
Mar				
Apr		Tidal Lagoon		
May		Swansea Bay		
Jun		Environmental		
Jul		Statement		
Aug		Table 9.12.		
Sept				
Oct				
Nov				
Dec				

	Comment	Supporting Evidence
Possible seasonal behavioural changes	Sandeel activity patterns have strong seasonal components. During autumn and winter they hibernate in the seabed, generally in coarse sands or fine gravel. During spring and summer they exhibit diurnal movements between the seafloor, where they bury themselves at night, and the water column, where they feed on plankton during daylight.	Wright <i>et al.</i> (2000); Holland <i>et al.</i> (2005); Winslade (1974); Freeman <i>et al.</i> (2004)
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	N/A	N/A
Resident Species / Stages : Preferred location in Bay if residential	Resident populations occur on suitable substrate across the Bay.	Tidal Lagoon Swansea Bay Environmental Statement
Hearing Sensitivity	<i>Ammodytes americanus</i> has a hearing range from 50 to 400 Hz. Ammodytiae are without a swim bladder. Little appears to be published on their hearing sensitivity but their diurnal and seasonal burial traits principally affect their vulnerability over any consideration of hearing. Studies carried out on <i>Ammodytes personatus</i> show the species as having an auditory threshold of 120 dB at 128 to 362 Hz.	Strobel & Mooney (2012); Drabble (2012); Suga <i>et al.</i> (2005)
Known attraction behaviour to flows / structures	During the autumn and winter sandeel burrow into the substrate.	Tidal Lagoon Swansea Bay Environmental Statement
Known avoidance behaviour to flows / structures		
Position in tide e.g. on flush of flood tide	The fish feed in the open waters during daytime, mainly in areas characterised by tidal currents where large quantities of plankton occurs.	Behrens & Steffensen (2007)
Diurnal variations (e.g. inactive/active at night)	During spring and summer they exhibit diurnal movements between the seafloor, where they bury themselves at night, and the water column, where they feed on plankton during daylight. The horizontal extent of these movements is not fully known, although in closely related species the pelagic feeding locations may be several km away from the benthic resting sites.	Wright <i>et al.</i> (2000); Holland <i>et al.</i> (2005); Winslade (1974); Freeman <i>et al.</i> (2004); Kühlmann & Karst (1967); Hobson (1986)
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	During spring and summer daylight hours.	Wright <i>et al.</i> (2000); Holland <i>et al.</i> (2005)
Feeding/foraging behaviour	During spring and summer they feed on plankton in the water column during daylight. The sandeel exhibit the rather unusual behaviour of alternating between swimming pelagically in well formed schools and lying buried in the sediment.	Wright <i>et al.</i> (2000); Holland <i>et al.</i> (2005); Behrens & Steffensen (2007)
Avoidance Ability		
Ability to Avoid : Burst swimming speed	Sandeel larvae ≥20 mm TL show strong sampling gear avoidance and are thus capable burst swimmers. The swimming ability probably improves substantially towards settlement (generally >55 mm TL).	Johannessen & Johnsen (2015)
Ability to Avoid : Sustained swimming speed	<i>A. americanus</i> (mean length 18.2 cm) at sea to be 30 - 50 cm/sec when schools were swimming undisturbed, and not engaged in feeding. Schools exhibiting feeding behavior were usually found to swim at about half the speed of undisturbed schools, or about 15-25 cm/sec. Mean swim speed 0.4 m/s, max swim speed 0.76 m/s. Routine swimming speed of lesser sandeel has been reported at 0.9 ± 0.06 bl s ⁻¹ .	Meyer <i>et al.</i> (1979); Tidal Lagoon Swansea Bay Environmental Statement Table 9.18; Behrens & Steffensen (2007)
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	Suitable substrate areas exist in the drawdown zone area.	Figure 6.22 TLP (2014)
Random distribution across Bay	Distributed in areas with suitable burrowing substrate. <i>A. marinus</i> were absent from sediments with a silt/clay content of .10% and densities declined between fractions from 2 to 10%. The apparent dislike for fine sediments was examined further by means of sediment choice experiments. These experiments confirmed the importance of the fine particle fraction in limiting distribution and indicated that sandeels would not be expected to inhabit such areas. The fish are highly specific in their choice of sediment, preferring clean sandy substrate with no mud or silt.	Figure 6.22 and 6.8 TLP (2014); Wright <i>et al.</i> (2000); Behrens & Steffensen (2007)
Concentration in surf-zone/littoral zone	Lesser sandeel (<i>Ammodytes tobianus</i>) is abundant in near-shore areas.	Behrens & Steffensen (2007)
Proportion of Fish Impacted as part of wider population		
Is species / life stage part of a discrete Swansea Bay population ?	Because of low adult mobility, sandeel populations operate as several discrete populations with somewhat limited connectivity.	Hamilton <i>et al.</i> (2014)
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)		

Figure 26: Spawning grounds of sandeels. Data layers indicate nominal spawning grounds of sandeels, giving the original polygons provided in Coull *et al.* (1998) and recent larval data from ichthyoplankton surveys. Recent, comparable data are lacking for north-western and south-western areas).

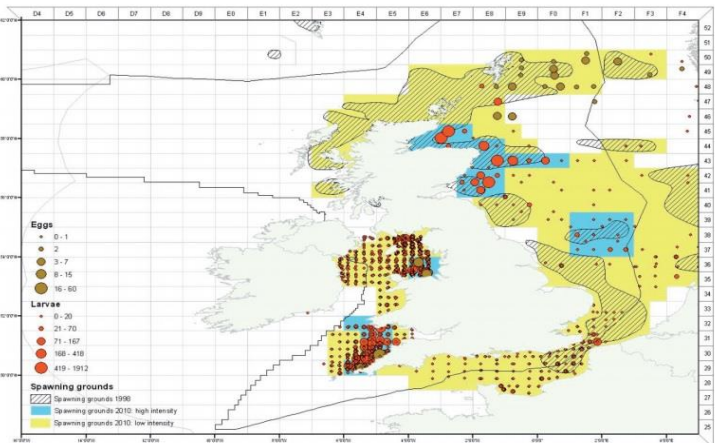
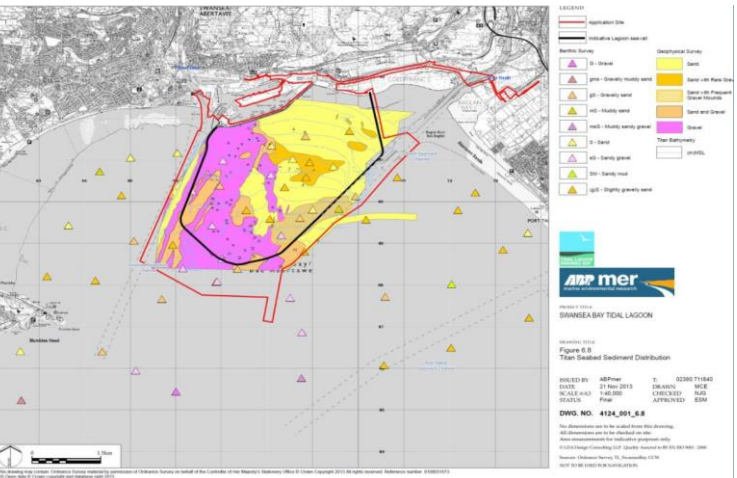
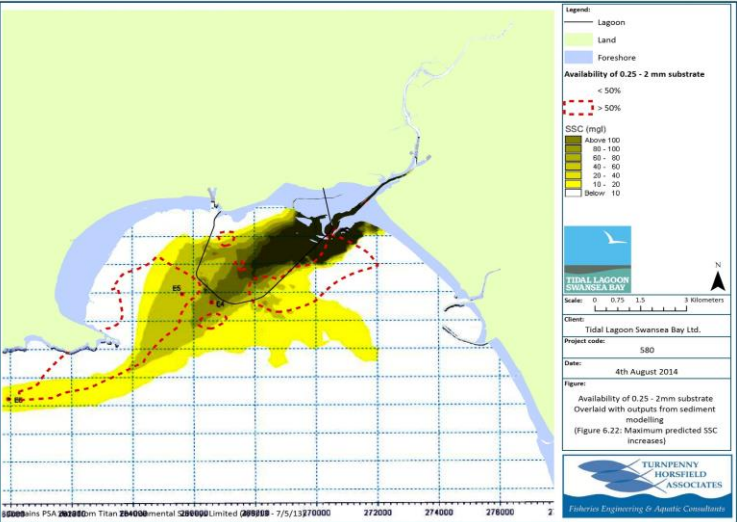
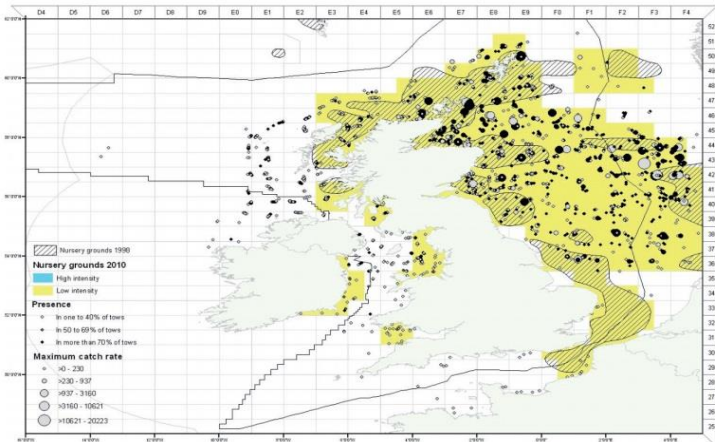


Figure 27: Nursery grounds of sandeels. Data layers indicate nominal nursery grounds of sandeels, as indicated by the presence of juveniles (<13 cm total length) in groundfish surveys. North Sea sites originally included by Coull *et al.* (1998) also shown.



Motivational Drivers		
Motivation to enter lagoon		
Chasing prey	Resident species	
Being chased by predators	Resident species	
Seeking new habitat	Resident species	
Protected environment	Juvenile sandeel have been recovered just outside the bounds of Swansea Bay. There is a lack of high resolution survey data for this species (Ellis et al., 2012) but it is likely that, given the environmental preferences of sandeel (especially <i>Ammodytes tobianus</i>), large numbers of juveniles are to be found within Swansea Bay itself.	Tidal Lagoon Swansea Bay Environmental Statement
Spawning	It should be assumed that any sandeel present within Swansea Bay would also spawn here.	Tidal Lagoon Swansea Bay Environmental Statement
Other	Resident species	
Motivation to exit lagoon		
Chasing prey	N/A	N/A
Being chased by predators	Sandeel form schools and are a key prey species that may be chased out of the lagoon.	van Deurs et al. (2011)
Spawning drive	N/A	N/A
Lack of niches/refuges to occupy	N/A	N/A
Lack of food availability	N/A	N/A
Spawning	N/A	N/A
Other	N/A	N/A

Other Factors

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FISH SPECIES DATASHEET

Species	Sea lamprey - <i>Petromyzon marinus</i>
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Life stages at risk	Adults
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Offsetting Units e.g. eggs , ammocoetes	ammocoetes in line with condition assessment monitoring
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Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan		(Hardisty, 1986; Abou-Seedo & Potter, 1979)	Potential residence in bay	Hardisty, 1986, Abou-Seedo & Potter, 1979
Feb	Migration into estuaries and rivers		Migration into estuaries & rivers	
Mar	Migration into estuaries and rivers		Migration into estuaries & rivers	
Apr	Migration into estuaries and rivers		Migration into estuaries & rivers	
May	Migration into estuaries and rivers		Peak migration into estuaries & rivers	
Jun			Peak migration into estuaries & rivers	
Jul			Potential residence in bay	
Aug			Potential residence in bay	
Sept			Potential residence in bay	
Oct			Potential residence in bay	
Nov			Potential residence in bay	
Dec			Potential residence in bay	

	Comment	Supporting Evidence
Possible seasonal behavioural changes	Spend between 18 & 28 months at sea before moving into estuaries/freshwater from February to June peaking in May and June. Some individuals may reside in the bay for some or all of this period.	(Hardisty, 1986, Abou-Seedo & Potter, 1979)
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Unknown - grow and mature in sea/coastal waters and also migrate through coastal areas to reach freshwater habitats to spawn but residency times in the bay are unknown	
Resident Species / Stages : Preferred location in Bay if residential	Unknown - grow and mature in sea/coastal habitats but preferred locations in general unknown. Herring and sprat are likely to be preferred prey species so may congregate in areas of high prey abundance.	
Hearing Sensitivity	Poor hearing physiology. Sea lamprey respond to 20-100 Hz	(Lenhardt & Sismour, 1995)
Known attraction behaviour to flows / structures	Move upstream with flooding tide. Attracted to freshwater habitats by scent of juveniles. Likely to move upstream in flow to conserve energy.	
Known avoidance behaviour to flows / structures	Relatively poor swimming ability means sea lamprey are unlikely to be able to escape rapid attraction flows. Stronger swimming ability than river lamprey adults.	
Position in tide e.g. on flush of flood tide	Poor swimming ability probably means they move towards freshwaters with flooding tide & move out of the flow during ebb tides to resting places however, no direct supporting evidence.	
Diurnal variations (e.g. inactive/active at night)	Migratory movement peaks two hours after nightfall and ceases by about 02:00	(Hardisty & Potter, 1971)
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Most upstream movement occurs with tidal currents so potential to be present at turbines during flooding tide when actively migrating. This is likely to be restricted to flood tides at night. Resident species likely to be moving with prey populations e.g. herring & sprat.	
Feeding/foraging behaviour	Parasitic feeding on a wide range of fish species while in coastal habitats, especially herring & sprat & migratory species such as salmonids and shad	(Bird, 2008)
Avoidance Ability		
Ability to Avoid : Burst swimming speed	Unknown - undulating swimming means poor swimmers compared to many other fish. Closest-related species for which burst swimming speed is known is American sea lamprey (390 cm s ⁻¹) but comparability is questionable	(Hunn & Youngs, 1980)
Ability to Avoid : Sustained swimming speed	Unknown - undulating swimming means poor swimmers compared to many other fish. Closest-related species for which sustained swimming speed is known is Pacific lamprey (56-94 cm/s) but comparability is questionable	(Dauble et al., 2006)
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	Resident individuals likely to be associated with prey abundance. Migrating individuals will be moving towards the Tawe and may therefore pass the drawdown zone.	

