Feasibility Study of Methods to Collect Data on the Spatial and Temporal Distribution of Diadromous Fish in Welsh Waters.

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Cyd-destun a diben

Mae Llywodraeth Cymru wedi darparu cymorth sylweddol i'r sector ynni adnewyddadwy morol sy'n dod i'r amlwg. Mae amcanion Cynllun Morol Cenedlaethol Cymru (Llywodraeth Cymru 2019) yn cynnwys cefnogi'r cyfle i ddatblygu amcanion morol adnewyddadwy yn gynaliadwy gyda'r 'datblygiad cywir yn y lle cywir', gan helpu i gyflawni amcanion diogelwch ynni a lleihau carbon y DU, wrth ystyried cydnerthedd ecosystemau yn llawn a diddordebau eraill. Mae'r cynllun yn nodi meysydd adnoddau potensial ar gyfer datblygiad a ffefrir.

Mae datblygiadau ynni morol yn gofyn am Asesiadau Effaith Amgylcheddol, Asesiadau Rheoliadau Cynefinoedd ac Asesiadau Cyfarwyddeb Fframwaith Dŵr. Efallai y bydd angen casglu tystiolaeth sylweddol ar gyfer yr asesiadau hyn ac mae nifer o fylchau mewn tystiolaeth ar gyfer rhywogaethau pysgod ymfudol yn nyfroedd Cymru. Mae mynd i'r afael â'r bylchau hyn mewn tystiolaeth yn hanfodol ar gyfer gwneud penderfyniadau effeithiol ac amserol.

Er mwyn helpu i fynd i'r afael â'r mater hwn, mae CNC wedi comisiynu'r adolygiad hwn er mwyn nodi'r dulliau gorau i helpu i lenwi bylchau mewn gwybodaeth benodol ar gyfer pysgod ymfudol. Mae'r adroddiad hwn yn cynnwys astudiaeth ddichonoldeb sy'n edrych ar yr offer monitro y gellir eu defnyddio i gasglu'r dystiolaeth sydd ei hangen. Mae adroddiad ar wahân yn ystyried yn fanwl y dyluniad olrhain araeau acwstig a strategaethau tagio i ddarparu gwybodaeth (*Clarke et al,* 2021b).

Bylchau mewn tystiolaeth

Y prif fylchau mewn tystiolaeth a nodwyd yng nghwmpas yr adolygiad yw presenoldeb / absenoldeb ac amseroedd preswylio rhywogaethau mewn maes adnoddau penodol, yn ogystal â gwybodaeth gadarn am lwybrau mudo rhywogaethau gwahanol ar gamau bywyd gwahanol. Mae angen y wybodaeth hon er mwyn cadarnhau a yw rhywogaeth neu uned boblogaeth yn debygol o fod mewn perygl o ddatblygiad ac i feintioli effaith bosibl y risg ar lefel boblogaeth.

Mae bylchau eilaidd mewn tystiolaeth yn cynnwys gwybodaeth benodol am rywogaethau / cyfnodau bywyd am ddyfnder nofio, cyflymder nofio a ffyddlondeb tuag at safle i afonydd gwreiddiol. Mae ffyddlondeb tuag at safle yn bwysig wrth ddeall graddfa'r poblogaethau a ellir eu heffeithio. Defnyddir dyfnder nofio a chyflymder nofio mewn modelau i asesu effeithiau posibl.

Rhywogaethau a gwmpesir

Mae'r rhywogaethau a gwmpesir gan yr adroddiad yn cynnwys eogiaid yr Iwerydd (*Salmo salar*), Brithyllod y môr (*Salmo trutta*), herlyn a gwangen (*Alosa alosa ac*

Alosa fallax fallax), llysywen bendoll yr afon a'r môr (*Petromyzon marinus L. a Lampetra fluviatilis*), llysywod Ewropeaidd (*Anguilla anguilla*) a brwyniaid Ewropeaidd (*Osmerus eperlanus*).

Dull gweithredu

I ddechrau, mae'r adroddiad yn mynd i'r afael â'r bylchau mewn tystiolaeth trwy edrych ar wybodaeth gyfredol. Mae dosbarthiad y rhywogaethau ymfudol mewn afonydd ledled Cymru wedi'i nodi gyda help staff CNC. Yn ogystal â hyn, adolygwyd yn gryno y llenyddiaeth ar y prif fylchau mewn tystiolaeth a'r rhai eilaidd ar gyfer pob rhywogaeth, gan ganolbwyntio'n bennaf ar dystiolaeth o ddyfroedd Cymru ar gyfer mudo, ac ar dystiolaeth ehangach ar gyfer ffactorau megis cyflymder nofio neu ddosbarthiad dyfnder. Adolygwyd cymhwysedd dulliau gwahanol er mwyn mynd i'r afael â bylchau data, gan ddefnyddio gwybodaeth ymarferol helaeth ein tîm adolygu. Yn olaf, ar sail y bylchau mewn gwybodaeth a'r offer ymchwilio y gellir eu defnyddio i lenwi'r bylchau hyn, mae'r adroddiad yn argymell dulliau ymarferol a rhai ymyriadau strategol.

Casgliadau

Amlinellir ein casgliadau llawn yn Adran 8. I grynhoi:

- Mae ffyddlondeb yn cael ei ddeall yn dda ar gyfer yr holl rywogaethau dan sylw, gyda lefel uchel o ffyddlondeb yn cael ei arddangos gan eogion yr Iwerydd, brithyll y môr, gwangen ac o bosib, brwyniaid Ewropeaidd (er bod gwybodaeth lenyddol yn wan). Mae llyswennod Ewropeaidd yn gatadromaidd a chredir eu bod yn cynnwys stoc Ewropeaidd unigol. Ystyrir bod gan y ddwy rywogaeth llysywen bendoll ffyddlondeb isel i systemau afonydd unigol.
- Ar gyfer eogiaid yr Iwerydd a brithyllod y môr, llyswennod Ewropeaidd, llysywen bendoll yr afon a'r môr, gellir eu casglu mewn meysydd adnoddau lle mae'n amlwg o'u dosbarthiad dŵr croyw fod yn rhaid iddynt fynd trwy'r ardal ddatblygu. Ar gyfer rhywogaethau a meysydd adnoddau eraill, mae ansicrwydd sylweddol yn parhau.
- Mae ychydig o wybodaeth gyffredinol yn disgrifio arferion morol y rhan fwyaf o'r rhywogaethau dan sylw. Fodd bynnag, ar hyn o bryd, nid oes unrhyw wybodaeth wedi'i chyhoeddi lle gellir ei defnyddio i feintioli eu presenoldeb mewn meysydd adnoddau morol o amgylch Cymru neu i ddisgrifio'r llwybrau mudo a ffefrir ar gyfer unrhyw un o'r rhywogaethau sy'n cael eu hadolygu yn nyfroedd arfordirol Cymru.
- Mae ychydig o wybodaeth yn bodoli ar gyfer y rhan fwyaf o rywogaethau sy'n disgrifio cyflymderau nofio a defnydd dyfnder, er bod hyn o ansawdd amrywiol.

Argymhellion

Technegau addas

- Mae'r prif offer ymchwilio yr ydym yn eu hargymell yn cynnwys arolygon eDNA (ar gyfer presenoldeb / absenoldeb), olrhain acwstig (ar gyfer llwybrau mudo a meintioli argaeledd mewn cyfresi adnoddau), tagiau synhwyrydd a thagiau storio data ar gyfer casglu gwybodaeth am gyflymder nofio a dyfnder nofio.
- Rydym wedi cynnwys argymhellion am leiafswm meintiau pysgod priodol ar gyfer tagio pob un o'r rhywogaethau.
- Pan nad yw camau bywyd yn addas ar gyfer astudiaethau tagio, efallai y bydd angen astudiaethau dal gan ddefnyddio rhwydi, treillrwydi, rhwydi plancton neu dechnegau tebyg eraill.Ymyriadau strategol
- O ystyried y wybodaeth gyfyngedig ar ddosbarthiad rhywogaethau pysgod ymfudol (a rhywogaethau eraill) yn nyfroedd morol Cymru, rydym wedi argymell y dylid comisiynu rhaglen samplu strategol dwy flynedd i ddarparu data eDNA i gadarnhau presenoldeb/absenoldeb a thoreth tymhorol cymharol o rywogaethau ym mhob un o'r meysydd adnoddau. Nod hwn fyddai darparu gwaelodlin gychwynnol ar gyfer pob asesiad o'r effaith amgylcheddol a gynhelir gan ddatblygwyr.

- Rydym hefyd yn argymell defnyddio rhaglen arae acwstig strategol helaeth, sy'n cwmpasu'r meysydd adnoddau, wedi'i hariannu'n ganolog a'i chefnogi gan araeau derbynnydd dwysach mewn lleoliadau datblygu penodol a ariennir gan ddatblygwyr. I ddechrau, dylai tagio ganolbwyntio ar salmonidau, gwangen a llysywod Ewropeaidd aeddfed, gyda thagio rhywogaethau eraill yn dibynnu ar ganlyniadau arolwg gwaelodlin eDNA. Mae hyn yn cael ei drafod ymhellach yn ein hail adroddiad (Clarke *ac eraill*., 2021b).

