# Appendix 9.5

# Accuracy and limitations

## 1.0 Fish and shellfish surveys and baseline data

1.0.0.1 Six intertidal sites were sampled as part of the site-specific surveys aimed at characterising the fish population of Swansea Bay. The intertidal sampling site at Langland Bay was discontinued due to safety considerations and replaced with a site at Pwlldu Bay in Quarter 2. This has very minor implications in terms of data coverage of the study area. However, it is considered that the sampling points surveyed provide suitable coverage of the study area.

1.0.0.2 Inclement weather, particularly in winter 2013, delayed the planned survey programme but all surveys were undertaken within the time constraints of the relevant season.

1.0.0.3 Unscheduled barrage lock closures, which meant that the vessel previously used was unavailable in 2013 resulted in delays and a change of survey vessel. Consequently, beam and otter trawl gear specifications changed between surveys. This also resulted in minor differences in terms of trawl speeds. Whilst this may result in differences in the composition of catch with regard to species abundance and length frequency it is unlikely to affect the qualitative seasonal characterisation of the stock to which this survey programme is contributing significantly.

1.0.0.4 Strong tides and the presence of rough ground, particularly in the vicinity of the Mumbles, resulted in unavoidable variation in trawl speeds and tracks, which are not atypical variables when surveying in such environments. As stated above, this is unlikely to affect the qualitative seasonal characterisation of the stock to which this survey programme is contributing significantly. The gear used in the inter- and subtidal fish fauna characterisation surveys targets certain species and lifestages and the methods agreed with the EA (now NRW) in a meeting with representatives from the Fisheries and Marine Monitoring teams at Llandarcy in January 2013. Intertidal survey methods tend to be biased towards juvenile lifestages while beam trawling tends to be biased towards small bodied and juvenile fish. In the relatively shallow environment of Swansea Bay pelagic species were numerous within the otter trawl. However, comparison of the gathered baseline with existing historic datasets indicates that the baseline is representative of fish populations in the wider Bristol Channel.

1.0.0.5 Mobile species such as fish exhibit varying spatial and temporal patterns. The seasonal surveys (both intertidal and subtidal) provide a ‘snapshot’ of the fish population. The surveys were not designed to specifically target pelagic fish; nevertheless surveys reported high numbers of pelagic fish species.

1.0.0.6 Migratory fish were not specifically targeted during surveys owing to the difficulty in the sampling low densities of transient diadromous populations within open coast environments. Migratory fish tend to be under-represented in WFD compliant surveys for this reason. This is taken into account in the EIA.

1.0.0.7 No migratory fish counter / trap data has been made available post-2001 for the Swansea Bay rivers. This meant that detailed long-term trends were harder to establish.

1.0.0.8 The accuracy of the Cefas data reflecting spawning and juvenile areas is limited, owing to difficulties in taxonomic identification and limitations of survey design. Overall, Cefas judges the information on spawning and nursery areas to have a low-to-medium confidence, based on data availability and quality. As a result, the data are to be interpreted with caution and supplemented with local knowledge.

## 2.0 Commercial fishing data

2.0.0.1 Vessels of less than 10m are not legally required to declare catches. This means that, whilst some <10m vessels do so on a voluntary basis, the majority of the fleets' fishing effort/location is unrecorded. As a result, some data regarding commercial angling effort and location is unavailable and this has implications when defining a baseline dataset, particularly in terms of the near-shore fisheries often targeted by the artisanal < 10m fleet - areas generally unprofitable and therefore not exploited by the > 10m fleet for which detailed data is available. Consultation with the commercial angling sector in Swansea Bay found that few < 10m vessels were present so data limitations have little impact on the baseline.

## 3.0 IBM modelling

3.0.0.1 The ability of the models of biology to predict the effect of a development on the populations of animals and plants that inhabit Swansea Bay will be dependent on three factors; 1) the use of an appropriate modelling method, 2) valid initialisation of the models based on knowledge of physiology of the target species and understanding of their behaviour, and 3) appropriate interpretation of the results as an aid to expert opinion on the likely effects. It must be appreciated that models of biology are inherently uncertain in comparison to models of physics and chemistry used for hydrodynamic models and water quality models respectively. Unlike the latter, there is always the possibility that animals will react in some way that is unknown, and unpredicted, as they are complex systems with unknown cognitive abilities and unknown, but usually highly elaborate, environmental sensitivities. Furthermore, living things are evolved to environments that do not necessarily presently exist in their pristine state, and which are subject to unknown and dynamic environmental changes as a result of human activities, and other factors, on a global scale (external environmental forcing). Finally the populations of species are themselves often chaotically dynamic with no clear understanding of the causes for dramatic change (which may be internal to the population), if indeed (as if formally chaotic) there are any causes. Animals are evolved to thrive in these externally and internally dynamic conditions, some are especially suited to them. Thus, expert opinion, is far more influential in assessment of the effects on animals and plants than is it on physical and chemical processes.