Random distribution across Bay	Unknown. Resident individuals likely to be associated with prey, migratory individuals likely to have a bias towards the freshwater plume of the Tawe but may search across the Bay and approach from either direction.	
Concentration in surf-zone/littoral zone	Unknown but resident presence likely to be dependent upon prey presence and habitat type. Could happen with migratory individuals if FW plumes track the shoreline.	
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	Unlikely, they don't natally home but are attracted to larval pheromones.	Maitland, 2000
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Unknown - widely distributed across north-western Europe but unknown whether discrete populations exist or whether they are broadly mixing. Depending on coastal movement likely to at least represent a Bristol channel/Severn Estuary population.	Maitland, 2000
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey	Potential motivation for resident species	
Being chased by predators		
Seeking new habitat		
Protected environment		
Spawning	Unlikely as will spawn in freshwater & unlikely to be larval pheromone cue exiting lagoon.	
Other		
Motivation to exit lagoon		
Chasing prey	Potential motivation for resident species	
Being chased by predators		
Spawning drive	Drive to migrate into freshwater to spawn in spring/summer	
Lack of niches/refuges to occupy		
Lack of food availability	If prey absent likely to seek to leave lagoon	
Spawning		
Other	Passively drift with downstream currents and tidal movements as juveniles	

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FISH SPECIES DATASHEET

Species	Sea lamprey - <i>Petromyzon marinus</i>
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Life stages at risk	Transformers
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Offsetting Units e.g. eggs , ammocoetes	ammocoetes in line with condition assessment monitoring
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Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan		(Lucas et al., 2006)	Downstream migration	Lucas et al., 2006
Feb			Downstream migration	
Mar			Potential residence in the bay	
Apr			Potential residence in the bay	
May			Potential residence in the bay	
Jun			Potential residence in the bay	
Jul			Potential residence in the bay	
Aug			Potential residence in the bay	
Sept			Downstream migration	
Oct	Migrate downstream into estuary		Peak downstream migration	
Nov	Migrate downstream into estuary		Peak downstream migration	
Dec	Migrate downstream into estuary		Peak downstream migration	

	Comment	Supporting Evidence
Possible seasonal behavioural changes	Migrate downstream to estuarine/marine habitats from October-December. Spend between 18 & 28 months at sea. Some individuals may reside in the bay for some or all of this period.	(Lucas et al., 2006)
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Unknown - grow and mature in sea/coastal waters and also migrate through coastal areas during downstream migration but residency times in the bay are unknown	
Resident Species / Stages : Preferred location in Bay if residential	Unknown - grow and mature in sea/coastal habitats but preferred locations in general unknown. Herring and sprat are likely to be preferred prey species so may congregate in areas of high prey abundance.	
Hearing Sensitivity	Poor hearing physiology. Sea lamprey respond to 20-100 Hz (not specified whether this refers to adult or juvenile sea lamprey but likely to be adults). Transformer detection likely to be less well developed than adults.	(Lenhardt & Sismour, 1995)
Known attraction behaviour to flows / structures	Tend to drift in deeper, faster currents in freshwater, behaviour in coastal waters unknown but likely to use selective tidal stream transport and move with the ebbing tide. Potential to be attracted with flow into turbines.	
Known avoidance behaviour to flows / structures	Relatively poor swimming ability and passive dispersal behaviour means they are likely unable to escape rapid attraction flows. Stronger swimming ability than river lamprey.	
Position in tide e.g. on flush of flood tide	Likely to use selective tidal stream transport when actively migrating. Will likely move seawards on the ebb tide and find resting places during the flooding tide however, no direct evidence to support this.	
Diurnal variations (e.g. inactive/active at night)	Migrate downstream to estuaries/coastal habitats between dusk and dawn	(Lucas et al., 2006)
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Migration movements poorly known but poor swimming ability suggests they migrate passively with currents. Their restriction of movement at night however, suggests that they have the ability to move out of flow lines during daylight. Active downstream migrants likely to be out of flow paths during the flooding tide.	
Feeding/foraging behaviour	Parasitic feeding on a wide range of fish species while in coastal habitats, especially herring & sprat & migratory species such as salmonids and shad	(Bird, 2008)
Avoidance Ability		
Ability to Avoid : Burst swimming speed	Unknown - undulating swimming means poor swimmers compared to many other fish. Beamish (1974) found adult swimming speed varied between 20-60cm but this test did not specifically test 'burst' swimming speed. Closest-related species for which burst swimming speed is known is American sea lamprey (390 cm s ⁻¹) but comparability is questionable	(Beamish, 1974; Hunn & Youngs, 1980)
Ability to Avoid : Sustained swimming speed	Unknown - undulating swimming means poor swimmers compared to many other fish. Beamish (1974) found adult swimming speed varied between 20-60 cm/s but did not test specifically for 'sustained' swimming speed. Closest-related species for which sustained swimming speed is known is Pacific lamprey (56-94 cm/s) but comparability is questionable	(Beamish, 1974; Dauble et al., 2006)
Distribution of population in Swansea Bay		

Fish concentrated in drawdown zone area	Resident individuals likely to be associated with prey abundance. Migrating individuals will be moving away from predominantly the Tawe and may therefore pass the drawdown zone during the ebbing tide.	
Random distribution across Bay	Unknown. Resident individuals likely to be associated with prey, migratory individuals likely to be biased towards areas of flow from the Tawe.	
Concentration in surf-zone/littoral zone	Unknown movement in coastal environments but resident individual presence likely to be dependent upon prey species. Potential for use of marginal habitat such as saltmarsh/creeks as nursery areas but no evidence to support this.	
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	Unlikely as don't natally home.	(Maitland, 2000)
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Unknown - widely distributed across north-western Europe but unknown whether discrete populations exist or whether they are broadly mixing. Depending on coastal movement likely to at least represent a Bristol channel/Severn Estuary population.	(Maitland, 2000)
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey	Potential motivation but limited swimming ability.	
Being chased by predators	Potential.	
Seeking new habitat	Migrate downstream from river habitats to grow and mature in	
Protected environment	Potential.	
Spawning		
Other		
Motivation to exit lagoon		
Chasing prey	Potential.	
Being chased by predators	Potential, especially if significant avian predators present.	
Spawning drive	Not until the adult stage.	
Lack of niches/refuges to occupy		
Lack of food availability	If prey absent likely to seek to leave lagoon.	
Spawning		
Other	Poor swimming ability and tendency to move in high flow zones could result in passive transport out of the lagoon.	

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FISH SPECIES DATASHEET

Species	Twaite Shad
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Life stages at risk	Juvenile
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Offsetting Units e.g. eggs , ammocoetes	
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Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan				Claridge & Gardner (1978);
Feb				
Mar				
Apr				
May				
Jun				
Jul	5%			
Aug	30%			
Sept	40%			
Oct	20%			
Nov	5%			
Dec				Aprahamian (1982)

	Comment	Supporting Evidence
Possible seasonal behavioural changes		
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	From studies on the Gironde juveniles can remain in the estuary from between 7 - 57 days with a median of 21 days - before going off to sea	Lochet et al. (2008)
Resident Species / Stages : Preferred location in Bay if residential		
Hearing Sensitivity	Af: 30-60 KHz peaking at 40-45 kHz @ 190dB. Aa: 40-120 KHz	Teague & Clough (2014); Wilson et al (2008, 2011)
Known attraction behaviour to flows / structures		
Known avoidance behaviour to flows / structures		
Position in tide e.g. on flush of flood tide	Juveniles tend to found at the surface and close inshore. Juveniles are ~9 times more abundant in the surface layers compared with samples taken 0.2m above the bottom	Taverney (1991); Castelnaud et al. (2001)
Diurnal variations (e.g. inactive/active at night)	Reported to undertake vertical diurnal migrations rythmically synchronized with ebb and flood tides allowing them to remain in the estuary.	deGroot (2002)
Likelihood of presence at turbines during flood generation e.g. two hours after low water.		
Feeding/foraging behaviour	Actively feeding on copepods and mysids	Aprahamian (1989)
Avoidance Ability		
Ability to Avoid : Burst swimming speed	Critical burst swimming speed (CBSS) varied between 16.0 cm s ⁻¹ and 29.5 cm s ⁻¹ with an average of 22.8 cm s ⁻¹ equating to approximately 8 bl s ⁻¹ (temperature 17°C ; n=11)	Apem (2008)
Ability to Avoid : Sustained swimming speed	The sustained (cruising in still water) swimming velocity of young-of-the-year twaite shad (mean length 29 mm; temperature 17°C; n=9) over two selected 3 second periods ranged from 0.008 to 11 cm s ⁻¹ with an average velocity of 2.5 cm s ⁻¹ equating to just under 1 bl s ⁻¹ .	Apem (2008)
Distribution of population in Swansea Bay		

Fish concentrated in drawdown zone area	Not known	
Random distribution across Bay	Not known	
Concentration in surf-zone/littoral zone	Not known	
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	No	
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Celtic Sea / Bristol Channel	Jolly et al (2012)
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey	Feeding -	
Being chased by predators		
Seeking new habitat		
Protected environment		
Spawning		
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators		
Spawning drive		
Lack of niches/refuges to occupy		
Lack of food availability		
Spawning		
Other - autumn seaward migration	Peak migration of juvenile Alosa fallax is associated with a decline in temperature below 19oC, with virtually none being caught once temperatures had fallen to less than 9oC.	Claridge & Gardner 91978); Aprahamian(1982)

Species	Twalite Shad
Life stages at risk	Adult - postspawners

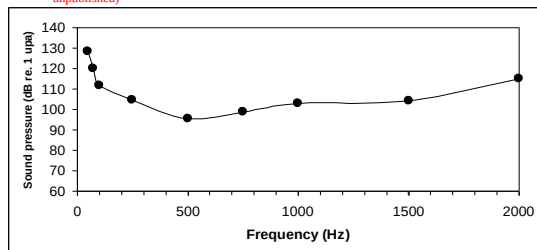
Offsetting Units e.g. eggs, ammocoetes	
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Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan				Based on catch data from the
Feb				
Mar				River Severn (1979-1998) -
Apr				
May				would expect post spawners
Jun			Present	
Jul			Present	to be present in coastal
Aug			Present	
Sept			Present	waters between Mid-June
Oct			Present	
Nov				
Dec				until the end of October

	Comment	Supporting Evidence
Possible seasonal behavioural changes	Resident (though temporary) as opposed to migrating actively past the Bay	Catch data indicates that post spawned adults can remain in the Estuary up until October
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Would suggest anywhere from 1-3 months	Based on catch data from the River Severn (1979-1998) and incidental catches from coastal waters around UK
Resident Species / Stages : Preferred location in Bay if residential		
Hearing Sensitivity	200KHz	Gregory & Clabburn (2003)
Known attraction behaviour to flows / structures		
Known avoidance behaviour to flows / structures		
Position in tide e.g. on flush of flood tide	Migrate towards the top of the tide	Purtcher catch data
Diurnal variations (e.g. inactive/active at night)	Diurnal catches in the estuary - higher during the day than night. Migrate during the day 05:00 - 20:00 (evidence from freshwater)	Aprahamian (1982); Clabburn (2002); Smith (2016)
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	High	Purtcher catch data
Feeding/foraging behaviour	Actively feeding on mysids, small fish and gammarids	Aprahamian (1989)
Avoidance Ability		
Ability to Avoid : Burst swimming speed	1- 2.5 ms ⁻¹ (mean 1.73 (95%CI=0.26)) @19.8- 21.5oC (Lt 300-390 mm)	Clough et al (2004)
Ability to Avoid : Sustained swimming speed	0.5 ms ⁻¹	Clough et al (2004)
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	Not known	
Random distribution across Bay	Not known	
Concentration in surf-zone/littoral zone	Not known	
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	No	
Wider Population unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Celtic Sea / Bristol Channel	Jolly et al (2012)
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey	Feeding - post spawning recovery	
Being chased by predators		
Seeking new habitat		
Protected environment	Avoid displacement on flood / ebb tide	
Spawning		
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators		
Spawning drive		
Lack of niches/refuges to occupy		
Lack of food availability		
Spawning		
Other	Falling temperature - moving offshore to overwintering grounds	

Mean audiogram for *A. fallax* . (Lovell and Nedwell, University of Plymouth unpublished)

Swimming capabilities of shad (0.30 to 0.50 m in length) from Larinier (1996).

Temperature (°C)	Maximum speed (ms ⁻¹)	Endurance at maximum speed (sec)	Cruising speed (ms ⁻¹)
10	2.75 – 3.30	15 – 60	0.8 – 1.5
15	3.50 – 4.30	10 – 25	
20	4.40 – 5.40	5 – 10	

Species	Twalite Shad
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Life stages at risk	Adult - prespawners
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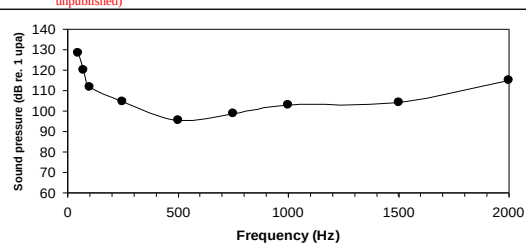
Offsetting Units e.g. eggs , ammocoetes	
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Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan		Used data in EU		Based on catch data from the
Feb		'Conserving Natura 200 Rivers Ecology Series No.3'		
Mar				
Apr	50%		30%	
May	50%		60%	
Jun			10%	
Jul				
Aug				
Sept				
Oct				
Nov				
Dec				River Severn (1979-1998)

	Comment	Supporting Evidence
Possible seasonal behavioural changes		
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Would look at the outputs from the IBM model - with fish moving on the flood and stemming displacement and moving inshore on the ebb, Migration rate of Aa through the Loire estuary estimated at 21 km/d and through the Gironde estuary of 17-23 km/d	Boisneau & Boisneau (1990); Mennesson-Boisneau et al (1999); Rochard (2001)
Resident Species / Stages : Preferred location in Bay if residential		
Hearing Sensitivity	200kHz	Gregory & Clabburn (2003)
Known attraction behaviour to flows / structures		
Known avoidance behaviour to flows / structures	In freshwater spwning migration halted at high flows (2000 MI/d in the Usk; 5000 MI/d in the Wye)	Smith (2016)
Position in tide e.g. on flush of flood tide	Migrate towards the top of the tide	Purtcher catch data
Diurnal variations (e.g. inactive/active at night)	Diurnal catches in the estuary - higher dring the day than night. Migrate during the day 05:00 - 20:00 (evidence from freshwater)	Aprahamian (1982); Clabburn (2002); Smith (2016)
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	High	Putcher catch data
Feeding/foraging behaviour	Not feeding on spawning migration	Aprahamian (1989)
Avoidance Ability		
Ability to Avoid : Burst swimming speed	1- 2.5 ms ⁻¹ (mean 1.73 (95%CI=0.26)) @19.8- 21.5oC (Lt 300-390 mm)	Clough et al (2004)
Ability to Avoid : Sustained swimming speed	0.5 ms ⁻¹	Clough et al (2004)
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	Not known	
Random distribution across Bay	Not known	
Concentration in surf-zone/littoral zone	Not known	
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	No	
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Celtic Sea / Bristol Channel	Jolly et al (2012)
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey		
Being chased by predators		
Seeking new habitat		
Protected environment	Avoid displacement on ebb tide	
Spawning	Spawning	On route to natal river
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators		
Spawning drive		
Lack of niches/refuges to occupy		
Lack of food availability		
Spawning	Spawning	On route to natal river
Other		

Mean audiogram for *A. fallax* . (Lovell and Nedwell, University of Plymouth unpublished)

Swimming capabilities of shad (0.30 to 0.50 m in length) from Larinier (1996).