Executive summary

Context and purpose

Welsh Government has provided substantial support to the emerging marine renewable energy (MRE) sector. The Welsh National Marine Plan objectives (Welsh Government 2019) include ‘supporting the opportunity to sustainably develop marine renewable objectives with the ‘right development in the right place’, helping to achieve the UK’s energy security and carbon reduction objectives, whilst fully considering ecosystem resilience and other interests. The plan identifies potential Resource Areas (RA) for preferred development.

Marine energy developments require Environmental Impact Assessments (EIA), Habitats Regulations Assessments (HRA) and Water Framework Directive (WFD) assessments. Substantial evidence collection may be required for these assessments and there are a number of evidence gaps for diadromous fish species in Welsh waters. Addressing these evidence gaps is critical for effective and timely decision making.

To help address this issue Natural Resources Wales (NRW) have commissioned this review to identify the best methods to help to fill specific information gaps for diadromous fish. This report comprises a feasibility study to look at the monitoring tools that can be applied to collect the evidence needed. A separate report looks in detail at the design of acoustic tracking arrays and tagging strategies to provide information (*Clarke et al.*, 2021b).

Evidence gaps

Primary evidence gaps identified in the review scope are the presence / absence and residence times of species in given RA, as well as robust information on the migration routes of different species at different life stages. This information is required to establish whether a species or population unit is likely to be at risk from a development and to quantify the potential impact of the risk at a population level.

Secondary evidence gaps are species and life stage specific information on site fidelity, swimming depth and swim speeds. Site fidelity is important in understanding the scale of the populations which may be impacted. Swimming depth and swim speeds are used in models to assess potential impacts.

Species covered

The species covered by the report include Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*), allis and twaite shad (*Alosa alosa* and *Alosa fallax fallax*), river and sea lamprey (*Petromyzon marinus* and *Lampetra fluviatilis*), European eel (*Anguilla anguilla*) and European smelt (*Osmerus eperlanus*).

Approach

The report initially approaches the evidence gaps by looking at existing knowledge. The distribution of the diadromous species in rivers across Wales has been identified with the help of NRW staff. In addition, literature on the primary and secondary evidence gaps for each species has been briefly reviewed, focussing primarily on evidence from Welsh waters for migration, and on wider evidence for factors such as swimming speed or depth distribution. The applicability of different methods to address data gaps has been reviewed, using the extensive practical knowledge of our review team. Finally, based on the information gaps and the investigative tools that can be applied to fill these gaps, the report recommends practical approaches and some strategic interventions.

Conclusions

Our full conclusions are set out in Section 8. In summary:

- Fidelity is well understood for all of the species in question, with a high degree of fidelity being exhibited by Atlantic salmon, sea trout, Twaite shad and probably European smelt (though literature information is weak). European eels are catadromous and are thought to comprise a single European stock. Both lamprey species are considered to have low fidelity to individual river systems.
- For Atlantic salmon and sea trout, European eels, river and sea lamprey presence can be inferred in resource areas where it is obvious from their freshwater distribution that they have to pass through the development area. For other species and resource areas significant uncertainty remains.
- There is some general information describing the marine habits of most of the species in question. However, there is currently no published information which can be used to quantify their presence in marine resource areas around Wales or to describe preferred migration pathways for any of the species under review in Welsh coastal waters.
- Some information exists for most species describing swimming speeds and depth utilisation, although this is of variable quality.

Recommendations

Suitable techniques

- The main investigative tools that we recommend include eDNA surveys (for presence/absence), acoustic tracking (for migration paths and quantification of availability in resource series), sensor tags and data storage tags for the collection of information on swimming speeds and swimming depths.
- We have included recommendations on appropriate minimum fish sizes for tagging each of the species.
- Where life stages are unsuitable for tagging studies, capture studies utilising nets, trawls, plankton nets or other similar techniques may be needed.

Strategic interventions

- Given the limited knowledge of the distribution of diadromous fish species (and other species) in Welsh marine waters, we have recommended that a strategic two-year sampling programme is commissioned to provide eDNA data to establish presence/absence and relative seasonal abundance of species in each of the resource areas. The aim of this would be to provide an initial baseline for all EIA's undertaken by developers.

- We also recommend deployment of an extensive strategic acoustic array programme, covering the resource areas, funded centrally and supported by developer funded more intensive receiver arrays in specific development locations. Initially tagging should focus on salmonids, twaite shad and adult European eel, with tagging of other species dependent on the results from the eDNA baseline survey. This is discussed further in our second report (Clarke *et al.*, 2021b).

1. Introduction

Wales' marine environment is a major asset, providing opportunities for recreation, production of low carbon energy, harvesting edible components and extraction of minerals, including sand and gravel. It is also home to a rich biodiversity.

The tidal and wave energy resources in Welsh waters include areas recognised as being of strategic significance to the UK as a potential source of low carbon energy (Crown Estate, 2012). The Welsh Government has provided substantial support to the development of a new MRE sector which can provide low carbon energy and create new jobs. Objective 3 of the Welsh National Marine Plan (WNMP) (Welsh Government, 2019) is to '*Support the opportunity to sustainably develop marine renewable objectives with the right development in the right place, helping to achieve the UK's energy security and carbon reduction objectives, whilst fully considering other's interests, and ecosystem resilience*'. This objective has to be balanced with Objective 10: '*Protect, conserve, restore and enhance marine biodiversity to halt and reverse its decline including supporting the development and functioning of a well-managed and ecologically coherent network of Marine Protected Areas (MPAs) and resilient populations of representative, rare and vulnerable species'.* The WNMP identifies potential Resource Areas (RA) for wave, tidal range, and tidal stream developments (Figure 1) to aid in marine spatial planning and minimise the risk of mutually exclusive developments being planned within the same areas.

Wherever MRE developments are located in Welsh waters they require a range of consents from regulators to be built and to operate. Consents often require extensive environmental evidence to support Environmental Impact Assessments (EIA), Habitats Regulations Assessments (HRA) and Water Framework Directive (WFD) assessments.

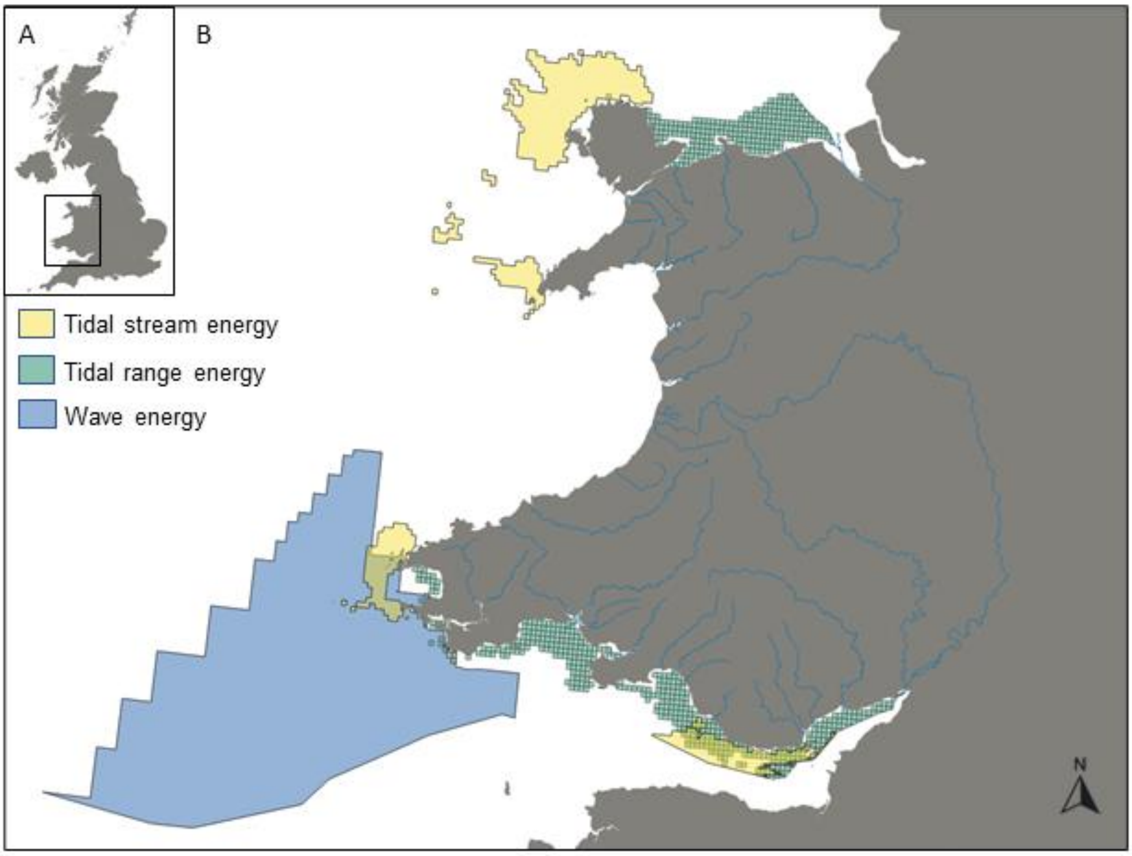

Figure 1. Map of marine renewable energy Resource Areas in Welsh waters (Welsh Government, 2019).