3.0.0.2 **Summary.** The process of modelling the effects of the proposed Lagoon development followed the same general procedure for each of the target fish species, in three sequential stages:

3.0.0.3 **1. Baseline.** Baseline cases run for all species in pre-project state to check they comply with expert opinion, and are **validated** by known facts and **literature calibrated**. Models use 10,000 model fish in an iterative process (run over and over again, up to 20 or 30 times in some cases) with level of variation within the population being determined in this process.

3.0.0.4 **2. Saturation.** Saturation model of impact in developed scenarios. These modelled the implication across estimated population variation using the parameters developed in the baseline assessment. Each model run included 10,000 model fish. Formally these are 10,000 independent instantiations of the same model with small variations to a few selected input parameters (most notably swimming speed, precise position and time of initialisation). The main output result was a probability of encounter with the turbines or sluices, also showing repeat passages through the turbines and predicting the variations in routes likely to be followed by migratory fish in project versus baseline states.

3.0.0.5 **3. Worst case scenario selection**. These were comparisons between runs of saturation models with overall different characteristics for the entire population – such as starting on spring tides rather than neap, or starting from the Tawe rather than the Neath. The worst case in terms of highest number of turbine/sluice encounters was selected to represent the species in question. A typical worst case selection considered spring tide start, neap tide start, top of tide start, bottom of tide start, and entry or exit from both the Tawe and Neath (8 potential scenarios). Many 'intermediate' cases (i.e less severe outcomes) before deciding on the worst case selections.

3.0.0.6 **Computer processing time and size of models.** Each model run for the IBM used 10,000 model fish, at a time step of 60 seconds, for runs which lasted about 3-4 days usually. The spatial resolution is effectively infinitely small (16 decimal places of a metre). Therefore around 60 million locations were storable after each run. The locations could include; x, y, (position) u, v, (water velocity – $ms^{-1}$), dir (direction of fish - radians), and depths of water and fish (m). In fact a separate output step was used to limit the computer memory requirement of storage – so these variables were recorded every 5 minutes or otherwise. These calculations were made on a relatively powerful desktop computer and each run took about 20-30 minutes to complete. In the process of exploration of the models and the iterative process of ensuring they reflect expert opinion, several hundred model runs were made before selecting the main set of worst case runs used for reporting. In the main set 36 runs were stored as videos. Many other runs were made for illustrative purposes, such as passive drifters to show water movements alone, or multiple species or scenarios to show realistic staying between rivers for diadromous species for instance. These are all important as they directly inform expert opinion.

3.0.0.7 **Appropriateness of the modelling scheme**. The underlying rule on which models of biology are based is the theory of evolution through natural selection. It is assumed that animals and plants have evolved to maximise their individual lifetime reproductive success. But the targeted prediction from these models is the effect of changes to the environment on the populations of animals and plants. However, one of the benefits of an individual based model (IBM) is that the focus is on the individual animal or plant which is the level where natural selection acts most strongly. That is, it is possible to predict that an animal will act in a way to maximise its individual lifetime reproductive success, whereas underlying causes are not so certain for changes to population level quantities. Another benefit is in certainty of initialisation because accurate measurements are often available on an individual level about swimming speed or response to various stimuli (called behavioural cues) whereas such accurate data are rarely available about population level statistics. Finally IBMs can be used to make predictions from root causes (using physiological information) about what might happen in system states that have never prevailed before. They can be used to extrapolate outside of known system states (but not outside known physiological states), where models of population statistics should not be used for this purpose. In other words, it is not important if fish behaviour around a particular type of development has not been observed or modelled before: it is only necessary that the relevant biological processes (such as swimming behaviour, navigational process, etc.) have been studied. Therefore the IBM modelling scheme is the most appropriate modelling method available and there is a long history of the use of this type of model to predict the effects of changes in a dynamic water environment.