Temperat (°C)	Maximum speed	Endurance at	Cruising speed (ms ⁻¹)
10	2.75 – 3.30	15 – 60	0.8 – 1.5
15	3.50 – 4.30	10 – 25	
20	4.40 – 5.40	5 – 10	

Species	Sole <i>Solea solea</i>
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Life stages at risk	Juvenile
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Offsetting Units e.g. eggs , ammocoetes	
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Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan		Sole is		
Feb		an abundant		
Mar		member of the		
Apr		fish assemblage		
May		between March		
Jun		and December		
Jul		(Henderson &		
Aug		Searby, 1994).		
Sept	Peak abundance	Maximum		
Oct		abundance		
Nov		normally occurs		
Dec		in September		

	Comment	Supporting Evidence
Possible seasonal behavioural changes	By September, sole are abundant on the flats. Seasonal patterns of flatfish abundance are related to migrations to both marine and upper estuarine habitats by the different age classes all of which use the Bay as a feeding ground.	Henderson & Holmes (1991); Rogers (1993)
Migrant species : likely time spent in Bay e.g. no. of tidal cycles		
Resident Species / Stages : Preferred location in Bay if residential	Resident species. Metamorphosing sole take approximately 33 days to cover the 100 km from the spawning ground at Trevoose Head in the Bristol Channel to the nursery grounds on the south Wales coast.	Henderson & Holmes (1991); Symonds & Rogers (1995)
Hearing Sensitivity	Sole perceives and reacts to horizontal variability in ambient noise levels.	Lagardère <i>et al.</i> (1994); Nedwell <i>et al.</i> (2007)
Known attraction behaviour to flows / structures	In the common sole, selective tidal transport is observed in juveniles when entering the Wadden Sea in spring. In adult sole this mechanism is a common feature in March to May during the spawning migration but no evidence for the use of this mechanism is available during other periods of the year. The sole thus is an example of a flatfish species using selective tidal transport in a restricted period and for special purposes only.	De Veen (1978)
Known avoidance behaviour to flows / structures	Not known	
Position in tide e.g. on flush of flood tide	Not known	
Diurnal variations (e.g. inactive/active at night)	Food intake and activity appears to be higher during the night than during the day. Sole displayed a circadian rhythm characterized by higher activity at night alternating with daytime rest.	Kruuk (1963); Sureau & Lagardère (1991)
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Not known	

Feeding/foraging behaviour	The adult sole is nocturnal, feeding on polychaetes and molluscs when feeding. Consequently, the sole is thought to depend mostly upon chemoreception and little on vision.	Batty & Hoyt (1995)
Avoidance Ability		
Ability to Avoid : Burst swimming speed	Not known	
Ability to Avoid : Sustained swimming speed	There are no data on critical speed of other Pleuronectiformes, but data available for routine speeds of Soleidae, Pleuronectidae, and Paralichthyidae report values of 0.5 to 3 cm s ⁻¹ . 0.6-0.7 bodylengths s ⁻¹ .	Faria <i>et al.</i> (2010); Sureau & Lagardère (1991)
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	Not known	
Random distribution across Bay	In the Bristol Channel 0-group and 1-group sole are caught at all depths .	Symonds & Rogers (1995)
Concentration in surf-zone/littoral zone	Not known	
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?		
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Bristol Channel population	Henderson & Searby (1994)
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey		
Being chased by predators		
Seeking new habitat		
Protected environment		
Spawning	Sole abundance in the lower Severn Estuary shows a high positive correlation with mean seawater temperature during April and May, which is the time of peak spawning in southern British population.	Henderson & Searby (1994)
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators		
Spawning drive		
Lack of niches/refuges to occupy		
Lack of food availability	By September, sole are abundant on the flats. Seasonal patterns are related to migrations to both marine and upper estuarine habitats by the different age classes all of which use the Bay as a feeding ground.	Henderson & Holmes (1991)
Spawning	The peak spawning period for sole occurs in March and April in water of more than 40 m in depth.	Henderson & Searby (1994)

Other	Migration into deeper waters enables young sole to avoid the low temperatures to which they are particularly susceptible.	Claridge & Potter (1987)
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Other Factors

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Species	Sea Trout
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Life stages at risk	Kelts
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Offsetting Units e.g. eggs , ammocoetes	Eggs
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Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan	20	a guess, based on		
Feb	25	peak spawning in		
Mar	15	(mid Nov)		
Apr	5			
May	5			
Jun	5			
Jul				
Aug				
Sept				
Oct				
Nov	5			
Dec	20			
100				

data from Panteg trap in TLP salmon v5 model

Month	days	cum.days	N.1SW	N.MSW	N.all
Jan	31	31	0	0	0
Feb	28	59	0	0	0
March	31	90	0	1	1
April	30	120	1	0	1
May	31	151	1	12	13
June	30	181	9	14	23
July	31	212	274	29	303
August	31	243	267	23	290
Sept	30	273	100	4	104
Oct	31	304	71	4	75
Nov	30	334	51	1	52
Dec	31	365	3	0	3
Total			777	88	865

	Comment	Supporting Evidence
Possible seasonal behavioural changes	Returning to sea post-spawning to feed and recover.	see refs below
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Not known for S Bay; Scandinavian studies for salmon suggest kelts may stay several weeks in estuaries, before starting any long distance migration. May be in sea for 3-5 months ("consecutive" spawners), or > 1yr ("alternate" spawners). For ST, multiple spawners spawn every year (mostly), so no "alternate" group. In N Sea kelts travel much less than maidens, so likely to be more "vulnerable" to TL; but can't quantify it.	Lindberg et al (2011); Thorstad et al (2011) and refs therein. R. Campbell/ LNS project
Resident Species / Stages : Preferred location in Bay if residential	As post1SW adults?	
Hearing Sensitivity		
Known attraction behaviour to flows / structures	Observed to swim against flood tide, same swimming speed as post-smolts reported in salmon.	Lindberg (2011)
Known avoidance behaviour to flows / structures	Not Known for kelts, but in river swim more slowly than pre-spawning fish.	see refs above, but non for behaviour in coastal zone
Position in tide e.g. on flush of flood tide	Probably in top (2m) layers	Lindberg 2011
Diurnal variations (e.g. inactive/active at night)	Not known	
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Likely to occur for part of the population, but can't quantify it with available data	
Feeding/foraging behaviour	Are resuming feeding so foraging for suitable food (larger prey items: sand eel and sprat mainly	CSTP report in press
Avoidance Ability		
Ability to Avoid : Burst swimming speed	As post 1SW adults, but at start of period will be in poorer condition and thus lowers swimming capacity	See post 1SW adults
Ability to Avoid : Sustained swimming speed	For 60cm fish at 10°C: 3.2m/sec (5.3BL/sec)	
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	Don't know. Might move along TL wall following outward FW plume on ebb	
Random distribution across Bay	Probably not random due to emergence from river in FW plume, then seeking food, which may or may not be randomly distributed	
Concentration in surf-zone/littoral zone	Possibly if FW plumes of food tracks the shoreline.	Salmon do occur in shallow (<2m) depths in shallow estuaries where Haaf nets operate
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	No	
Wider Population unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Population units are the individual rivers, principally Tawe and Neath, plus others that have sea trout straying into swansea bay, particularly those lying east of S Bay.	
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey		
Being chased by predators		
Seeking new habitat		
Protected environment		
Spawning	No	
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators		
Spawning drive	No	
Lack of niches/refuges to occupy		
Lack of food availability	Probably	
Spawning	No	
Other		

Other Factors

References

Bendall talk to LNS

CSTP Report 2016 Celtic Sea Trout Project. In press

Degerman, E., Leonardsson, K, and Lundqvist, H. (2012) Coastal migrations, temporary use of neighbouring rivers, and growth of sea trout (*Salmo trutta*) from nine northern Baltic Sea rivers. ICES Journal of Marine Science 69, 971-980.

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FISH SPECIES DATASHEET

Species	Sea trout
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Life stages at risk	Adults
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NB this refers to post 15W adults, maidens and previous spawners (kelts)

Offsetting Units e.g. eggs , ammocoetes	Eggs
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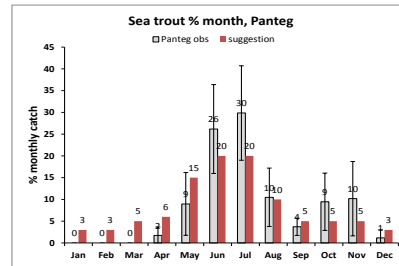
Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	%month	Basis	Alternative Suggestion	Basis
Jan	0.0		3	note high variance between years (+/- 1SD shown on fig). Data for 1991-2002.
Feb	0.0		3	Note the Oct/Noc incr - is this genuine?
Mar	0.0		5	Panteg data are for that component that enters river, in ST many stay at sea
Apr	1.7		6	
May	9.0		15	
Jun	26.2		20	
Jul	29.9		20	
Aug	10.5		10	
Sept	3.7		5	
Oct	9.5		5	
Nov	10.2		5	
Dec	1.1		3	
	102		100	

"suggestion"

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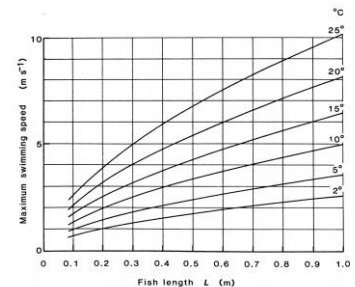
	Comment	Supporting Evidence
Possible seasonal behavioural changes	A shift from sea feeding to maturation and return to spawn, progresses during summer	CSTP maturity schedules and patterns of returns in rod catches and trap catch
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	ST likely to be present all year round. Large part of the mature marine population migrates up-river during summer and thus the marine pool is depleted (in addition to mortality losses); but it is reinforced by (a) annual Tawe smolt runs in April/May and (b) return migration of kelts (December -March) and (c) some straying from adjacent rivers (all year). For example 46% of sea trout from the River Dee remain at sea over their first post-smolt winter (i.e. they are destined to become 1 or 2+ maidens) and 19% over their second sea winter	All studies show sea trout remain comparatively local to their natal rivers - of the order 10-100km migration distance, but with some exceptional 200+km travels too. HD modelling suggest comparatively high proportion of S Wales ST remain in S Walescoastal waters. Davidson, unpublished; CSTP 2016 and Milner et al in prep
Resident Species / Stages : Preferred location in Bay if residential	ST presence in coastal zone will be determined by feeding opportunity (sandeel, sprat and small crustaceans). This is not known for S. bay.	
Hearing Sensitivity		
Known attraction behaviour to flows / structures	Return migrating post-smolt and adult sea trout are likely to home to natal river FW flows. Positive rheotactic response to FW flow increase reported from sandy estuary. Temporary delay at road bridge cill and cyclodial tidal doors in estuary.	Homing is evident in sea trout. Seen in tagging studies (Dee Stock Assessment Programme (Davidson et al 2006; Sambrooke unpublished) Flow / obstruction response from tagging (Milner et al 1982)
Known avoidance behaviour to flows / structures	Temporary delay at road bridge channel constriction and at cyclodial tidal doors at estuary/river boundary	Milner et al 1982
Position in tide e.g. on flush of flood tide	Occupy top 1-3m with occasional deeper (to 28m) dives in saline stratified fjord. Tyne estuary	Rikardsen et al. (2007) (talk to LNS project) Bendall
Diurnal variations (e.g. inactive/active at night)		
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Likely to occur more frequently than salmon, but can't quantify it with available data	
Feeding/foraging behaviour		
Avoidance Ability		
Ability to Avoid : Burst swimming speed	For 45cm fish at 5°C: 2.2m/sec (4.9 BL/sec) For 45cm fish at 10°C: 3.2m/sec (7.1 BL/sec) For 45cm fish at 20°C: 5.1m/sec (11.3 BL/sec)	EA Fish pass Manual Fig 4 and Table 2 (see worksheet here) NB bit wary of the higher vals????
Ability to Avoid : Sustained swimming speed	For 45cm fish at 10°C: 2.8m/sec (6.2BL/sec)	
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	Possibly, if prey species concentrated	
Random distribution across Bay	Following prey concentrations	
Concentration in surf-zone/littoral zone	as above	
Proportion of Fish impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	Part of local river populations, some small straying to and from non-natal rivers (<3%)	
Wider Population unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	No	
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey	Seeking prey (foraging) possible. May feed on juvenile fish (sandeel/ sprat) disabled by the ebb generation flow	see diet Table from CSTP in press
Being chased by predators	Unlikely	
Seeking new habitat		
Protected environment		
Spawning	Might be attracted to high flows on ebb generation flow (but wouldn't enter the turbines (due to swimming speed)	
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators		
Spawning drive	Will be searching for FW natal rivers homing cues; moroso as they mature towards spawning time (say September - October), but can't quantify this	see maturation fig from CSTP report in press
Lack of niches/refuges to occupy		
Lack of food availability		
Spawning		
Other		

Other Factors

References

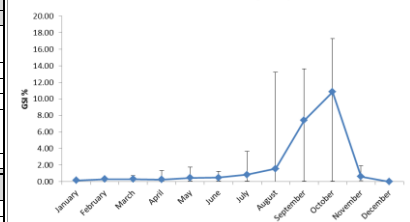
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Prey Item	%A _i	%F _i
Sand eel	62.560	55.617
Sprat	17.773	27.993
Herring	8.239	1.657
Sea Scorpion	0.055	0.368
Mackerel	0.961	0.184
Clupeid	0.150	0.368
Benthic Fish	0.055	0.184
Other Fish	6.241	21.547
Crabs	0.019	0.368
Prawn/Shrimp	0.161	0.552
Amphipods	0.149	4.788
Polychaetes	0.063	0.368
Other invertebrates	0.181	4.420
Mush	3.394	8.840
Total	100	

Fig 4. Mean GSI (and min-max) by month (pooled years) for female sea trout from the Irish Sea (n=651)



Milner, N.J. (1982) The effects of tidal doors on sea trout in the Glaslyn estuary . Welsh Water Technical Report NFTU/82/04. 25pp.