Preparing the required assessments for fish species can be problematic, because information about the distribution, abundance, and migration of diadromous fish in the marine environment is often limited. For instance, although there may be a generalised understanding of the distribution of species such as Atlantic salmon (*Salmo salar*) at sea, migration pathways in Welsh waters are poorly understood. For other species such as European smelt/sparling (*Osmerus eperlanus*) there is little meaningful information on their marine distribution around Wales. Acquiring the relevant evidence on diadromous fish species to support assessments is expensive and time consuming and could potentially limit or delay projects. Assessments conducted without the relevant evidence have a high degree of uncertainty associated with them that is complex to understand and manage within the consenting process.

To help address the issue of the limited available evidence, this review has been commissioned by Natural Resources Wales (NRW) to investigate methods to collect data to fill specific information gaps for diadromous fish species. The review comprises two elements:

(i) A feasibility study of the monitoring tools which could be applied to collect the evidence needed.

(ii) Design of acoustic tracking arrays to collect data on distribution, abundance and migration of diadromous fish species in Resource Areas.

The overall purpose of this review is to enable NRW and developers to identify methods to fill the evidence gaps and answer questions such as:

- Are particular species likely to be found in specific development areas, and if so at what times of year?
- What proportion of a fish population might interact with a given MRE device (or device array)?
- How long are fish likely to remain in the vicinity of a device and hence potentially be available to interact?

Techniques to monitor near-field interactions, such as avoidance or evasion behaviour is covered in a separate Swansea University report for Welsh Government (Clarke *et al.,* 2021a; Contract ref**:** MEFA02/20/21)

Understanding how to fill these evidence gaps can help to reduce the uncertainty around key consenting issues at both a strategic and project level.

This report comprises part (i) of the work required. The array design is presented in a separate report (Clarke *et al.*, 2021b).

2.Evidence gaps and report scope

2.1. Evidence gaps

Strategic evidence gaps for assessing the effect of marine energy projects on marine mobile species, such as marine mammals, fish and birds have been identified by, amongst others, the Offshore Renewables Joint Industry Programme (ORJIP Ocean Energy, 2017, 2020). Identified evidence gaps include:

- Collision risk
- Underwater noise
- Electromagnetic fields from transmission cables
- Displacement.

ORJIP (2017) specifically identify the lack of strategic baseline data for migratory fish (distribution, abundance, seasonality etc) as an evidence gap. They note that further data on mobile species populations, particularly those that are qualifying features of sites designated under The Conservation of Habitats and Species Regulations 2017 (the Habitats Regulations) or equivalent, would aid population modelling and understanding of population level impacts, improving confidence in EIAs and HRAs.

2.2. Report scope

The overall scope of this report aligns with the ORJIP Ocean Energy (2017, 2020) recommendations, and focusses on migratory diadromous species designated under the European Habitats Directive Annex II in Wales:

- Atlantic salmon (*Salmo salar*)
- Allis and twaite shad (*Alosa alosa* and *Alosa fallax fallax*)
- River and sea lamprey (*Petromyzon marinus* and *Lampetra fluviatilis).*

The scope also includes other diadromous fish species of conservation interest in Wales including sea trout (*Salmo trutta*), European eel (*Anguilla anguilla*) and European smelt/sparling (*Osmerus eperlanus*).

For each species we look at primary and secondary evidence gaps. Primary evidence gaps identified in the specification of work include the following for relevant life stages of target species:

- Presence / absence in resource areas
- Migration routes in resource areas
- Duration of presence and/or residence times in resource areas.

These data are important to establish whether or not a species is likely to be at risk from a marine energy development, and to quantify the potential impact of the risk at a population level.

Secondary information gaps include species and life stage specific information on site fidelity, swimming depth and swim speed.

Site fidelity is important in understanding the likelihood of population scale impacts. For example, only four spawning populations of twaite shad are known to exist in Wales, in the Rivers Severn, Usk, Wye and Tywi. Fidelity is high within these populations and each are likely to be genetically discrete. Understanding the risks to different populations is therefore important, and localised impacts may be significant for discrete populations. In contrast, the European eel population is considered to be a single population, spawning together in the Sargasso Sea, though different regions and countries may make different contributions.

Swimming speed and depth are important parameters in modelling predictions of interaction with MREs. Swimming depth is important in considering the impact of different turbine designs. For example, for a species such as Atlantic salmon which is thought to spend most of the time in sea surface layers, a turbine operating on the seabed may pose less risk than a floating device operating near the surface. Swimming speed is used when modelling, to parameterise models for factors such as movement around an area, and when modelling the potential for fish to exhibit near-field avoidance to evade operating tidal stream turbines or be drawn into tidal range lagoons.

ORJIP Ocean Energy (2020) has additionally emphasised the importance of collecting fine scale data for marine mobile species, in particular behavioural data in the immediate vicinity of turbines (avoidance or attraction) and evidence of the effects of turbine interactions on the animals affected. A review of methods to collect these data are not technically within the scope of this report, and Swansea University reviewed monitoring approaches for near field interactions and turbine strikes in more depth in a report for Welsh Government (Clarke *et al*., 2021a). In the current report we have identified where monitoring techniques such as fine scale tracking and visual / acoustic camera studies can contribute to the evidence base for these issues.

3. Approach and methods

The approach we have taken to this review brings together existing knowledge of the project partners (Swansea University, the Atlantic Salmon Trust and the Game and Wildlife Conservation Trust). We have combined that with literature searches, knowledge from local NRW staff, discussions with equipment suppliers, and discussions with regulators and other researchers. We have contacted suppliers to determine costs and seek information on developing tools and methods.

We have considered a very wide range of techniques and combinations of methods to fill the primary and secondary evidence gaps. This has included a brief literature review, to establish information which is already present on capture methods, tag types and methods (including tag burden and best practice for applying acoustic tags), cameras, active acoustics, eDNA and stable isotopes. A summary of the utility of each method to address the evidence gaps is included in Table 1.

Table 1. Summary of methods identified to fill the primary and secondary evidence gaps defined in Section 4.2. Preferred / most practical methods in bold. Cell colour indicates no literature (red), limited literature available (yellow) or literature available (green). Secondary evidence gaps also includes wider literature from areas other than Wales.

	Presence/absence in Resource Areas	**Migration paths in Welsh waters**	**Duration of presence and / or residence times in Resource Areas**	**Swimming depth**	**Swim speed**	**Site fidelity to natal rivers**
Species	**Primary evidence gaps**			**Secondary evidence gaps**		
Atlantic salmon - adult (*Salmo salar*)	**Adult catch data in some cases**, **eDNA, acoustic tracking,** satellite tags, presence can be inferred from in river	**Acoustic tracking, netting,** satellite tags, data storage tags	**Acoustic tracking,** data storage tags, satellite tags	**Data storage tags, sensor tags,** satellite tags	**Acoustic tracking, data storage tags,** flume studies	**Basic tags and marks (Carlin, Floy, microtags), PIT tags,** acoustic and radio tracking, molecular studies
Atlantic salmon – smolt (*Salmo salar*)	**Adult catch data in some cases**, **eDNA, acoustic tracking,** presence can be inferred from in river, midwater research trawls	**Acoustic tracking,** midwater research trawl	**Acoustic tracking,** midwater research trawls	**Sensor tags**	**Acoustic tracking**, flume studies	**Basic tags and marks (Carlin, Floy, microtags), PIT tags,** acoustic and radio tracking, molecular studies
Sea trout - adult (*Salmo trutta*)	**Adult catch data in some cases, survey trawls, eDNA, acoustic tracking**, netting, satellite tags, presence can be inferred from in river	**Acoustic tracking,** netting, satellite, data storage tags	**Acoustic tracking**, satellite tags, data storage tags	**Data storage tags, sensor tags**	**Acoustic tracking**. Data storage tags, flume studies	**Basic tags and marks (Carlin, Floy, microtags), PIT tags**, acoustic and radio tracking, molecular studies