3.0.0.8 **Individual based modelling of fish**. Individual based models have a 40 year history of scientific use in marine fisheries. One of the most intractable problems of management of a marine fishery is the relationship between standing stocks (the existing population) and recruitment (the number of new individuals that join the population as a result of spawning). IBMs have proven the best way to predict how environmental conditions, including currents, impact recruitment to marine fisheries and there are several thousands of scientific peer reviewed papers that document the progression of the science. IBMs also have a rich history of use to predict traffic and movements of people for urban planning, telephony usage, and the movements of many terrestrial animals, plants and inert particles, also in the past ten years they have been used for the modelling of water. In fact IBMs are almost as pervasive and well established as the mathematical 'mean field' models which preceded them. The IBM field has advanced as computer resources have become available. There are clear industry standard methodologies outlined in a set of ICES[1] working groups which relate to techniques and interpretation. With respect to examples of salmon for instance, there are three main groups working on IBMs dealing with the prediction of impact to fish populations from built structures in rivers and estuaries; THA (the authors) working with the International Centre for Ecohydraulic Research (ICER) at Southampton University; the USACE (US Army Corps of Engineers) and Humboldt State's Department of Mathematics with consultants Lang, Railsback & Associates. Between them these teams have published many cases which outline a clear set of examples and common practices.

3.0.0.9 **Rules and parameters**. Objects (or individuals) in IBMs have rules and parameters. The rules define what the fish 'object' will do in response to the situation it finds itself in at each step, and the parameters define its capabilities to act. So a rule might be to avoid land if the fish objects attempts to swim to a position in the model which has a depth of less than zero, and a parameter might be to swim at 1.5 m $s^{-1}$. The rules and parameters of the models used in this study are summarised in table following:

3.0.0.10 **Table 1**. Rules and Parameters of IBM. Rules 1-4 were applied to all fish of all species, whereas 5 and 6 were only applied to eels and lamprey.

| | Rule | Trigger | Notes |
|---|---|---|---|
| 1 | Land avoid | Hits land | Turn left or right by 90 degrees (chosen randomly) |
| 2 | Beach avoid | In water of less than minimum target depth | Use custom random walk to move to nearest area of acceptable depth. |
| 3 | Swim | Continuous | |
| 4 | Navigate to point or path | Periodic provision of direction to next appropriate waypoint | Change direction to aim at waypoint |

[1] International Council for the Exploration of the Sea

| | | | |
|---|---|---|---|
| | | on path, or target position. (the target position may be a single point or different for every fish) | |
| 5 | Selective tidal transport | Tidal state (flood or ebb) | Move to bed on tide flowing in the inappropriate direction |
| 6 | Selective light based swimming | Elevation of the sun | Move to bed during daylight or darkness |
| | **Parameters** | **Value** | |
| 1 | Swim speed | $m\ s^{-1}$ | |
| 2 | Directedness | Radians | Magnitude of error added at each step to the correlated random walk of the fish – i.e. it maintains a heading with this level of error added at each step |
| 3 | Navigational period | Numeric | Average number of steps between navigation information provision |
| 4 | Max/min depths | M | Parameters used to avoid becoming beached |
| 5 | Sensitivity to tide state | $m\ step^{-1}$ | Used to define the change of state of tide (depth change at a location) |