Moore, A., Ives, M., Scott, M. and b, S. Bamber, S. (1998) The migratory behaviour of wild sea trout *Salmo trutta* L./ smolts in the estuary of the River Conwy, North Wales. *Aquaculture* 168 57–68

Nedwell et al 2006 An investigation into the effects of underwater piling noise on salmonids. *J. Acoustic Soc Am.*, 120, 2550-4.

Rikardsen, A.H., Diserud, O.H., Elliott, J.M., Dempson, J.B., Sturlaugsson, J., and Jensen, A.J. 2007. The marine temperature and depth preferences of Arctic charr (*Salvelinus alpinus*) and sea trout (*Salmo trutta*), as recorded by data storage tags. *Fisheries Oceanography*, 16: 436–447.

FISH SPECIES DATASHEET

Species	Sea trout	
Life stages at risk	Whiting	NB this refers to post-smolts and whiting (returners before 1st sea winter for shelter and/or spawning). Included here separately due to different behaviour and size vs post-15W adults. BUT caution over double counting populations with the post-15W adults.
Offsetting Units e.g. eggs , ammocoetes	Eggs	

Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current %	Basis	Alternative Suggestion	Basis
Jan	0	(CSTP/Harris/step Growth -2/SH7)		
Feb	0			
Mar	0			
Apr	0			
May	0			
Jun	11			
Jul	51			
Aug	30			
Sept	6			
Oct	1			
Nov	0			
Dec	0			

100

	Comment	Supporting Evidence
Possible seasonal behavioural changes		
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Marine duration ranges 1-4 months. They are at sea seeking foraging opportunities, which might be in Swansea bay to start. See dispersal comment below.	They return to rivers in first post smolt year (July-Aug) and migrate to sea mainly April-May.
Resident Species / Stages : Preferred location in Bay if residential	Smolts termed post-smolts after sea entry and begin feeding quickly and disperse towards feeding areas. NB the whiting component are those that will return to the river in same year as smolting, for breeding or for shelter.	Degerman et al 2012; CSTP report in press
Hearing Sensitivity	less sensitive than salmon (see Nedwell et al 2006)	
Known attraction behaviour to flows / structures	Not reported for post-smolts specifically -likely to be same as adults.	
Known avoidance behaviour to flows / structures	Not reported for post-smolts specifically -likely to be same as adults	
Position in tide e.g. on flush of flood tide	Not known	
Diurnal variations (e.g. inactive/active at night)	Not Known	
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Likely to occur, but can't quantify it with available data	
Feeding/foraging behaviour	Feeding at first on crustaceans and then (>15cms) progressively more on juvenile sandeel and sprat	CSTP report in press diet fig (Irish Sea average) shown
Avoidance Ability		
Ability to Avoid : Burst swimming speed	For 30cm fish at 5°C: 1.8m/sec (6.0 BL/sec) 30cm fish at 10°C: 1.2.5m/sec (8.3 BL/sec) fish at 20°C: 4.0m/sec (13.3 BL/sec)	For 30cm EA Fish pass Manual Fig 4 and Table 2 (see worksheet here) NB bit wary of higher vals
Ability to Avoid : Sustained swimming speed	For 30cm fish at 10°C: 2.2m/sec (7.2BL/sec)	
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	Not known	
Random distribution across Bay	Will be seeking feeding opportunity, juvenile sandeel and sprat, some crustaceans	see CSTP report figure
Concentration in surf-zone/littoral zone	Quite possible, see above	
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	as adults	
Wider Population unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	as adults	
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey	Seeking prey (foraging) possible. May feed on juvenile fish (sandeel/ sprat) disabled by the ebb generation flow	see Fig opp. from CSTP in press
Being chased by predators		
Seeking new habitat		
Protected environment		
Spawning	Some will return as whiting, therefore same as post 15W adults	
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators		
Spawning drive	for the whiting component (approx 45% of this group)	See adults (Dee data, CSTP, Davidson etc)
Lack of niches/refuges to occupy		
Lack of food availability		
Spawning		
Other		

Other Factors

References

Bendall talk to LNS

CSTP Report 2016 Celtic Sea Trout Project. In press

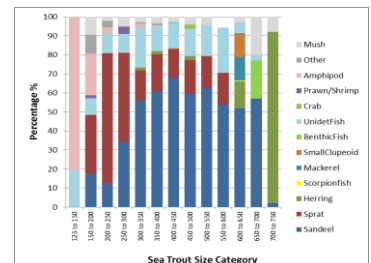
Degerman, E., Leonardsson, K, and Lundqvist, H. (2012) Coastal migrations, temporary use of neighbouring rivers, and growth of sea trout (*Salmo trutta*) from nine northern Baltic Sea rivers. ICES Journal of Marine Science 69, 971-980.

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FISH SPECIES DATASHEET

Species	Sea trout
Life stages at risk	Smolts
Offsetting Units e.g. eggs, ammocoetes	Eggs

Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan		tend to smolt earlier than salmon but no specific Tawe / Neath data		
Feb				
Mar	5			
Apr	25			
May	40			
Jun	30			
Jul				
Aug				
Sept				
Oct				
Nov				
Dec				

100

	Comment	Supporting Evidence
Possible seasonal behavioural changes		
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Uncertain, but likely less directed marine migration than salmon, but will be seeking foraging opportunities, which might be in Swansea Bay to start. See dispersal comment below.	They don't make the long distance migration of salmon, being more restricted to coastal zones CSTP report in prep. and refs therein
Resident Species / Stages : Preferred location in Bay if residential	After sea entry they quickly begin feeding and will be expected to (a) mainly leave river on ebb tide and (b) disperse towards feedin areas, which might be in the Bay for an undetermined but probably significant proportion of the population, because see trout tend to remain more coastal than salmon (see comment in post-smolt/whirling and adult section)	
Hearing Sensitivity		
Known attraction behaviour to flows / structures	Not reported for marine habitats, but estuarine passage reported along shoreline and hence vulnerability to power station intake (Ukrmouth)	
Known avoidance behaviour to flows / structures	Not reported for marine habitats, but may behave like salmon smolts. In river they delay during downstream migration at structures (weirs, dams) and on flood tide in estuaries.	
Position in tide e.g. on flush of flood tide	emigration on ebb tide with directed downstream swimming	Moore et al 1998 (Conwy estuary)
Diurnal variations (e.g. inactive/active at night)	nocturnal migration in river become less so in estuary	Moore et al 1998 (Conwy estuary)
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Likely to occur, but can't quantify it with available data. See salmon smolts, may orientate along TL walls	
Feeding/foraging behaviour	Feeding at first on crustaceans and then (>15cms) progressively more on juvenile sandeel and sprat	CSTP report in press fig shown
Avoidance Ability		
Ability to Avoid : Burst swimming speed	For 18cm fish at 5°C: 1.4m/sec (7.8 BL/sec) For 18cm fish at 10°C: 1.9m/sec (10.6 BL/sec) For 18cm fish at 20°C: 1.0m/sec (16.7 BL/sec)	EA Fish Pass Manual Fig 4 and Table 2 (see wkshheet here) Bit wary of higher values
Ability to Avoid : Sustained swimming speed	For 18cm fish at 10°C: 1.6m/sec (9.1BL/sec)	as above
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	may concentrate along "shoreline" of the TL wall.	
Random distribution across Bay	Unlikely, some shoaling behaviour expected on sea entry, then association with food availability.	
Concentration in surf-zone/littoral zone	Possibly, if food item concentrated there, but unlikely to be in surf zone, due to swimming ability.	
Proportion of Fish Impacted as part of wider population		
Is species / life stage part of a discrete Swansea Bay population ?	Part of local river population unit	
Wider Population unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	No, apart from some small proportion (probably<3%) straying to other rivers.	
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey	Seeking prey (foraging) possible. May feed on juvenile fish (sandeel/ sprat) disabled by the ebb generation flow	see Fig opp. from CSTP in press
Being chased by predators	Possibly	
Seeking new habitat		
Protected environment		
Spawning	No.	
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators	Possibly	
Spawning drive		
Lack of niches/refuges to occupy		
Lack of food availability	Possibly	
Spawning	No	
Other		

Other Factors

References

Bendall talk to LNS

CSTP Report 2016 Celtic Sea Trout Project. In press

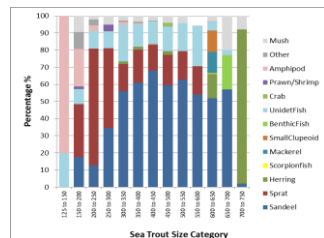
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Species	Salmon
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Life stages at risk	Kelts
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Offsetting Units e.g. eggs , ammocoetes	Eggs
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Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan	20	a guess, based on peak spawning in mid Nov)		
Feb	20			
Mar	25			
Apr	15			
May	5			
Jun	5			
Jul	5			
Aug				
Sept				
Oct				
Nov				
Dec	5			
100				

	Comment	Supporting Evidence
Possible seasonal behavioural changes	Returning to sea post-spawning to feed and recover.	see refs below
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Not known for S Bay; Scandinavian studies suggest kelts may stay several weeks in estuaries, before starting any long distance migration. May be in sea for 3-5 months ("consecutive" spawners), or > 1yr ("alternate" spawners).	Lindberg et al (2011); Thorstad et al (2011) and refs therein
Resident Species / Stages : Preferred location in Bay if residential	Not known	
Hearing Sensitivity	see opposite (assume same)	
Known attraction behaviour to flows / structures	Observed to swim against flood tide, same swimming speed as post-smolts reported	Lindberg (2011
Known avoidance behaviour to flows / structures	Not Known for kelts, but in river swim more slowly than pre-spawning fish.	see refs above, but non for behaviour in coastal zone
Position in tide e.g. on flush of flood tide	Probably in top (2m) layers	Lindberg 2011
Diurnal variations (e.g. inactive/active at night)	Not known	
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Likely to occur for part of the population, but can't quantify it with available data	
Feeding/foraging behaviour	Are resuminf feeding so foraginf for suiatbeo food (larger prey items: fish ans freeswimming crustaceans)	general knowledge of salmon biology (e.g. Aas et al 2011)
Avoidance Ability		
Ability to Avoid : Burst swimming speed	For 60cm fish at 5°C: 2.7m/sec (4.5 BL/sec) For 60cm fish at 10°C: 3.7m/sec (6.2 BL/sec) For 60cm fish at 20°C: 6.0m/sec (10.0 BL/sec)	EA Fish pass Manual Fig 4 and Table 2 (see wksheet in sea trout file)NB bit wary of the higher vals????
Ability to Avoid : Sustained swimming speed	For 60cm fish at 10°C: 3.2m/sec (5.3BL/sec)	
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	Don' t know. Might move along TL wall following outward FW plume on ebb	
Random distribution across Bay	Probably not random due to emergence fomr river in FW plume, then seekgin foddoo which may or may not be randomly distributed.	
Concentration in surf-zone/littoral zone	Possibly if FW plumes of food tracks the shoreline.	Salmon do occur in shallow (<2m) depths in shallow estuares where Haaf nets operate
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	No	
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Population units are the individual rivers, principally Tawe and Neath, plus others that have salmon straying into swansea bay, particularly those lying east of S Bay.	
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey		
Being chased by predators		
Seeking new habitat		
Protected environment		
Spawning	No	
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators		
Spawning drive	No	
Lack of niches/refuges to occupy		
Lack of food availability	Probably	
Spawning	No	
Other		

Other Factors

References

Aas et al 2011

Aprahamian, M.A. and Jones, G.O. (1997) The seaward movement of Atlantic salmon smolts in the Usk estuary, Wales, as inferred from power station catches. Journal of Fish Biology (1997) 50, 442–444

Banks, J.W. (1969) A review of the literature on the upstream migration of Adult salmonids. Journal of Fish Biology **1**, 85-136.

data from Panteg trap (period??) in TLP salm v5 model

Month	days	cum.days	N.1SW	N.MSW	N.all
Jan	31	31	0	0	0
Feb	28	59	0	0	0
March	31	90	0	1	1
April	30	120	1	0	1
May	31	151	1	12	13
June	30	181	9	14	23
July	31	212	274	29	303
August	31	243	267	23	290
Sept	30	273	100	4	104
Oct	31	304	71	4	75
Nov	30	334	51	1	52
Dec	31	365	3	0	3
Total			777	88	865

from Harding et al 2016 Scottish Office Mar and FW Sci 7, (11)

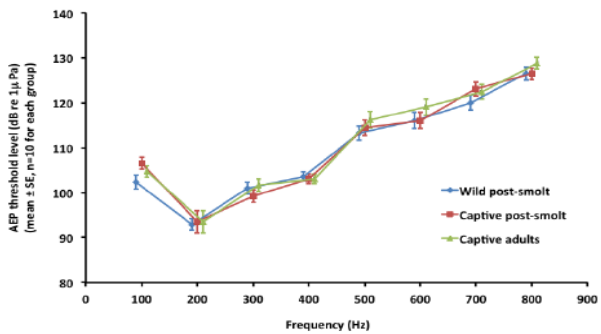


Figure 1: Audiograms based on mean ($\pm$ SE) minimum received levels (dB re 1 μ Pa) that elicited a characteristic auditory evoked potential. Three groups of Atlantic salmon (*Salmo salar*) were tested (n = 10 in each case): Wild post-smolt, Captive post-smolt, Captive adults. See Table 1 for mean values and size distributions of fish.