	Presence/absence in Resource Areas	**Migration paths in Welsh waters**	**Duration of presence and / or residence times in Resource Areas**	**Swimming depth**	**Swim speed**	**Site fidelity to natal rivers**
Sea trout – smolt (*Salmo trutta*)	**Inferred from in river adult catch data, survey trawls, eDNA, acoustic tracking**	**Acoustic tracking,** midwater research trawl	**Acoustic tracking,** midwater research trawl	**Sensor tags**	**Acoustic tracking**, flume studies	**Basic tags and marks (Carlin, Floy, microtags), PIT tags**, acoustic and radio tracking, molecular studies
Allis shad – adult (*Alosa alosa*)	**eDNA**	N/A	N/A	N/A	N/A	N/A
Allis shad – juvenile (*Alosa alosa*)	**eDNA**	N/A	N/A	N/A	N/A	N/A
Twaite shad – adult (*Alosa fallax*)	**eDNA, acoustic tracking,** inferred from in river catch data, survey trawls**,**	**Acoustic tracking**	**Acoustic tracking**	**Sensor tags**	**Acoustic tracking**, flume studies	**Acoustic tracking**, basic tags and marks (Carlin, Floy, microtags)
Twaite shad – juvenile (*Alosa fallax*)	**eDNA,** survey trawls	**eDNA,** research trawls	**eDNA,** research trawls	N/A	**Flume studies**	**Small basic tags and marks (PIT, microtags)**
Sea lamprey– adult	**eDNA,** acoustic tracking (if catchable in sensible locations)	**Acoustic tracking**	**Acoustic tracking**	**Sensor tags**.	**Acoustic tracking**, flume studies	N/A

	Presence/absence in Resource Areas	**Migration paths in Welsh waters**	**Duration of presence and / or residence times in Resource Areas**	**Swimming depth**	**Swim speed**	**Site fidelity to natal rivers**
(*Petromyzon marinus*)						
Sea lamprey–juvenile (*Petromyzon marinus*)	**eDNA,** chance catches	N/A	N/A	Trial plankton surveys at fixed depths	**Flume studies**	N/A
River lamprey–adult (*Lampetra fluviatilis*)	**eDNA**, chance catches, acoustic tracking (if adults catchable in sensible locations)	N/A	N/A	**Sensor tags**	**Acoustic tracking, flume studies**	N/A
River lamprey–juvenile (*Lampetra fluviatilis*)	**eDNA**, chance catches.	Plankton surveys	Plankton surveys	Trial plankton surveys at fixed depths	**Flume studies**	N/A
European eel - adult (*Anguilla Anguilla*)	**Inferred from in river catch data, eDNA**, acoustic tracking, survey trawls	Acoustic tracking, satellite tags	Acoustic tracking	**Sensor tags, data storage tags**, satellite tags	**Acoustic tracking, satellite, data storage tags, flume studies**	Single European stock spawning at sea. No river level or regional fidelity

	Presence/absence in Resource Areas	**Migration paths in Welsh waters**	**Duration of presence and / or residence times in Resource Areas**	**Swimming depth**	**Swim speed**	**Site fidelity to natal rivers**
European eel – juvenile (*Anguilla Anguilla*)	**eDNA**, artificial substrate traps and plankton surveys	artificial substrate traps, plankton surveys, eDNA	**Artificial substrate traps, plankton surveys**	Trial plankton surveys at fixed depths	Flume studies	Single European stock spawning at sea. No river level or regional fidelity
European smelt/ sparling (*Osmerus eperlanus*) adults	**eDNA, acoustic tracking**, survey fishing	**Acoustic tracking**	**Acoustic tracking**	**Sensor tags**	**Acoustic tracking, flume studies**	**Small basic tags and marks (PIT, microtags)**
European smelt/ sparling (*Osmerus eperlanus*) Juveniles	**eDNA,** trial survey fishing	Trial survey fishing	Trial survey fishing	Unable to advice on appropriate methods.	Flume studies	**Small basic tags and marks (PIT, microtags)**

4. Reviewing existing knowledge on diadromous species

Reviewing existing literature is a sensible prerequisite for determining whether new work is required. Understanding life cycles, information on seasonality, size etc is also important in determining approaches to survey and tagging programmes. In some instances, this may be the only viable way forward - for example, the presence of a breeding population of allis shad is uncertain in the study area, limiting the ability to undertake tagging and tracking work on this species. While a full literature review of existing data for each species is beyond the scope of this review, this work has identified where relevant information exists for each species and some key references have been included to illustrate the current level and quality of information available.

For the primary evidence gaps (presence / absence, migration paths and availability / residence times) we have focussed primarily on evidence specific to Welsh waters, though have described general behaviour from wider studies where relevant.

For swim speeds and depths, we have looked at the wider literature, focussing on evidence specific to the species in hand. This is not intended as a comprehensive review but is included to illustrate the nature and variable quality of existing information.

The known presence for each species in primary river systems around Wales (Figure 2) is documented in Appendix A and the statutory protections for each species are outlined in Appendix B.

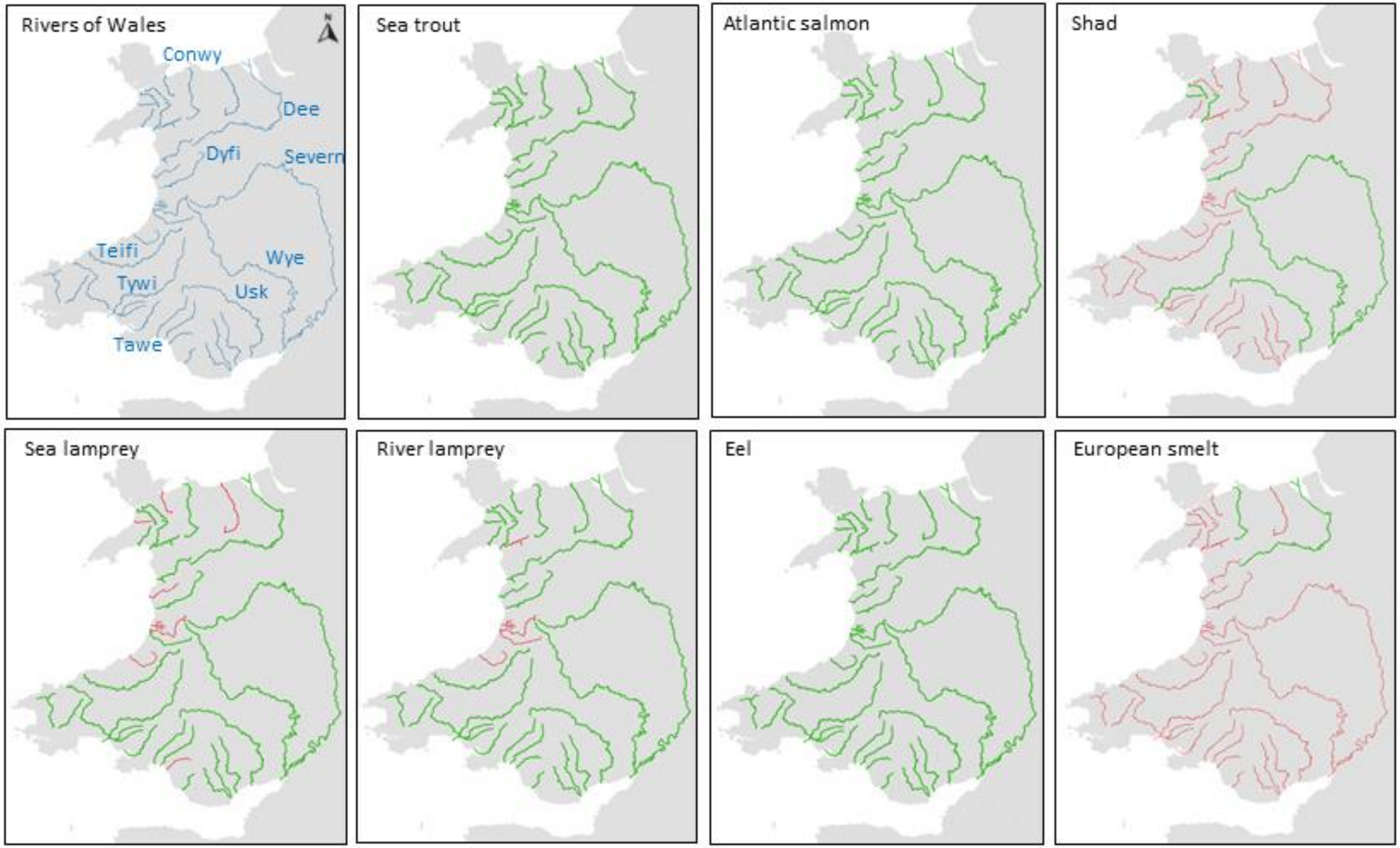

Figure 2. Diadromous species presence (green and absence (red) in the major rivers in Wales .

4.1. Salmonids: Atlantic salmon (*Salmo salar*) and sea trout (*Salmo trutta*)

4.1.1. Life cycle and general distribution

Salmonids (both Atlantic salmon *Salmo salar* and sea trout *Salmo trutta*) are widely distributed around Wales, being found in all major rivers (Appendix A). Both species are anadromous, laying eggs in gravel nests (redds) in freshwater. After hatching the fry mature into parr or brown trout. After a period (typically one to three years) most salmon parr and a proportion of sea trout parr migrate to sea as smolts, where they feed and rapidly increase in size. Some male Atlantic salmon may mature in-river without going to sea (precocious parr), and some trout of both sexes may remain in the river, maturing and spawning as brown trout.