3.0.0.11 **Accuracy**. There is a clear distinction between precision and accuracy for these models. They are precise with a time step of 60 seconds, and an infinitesimal spatial resolution (to 16 decimal places of a metre). Whereas the accuracy is defined by the spread of the results, otherwise described as uncertainty. Each run uses 10,000 model objects which are designed to explore the implication of a full range of plausible input parameters. Some parameters for instance are randomly selected from a uniform random distribution (e.g. starting times) and others from a normal random distribution (e.g. swimming speeds). As mentioned above, the pristine original population may be highly variable (among individuals) and will be potentially highly dynamic, potentially chaotic (which is difficult to capture mathematically – for instance may not have a well-defined mean state) and therefore the predictions of the model can never be more accurate than the present knowledge of the population, which is usually highly inaccurate. In reporting the results – this probabilistic nature of the data is explicit. The result of 10,000 instantiations of the same model each with slightly different input parameters should be viewed directly as the predicted probability of some output condition; given the uncertainty about the real population. The confidence intervals are quoted which relate to the variation caused by the combined STRIKER and IBM modelling process alone, and these are not a substitute for the probabilistic results themselves. Confidence intervals for the IBM alone are variable and are wider (less accuracy and precision) for lower impacts because these are sampled less often. For instance if the results of three runs of 10,000 produces 3 overall encounter results for two species; the first species is: 1, 0, 1, and the other: 603, 606, 600, it can be seen that the first is a mean of 0.667 and standard error of about 0.6 (which is about 90% of the mean) whereas the second is mean 603 +/- 3 (0.5% of the mean). This decrease in relative accuracy for seldom sampled results is well understood and logical (See references: Willis, 2011); it is generally ignored unless results with very low probabilities are catastrophic, in which case the number of runs should be increased in order to sample the probability more accurately. The potential false impression of accuracy due to precision is the primary reason why the magnitude of impact statements based on broad classifications from 'likely to be negligible', through to, 'likely to be high impact' are a true reflection of the accuracy of the modelling combined with expert opinion. The models here were tested for the variations between runs of 10,000 (up to 10 similar runs were made of a standard set-up) and the random variation in results was confirmed to be exactly as expected for models of this type and was, as expected, dependent on size of target (encounter rate for different scenarios).

3.0.0.12 **Assumptions.** The key assumption of this modelling is that the hydrodynamic model is true (with dimensionally greater certainty and accuracy than the biological components). The IBM modelling contrasts the situation before the project is installed to that after it is installed. Therefore two hydrodynamic models form the basis of the IBM. The baseline situation, before, is used by the fish modelling team to calibrate and validate the model to ensure the chosen parameters produce the most likely approximation to what is known of the present fish behaviour in and around Swansea Bay. This includes the time of passage for migrating fish and the patterns of spatial use by others. The uncertainty in the behavioural models is high in contrast to the hydrodynamic models and thus we assume that the hydrodynamic models are perfectly accurate. If we noticed any anomalies during our modelling we discussed these with the hydrodynamic modelling teams to ensure that they are an accurate representation of reality.

3.0.0.13 **Uncertainty.** An assessment of uncertainty in the assessment of the impacts of the Project is undertaken throughout the IBM project. The interpretation of an IBM is largely the interpretation of uncertainty. All input parameters are tested for sensitivity, in order to highlight any area where lack of certainty has a disproportionate influence on the result. The result is a probabilistic output based on the dispersion of the input parameters. The aim is to include all plausible situations in the model and to focus on the large scale worst cases. The aim is also to capture the real variation in the species, and to use this information to see if any sub-sections of the population are likely to be influenced to any greater degree than any other. Thus the real variation in the population is in itself a set of input parameters to the model.

3.0.0.14 **Limitations.** The modelling is limited to the specific life stages outlined for each species. For the migrating species (salmon, trout, eel, lamprey, etc.) this is limited to the period of their lives when they either enter their natal or other river from the ocean, or when they leave the rivers and swim toward the open ocean. These models do not cover all or any other stages of their lives where they may conceivably use Swansea Bay, and do not cover any times when the fish are meandering around with no particular aim (if in fact they ever exhibit this behaviour in their lives). The models also do not incorporate any avoidance (or attraction) behaviour towards the turbines, sluices or lagoon wall structures. It is likely that most species will have evolved to avoid being drawn by fast moving flows into dark spaces (with tidal caves and lagoons being reasonably common natural analogues) and evolved to avoid crashing turbulence near rocky shores, but since these reactions are largely unknown in reality we have taken the worst case of no behaviour related to these effects. Some species may be attracted to the environmental changes caused by the turbines (enhanced turbulence) and these are usually evolved to be strong swimmers with robust bodies (bass and mackerel for instance). The models do not incorporate the effects of winds and waves, which can impart currents in shallow water with a strong 3D structure. These impacts on fish are usually minimal as they have evolved behaviours to avoid danger from wind and waves and the currents produced usually attenuate swiftly at depth which provides a simple refuge strategy. Wind and waves are thus only usually a major impact to fish which inhabit the surf zone and these species have evolved behaviours and the physiology to cope with all but the worst cases. In any case the IBM modelling developed here would be inappropriate to predict impact in these situations for these species. The model does incorporate a function incorporating behaviour by which fish avoid being stranded on beaches as this most often reflects reality.