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Species	Salmon
Life stages at risk	Adults
Offsetting Units e.g. eggs , ammocoetes	Eggs

Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan		see across. Split		Could introduce a lag (ie advance the nukber
Feb		1SW and MSW		by couple of weeks, to allow for movement
Mar		At moment it's		from Bay to P Trap. Check against catch
Apr		based on the		stats for lower Tawe beats if available
May		Panteg trap. Can		(noting the angling season truncation). The
Jun		we show the		values indicate the run is over by end
Jul		period this was		November. NB note diff timings (on right
Aug		for?		)for 1SW and MSW. Plus comment made in
Sept				separate response doc on the vulnerability of
Oct				fish depending on residency, time of year
Nov				and river flow
Dec				

data from Panteg trap (period??) in TLP salm v5 model

Month	days	cum.days	N.1SW	N.MSW	N.all
Jan	31	31	0	0	0
Feb	28	59	0	0	0
March	31	90	0	1	1
April	30	120	1	0	1
May	31	151	1	12	13
June	30	181	9	14	23
July	31	212	274	29	303
August	31	243	267	23	290
Sept	30	273	100	4	104
Oct	31	304	71	4	75
Nov	30	334	51	1	52
Dec	31	365	3	0	3
Total			777	88	865

	Comment	Supporting Evidence
Possible seasonal behavioural changes	Thought to become progressively more inclined to enter FW, irrespective of FW flows, as maturation proceeds	see refs below
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Not known for S Bay; most data from estuarine and inriver studies. It . Will be site-specific (e.g. open sea- coast-bay- estuary) and dependent upon FW flow, maturation state and antecedent residency A guess is that average time might lie bewteen 1 and 10 days; but extended marine duatyon particularly of fish displaced back from the estuary/river is commonly report for period up to 130 days	see refs in Banks, (1969); Thorstad et al., (2008); Milner et al (2010, 2012) and account in attached document. Plus Godfrey et al 2016, Davidsen et al 2013, Lindberg et al 2011.
Resident Species / Stages : Preferred location in Bay if residential	Not known for S Bay but likely to be some search activity and homing along FW plume	
Hearing Sensitivity	see opposite	
Known attraction behaviour to flows / structures	Positive response to FW discharge,highly site specific (see refs). Tend to prefer upstrem (positive rheotaxs) towards faster flows in rivers if faced with a choice and no other cues than discharge .	e.g. Thorstad et al 2008; 2011 and many others
Known avoidance behaviour to flows / structures	Likely to avoid or be wary of artifical structures, rapid flow increases, if they follow behaviour in rivers.	see refs above, but non for behaviour in coastal zone
Position in tide e.g. on flush of flood tide	Likely to occupy top 1-5m, occasional divesto sea bed	Godfrey <i>et al.</i> , 2016, See also Lindberg 2011; Thorstad et al2011
Diurnal variations (e.g. inactive/active at night)	In coastal zone, evidence of deeper watre at night (but in deepre wat that offered by Swansea bay. Estuary entry likelt at nighn when FW flow low.	Godfrey <i>et al.</i> , 2016
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Likely to occur for part of the population, but can't quantify it with available data	
Feeding/foraging behaviour	probably little feeding at this stage in return migration	general knowledge of salmon biology (e.g. Aas et al 2011) - they do not feed in freshwater and expectation is that their feeding reduced as they mature and approach FW
Avoidance Ability		
Ability to Avoid : Burst swimming speed	For 60cm fish at 5°C: 2.7m/sec (4.5 BL/sec) For 60cm fish at 10°C: 3.7m/sec (6.2 BL/sec) For 60cm fish at 20°C: 6.0m/sec (10.0 BL/sec)	EA Fish pass Manual Fig 4 and Table 2 (see wksheet in sea trout file)NB bit wary of the higher vals????
Ability to Avoid : Sustained swimming speed	For 60cm fish at 10°C: 3.2m/sec (5.3BL/sec)	
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	Don' t know. Might move along TL wall following homing cues in FW plume	
Random distribution across Bay	Likely to be homing to FW cues boren on FW plume and therefore not random.	
Concentration in surf-zone/littoral zone	Unlikely see above, but could happen if FW plumes track the shoreline.	Salmon do occur in shallow (<2m) depths in shallow estuaries where Haaf nets operate
Proportion of Fish Impacted as part of wider population		
Is species / lifestage part of a discrete Swansea Bay population ?	No	
Wider Populaiton unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	Population units are the individual rivers, principally Tawe and Neath, plus others that have salmon straying into swansea bay, particularly those lying east of S Bay.	
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey		
Being chased by predators		
Seeking new habitat		
Protected environment		
Spawning	might be attracted by faster flow on ebb generation. Less likely to be drawn in on flood generation.	
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators		
Spawning drive	Probably seeking migration route, through homing mechanisms	
Lack of niches/refuges to occupy		
Lack of food availability		
Spawning		
Other		

Other Factors

Aprahamian, M.A. and Jones, G.O. (1997) The seaward movement of Atlantic salmon smolts in the Usk estuary, Wales, as inferred from power station catches. Journal of Fish Biology (1997) 50, 442–444

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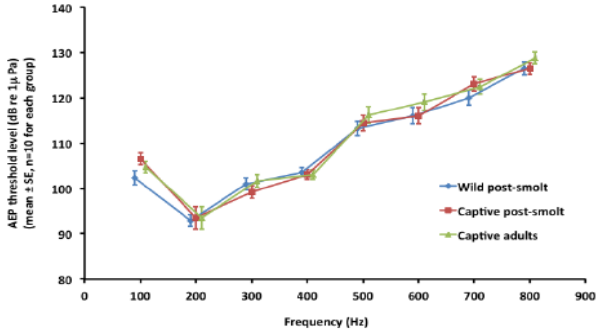


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Species	Salmon
Life stages at risk	Smolts
Offsetting Units e.g. eggs , ammocoetes	Eggs

Seasonality

Months of presence in Swansea Bay and estimated proportion of stock

	Current	Basis	Alternative Suggestion	Basis
Jan		at moment it's on the Panteg trap. Can we show the period this was for?		Could check against catch stats for lower Tawe beats if available. The values indicate the run is over by end November. NB note diff timings (on right)for 1SW and MSW. Plus comment made in separate response doc on the vulnerability of fish depending on residency, time of year and river flow
Feb				
Mar				
Apr				
May				
Jun				
Jul				
Aug				
Sept				
Oct				
Nov				
Dec				

data from Panteg trap (period??) in TLP salm v5 model

Month	days	cum.days	N.1SW	N.MSW	N.all
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Oct	31	304	71	4	75
Nov	30	334	51	1	52
Dec	31	365	3	0	3
Total			777	88	865

	Comment	Supporting Evidence
Possible seasonal behavioural changes		
Migrant species : likely time spent in Bay e.g. no. of tidal cycles	Average duration in bay might be 1-7days. In fjords, after leaving rivers, smolts travel 31kms in 1.5days (but note different environments from Swansea Bay) Smolt migration occurs of 3-7 weeks most fish going within 1-2 weeks and moving in shoals; so they are a particularly vulnerable stage of the life cycle.	Thorstad et al 2011; 2012; Davidsen et al (2009)
Resident Species / Stages : Preferred location in Bay if residential	NA	
Hearing Sensitivity		
Known attraction behaviour to flows / structures	follow FW plume initially on leaving river, may seek warmer water layer, depth prefers as below	Plantalech Manel-La et al (2009)
Known avoidance behaviour to flows / structures	Likely to avoid or be wary of artificial structures, rapid flow increases, if they follow behaviour in rivers. Likely to avoid flood flow (displacement back towards rivers) and may seek shelter from such flows next to TL wall	see refs above and Aprahamian and Jones, 1997; but none re this question, for behaviour in coastal zone
Position in tide e.g. on flush of flood tide	No known for S Bay specifically, but likely to occupy top 1-3m, possibly seeking warmer water; occasional dives to 6.5m. Conflicting results in diurnal variation in swimming activity likely due to differences in studied habitats; probably slower at night in SB. Active swimming (in Fjords) 1.2BLs-1 More active swimming likely in estuary and perhaps in first open sea (next TL) using selective tidal transport (outward swimming on ebb). Active migration with overall seaward vector Some studies show departure from river on ebb at night, but this likely variable depending on local circumstances. Plus see below.	Davidsen et al 2009; Godfrey et al., 2016, See also Lindberg 2011; Økland et al 2006; Moore et al 1995; Thorstad et al (2011,2012); Drenner et al 2012,
Diurnal variations (e.g. inactive/active at night)	In coastal zone, evidence of deeper water at night (but based on studies in deeper water than Swansea Bay. Nocturnal in early part of smolt run, day & night later. Swim closer to surface at night and probably slower than in the day.	Godfrey et al., 2016; Moore et al 1995; Thorstad et al 2012 (and refs therein)
Likelihood of presence at turbines during flood generation e.g. two hours after low water.	Likely to occur, but can't quantify it with available data	
Feeding/foraging behaviour	Begin sea feeding on fish larvae (<30% of their body length which is about 12 cms at this point) and crustaceans.	Thorstad et al. 2012
Avoidance Ability		
Ability to Avoid : Burst swimming speed	For 12cm fish at 5°C: 1.0m/sec (8.3 BL/sec) For 12cm fish at 10°C: 1.4m/sec (11.7 BL/sec)	
Ability to Avoid : Sustained swimming speed	For 12cm fish at 10°C: 1.2m/sec (10.1 BL/sec)	
Distribution of population in Swansea Bay		
Fish concentrated in drawdown zone area	swim faster in more saline water	Thorstad et al (2011) and refs therein
Random distribution across Bay	Unlikely to be random. Aggregation through shoaling behaviour and by orientation (in immediate coastal zone) probably by water current, so exit along any residual FW flow in S Bay. But also evidence in some studies of orientation by moving along shore (this may be less likely in Swansea where fish are "spat out" of extended harbour walls; but could lead to smolts following the TL wall..	Thorstad et al 2012 and refs therein
Concentration in surf-zone/littoral zone		
Proportion of Fish Impacted as part of wider population		
Is species / life stage part of a discrete Swansea Bay population ?	No, Part of river specific populations	
Wider Population unit (eg. Bristol Channel / Celtic Sea/ Atlantic)	NA	
Motivational Drivers		
Motivation to enter lagoon		
Chasing prey		
Being chased by predators	Possibly	
Seeking new habitat		
Protected environment		
Spawning		
Other		
Motivation to exit lagoon		
Chasing prey		
Being chased by predators	Possibly	
Spawning drive		
Lack of niches/refuges to occupy		
Lack of food availability	Possibly	
Spawning		
Other	will be on a long distance migration to N Atlantic feeding grounds, but navigation and orientation mechanisms uncertain	

from Harding et al 2016 Scottish Office Mar and FW Sci 7, (11)

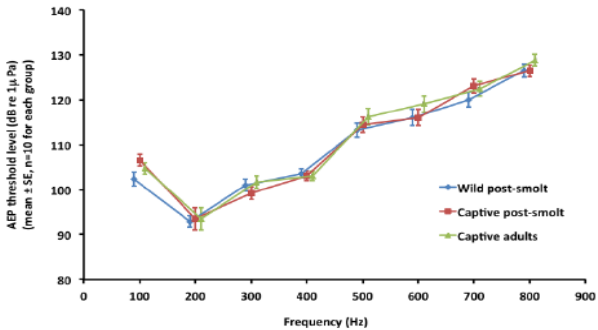


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Other Factors

caution on use of some literature due to the specific nature of the habitats which affect smolt behaviours (e.g. fjords vs shallow bays; or cold northern vs warmer southern latitudes)

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Appendix 3: Sensitivity Testing

1 Sensitivity testing

1.1 Sensitivity Test 1: Population Ranges

- 1.1.1 **Area of Uncertainty:** The application of different population ranges for fish within the Alternative Draw Zone approach.
- 1.1.2 **Background:** The geographical population range of each species will be an important factor relating to the likelihood of encountering the lagoon. Whilst in some cases this may be seasonal, their presence will nevertheless lead to a degree of encounter risk albeit over a restricted period of time.
- 1.1.3 The risk for fish which spend much of their marine life in distant waters, such as Atlantic salmon, will only manifest itself when the fish are leaving their natal rivers as smolts, or returning as spawning adults. In such cases where fish are returning to their natal rivers it has been assumed that Swansea Bay is their range during the migration period.
- 1.1.4 A population range has been identified for each key species based upon literature and expert guidance and details are provided in Appendix 2. It is assumed that populations of fish are randomly distributed within their range. This approach is appropriate given the lack of information regarding any alternative distribution.
- 1.1.5 The IBM approach considers fish homing to Swansea Bay rivers on a directed navigational path in order to calculate encounter rates, therefore all impacts predicted are solely focused on fish within Swansea Bay. In reality, the majority of fish present within Swansea Bay are part of a larger population unit across the wider Bristol Channel or Celtic Sea.
- 1.1.6 The Draw Zone and Alternative Draw Zone methods use available knowledge on the population ranges of the fish species at their different lifestages to define the area that a fish will be occupying, randomly distributed within and swimming in random directions within, for the purposes of the model, to define their likelihood of encountering the lagoon.

Resident Sea Trout and Salmon

- 1.1.7 For example, salmon and sea trout, as they home to their natal river, will have to pass through Swansea Bay to reach their spawning rivers. Then, when leaving the river as smolts, whiting or kelts, they will again need to pass through Swansea Bay. Therefore, the population range applied for the migratory lifestages of these species is Swansea Bay. As this is known, different population ranges will not be tested. For salmon, the outward migrants swim towards the North Atlantic and so it is assumed that there will be no resident lifestages to be impacted upon by the Project. For sea trout, there is some suggestion that the migratory population remains resident within the Bristol Channel, or the wider Celtic Sea, however information on the proportions of fish that remain within the Bristol Channel or

exchange rates with fish in the Celtic Sea is limited. As such, both of these population areas have been tested.

Table 1: Sea Trout resident population range sensitivity test – Alternative Draw Zone Approach

Resident Sea Trout lifestage	Population range	
	Bristol Channel (% Annual Mortality) (current value)	Celtic Sea (% Annual Mortality)
1SW	1.24	0.26
2SW	1.41	0.29
3SW	1.55	0.32
4SW	1.61	0.33
5SW	1.75	0.36
6SW	1.75	0.36
7SW	1.75	0.36

- 1.1.8 In Table 5.1 in the Alternative Fish Impact Assessment Results, the sea trout lifestages are assumed to all be taken from a Bristol Channel resident population, with the percentage annual mortality calculated by considering the risk of encounter and injury whilst both resident in the Bristol Channel and then migrating into Swansea Bay. If a discrete population of resident sea trout exists within the Bristol Channel, that is isolated/independent from the wider Celtic Sea population and does not exchange, then the model would be reflective of this situation. However some of the migratory fish are likely to be migrating from the Celtic Sea rather than the Bristol Channel and so their potential risk of encounter and injury whilst resident will be lower.

Other Resident lifestages

- 1.1.9 In the case of other migratory species where the resident lifestage has been applied (shad, sea lamprey, river lamprey and eel), a population range of the Bristol Channel has been assumed. It is likely that a proportion of the shad or lamprey that migrate to the rivers in the Severn or Carmarthen Bay to spawn will have come from a wider area and will therefore be less likely to have encountered the lagoon than has been assumed in the model. As such the model is precautionary. The impact of a wider population range is considered in Table 2.
- 1.1.10 For the resident eels, as the elvers migrate from the Sargasso Sea across the mid-Atlantic, they are predominantly distributed across the Western seaboard of Europe and the associated rivers and estuaries, where they mature as yellow eels before transforming into silver eels prior to their return to the Sargasso to spawn. It is thought that some of these elvers remain in the Bristol Channel to eventually

mature into silver eels before migrating out again to the Sargasso Sea to spawn, and it is this population of residents that are considered.