Following sea growth, Atlantic salmon typically return to the river after one to three years, with the large majority of Welsh fish returning to spawn after one or two years at sea. Atlantic salmon are capable of surviving spawning, though the percentage of multiple spawners has declined in recent decades and is now in low single figures. Sea trout smolts may return in their first summer or overwinter at sea for one to two years before returning to spawn. Sea trout may spawn multiple times, typically repeating their marine migration each year after first spawning. The repeat spawning portion of the adult population returning for a second or more time makes a significant and important contribution to the spawning, circa 50-30% in numbers and potentially much higher in terms of egg contribution (CSTP, 2016).

This life strategy provides salmonid populations with a degree of resilience, as various elements of the stock are in the river or at sea at any given time, reducing the effect and risk of extreme environmental events such as drought. Sea trout are generally thought to travel shorter distances (CSTP, 2016; Thorstad *et al.,* 2016) and are therefore more likely to remain within the resource areas identified by this study, which would increase exposure. Modelling studies carried out for the proposed Swansea Bay Tidal Lagoon have shown that MRE and other developments along the migration path may have greater impact on sea trout stocks, as the fish may have to pass through the hazard multiple times, resulting in increasing risk and cumulative reduction of survival.

There are important recreational fisheries for both species. There are, or have been, licenced commercial fisheries in estuaries (and in some cases inshore waters), although these have been heavily restricted over recent years. Catch returns are a statutory requirement for both rod and net fisheries and there are long data records of both rod and net catches (CSTP, 2016; CEFAS, 2020). Some private personal and fishery records also exist. While it is possible to estimate abundance from the rod catch statistics, this is more difficult for data from the net fisheries, as a consequence of changing fishing effort, regulatory changes to seasons, fishing methods etc.

Data on population status from repeatable and more quantifiable methods are less extensive. A notable exception is the Atlantic salmon index research facility on the River Dee in North Wales, where a trap and fish counter have been operated since 1991. Fish counters are also run on the Teifi, Tywi, Taff and Dee. For broad trends, data from outside Wales may also be valuable, and index river data covering many years are available from the Rivers Tamar and Frome in England. In Welsh rivers, juvenile salmonid surveys have also been undertaken since the mid-1980s through the Regional Juvenile Atlantic Salmonid Monitoring Programme (RJSMP) and more recently the National Fish Classifications Scheme (NFCS). They are also a key component of the Water Framework Directive fisheries classification (WFD-UKTAG, 2014).

All the above methods have limitations. They do, however, demonstrate widespread distribution of salmonids along the coast of Wales. Taken together they can provide a broad indicator of trends in abundance and used with other data such as trap and survey data, they may make useful contributions to Environmental Impact Assessment (EIA).

4.1.2. Presence / absence and residence time in resource areas

For estuaries, and some inshore sites, the presence of salmonids can be inferred from catch or other survey data from rivers discharging into the area. Given the extensive distribution of Atlantic salmon and sea trout populations in rivers around Wales, it is also probably reasonable to assume that both post-smolts and adults migrate through the identified resource areas, and in some cases that they may remain for longer periods to feed. However, at the level of individual developments covering much smaller offshore areas, this may not hold true, as migration paths may be more specific.

Some pilot data on residence times in Swansea Bay have been collected by Swansea University, supported by NRW, for sea trout acoustically tagged in the River Tawe. Estuarial migration travel times have been collected using radio tags in the Tywi and Dee estuaries.

At the present time there are no data confirming absence in any area.

4.1.3. Migration paths

There is information describing general aspects of marine behaviour for both Atlantic salmon and sea trout (see review by Thorstad *et al.*, (2012) for Atlantic salmon and Thorstad *et al.,* (2016) for sea trout). Sea trout populations and life histories are very varied and highly adapted to their local environment. Research carried out to date has shown that although the majority of sea trout are to be found near shore and adjacent to their native rivers, some fish migrate for distances up to 300 km from their home rivers (CSTP, 2016).

There is some limited information on the presence of small numbers of sea trout in specific locations along the Welsh coast (CSTP, 2016). The origin and location of some sea trout in the Irish Sea is available from the Report of the Celtic Sea Trout Project but the numbers of Welsh sea trout located and sampled at sea were insufficient to define migration corridors (CSTP, 2016). Apart from historic catches in beach and estuarial net fisheries there is little or no information available for salmon.

4.2. Allis and twaite shad (*Alosa alosa, Alosa fallax*)

4.2.1. Life cycle and general distribution

Both species of shad are anadromous, spawning in the lower and middle reaches of river systems.

Allis shad are thought to mature after three to six years, spawning in the spring (Bagliniere *et al.,* 2003). Larvae hatch within four to eight days and they migrate to sea in the autumn after spending a summer in freshwater (Aprahamian *et al.,* 2015). Unlike twaite shad, allis shad are generally thought to spawn once (Douchemont, 1981, cited by Maitland, 2003; Sabatie, 1990), though there is some evidence of limited repeat spawning (Taverny, 1991).

Twaite shad are divided into three subspecies, *Alosa fallax fallax*, *Alosa fallax rhodanensis* and *Alosa fallax nilotica*. The species inhabiting Wales is *Alosa fallax fallax*, which is the most northern group. They mature after two to nine years with most females maturing at age four to five and the males one year earlier (Aprahamian *et al.,* 2003). In Wales, spawning typically occurs in May with river entry from late April. They may spawn multiple times and live until twelve years old (Douchemont, 1981). While at sea they are therefore potentially at risk of MRE impacts, and their multiple spawning habit means that they are subject to any impacts annually, potentially resulting in cumulative losses and increasing population risk. 0+ fish enter the estuary from July, when they are 2.5 - 3cm long, and increase in size to 4.9 - 5.6 cm in October (Aprahamian, 1988).

Twaite shad occur along most of the west coast of Europe from Norway to the Mediterranean. In Britain spawning populations are found in the rivers Severn, Wye, Usk and Tywi. There is no evidence of spawning in Wales outside of the Bristol Channel area.

Allis shad populations are mainly found in the south west of France, Spain and Portugal. With the exception of the river Tamar in Cornwall (Hillman, 2020), there are now no spawning sites for allis shad in Britain (Maitland and Hatton-Ellis 2003), although they may previously have spawned in the Severn and were reported by Ellison (1935) as breeding in the Wye. They are categorised by Maitland and Hatton-Ellis (2003) as 'very rare' in the Severn, and there is evidence of hybridisation between the two species in unpublished data reported by the Unlocking the Severn (UtS) project (Jon Bolland pers. comm, 2020), as well as in populations in the Wye, Usk and Tywi (Harduin *et al, 2013)*. However, given the rarity of 'pure' allis shad in Welsh waters it is impractical to design a sampling programme for them.

4.2.2. Presence / absence and residence time in resource areas

Juvenile twaite shad are present in the Severn estuary from July until they emigrate seaward during the autumn. At least some 1+ fish re-enter the estuary the following April-May and remain until late summer/early autumn before once more migrating seaward (Aprahamian, 1988).

For mature adults there is limited information based on recent studies following acoustic tagging in the freshwater Severn by the 'Unlocking the Severn' project. Davies *et al.,* (2020) report that 12 adult shad, tagged in the Severn, were detected in the Taw / Torridge area during the summer of 2018.

Swansea University deployed an array, located in Swansea Bay and detected approximately 25% of tagged fish leaving the Severn in the spring of 2019, over the period June to October 2019. Similarly, approximately 25% of the tagged shad which successfully returned to spawn in the Severn were detected in Swansea Bay during March and April 2020. Two fish were detected in Ireland showing that at least some reach and cross the Celtic Sea.

4.2.3. Migration paths

Overall, initial evidence suggests that at least some twaite shad on the River Severn feed along the Bristol channel coasts and into the Celtic Sea and in some cases migrating as far as Ireland, before returning to spawn (Davies et al 2020, Swansea University unpublished data). It is unclear whether stocks emigrating from other rivers follow the same pattern.

4.3. Sea and river lamprey (*Petromyzon marinus* and *Lampetra fluviatilis*)

4.3.1. Life cycle and general distribution

Lamprey are found on both sides of the Atlantic Ocean. In Europe sea Lamprey and most river lamprey populations are anadromous with a freshwater larval stage and a marine adult stage.

In freshwater, the larval ammocoete feeds on micro-organisms and organic particles, while buried in fine sediment deposits within rivers (Almeida *et al.*, 2002; Dawson *et al.,* 2015; Hardisty and Potter, 1971a,b). Larvae metamorphose after 3-7 years in freshwater, with the period depending on local conditions (Beamish and Potter, 1975; Quintella *et al.*, 2003; Dawson *et al.,* 2015; Silva *et al.,* 2016.).