3.0.0.15 **Limitations, swimming and navigation.** The IBM is calibrated by taking telemetry data (where it is available) and matching ground speed of tagged fish, with ground speed of model fish which is recorded as a result of the input parameters of the model fish, including both the mean values and the recorded variation in values. Model fish parameters are: 1) instantaneous 'in water' speed which is derived from the scientific literature, 2) directedness (otherwise called steadfastness or ability to maintain a heading) and 3) periodic navigation frequency – how often the fish is provided with the correct heading to its destination or next waymark. Directedness is incorporated as a random noise added at each step (there is a similar random walk added to model turbulence below the spatial scale of the hydrodynamic model). Predators, small scale changes to bed shape, structure or constitution, conspecific behaviour (schooling and territorial behaviour) and any other factors likely to impact direction finding and navigation of the model fish are thus all incorporated in the navigation parameters. A limitation is that there may be some unique or different collection of conditions present in Swansea Bay that were not present in the location of the tagging (although, given the overall calibration in the baseline case and the consistency across many studies of these and similar species, this is considered highly unlikely).

## 3.1 Exploration, initialisation and identification of worst cases for the IBM model

3.1.0.1 **Introduction.** A key tenet of the modelling is to reduce the focal target of the model to the worst case – which means the highest encounter rate between model fish and the entrance to the Lagoon. The worst case for an individual fish is an encounter and the associated potential mortality (which is predicted using the combination of the IBM and the STRIKER model, explained elsewhere in this document). So the worst case scenario in terms of the IBM is a description of the broad set of circumstances which cause the highest probability of encounter.

3.1.0.2 **Sources of variation in the model – small scale saturation.** Each model run is a set of 10,000 instantiations of the same model with a randomly selected range of initialisation parameters. The simple variable parameters are: swim speed, start time, start position. These parameters are constant and different for each one of the 10,000 fish throughout a model run. These parameters model population variability – especially swimming speed which is correlated to fish size. There are also 3 parameters which in themselves are definitions of variation; 1) directedness, which determines tortuosity of track, 2) navigation period (which also determines track shape), and 3) coefficient of dispersion which is a physical property modelling random movements due to turbulence. These parameters are constant for all fish objects but define a level of variation that happens at each step of the model. So two fish with identical initial parameters will take different tracks through the model at each step and therefore their chances of encounter will also be subtly different. These parameters represent our uncertainty about how an object might progress in the model given identical set-up conditions and are a common feature of probabilistic models of particles moving in hydrodynamic models. Formally this type of model is known as a Markov Chain in mathematics which is very often used to represent processes which build up sequentially. These 'constants of variation' also model random unknowns such as predator interactions, or innate navigational ability, and so forth, which may impact two identical fish differently in reality, or the same fish differently at two different times, and places. The intention with each model run is to saturate the local parameter space with 10,000 slightly different fish objects in 10,000 slightly different environments. This level of saturation is expected to give a high level of detail about the conditions under which encounter takes place. So for instance the results can be analysed to check if a particular range of start times, or swimming speeds is, on average, any more likely to cause an encounter or not. This level of saturation can also give very useful information that can be used to cross check the results, or help refine the best places to monitor the effects after the structure is built, as information such as cinch points or common paths under practically all conditions is readily available. For instance, salmon smolt may be programmed to leave a river mouth on the incoming tide, but the model may clearly show that they do not progress as they are too weak swimmers to overcome the incoming tide at any location across the river mouth channel. So the model might show (in a certain river) that smolt always leave on the top of the tide or on the outgoing tide, because they are unable to do so at any other time.