Table 2 Resident diadromous species population range sensitivity test – Alternative Draw Zone Approach

Species	Population range	
	Bristol Channel (% Annual Mortality) (current value)	Celtic Sea (% Annual Mortality)
Resident Shad	0.89	0.18
Resident Eel	1.95	0.41
Resident Sea Lamprey	1.49	0.31
Resident River Lamprey	0.54	0.11

Other migratory lifestages

- 1.1.11 The population ranges for other migratory species considered are generally wider as there is no evidence that they home to their natal rivers and so they could migrate to any of the rivers within their population range to spawn. The Swansea Bay population range has been applied for lamprey transformers, elvers and silver eels, however for returning lamprey migrants that do not show natal homing behavior, a wider population range has been applied for returning migrants to spawn as they could return to any one of a number of rivers.
- 1.1.12 As discussed above, elvers are distributed very widely post-migration, however the Swansea Bay population of incoming elvers and out-migrating silver eels has been considered in order to explore the local impact on the population. It should be noted that the impact on elvers or silver eels predicted in one year will have a negligible influence on the numbers returning the next year as the Swansea Bay eels and elvers from part of a widely distributed North Atlantic stock.
- 1.1.13 For shad and lamprey, it is acknowledged that there is a population that migrate through the Bristol Channel to the Severn Estuary and Carmarthen Bay. There is limited data on the frequency of occurrence of these species within Swansea Bay and no evidence of shad spawning in the associated rivers and whilst the model has applied a random distribution of fish across the population range, it is likely that the greatest concentration of these species, during migration, will occur around their known spawning rivers (Usk, Wye, Severn and Tywi). As such, the models are precautionary in assuming an even distribution of these species across their population range including within Swansea Bay.

1.2 Sensitivity Test 2: Maximum Sustained Swimming Speed (MSSS) and Draw Zone

1.2.1 **Area of uncertainty:** Testing the impact of faster/slower swimming speeds and changes in resultant changes in Draw Zone sizes

1.2.2 **Background:** Swimming speeds of fish vary according to a range of factors including species, size of individuals and water temperature. This is an important consideration when assessing impacts particularly because the impacts predicted by the Draw Zone and Alternative Draw Zone approaches rely on swim speed and the likelihood that this will bring fish into the proximity of the lagoon.

1.2.3 The Draw Zone and Alternative Draw Zone approaches that have been taken to try and determine an estimate of fish encounter with the lagoon turbines and sluices is predicated on key assumptions:

- (1) That the fish are randomly distributed within their population range.
- (2) That they swim at a constant speed, their Maximum Sustained Swimming Speed (MSSS) (see Appendix 3).
- (3) That if the fish enter the Draw Zone in front of the turbines and sluices, and that flow velocity is in excess of their MSSS, then the fish will be drawn through the turbine/sluice housing.

1.2.4 Points (2) and (3) are conservative in their nature given that :

- Fish don't necessarily swim at their MSSS and could opt to swim more efficiently at slower speeds, thereby covering less distance but still having the same Draw Zone area as their point of no return, meaning that the likelihood of encounter would be lower.
- Fish entering the Draw Zone may still be able to use their burst speed to escape to an area of safety with lower velocity flows.
- It is assumed that the fish swim constantly and do not retrace their steps thus covering the maximum distance possible in a particular amount of time, always covering new ground.

1.2.5 Where fish are known to migrate towards, or from, the rivers feeding into Swansea Bay then a migrant life stage has been used to model their risk of entering the Draw Zone.

1.2.6 **Potential result on model outputs:** Tested using Alternative Draw Zone Model only. Higher MSSS would result in more area potentially being covered by a fish during an operational cycle. However higher MSSS would also mean a smaller Draw Zone area that a fish will encounter from which it cannot escape from due to fast flows. Conversely, lower MSSS would result in less area being covered by a fish but a larger Draw Zone area.

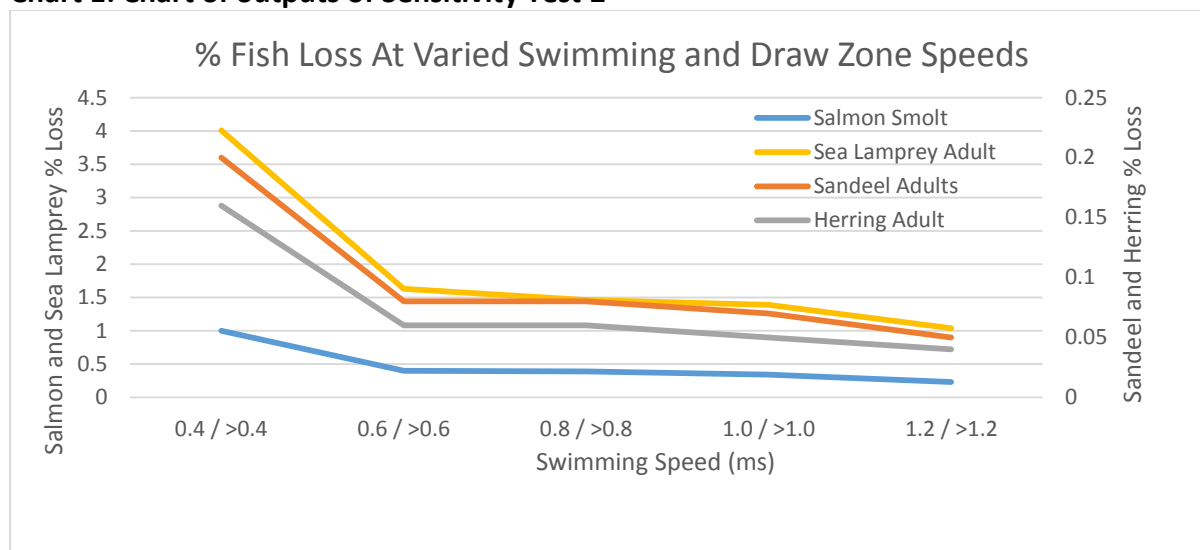
1.2.7 **Alternative Scenarios:** The MSSS of salmon smolts, sandeels, herring and sea lamprey have been tested and matched to corresponding Draw Zone flow band velocities.

Table 3 Sensitivity Test 2 Results

(***bold italics*** shows current value)

Value Being Tested: Equal MSSS and Draw Zone Flow Velocity					
MSSS / Draw Zone Velocity	0.4 / >0.4	0.6 / >0.6	0.8 / >0.8	1.0 / >1.0	1.2 / >1.2
Salmon					
Salmon Smolt (% Annual Mortality)	1.00	0.40	0.39	0.34	0.23
Sandeel					
Sandeel Adults (% Annual Mortality)	0.20	0.08	0.08	0.07	0.05
Herring					
Herring Adult (% Annual Mortality)	0.16	0.06	0.06	0.05	0.04
Sea Lamprey					
Sea Lamprey Adult –Residents (% Annual Mortality)	4.01	1.63	1.49	1.39	1.04

Chart 1: Chart of outputs of Sensitivity Test 2



1.2.8 **Interpretation:** The chart above indicates that as swimming speed increases then the % loss (encounter with turbines/sluices) of fish decreases. The % loss increases more rapidly when flow velocities in the Draw Zone velocities and fish swimming speeds are less than 0.6ms^{-1} .

1.2.9 This relationship implies that faster swimming fish may have a greater chance of avoiding being drawn into the lagoon despite the presence of a Draw Zone of similar speed. Draw Zone values of 0.2ms^{-1} and below could not be tested because the Draw Zone flow velocities are indistinguishable from background

flow speeds in the wider Swansea Bay and Bristol Channel. Fish of such low swimming speed would not be any more likely to be taken into the turbines/sluices as they would be carried elsewhere on the tidal currents.

- 1.2.10 At flows above 1.2ms^{-1} the Draw Zone itself will be at the face of the turbine housing or within the draught tubes themselves.

1.3 Sensitivity Test 3: 1SW to MSW Salmon Ratio

1.3.1 **Area of Uncertainty:** Relative Egg Loss Impacts from 1SW or MSW salmon.

1.3.2 **Background:** The loss of multi-sea winter (MSW) fish contributes to greater egg losses than the loss of younger 1 sea-winter fish (grilse) as the MSW fish spawn a greater number of eggs. This test considers alternative ratios of 1SW and MSW salmon to assess what effect changing these may have on egg loss calculations.

1.3.3 **Model Used:** Alternative Draw Zone

1.3.4 **Alternative Scenarios:** The current ratio of 90.54% 1SW to 9.46% MSW fish derived from Panteg Trap data has been adjusted to either increase or decrease the proportion of 1SW fish in the overall population. The alternative values chosen are :

72% 1SW : 28% MSW – values from more recent NRW EDR data (2015).

0% 1SW : 100% MSW - arbitrary value to show extreme range

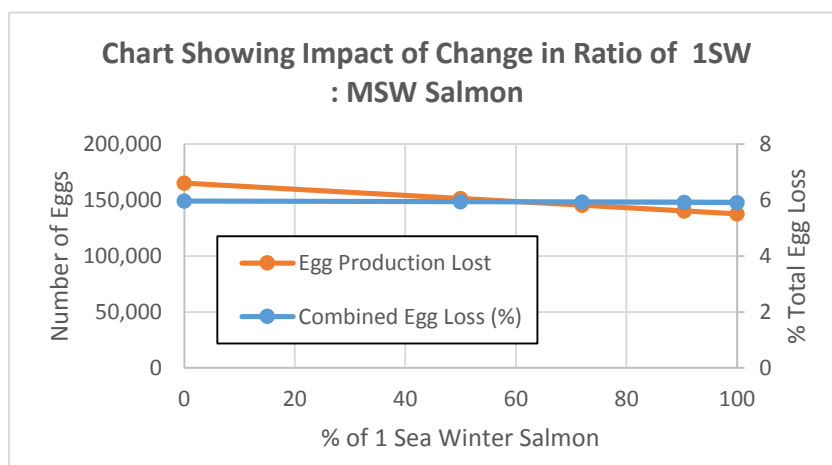
100% 1SW : 0% MSW - arbitrary value to show extreme range

50% 1SW : 50% MSW - arbitrary value to equal ratio

Table 4 Results of changes of Sensitivity Test 3 – Alternative Draw Zone Approach

Value Being Tested: 1SW to MSW Ratios and impact on % egg loss					
Alternative Scenario			Rod Catch Ratio	Current Value	
Input Value (% of 1SW Fish)	0%	50%	72%	90.54%	100%
Combined (annual % egg loss from 1SW and MSW fish)	5.97%	5.94%	5.93%	5.92%	5.69%

Chart 2 : Chart of outputs of Sensitivity Test 3



- 1.3.5 When combined the results show that the ratio of 1SW to MSW fish does not significantly impact on the combined egg loss proportion, as the annual mortality rates between 1SW and MSW fish are similar. However, due to their greater numbers, 1SW fish contribute a greater overall amount to the total number of eggs and this manifests itself in the slight increases in lost egg production as the ratio of 1SW to MSW decreases.

1.4 Sensitivity Test 4: Seasonal Population distributions

- 1.4.1 **Area of Uncertainty:** Alternative monthly population scenarios applied to gadoids (cod/whiting), MSW Salmon and pre-spawning shad, as well as alternative distributions and cut-off dates for salmon smolts and migrant adults.
- 1.4.2 **Background:** Seasonality of fish movements.
- 1.4.3 Individual fish species, or lifestages thereof may only be present in Swansea Bay and adjacent waters for limited periods of the year depending upon foraging and spawning habits in particular. This may vary from year to year dependent upon a range of conditions including, for example, water temperature or, in the case of migratory fish, suitable attraction flows from natal rivers.
- 1.4.4 Where possible an attempt has been made to describe the population distribution of each species and lifestage over a period of at least 12 months. In certain cases, such as salmon, alternative distributions have been suggested using other sources of data (e.g. Panteg data) and these have been used in the sensitivity testing.
- 1.4.5 Cut-off dates of the 1st July for salmon smolts and 1st December for salmon adults have been used, after which date it is assumed that any fish remaining within the lagoon is lost due to delays causing failed spawning of adults or failed out-migration and thus increased predation of smolts. These dates have been sensitivity tested below.
- 1.4.6 **Model Used:** Draw Zone and Alternative Draw Zone
- 1.4.7 **Alternative Scenarios:** Three alternative monthly distribution scenarios have been tested against cod/whiting, pre-spawning shad and Multi-Sea Winter (MSW) Salmon. These are :
- (1) Constricting the current season of fish presence.
 - (2) Assuming an even distribution of fish throughout the season without any peaks in numbers.
 - (3) Assuming that the population of fish is only present for two months.
- 1.4.8 An additional monthly distribution scenario has been proposed for 1SW sea trout in Appendix 2, and the results for this are also shown below in Tables 5 to 7. The appropriate mortality calculations were subsequently made using Volumetric, Draw Zone and Alternative Draw Zone approaches.
- 1.4.9 Finally an alternative monthly one sea winter (1SW) sea trout distribution was proposed (APEM Ltd) which spread the fish population over 12 months. This is indicated in Chart 3 below and the results presented in Table 8.

Table 5 Results of changes of Sensitivity Test 4 – Cod/Whiting

Cod/Whiting (Gadoids)	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Draw Zone	Alt. Draw Zone
	Proportion of fish population													% Annual Mortality	
Current	0	0	0	0	0.08	0.2	0.2	0.2	0.08	0.08	0.08	0.08	0	0.31	0.34
Alternative 1 – Constricted season	0	0	0	0	0	0	0.25	0.25	0.25	0.25	0	0	0	0.31	0.34
Alternative 2 - even nos. over original season	0	0	0	0	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0	0.31	0.34
Alternative 3 – all in two months	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0.31	0.35

Table 6 Results of changes of Sensitivity Test 4 – Shad Pre-spawning adults

Shad – Pre-spawning	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Draw Zone	Alt. Draw Zone
	Proportion of fish population												% Annual Mortality	
Current	0	0	0	0.3	0.6	0.1	0	0	0	0	0	0	0.13	0.15
Alternative 1 – Constricted season	0	0	0	0	1	0	0	0	0	0	0	0	0.13	0.15
Alternative 2 - even nos. over original season	0	0	0	0.333	0.333	0.333	0	0	0	0	0	0	0.13	0.15
Longer Season	0	0	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0	0	0.13	0.15

Table 7 Results of changes of Sensitivity Test 4 – Salmon MSW

Salmon MSW	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Draw Zone	Alt. Draw Zone
	Proportion of fish population												% Annual Mortality	
Current	0	0	0.01	0	0.14	0.16	0.33	0.26	0.05	0.05	0.01	0	5.13	5.75
Alternative 1 – Constricted season	0	0	0	0	0	0.25	0.25	0.25	0.25	0	0	0	4.93	5.54
Alternative 2 - even nos. over original season	0	0	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0	6.35	7.03
Alternative 3 – all in two months	0	0	0	0	0	0.50	0.5	0	0	0	0	0	4.93	5.54

1.4.10 Key findings

- Increasing the number of fish later in the season (September, October and November) for salmon, as done in Alternative 2 in Table 7 results in higher % Annual Mortalities due to an increased number of fish present within the lagoon at the cut-off point of the 1st December where losses of fish within the lagoon assumed.
- For both shad and cod/whiting, changing the seasonal distribution does not lead to any change in % Annual Mortality, with the exception of slight variations due to the variation in the number of tides per month.