Sea and river lamprey metamorphose and emerge as ‘transformers’, before migrating to the sea to feed on other fish, though the period between emergence and migration can take 3-4 months (Hardisty *et al.*, 1970; Potter and Huggins 1973, Silva 2013). Generally, they are too small to apply acoustic tags at this stage (Bolland pers. comm). They die after spawning and therefore tagging of post spawned adults is not viable.

Migration is undertaken at night (Pavlov *et al.,* 2017). The marine phase is poorly known for both species but is thought to last approximately two years. River lamprey are thought to stay close to estuaries and in shore waters, while sea lamprey have been recorded in both shallow coastal and deep offshore waters (Maitland, 2003). The adults then return to the river where they build nests and spawn before dying (Hardisty, 1986; Moser *et al*., 2015).

Fisheries for sea lamprey occur in France, Portugal, and Spain, but no active fisheries have been found for them in the UK.

River lamprey are distributed throughout much of Europe with fisheries in a number of countries. In the UK they have been subject to commercial fishing in the River Ouse, originally as by-catch in the eel fishery, with lamprey specific legislation introduced in 2011 to regulate the fishery (Foulds and Lucas, 2014). They are used as bait and eaten as food.

4.3.2. Presence / absence and residence time in resource areas

Although both river and sea lamprey are thought to be widely distributed around Welsh rivers (Annex B), in many cases this is based on anecdotal evidence. There are no marine fisheries and understanding of their distribution in coastal waters around Wales remains poor.

4.3.3. Migration paths

There is little information about how long the adults remain at sea, though Silva *et al.,* (2013) suggests 18-20 months and Beamish (1980) suggests 23-28 months. They then migrate back to the river to spawn. In the southern UK the peak migration is thought to occur in May / June. Specific data for in-river migration of adult sea lamprey in Wales are available from NRW ARIS camera counters on the Tywi and the Teifi, as well as from trap data on the River Dee, highlighting that migration begins as early as April in the Tywi (Griffiths and Clabburn, 2009; Davies and Griffiths 2011).

4.4. European eel (*Anguilla anguilla*)

4.4.1. Life cycle and general distribution

The European eel is a long-lived catadromous fish which is widely dispersed. It spawns once in its life, which may last from two to more than fifty years. The spawning area is in the Sargasso Sea, and is thought to be situated between latitude 23° and 29.5°N but on a wider longitudinal range from 48° to 78°W (Miller *et al.,* 2019). The larvae (leptocephali) drift with the ocean currents from the Sargasso Sea to the continental shelf of Europe and North Africa. There they enter continental waters and metamorphose into glass eels (McCleave *et al.*, 1987; Tesch and Wegner, 1990) and then elvers. The main growth stage, known as yellow or brown eel, may take place in marine, brackish (transitional), or freshwaters (Daverat and Tomas, 2006). The yellow eel stage lasts from two to as much as fifty plus years, with this period being typically shorter in warmer waters and longer in colder, base poor waters because growth and maturation rates are slower. Subsequently, they metamorphose into the silver eel stage (Bevacqua *et al.*, 2006). Silver eels migrate to the Sargasso Sea where they spawn and are presumed to die after spawning. European eels are distributed throughout Europe, ranging from northern Norway to North Africa, and throughout the Baltic and Mediterranean seas (Als *et al.*, 2011; Pujolar *et al.*, 2014).

4.4.2. Presence / absence and residence time in resource areas

Although eels are thought to be widely distributed around Welsh rivers and estuaries (Appendix A), there are now no commercial or recreational marine fisheries around Wales. Data is available from power station intakes.

The arrival of glass eels usually begins around February, reaches a peak in April, and in some exceptional years may continue until June. Adults generally begin their spawning migrations from European rivers and coasts during the autumn of each year, predominantly from October to December (Righton *et al.,* 2016). Eels may remain in rivers and estuaries for many years as yellow eels; further information is needed to determine whether they inhabit RA during this life stage.

4.4.3. Migration paths

The literature contains general information on eel migration behaviour, including marine migration. Data in Welsh waters is very limited. CEFAS (BEEMS Technical report TR274), report that glass eels use the full width of the Bristol channel in the Hinkley point area. Yellow eels have also been regularly caught at Hinkley point (Hendersen *et al.,* 2012).

Righton *et al.,* (2016) describe migration of European silver eels from coastal waters to the Azores.

Nevertheless, understanding of the behaviour of silver eels in coastal water and estuaries during their migration remains limited. Walker *et al.,* (2013) have shown that in the case of yellow eels inhabiting estuaries, activity was generally, but not exclusively, nocturnal, with the start and end times closely associated with sunset and sunrise, respectively. Neither direction of travel nor average ground speed was influenced by the direction of tidal flow and seasonal declines in water temperature did not appear to influence behaviours. The results from this study on distance travelled during regular, nocturnal movements provide valuable insights into the spatial and temporal distribution of yellow eels in an estuarine environment.

However, Verhelst *et al.,* (2018) did find in their study that eels migrating through an estuary can distinguish between ebb and flood. They suggested that tides can play a role in orientation, either directly or indirectly. The general migration speed was higher in the downstream part of the estuary compared to the upstream part, while tidal migration speed was equal in both parts, indicating that eels migrated more consistently in the downstream part. The results of this study give an insight into how a diadromous species migrates through an estuary and underline the importance of the tides in this environment. In the case of silver eels Aarestrup *et al.,* (2008) found that, generally, eels quickly left the River Gudenaa (67% within 2 days) and stayed for up to 4.3 months (mean 1.7 months) in the inner fjord. They describe a two-step migration pattern, with silver eels migrating out of the river in spring, followed by a substantial residence period in the inner part of the fjord before continuing the migration. The results suggest that silver eel migration may not always be a direct journey to the ocean but may include variable resident periods in coastal areas.

It is unknown if glass eel (leptocephali) travel to the continental shelf using passive and/or active processes (Cresci, 2020), and it is thought that silver eels use directional tidal streams to cross the continental shelf (van Ginneken *et al.,* 2005).

4.5. European smelt / Sparling (*Osmerus eperlanus*)

6.5.1. Life cycle and general distribution

The European smelt is an anadromous species that is predominantly found close to inshore areas and estuaries and only very occasionally occur in open coastal areas. In some areas of the UK, primarily on the east coast, there is a licensed fishery for European smelt with a peak reported catch of 14.2 tonnes in 2013 (Wilson and Vaneratna, 2019). They are often caught when spawning in the spring, during their migration to the lower reaches of rivers from the coast. Lyle and Maitland (1997) found that in Scotland the species migrate to spawning sites in February/March. The species begin to congregate in estuaries just before migrating together en mass between February-March. Although there is a high mortality rate following spawning, the individuals that do survive will return to spawn again in subsequent years after recovering at sea (Shpilev *et al.,* 2005). Once the young have hatched out, they drift with the current until they are large enough to swim independently and have reached estuarine habitats which are used as juvenile nursery. The size of smelt larvae increases from 0.5-0.54 cm to 2.54 cm within three months of hatching (Arula *et al.,* 2017; Ellis, 1965).

Fisheries data suggested that there are no records of European smelt in the Severn Estuary and Bristol Channel. There is some documentation of European smelt in Milford Haven, however it cannot be confirmed which species this refers to and sand smelt are definitely present (Clarke, pers. comm; reports from Pembroke Power station surveys). There is confirmed presence in several sea areas from Bardsey Island to the north (Potts and Swaby, 1993). In northwest Wales there is a population of European smelt in the estuary of the River Conwy and a small population in the River Dee estuary (Maitland, 2003a).

Migrating populations tend to live longer than non-migrating populations and become sexually mature after three to four years in contrast to one two years (Maitland, 1997). Migrating populations tend to be larger individuals, reaching lengths between 15-18 cm at maturity. The non-migrating populations do not tend to exceed 8-10 cm. However, the species has been recorded to reach up to 30 cm (Maitland, 1997).

4.5.2. Presence/absence and residence time in resources areas

Only one spawning site has been identified in Wales (on the River Conwy near Llanrwst) despite the species being present in sites north of Bardsey Island (Maitland, 2003a). There is no meaningful research which describes the presence or absence in potential resources areas, residence times, or the proportion of populations which could be affected.

4.5.3. Migration paths

There is no meaningful data on migration paths or timing of migration in Welsh waters.

4.6. Secondary evidence gaps

4.6.1. Fidelity to home river

For salmonids, while there is some straying, there are many papers demonstrating fidelity to the home river (Dittman and Quinn, 1996; Webb *et al.,* 2007; Thorstad *et al.,* 2010).