3.1.0.3 **Sources of variation – large scale options and olfactory paths.** In addition to the small scale variations outlined above, the model initialisation can be changed on a large scale. For instance smolt leaving the Neath as opposed to the Tawe; or adult fish approaching from the east, when it is usually assumed that they approach from the west. These larger scale changes most often involve a change in the olfactory path (in cases where fish are assumed to be following one). The olfactory path is therefore, in itself, potentially a major source of overall variation in the model. To a certain extent initialisation position for fish following an olfactory trail is irrelevant. In time, they will find the start of the trail and follow the trail regardless of where they start in the model. In these cases the initialisation zones are placed in convenient areas where fish are likely to join the path quickly to avoid unnecessary use of computer time. If fish are placed in positions where they cannot reasonably find or reach the start of the path, before potential interaction with the lagoon, then the model set-up is illogical and other paths or starting positions should be used. The model fish do not follow the olfactory paths very closely. They generally aim for the way mark on the path which is nearest to their present position, and they are provided with this information on a periodic basis (on a randomly chosen step, on average 4, or 5 steps apart usually, although a wide range of variations on this were explored as explained in the section on calibration). If fish are within 3 km of a way mark (cut off zone) they aim for the next way mark in sequence so as to avoid the waymarks themselves becoming any more than general directional influences. The waymark system was developed after placing model fish in a full water quality model (in this case it was of the Severn Estuary for the Severn Tidal Barrage Strategic Environmental Assessment mentioned in references) A spatial gradient in olfactory cue at every location in the model was defined. It was shown that waymarks approximately on the 'ridge' of the gradient surface (the highest points on cross-sections of the main estuarine channel) leading to the destination were equally accurate in comparison with a reaction to the exact modelled gradient of the olfactory surface, given the wide uncertainty in respect of the navigational abilities of the fish. If necessary the olfactory path can be tightened up considerably, with more way points and a shorter cut off zone at waymarks, but there is a clear limit in terms of fish swimming capabilities and tidal forces which mean that even if fish were assumed to be perfectly aligned at all times, they would still not be able to follow a path exactly. Indeed where very strong tidal currents are perpendicular to the olfactory path, perfect orientation to a very detailed path can be highly inefficient. In the models for this study, the least waymarks have been used to ensure the olfactory trail is a logical progression – for instance the next waymark in a progression should not be occluded by land, or by the walls of the lagoon as this would lead to illogical directionality in the model fish. Therefore the exact placement and number of the waymarks, although defined by the custom olfactory models (built as part of this modelling), and cross checked with the water quality models, were not a significant influence on the outcome of the models.

3.1.0.4 **Identification of worst case scenarios.** The worst case selection process was focused on the large scale variation with some overall options for the initialisation. For instance, smolt leaving from the Neath in contrast to smolt leaving from the Tawe, or fish starting on the spring tide as opposed to the neap. As opposed to the small scale variations in the saturation sampling described above encompassed in each run of 10,000. The saturation samples provided a probabilistic indication of the likely impact of the works in contrast to the baseline cases. The saturation samples were examined to see if there were any systematic variations in outcome dependent on input variables, which highlight any sensitivity in the model to precise choices of parameters, or sensitivity pattern of random distributions of variables. These systematic variations would show any particular ranges of variables that represent 'worst cases' within the overall saturation sampling range, and may lead to further investigation and justification for the overall range of variation. No such systematic variations were identified as explained in the example in the section on calibration. The extent of the variation within the saturation sampling (10,000 in number) was designed to sample the true population parameters of a species, and thus is a product of physiological knowledge and expert opinion about the species in question. The major scenario variation was designed to contrast various plausible major differences in the system, and to contrast sub-populations that would definitely have different initialisation parameters. Since major scenario variations always included at least one run of 10,000 they could be compared using the overall encounter probability.

3.1.0.5 **Example of process for identification of worst case scenarios.** For each species a range of scenarios were run with major changes to the starting conditions. Table 2 below shows a small selection of the results of 8 such runs for a single species. In these cases the impact of eastern and western starts and the impact of spring or neap tides were combined with some variations of navigational parameters. The variation of minor calibration parameters was explored when different sets of parameters led to similar calibration in terms of matching expert opinion and literature studies but were different and equally valid. As the table shows the impact of variation of these parameters was minimal. The table also shows the impact of a change to olfactory path (05E/06E) is minimal (notes 4, 5 and 6). In the final analysis a scenario which led to a number of fish encountering the turbines and sluices of 2044 (3096 crosses) was used (not shown on this selection, see final summary tables) as this was the worst overall case for adult trout.