Alternative Monthly Distribution of 1SW Sea Trout

- 1.4.11 An alternative monthly one sea winter (1SW) sea trout distribution was proposed within the Fish Datasheets (Appendix 2) which spread the fish population over 12 months. This is indicated in Chart 3 below.

Chart 3 Alternative sea trout distribution

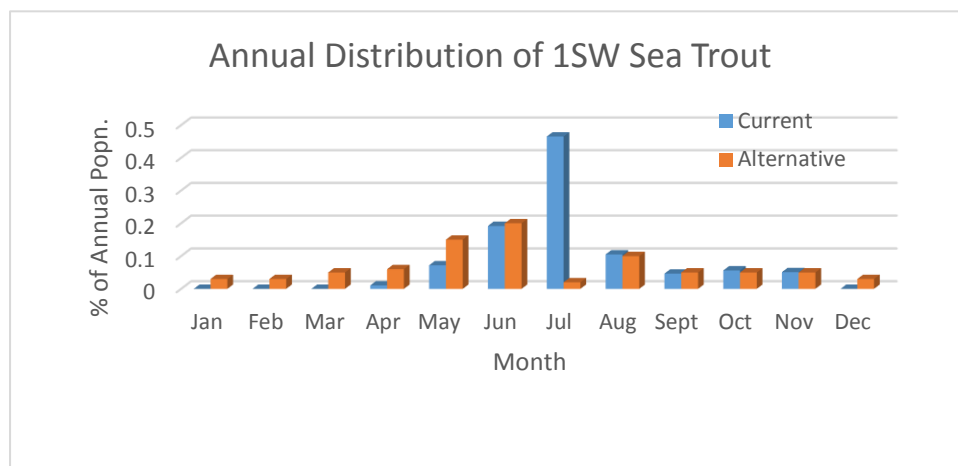


Table 8 Results of Impact Assessments Based on alternative distribution of 1SW Sea Trout

	Draw Zone Approach		Alternative Draw Zone Approach	
	Current Distribution Impact	Revised Distribution	Current Distribution	Revised Distribution
1SW Resident	1.19	1.19	1.32	1.32
1SW Migrant	3.34	3.31	3.76	3.04
1SW Combined	4.55	4.77	5.09	4.62

- 1.4.12 The results show that the impact on resident sea trout is the same for each distribution and assessment Approach. It is assumed that such fish are present year round and the proposed distribution only considers the proportion of migratory individuals present in each month.
- 1.4.13 The revised distribution results in a slight reduction for both Draw Zone approaches (3.31% from 3.34%, and 3.04% from 3.76% for Draw Zone and Alternative Draw Zone, respectively).
- 1.4.14 Finally, adjusting the cut-off dates for salmon adults and smolts has been tested in the Alternative Draw Zone Approach, by taking an earlier cutoff date for salmon adults and an earlier smolt run and cutoff date for salmon smolts. The cutoff date for salmon adults has limited scope for change as fish have been observed at

Panteg into December, indicating that migration still occurs during this month (9% of salmon caught in Panteg Trap after 15th Nov).

- 1.4.15 The current seasonal population distribution has assumed that fish are present in Swansea Bay on the same dates as those caught at Panteg. Given the location of Panteg Weir fish trap is situated 18km up river, and the fact that the fish must negotiate the Tawe Barrage there would inevitably be a time lag between fish migrating through Swansea Bay and being caught at Panteg trap and this hasn't been incorporated into the models, thus resulting in more fish being impounded after the cut-off date currently applied.

Table 9: Results of changing cut-off dates for salmon smolts and migrating adults

	% Annual Mortality	
	May smolt run, 1 st July cut-off (current)	May smolt run, 15 th June cut-off
Salmon smolts	0.23	0.51
	1 st December cut-off (current)	15 th November cut-off
Salmon 1SW migrants	5.69	7.27
Salmon MSW migrants	5.75	6.11

1.5 Sensitivity Test 5: Sex Ratios

1.5.1 **Area of Uncertainty:** Sex Ratios and Egg Loss impacts to Atlantic Salmon

1.5.2 **Background:** Consider alternative sex ratios for salmon and sea trout which might impact on egg losses.

1.5.3 **Current sex ratios:** 1SW = 0.49 females : 0.51 males. MSW = 0.42 females : 0.58 males based on EDR Assessment (2015).

1.5.4 **Model Used:** Alternative Draw Zone Approach

1.5.5 **Alternative Scenarios:** The current ratio of 1SW females:males has been adjusted to increase and decrease the proportion in the population and applied firstly to 1SW fish only, then MSW fish only before applying to both ages of fish.

Table 10: Results of Sensitivity Test 5 – sex ratios in Salmon

Value Being Tested: Effect of change in proportion of 1SW Females:Males salmon on annual egg losses (% egg loss)					
Proportion of 1SW Females:Males	0.4	0.49 (current value)	0.5	0.6	1.0
Combined Result	5.70	5.70	5.70	5.70	5.70
Value Being Tested: Effect of change in proportion of MSW Females:Males on annual egg losses (% egg loss)					
Proportion of MSW Females:Males	0.3	0.42 (current value)	0.5	0.6	1.0
Combined Result	5.70	5.70	5.70	5.70	5.71
Value Being Tested: Effect of change in proportion of 1SW & MSW Females:Males on annual egg losses (% egg loss)					
Proportion of 1SW / MSW Females:Males	0.4/0.3	0.49 (1SW)/0.42 (MSW)	0.5/0.5	0.6 / 0.6	1.0 / 1.0
Combined Result	5.70	5.70	5.70	5.70	5.70

1.5.6 Only very minor changes occur from changing these ratios, with a greater proportion of females being present resulting in a marginally higher resultant egg loss.

1.6 Sensitivity Test 6: Tide to Tide Non-replenishment

1.6.1 **Area of Uncertainty:** Assessing impact of not assuming replenishment of stocks between each tide.

1.6.2 **Background:** Present models assume that the same number of fish are present on each tide. Thus, there will be the same number present on tide 1 in each month as tide 60. Thus, no allowance is taken of those fish which are lost through injury or impoundment, or returned to the Bay. Replenishment may feasibly take place for resident populations as there are no boundaries between Swansea Bay and the wider Bristol Channel. However, replenishment might not take place for migrant fish arriving more spasmodically en-route to their natal rivers.

1.6.3 **Model Used:** Alternative Draw Zone Approach

1.6.4 **Alternative Scenario:** The Average population figure for each lifestage of salmon has had the number of fish entering the lagoon subtracted and then, the number of fish successfully returning to the Bay added.

Table 11: Results of changes of Sensitivity Test 6

	Current % Annual Mortality	% Annual Mortality considering losses on previous tides
Smolts	0.23%	0.23%
1SW	5.69%	5.68%
Kelts	4.94%	4.94%
MSW	5.75%	5.75%

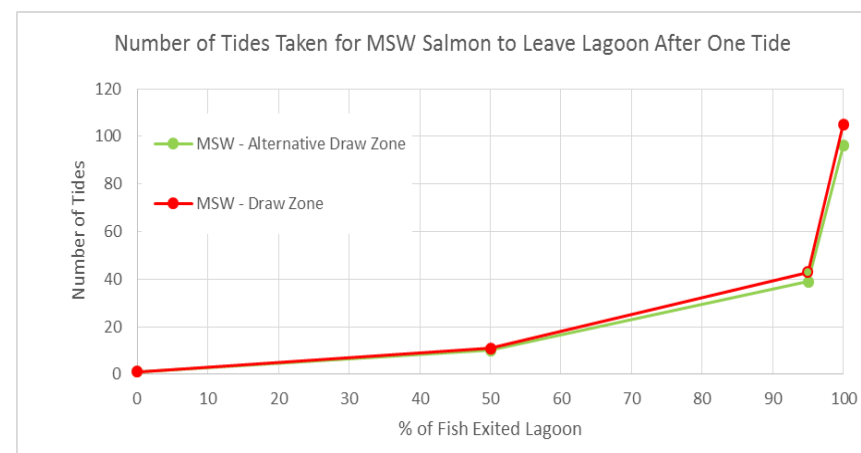
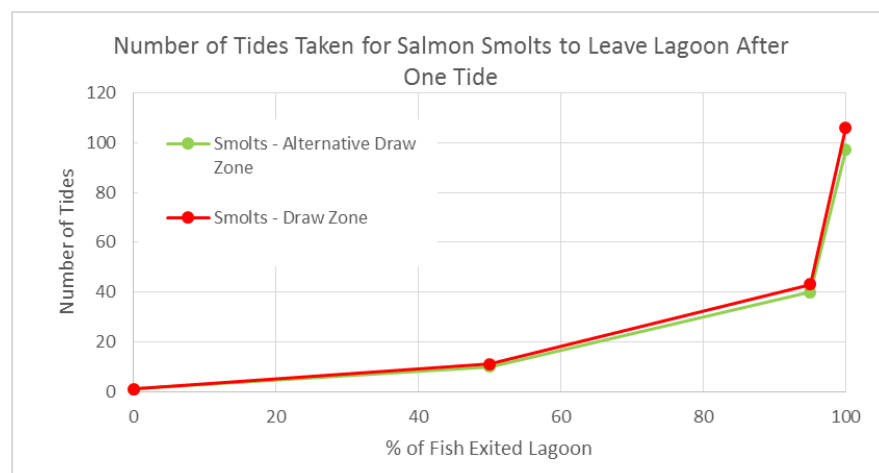
1.6.5 In general, assuming no replenishment of those fish lost generally has a minor effect on the % Annual Mortality figures, with only very slight reductions in % Annual Mortality shown across all lifestages of salmon in this test. The current assessment is therefore slightly precautionary.

1.7 Sensitivity Test 7: Fish retention time in lagoon

- 1.7.1 **Area of Uncertainty:** Concern expressed about the fate of fish which enter the lagoon and how long they will be retained within it before returning into Swansea Bay.
- 1.7.2 **Background:** Any fish that enter the lagoon on a flood tide must, if a diadromous species, exit the lagoon in order to complete its inward or outward migration. The likelihood of a fish leaving the lagoon is greater than entry because approximately 50% of the water volume of the lagoon will exit via the turbines and sluices on each tide.
- 1.7.3 **Potential result on model outputs:** Currently, as a precaution, it is assumed that salmon smolts that are retained in the lagoon after the 1st July are effectively lost from the population (See above for alternative scenarios). This is on the assumption that if they exit after the 1st July they will be more susceptible to predation as they will have lost the opportunity to be part of a shoal.
- 1.7.4 **Alternative Scenario:** The Draw Zone and Alternative Draw Zone models to estimate the number of days it would take for a population of salmon smolts, 1SW, kelts and MSW fish to exit the lagoon having entered on one tide.
- 1.7.5 **Discussion:** The table below contains the results of the assessment undertaken for the four key lifestages of salmon (Smolt / 1SW / Kelts / MSW).
- 1.7.6 The Alternative Draw Zone approach predicts that 95 % of smolts will have exited the lagoon within 40 tides (~20days) and all the smolts will have exited after 97 tides (49 days).
- 1.7.7 Similar relationships illustrated for 1SW, kelts and MSW fish with Alternative Draw Zone and Draw Zone approaches producing very similar values. The retention time for adult fish is longer than that of smolts with retention periods of up to 105 (Draw Zone) tides.

Table 12 Results of Sensitivity Test 7 – Retention time (number of tides) in lagoon

% Exiting Lagoon	Smolts - Draw Zone	Smolts - Alternative Draw Zone	1SW - Draw Zone	ISW - Alternative Draw Zone	kelts- Draw Zone	Kelts - Alternative Draw Zone	MSW - Draw Zone	MSW - Alternative Draw Zone
0	1	1	1	1	1	1	1	1
50	11	10	11	10	11	10	11	10
95	43	40	43	39	43	43	43	39
100	106	97	105	96	104	96	105	96

Chart 4 & 5: Chart of outputs of Sensitivity Test 7


1.8 Sensitivity testing summary

- 1.8.1 The alternative scenarios have been sensitivity tested for the key parameters included within the model that are variable depending on lagoon operating procedures or subject to uncertainty in terms of fish biology. In addition, a number of tests have been run on the models to investigate the retention time of fish within the lagoon.
- 1.8.2 For the Draw Zone and Alternative Draw Zone approaches the population range (Sensitivity Test 5) is shown to be a sensitive component of the model. The population range defines the area that a fish of that species could be occupying, and then the fish is randomly distributed within this area swimming in a random direction. The smaller the population range (ranging from Swansea Bay to the North Atlantic), the smaller area that a fish could occupy. As a consistent number of fish (nominal 100,000) within the population is assumed, and it is also assumed that the population is randomly distributed, there is therefore a higher likelihood of a fish entering the Draw Zone across smaller population ranges. For a smaller population range, a fish swimming at its MSSS will cover a greater proportion of its population range, resulting in an increased risk of encounter with the Draw Zone. Therefore, smaller population ranges will give higher % Annual Mortality figures.
- 1.8.3 In the case of salmon and sea trout smolts and migrants, the smaller population ranges of Swansea Bay have been applied as these species home to their natal rivers to spawn, so there will be distinct populations of Tawe, Neath and Afan salmon and sea trout. For other migratory, marine and resident species and lifestages, wider population ranges have been used to reflect the non-natal homing behaviour of migrants, and the wider distribution of marine and resident species and lifestages. It is theoretically possible to apply a smaller population range, for example of Swansea Bay, to each species to give a % Annual Mortality figure for fish populations present within Swansea Bay. However this would result in artificially inflated % Annual Mortality figures not reflective of potential effects as it would concentrate the entire population of fish into Swansea Bay and would assume a discrete population of fish within Swansea Bay that do not leave. If this population range was assumed for any species, it would be necessary to make assumptions on the proportion of the wider population of that species present within Swansea Bay, which is largely unknown. For shad or river/sea lamprey there is limited evidence of their presence within Swansea Bay. In the case of shad they do not generally migrate up Swansea Bay rivers, but migrate to the Severn Estuary rivers or Carmarthen Bay (Tywi) to spawn.
- 1.8.4 The other sensitivity tests undertaken show generally small changes in % Annual Mortality figures and, for example for the operational procedures tested (changing the % of flows passing through turbines or sluices), these may only occur for a fraction of the year so changes are unlikely to be significant.