For twaite shad there is strong evidence of fidelity to home river and indeed some evidence of fidelity to tributary, based on acoustic tracking data from the UTS project (Jon Bolland, pers. coms). Genetic and morphological studies have also reached similar conclusions (Alexandrino, 1996; Sabatie *et al.,* 2000). Martin *et al.,* (2015) and Randon *et al.,* (2017) reported that although most *Alosa alosa* individuals returned to their natal watersheds, some fish did stray. This straying occurred most frequently between neighbouring river basins.

As a consequence of a shared spawning area the European eel population is thought to be panmictic, i.e., a single mixed population. However, selection pressures may vary in different areas, and with the extensive yellow/brown eel phase, this may result in genetic variation between areas in the surviving members of the population (Pujolar *et al*., 2014).

There is little evidence of fidelity to home river for either sea or river lamprey. (Waldman *et al.,* (2008), Moser *et al*., 2015). They are thought to be drawn into particular catchments by pheromones released by the ammocoetes or larvae already residing there (Bjerselius *et al*., 2000). This conclusion is consistent with genetic studies (Rodriguez-Munoz *et al.*, 2004; Genner *et al.*, 2012). They may navigate towards shore by moving towards shallower water, even when this does not take them on the most direct route (Meckley *et al.,* 2017). As with sea lamprey, river lamprey are not thought to have a homing instinct.

There are no meaningful published records on site fidelity of European smelt. However, some fidelity is implied by their localised distributions.

Summary of fidelity

With the exception of European smelt, fidelity information is available and generally reasonably well understood. Table 2 summarises current understanding.

Table 2. Summary of fidelity to home river for diadromous species

Species	Fidelity to home river	Comments
Atlantic Salmon	High	Strong evidence, some straying but population structuring occurs.
Sea trout	High	Strong evidence, some straying but population structuring occurs.
Allis shad	Moderate	No spawning populations in Wales. Evidence of hybridisation with twaite shad, homing but little population structuring
Twaite shad	High	Evidence from UTS of tributary level homing; hybridisation as above
Sea lamprey	Low or none	Pheromone ID of catchments but non-specific
River lamprey	Low	Pheromone ID of catchments but non-specific
European eel	None	Panmictic population, spawns at sea
European smelt	Unclear	Localised distribution may imply fidelity

4.6.2. Swimming and migration speeds

Swimming speed is the speed at which a fish moves through water, measured in a straight line. Swimming speed is often measured using flume studies, e.g. (Clough *et al.,* 2004a & 2004b) where fish swim directly against a measured current. Migration speed may differ from swimming speed, as migration often involves indirect travel between points such as acoustic receivers (Thorstad *et al.,* 2004), and may include periods of inactivity, e.g. where fish migrate at night (e.g., Moore *et al.,* 1998). It should be noted that, within the literature, these two terms are often used interchangeably, which can lead to confusion.

Swimming speeds and migration speeds are often presented as ground speed, which is the net sum of swimming speed and water current speed around the fish (Madison, 1972). Tides and river flows can be used to increase migration speeds in the tidal reaches to and from the marine environment (Moore *et al.,* 1998; River Dee, 2016).

Atlantic salmon

Migration speeds for Atlantic salmon smolts in the early marine stage, calculated as the ground speed of an individual between two receivers, have been observed in Scottish Waters as equivalent to 7.37 to 7.7 km d^{-1} (Lothian *et al.*, 2017; Newton *et al.,* 2017) and up to 40.8 km d^{-1}, although it should be noted that the higher values, at the mouth of the Scottish River Dee, were thought to be enhanced by a combination of high flows and ebbing tides (River Dee, 2016). Migrating smolts in the Welsh Dee travelled at a median speed of 2.5 to 3.84 km h^{-1} in the outer estuary, assisted by the tide. A study of seven rivers on the Moray Firth found median estuarine migration speeds ranging from 0.08 to 1.02 m s^{-1}, with marine migration speeds ranging from 0.24 to 0.41 m s^{-1} (Atlantic Salmon Trust, 2020). In a flume study, Tang & Wardle (1992) observed a maximum swimming speed of 0.54 m s^{-1} in smolts.

Salmon smolts generally do not spend a lot of time in the coastal zone, moving quickly towards the outer sea (Moore *et al.,* 1998; Thorstad *et al.,* 2004; Lefèvre *et al.,* 2013) although there are examples for smolts spending much longer time periods in coastal areas, dependent on body condition (e.g., Crossin *et al.,* 2016) or tidal cycle (e.g., Moore *et al*.,1998). Lothian *et al.,* (2017) observed that marine migration speed decreased with increasing environmental noise levels.
There is surprisingly little data on adult Atlantic salmon swimming speeds at sea. Average migration speeds of post spawning adults entering the Labrador Sea, from the river mouth to the Strait of Belle Isle, ranged from 19.4 to 26.1 km d^{-1} based on the most likely movement paths (Strøm *et al.,* 2017). Hubley *et al.,* (2008) observed that the rate of migration in kelts in the LaHave River, Nova Scotia ranged from 1.61 to 16.2 km d^{-1}, with 40% of fish lingering in the lower estuary during their journey. In a flume study, Tang & Wardle (1992) observed a maximum swimming speed of 0.91 m s^{-1} in adult salmon 0.45 m long.

In Wales, migration speeds are available from estuarial studies of a 2.7 km reach of the River Tywi (Clarke and Purvis, 1989), with median speeds of 0.45 km h^{-1} and maximum speeds of 2.7 km h^{-1}. Data are also available from the River Dee, (Purvis *et al.,* 1994), with median migration speeds ranging from 0.41 to 1.64 km h^{-1} in the upper and middle reaches of the estuary, and individual speeds up to 3.8 km h^{-1}.

Sea trout

There are little data for marine swimming speeds of both young and adult sea trout. Accurate rates of movement for migrating trout smolts are difficult to measure due to the smolts' indirect swim paths and variable residency times during their freshwater and marine migrations, when cohorts can take hours or days to travel through the same stretch of water (e.g. Clarke *et al.,* 1989; Thorstad *et al.,* 2004; Moore *et al.,* 2018; Atlantic Salmon Trust, 2020).

Median ground speed values 0.45 km h^{-1} (0.12 to 2.6 km h^{-1}; Clarke *et al.,* 1989) and 0.98 km h^{-1} (0.06 to 1.8 km h^{-1}; Evans *et al.,* 1991) have been recorded for radio tagged adults over a 2.7 km distance in the Tywi estuary, during their upstream migration. Unpublished data collected by Swansea University provide information for migration rates for 25 smolts and 11 post spawned adults (kelts) migrating through Swansea bay, and further data are expected to be collected spring 2021.

Twaite and allis shad

There is little information about the swimming ability and endurance of *Alosa alosa* and *Alosa fallax.* Litaudon (1985) estimated that the burst swimming speed of *Alosa alosa* ranged from 3.1 m s^{-1} to 4.7 m s^{-1} at temperatures of 16 to 17ºC. At these temperatures the fish could maintain such speed for approximately 6.5 s. The maximum speed was estimated at between 4.1 m s^{-1} and 6.1 m s^{-1}, but could only be sustained for a few seconds. Larinier (1996) gave maximum swimming speeds of 2.75 - 5.40 m s^{-1} for shad of 0.3 - 0.5 m in length at temperatures between 10 - 20°C.

For *Alosa fallax fallax* (L_f = 300-390 mm), at temperatures ranging from 19.8 to 21.5°C, Clough *et al*. (2004) reported a range in the maximum burst swimming speed of between 1 and 2.5 m s^{-1} (8.3 bl s^{-1}) with a mean of 1.73 m s^{-1} (95% CI = 0.26). The maximum sustainable swimming speed (endurance speed) was around 0.5 m s^{-1}, at temperatures ranging from 12.8 to 17.0°C. The latter is lower than that reported by Magnan (1929) of 0.75 m s^{-1} (2.5 bl s^{-1}), but is similar to the cruising speeds in a rotational stock tank observed by Clough *et al.* (2004) of between 0.34 and 0.57 m s^{-1}. These studies were undertaken in swimming tunnels.

The sustained (cruising in still water) swimming velocity of young-of-the-year twaite shad (mean length 29 mm; temperature17°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}. 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} (temperature17ºC; n=11; APEM, 2008).

Unpublished acoustic tracking data collected by Swansea and Plymouth Universities, working with the ‘Unlocking the Severn’ project, will allow migration speeds and local speeds over the ground to be calculated.

Swimming speed of adult twaite shad have been estimated using water tunnels and a low-speed flume (Clough *et al.,* 2004a). Burst speeds ranged from 1 to 2.5 m s^{-1} (mean 1.73 m s^{-1} while maximum sustainable swimming speed was 0.5 m s^{-1}. These are applicable for modelling of escape speeds.

European eels

Swim tunnel experiments have shown that eels can swim continuously at between 0.4 and 0.7 bl s^{-1} continuously for up to 173 days (22-42 km d^{-1}; van Ginneken *et al*., 2005). Various telemetric studies (Tesch, 1974; Verbiest *et al.*, 2012; Aarestrup *et al*., 2010; Bultel *et al.*, 2014) have recorded migration speeds in estuarine environments, ranging from 0.22 – 0.7 m s^{-1}.