**Table 2 Example results for adult trout for N=10,000**

| | West Crosses | Sluice Crosses | East Crosses | No. fish turbine encountering turbines | 1 turbine cross | 2 turbine crosses | 3 turbine crosses | 4 turbine crosses |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| **Spring[1]** | 881 | 530 | 165 | 621 | 273 | 291 | 39 | 17 |
| | 873 | 489 | 175 | 625 | 275 | 298 | 34 | 15 |
| **Spring[2]** | 639 | 328 | 73 | 427 | 193 | 198 | 24 | 9 |
| **Spring[3]** | 1301 | 766 | 176 | 752 | 291 | 313 | 76 | 48 |
| **Spring[4]** | 254 | 194 | 37 | 149 | 62 | 52 | 21 | 10 |
| **Spring[5]** | 343 | 196 | 24 | 174 | 54 | 79 | 20 | 14 |
| **Neap[6]** | 203 | 144 | 29 | 110 | 39 | 48 | 9 | 8 |
| **Neap[7]** | 8 | 9 | 1 | 5 | 1 | 4 | 0 | 0 |

1 Western approach Navstep 5, determination 0.2, speed 1.233 bl
2 Western approach Navstep 4, determination 0.1, speed 1.5 bl
3 Eastern approach, nav 4, det 0.2, 1.5 bl, route 05E
4 Eastern approach, 4, 0.2, 1.5, route 05E
5/6 Eastern approach, 4, 0.2, 1.5, route 06E
7 Eastern approach

3.1.0.6 **Summary of runs and scenarios.** The output tables have been reproduced and extended to show which rules were used for each model run and the minimum extent of the worst case scenario testing.

| **Baseline without lagoon** | **Video file name** | **Behaviour style and rule numbers used.** | |
|---|---|---|---|
| Salmon adult | TEMb-A01 | Trail follow (1-4) | |
| Salmon smolt | TEMb-J01 | Trail follow (1-4) | |
| Sea trout adult | TEMb-A02 | Trail follow (1-4) | |
| Sea trout smolt | TEMb-J02 | Trail follow (1-4) | |
| Shad | TEMb-A03 | Trail follow (1-4) | |
| Herring adult | TEMb-A04 | Homing zone (1-4) | |
| Eel adult | TEMb-A05 | Trail follow (1-6) | |
| Eel elver | TEMb-J05 | Trail follow (1-6) | |
| River Lamprey adult | TEMb-A06 | Trail follow (1-6) | |
| River Lamprey transformer | TEMb-J06 | Trail follow (1-6) | |
| Sea Lamprey Adult | TEMb-A07 | Trail follow (1-6) | |
| Sea Lamprey transformer | TEMb-J07 | Trail follow (1-6) | |
| Bass adult | TEMb-A08 | Area usage (1-4) | |
| Bass juvenile | TEMb-J08 | Area usage (1-4) | |
| Plaice juvenile | TEMb-J09 | Area usage (1-4) | |
| Neath adult salmon | TEMb-A10Ne | Trail follow (1-4) | |
| **Lagoon in place** | **Video file name** | **Behaviour style and rule numbers used.** | **Minimum worst case exploration** |
| Salmon adult | TEM-A01 | Trail follow (1-4) | **H L S N E W T** |
| Salmon smolt | TEM-J01 | Trail follow (1-4) | **H L S N T Ne** |
| Sea trout adult | TEM-A02 | Trail follow (1-4) | **H L S N E W T Ne** |
| Sea trout smolt | TEM-J02 | Trail follow (1-4) | **H L S N T Ne** |
| Shad | TEM-A03 | Trail follow (1-4) | **E W** |
| Herring adult | TEM-A04 | Homing zone (1-4) | |
| Eel adult | TEM-A05 | Trail follow (1-6) | **H L S N T Ne** |
| Eel elver | TEM-J05 | Trail follow (1-6) | **H L S N E W T Ne** |
| River Lamprey adult | TEM-A06 | Trail follow (1-6) | **H L S N T Ne** |
| River Lamprey transformer | TEM-J06 | Trail follow (1-6) | **H L S N E W T Ne** |
| Sea Lamprey Adult | TEM-A07 | Trail follow (1-6) | **H L S N T Ne** |
| Sea Lamprey transformer | TEM-J07 | Trail follow (1-6) | **H L S N E W T Ne** |
| Bass adult | TEM-A08 | Area usage (1-4) | |
| Bass juvenile | TEM-J08 | Area usage (1-4) | |
| Plaice juvenile | TEM-J09 | Area usage (1-4) | |
| Neath adult salmon | TEM-A10 | Trail follow (1-4) | **H L S N E W Ne** |
| Sandeel | TEM-A11 | Area usage (1-4) | |
| **H L S N** | **High tide, low tide, spring, neap** | | |
| **E W** | **Eastern approach, western approach** | | |
| **T Ne** | **Tawe, Neath (either to or from)** | | |