- 1.8.5 Those parameters within the model that are shown to be most sensitive will be subject to evidence gathering through monitoring to reduce the uncertainty within their parameterisation, where possible. namely:
- fish behaviour on encountering the turbines and sluices, draught tubes and increased flows;
 - fish accumulation in the area in front of the turbines and sluices where water is drawn from;
 - fish populations present within Swansea Bay; and
 - the parameters subject to uncertainty within the IBM and STRIKERv.4 models.
- 1.8.6 The monitoring to be undertaken is described within *Fisheries Assessment: Mitigation, Monitoring and Offsetting Framework* (TLSB, May 2016).

Appendix 4: Summary of VERS, Input Parameters and References

Appendix 4: Summary of VERs Input Parameters and References

VERs	Life stage	Swimming Speed Used (maximum discernable speed of Draw Zone flow is 1.2ms ⁻¹).	Alternative Swimming Speed	Source	Draw Zone Used	Alternative Speed Used	Reason	IBM Population Range	Draw Zone and Alternative Population Range	Source
Salmon	Smolt	1.2		EA FP Manual	>1.2		The draw-zone for the MSSS would in effect be within the turbine housing itself.	Swansea Bay	Swansea Bay	
	Kelt	3.2	3.2	EA FP Manual	>1.2	1.2			Swansea Bay	
	1SW	3.2	3.2	EA FP Manual	>1.2	1.2			Swansea Bay	
	MSW	4.5	4.5	EA FP Manual	>1.2	1.2			Swansea Bay	
Shad	Juveniles	0.025		APEM, 2008	>0.2			Swansea Bay	Bristol Channel	Jolly et al (2012)
	Pre-spawners	0.5		Clough et al, 2004	>0.4				Bristol Channel	
	Post-spawners	0.5		Clough et al, 2004	>0.4				Bristol Channel	
	Resident	0.5		Clough et al, 2004	>0.4				Bristol Channel	
Eel	Elver	0.117 - 0.133		Wuenschel & Able, (2008); Clough and Turnpenny, (2001)	>0.2	0.13		Swansea Bay	Swansea Bay	Aprahamian - TLSB Datasheet, 2016
	Silver	0.61 - 0.68		Palstra et al, (2008)					Swansea Bay	
	Resident	0.43 - 0.62		Turnpenny, Horsfield, Jacobs UK Ltd	>0.4				Bristol Channel	
River Lamprey	Transformer	0.56 - 0.94		Dauble et al, (2006)	>0.6			Swansea Bay	Swansea Bay	Maitland (2000)
	Adult - Migrant	0.56 - 0.94		Dauble et al, (2006)	>0.6				Bristol Channel	
	Adult - Resident	0.56 - 0.94		Dauble et al, (2006)	>0.6				Bristol Channel	
Sea Lamprey	Transformer	0.56 - 0.94		Dauble et al, (2006)	>0.8			Swansea Bay	Swansea Bay	Maitland (2000)
	Adult - Migrant	0.56 - 0.94		Dauble et al, (2006)	>0.8				Bristol Channel	
	Adult - Resident	0.56 - 0.94		Dauble et al, (2006)	>0.8				Bristol Channel	
Herring	Juveniles	0.25 - 0.35			>0.2			Swansea Bay	Bristol Channel	ICES (2015) : Titmus et al (1978)
	Adults	1.02		Turnpenny, (1983); Batty and Blaxter, (1992); Huse and Ona, (1996)	>1.0				Bristol Channel	
Sandeel		0.4		Christensen, (1983)	>0.4			Swansea Bay	Bristol Channel	ES Chapter 9 , Appendix 9.1
Cod / Whiting		0.6-0.8		Winger et al , 1997; He, (1993); He & Wardle, (1988); Breen et al, (2	>0.4			Swansea Bay	Bristol Channel	Parker - Humphreys (2004)
Bass	Juvenile	0.29			>0.2			Swansea Bay	Bristol Channel	House of Commons (2016)
	Adult	1.4	1.4	Turnpenny, 1981	>0.4				Bristol Channel	
Plaice	Juvenile	0.01		DFR (1994); Videler (2012)	>0.2			Swansea Bay	Bristol Channel	Dunn & Pawson (2002)
Sole	Juvenile	0.005 - 0.035		Faria et al. (2010); Sureau & Lagardère (1991)	>0.2			Swansea Bay	Bristol Channel	Henderson & Searby (1994)
Sea Trout	Smolt	1.6		EA FP Manual	>1.2	1.2	The draw-zone for the MSSS would in effect be within the turbine housing itself.	Swansea Bay	Swansea Bay	CSTP (2016) Milner et al in prep.
	Whitling	2.2		EA FP Manual	>1.2	1.2			Bristol Channel (Resident) / Swansea Bay (Migrants)	
	1SW									
	1SW Kelt									
	2SW									
	2SW Kelt									
	3SW									
	3SW Kelt									
	4SW									
	4SW Kelt									
	5SW									
	5SW Kelt									
	6SW									
	6SW Kelt	3.2		EA FP Manual	>1.2	1.2				
	7SW									
	7SW Kelt	3.975		EA FP Manual	>1.2	1.2				

Appendix 5: Turbine Entrainment and Injury Models

Appendix 6: Turbine Entrainment and Injury Models Summary Results

Alternative Drawzone Approach - Bass

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		Proportion Impounded	Proportion Lost	in + out loss	Survival at stage	Probability of survival to stage
Juveniles		0.0000	0.0008	0.0008	0.9992	0.9992
Adults		0.0000	0.0002	0.0002	0.9998	0.9990

Draw Zone Approach - Bass

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		Proportion Impounded	Proportion Lost	in + out loss	Survival at stage	Probability of survival to stage
Juveniles		0.0000	0.0008	0.0008	0.9992	0.9992
Adults		0.0000	0.0002	0.0002	0.9998	0.9990

Alternative Drawzone Approach - Cod/Whiting

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	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage	Cumulative survival to stage
All	0.000	0.0034	0.0034	0.9966	0.9966

Draw Zone Approach - Cod/Whiting

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	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage	Cumulative survival to stage
All	0.000	0.0031	0.0031	0.9969	0.9969

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Alternative Draw Zone - Eel

	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage
Elver/Glass Eel	0.0000	0.00924	0.0092	0.9908
Adults - Silver Eel	0.0000	0.01574	0.0157	0.9843
Adult - Resident Eel	0.0000	0.01949	0.0195	0.9805

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Draw Zone Approach - Eel

	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage
Elver/Glass Eel	0.0000	0.00901	0.0090	0.9910
Adults - Silver Eel	0.0000	0.01408	0.0141	0.9859
Adult - Resident Eel	0.0000	0.01763	0.0176	0.9824

Alternative Draw Zone Approach - Herring

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	Sea age	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage	Cumulative survival to stage
Juveniles		0.0000	0.0004	0.0004	0.9996	0.9996
Adults	1	0.0000	0.0005	0.0005	0.9995	0.9992

Draw Zone Approach - Herring

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	Sea age	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage	Cumulative survival to stage
Juveniles		0.0000	0.0004	0.0004	0.9996	0.9996
Adults	1	0.0000	0.0007	0.0007	0.9993	0.9989

Alternative Draw Zone - Plaice

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	Sea age	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage	Probability of survival to stage
Juveniles	0	0.0000	0.0001	0.0001	0.9999	0.9999

Draw Zone - Plaice

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	Sea age	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage	Probability of survival to stage
Juveniles	0	0.0000	0.0001	0.0001	0.9999	0.9999

Alternative Draw Zone - River Lamprey

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	Sea age	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage
Transformers		0.000	0.01186	0.0119	0.9881
Adult - Resident		0.000	0.00536	0.0054	0.9946
Adult - Migrant		0.000	0.00091	0.0009	0.9991

Draw Zone - River Lamprey

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	Sea age	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage
Transformers		0.000	0.01065	0.0107	0.9893
Adult - Resident		0.000	0.00477	0.0048	0.9952
Adult - Migrant		0.000	0.00081	0.0008	0.9992

Alternative Draw Zone approach - Salmon

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	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage
Smolts	0.000	0.002	0.0023	0.9977
1SW	0.000	0.057	0.0569	0.9431
Kelts	0.000	0.049	0.0494	0.9506
MSW	0.000	0.058	0.0575	0.9425

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Draw Zone approach - Salmon

	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage
Smolts	0.000	0.002	0.0022	0.9978
1SW	0.000	0.051	0.0513	0.9487
Kelts	0.000	0.044	0.0440	0.9560
MSW	0.000	0.051	0.0513	0.9487

Alternative Draw Zone - Sandeel

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	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage	Probability of survival to stage
All	0.000	0.002	0.0020	0.9980	0.9980

Draw Zone - Sandeel

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	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage	Probability of survival to stage
All	0.000	0.002	0.0018	0.9982	0.9982

Alternative Draw Zone - Sea Lamprey

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		Proportion Impounded	Proportion Lost	in + out loss	Survival at life stage
Transformers		0.000	0.009	0.0085	0.9915
Adults - residents		0.000	0.015	0.0149	0.9851
Adults - inward migrants		0.000	0.003	0.0025	0.9975

Draw Zone - Sea Lamprey

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		Proportion Impounded	Proportion Lost	in + out loss	Survival at life stage
Transformers		0.000	0.008	0.0076	0.9924
Adults - residents		0.000	0.013	0.0132	0.9868
Adults - inward migrants		0.000	0.002	0.0022	0.9978

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Draw Zone Approach - Sea Trout

Resident Sea Trout - no egg loss predicted as resident sea trout migrate to spawn and losses to migratory fish (smolts, whiting, kelts and in-migrating fish for spawning) below incorporate potential losses while resident (column E, ' Proportion Lost during residency)

	Sea age	Proportion Impounded	Proportion Lost	in + out loss	Survival at life stage
1SW	1	0.003	0.009	0.0113	0.9887
2SW	2	0.003	0.010	0.0128	0.9872
3SW	3	0.003	0.011	0.0140	0.9860
4SW	4	0.003	0.012	0.0145	0.9855
5SW	5	0.003	0.013	0.0157	0.9843
6SW	6	0.013	0.0157	0.0157	0.9843
7SW	7	0.003	0.013	0.0157	0.9843

Migrant Sea Trout

	Sea age	Proportion Impounded during migration	Proportion Lost during migration	Proportion Lost during residency prior to migration	in + out loss	Survival at life stage
Smolt		0.000	0.002	0.000	0.0019	0.998
Whiting	0	0.000	0.021	0.000	0.0208	0.979
1SW	1	0.000	0.0385	0.0084	0.0469	0.953
Kelts		0.000	0.0312	0.0000	0.0312	0.969
2SW	2	0.000	0.0412	0.0096	0.0507	0.949
Kelts		0.000	0.0367	0.0000	0.0367	0.963
3SW	3	0.000	0.0465	0.0105	0.0569	0.943
Kelts		0.000	0.0411	0.0000	0.0411	0.959
4SW	4	0.000	0.0522	0.0109	0.0630	0.937
Kelts		0.000	0.0431	0.0000	0.0431	0.957
5SW	5	0.000	0.0576	0.0118	0.0694	0.931
Kelts		0.000	0.0477	0.0000	0.0477	0.952
6SW	6	0.000	0.0473	0.0118	0.0591	0.941
Kelts		0.000	0.0477	0.0000	0.0477	0.952
7SW	7	0.000	0.0473	0.0118	0.0591	0.941
kelts		0.000	0.0477	0.0000	0.0477	0.952

Alternative Draw Zone approach - Sea Trout

Resident Sea Trout - no egg loss predicted as resident sea trout migrate to spawn and losses to migratory fish (smolts, whiting, kelts and in-migrating fish for spawning) below incorporate potential losses while resident (column E, ' Proportion Lost during residency)

	Sea age	Proportion Impounded	Proportion Lost	in + out loss	Survival at life stage
1SW	1	0.003	0.010	0.0124	0.9876
2SW	2	0.003	0.011	0.0141	0.9859
3SW	3	0.003	0.013	0.0155	0.9845
4SW	4	0.003	0.013	0.0161	0.9839
5SW	5	0.003	0.015	0.0175	0.9825
6SW	6	0.003	0.015	0.0175	0.9825
7SW	7	0.003	0.015	0.0175	0.9825

Migrant Sea Trout

	Sea age	Proportion Impounded during migration	Proportion Lost during migration	Proportion Lost during residency prior to migration	in + out loss	Survival at life stage
Smolt		0.000	0.002	0.000	0.0021	0.998
Whitling	0	0.000	0.023	0.000	0.0233	0.977
1SW	1	0.000	0.0427	0.0093	0.05206	0.948
Kelts		0.000	0.0351	0.0000	0.0351	0.965
2SW	2	0.000	0.0459	0.0106	0.0565	0.943
Kelts		0.000	0.0413	0.0000	0.0413	0.959
3SW	3	0.000	0.0518	0.0116	0.0634	0.937
Kelts		0.000	0.0463	0.0000	0.0463	0.954
4SW	4	0.000	0.0580	0.0121	0.0701	0.930
Kelts		0.000	0.0484	0.0000	0.0484	0.952
5SW	5	0.000	0.0641	0.0131	0.0772	0.923
Kelts		0.000	0.0537	0.0000	0.0537	0.946
6SW	6	0.000	0.0532	0.0131	0.0663	0.934
Kelts		0.000	0.0537	0.0000	0.0537	0.946
7SW	7	0.000	0.0532	0.0131	0.0663	0.934
kelts		0.000	0.0537	0.0000	0.0537	0.946

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Alternative Draw Zone Approach - Shad

	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage
Juveniles	0.0000	0.0001	0.0001	0.9999
Residents	0.0000	0.0089	0.0089	0.9911
Pre-spawners	0.0000	0.0015	0.0015	0.9985
Post-spawners	0.0000	0.0015	0.0015	0.9985

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Draw Zone Approach - Shad

	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage
Juveniles	0.0000	0.0001	0.0001	0.9999
Residents	0.0000	0.0079	0.0079	0.9921
Pre-spawners	0.0000	0.0013	0.0013	0.9987
Post-spawners	0.0000	0.0013	0.0013	0.9987

Alternative Drawzone Approach - Sole

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	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage	Probability of survival to stage
Juveniles	0.000	0.001	0.0006	0.9994	0.9994

Draw Zone Approach - Sole

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	Proportion Impounded	Proportion Lost	in + out loss	Survival at stage	Probability of survival to stage
Juveniles	0.000	0.001	0.0006	0.9994	0.9994