Sea lamprey

Some limited data are quoted in Clough *et al.,* (2004b). From telemetry studies Stier and Kynard (1986) reported the mean ground speed of upstream migrating sea lamprey to be 36 bl min^{-1} or 0.6 bl s^{-1}. Almeida *et al.*, (2000) found a mean ground speed for upstream migrating sea lampreys of 22.5 bl min^{-1}, equivalent to 0.38 bl s^{-1}. These values do not take into account water movement. Quintella *et al.,* (2009) observed in the river, when swimming through slow-flow stretches, sea lampreys maintained a constant pattern of activity, attaining an average ground speed of 0.76 bl s^{-1} (2.5 km h^{-1}).

Data from ARIS/Didson acoustic cameras (Clabburn, pers comm.) on swim speed of lamprey in the Tywi enables the swim speed of fish in the Cleddau and Teifi to also be calculated. Here, swim speeds ranged between of 1.20 km h^{-1} and 4.75 km h^{-1} with an average swim speed of 2.78 km h^{-1} (sd ± 0.90)

All these studies are based on in-river migration, and no data are available for marine swimming speeds. While they may provide reasonable estimates of the capability of an unattached adult at sea, the rate of movement at sea will depend on whether they are attached to a host, and if so, the swimming ability of the host.

River lamprey

No data have been found on swimming speeds of river lamprey. As with Sea lamprey migration speeds may depend on hosts.

European smelt

One published report, based on active acoustic data, reported a swim speed of 5-50 cm s^{-1} for European smelt (Jurvelius and Marjomaki, 2004).

Swimming speed summary

The information provided above is not a comprehensive review of the available literature, which could be commissioned as a study in its own right. However, it demonstrates that swim speed data is both incomplete and inconsistent with a wide range of data types. These range from flume studies of burst speed and sustained swim speeds, which may have value for near field escape, to migration speeds over short and long distances. The latter are very variable depending on factors such as tide or holding periods.

4.6.3. Swimming depths

Atlantic salmon

Migrating salmon smolts exhibit a significant diurnal effect in their swimming depth, and changes in swimming depth have been related to light conditions (Reddin and Short, 1991; Davidsen *et al*., 2008; Hedger *et al*., 2008). Smolts are significantly deeper during the day than at night. In the marine area, studies using sensor tags recording depth and/or temperature reported that they are predominantly recorded within the top five metres of the water column (e.g., Davidsen *et al*., 2008; Renkawitz *et al*., 2012; Newton *et al.,* 2017).

Swimming depth of adult Atlantic salmon have been studied using data storage / pop up satellite tags with depth sensors. Adult Atlantic salmon are thought to use the full depth of the water column (Godfrey *et al.*, 2015), with regular dives up to 30 m and maximum recorded depth of 909 m (Strøm *et al.,* 2018) although most satellite tracking studies suggest that they are generally found in the upper 10 metres (80 to 90% of the time; Davidsen *et al*., 2013; Godfrey *et al.*, 2015; Strøm *et al.,* 2018). Migration depth of adult Atlantic salmon is reported to diurnally vary however patterns are still unclear as Godfrey *et al.*, 2015 reported deeper depths at night while Strøm *et al.,* (2018) described the opposite trend (deeper depths during the day) with seasonal variation.

Sea trout

Sea trout are mainly found within the first 3 first metres of the water column (Thorstad *et al.,* 2016), but they may at times dive to a depth of 64 m or to the seabed. Migrating sea trout smolts from the River Conwy were recorded staying close to the surface during their estuarine migration (Moore *et al.*, 1998). However, archival tags inserted in sea trout kelts as part of the SAMARCH Project (https://samarch.org), from 2018 to 2020, show that sea trout in the English Channel can spend up to 80% of their time deeper than three metres, with multiple dives to 50 or 60 m each day. Diving behaviour and swimming depth is variable and may differ between sea trout populations. Given this variable behaviour, it is likely that sea trout and Atlantic salmon, feeding or migrating in the vicinity of marine renewable energy developments may interact with the equipment.

Allis and twaite shad

Bao *et al.*, (2015) derived the swimming depth of both shad species *Alosa alosa* and *Alosa fallax* from data recorded by observers on commercial fleet fishing over the continental shelf in Northwest Iberian Peninsula waters. *Alosa alosa* was reported between 9 to 311 m (mean depth 174 m) and *Alosa fallax* between 18 and 390 m (mean depth 148 m). Trancart *et al.*, (2014) found a preference of both species for < 100 m waters by analysing bycatch data of French fishery survey. Other studies, whom methodology was not found, confirm these findings. Taverny 1991, reported *Alosa fallax* from 10 to 110 m with a preference for water of 10 to 20 m deep and *Alosa alosa* has been reported from depths ranging from 10 to 150 m (Laroche 1985; Taverny, 1991) up to 300 m (Roule, 1933; Dottrens ,1952; Lithogoe and Lithogoe 1971).

European eels

European eels are more active at night, swimming within 0.5 m of the surface and resting on the seabed during the day (Tesch, 1989; Westerberg *et al.*, 2007). During the day eels will dive to considerable depths and have been measured at 400 - 700 m (Tesch, 1978; Tesch, 1989).

Glass eels are reported to descend to depths of 300 - 600 m during the day and ascend to 35 - 100 m during the night (Cresci, 2020; Bardonnet *et al.*, 2005). A similar diurnal behaviour is reported for glass eels in coastal environments, with tidal influence also a factor (Harrisson *et al.*, 2014). During the flood glass eels are dispersed throughout the water column whereas they remain on the bottom during the ebb.

Sea lamprey

A limited record of 80 sea lampreys captured in the northwest Atlantic indicated that those less than 39 cm in length were almost all taken in bottom trawls on the continental shelf or in coastal trap nets whereas most animals over 56 cm in length were captured in mid-water trawls along the shelf edge or over the continental slope (Halliday, 1991).

Trawl data for at sea capture from EA, ICES and Marine Scotland surveys, from start of survey programmes to 2019 give capture depths of 25 - 295 m (Environment Agency, 2020; ICES$_{abcde}$; Moriarty and Greenstreet, 2017). Heessen *et al.,* (2015) report a wide depth range (2 – 321 m) with all fish larger than 40 cm caught at depths greater than 50 metres in the Celtic Sea, Baltic Sea and North Sea. As most trawls occurred during the day, the data is insufficient to comment on diurnal patterns in swim depths.

River lamprey

Trawl data for at sea capture from ICES and Marine Scotland surveys, from start of survey programmes to 2015 give capture depths of 13 – 56 m (ICES$_{ab}$; Moriarty & Greenstreet, 2017). There is too little data to comment on diurnal patterns in swim depths.

European smelt

Data on depth distribution of European smelt are limited to lakes, with no data were found for the species in estuary or marine habitats. Jurvelius and Marjomaki (2004) detected European smelt with a downward facing stationary 120 kHz split beam echo-sounder between 12 to 19 m depth. Gastauer *et al.*, (2013), also deploying a multibeam sonar, found that in general smelt were found throughout the entire water column, but were more dispersed during the morning before sunrise and the evening after sunset.

Summary of depth distribution data

Availability of data on depth distribution varies considerable between species. For both salmon and sea trout data are available from sensor/DST tagging, and demonstrate a wide range of depth use with an overall bias toward surface layers. In contrast marine data for European smelt appear to be lacking. Data for allis and twaite shad appear to show a wide range of depth use, but the data is limited and nature of the data (often catches) means that it is not always clear whether references are to the depth of the water or the swimming depth of the fish. Data for both river and sea lamprey as well as European eel are also of variable quality.

4.7. Marine Renewable Energy implications

Atlantic salmon and sea trout

Both Atlantic salmon and sea trout populations are widely dispersed in Welsh waters, with both juveniles and adult life stages likely to encounter MRE device deployments in all Resource Areas. They are therefore exposed to MRE developments at least twice to complete their life cycle. Sea trout are thought to spend more of their life cycle in coastal inshore waters, and are routinely multiple spawners, resulting in cumulative exposures and hence potentially increased risk compared to Atlantic salmon. The extent to which this is an issue depends on marine habitat use and migration paths around Wales which are not well understood. This is a priority evidence need.

While broad distribution data may be inferred from available data, no evidence of data describing specific migration paths of Atlantic salmon or sea trout in the Welsh marine zone have been found. Studies to confirm migration paths from major systems are therefore required; these should contribute to confirmatory studies regarding wider migration patterns and distribution of different age classes at sea. Generally, both Atlantic salmon and sea trout appear to preferentially utilise surface layers, though sea trout may also be found in deeper waters. Devices deployed near the surface are therefore likely to have greater impact but impacts of devices deployed on the seabed cannot be excluded.

Although some straying occurs, genetic structuring is seen between populations in different rivers and fishery management assumes that the populations of each species are different in different river systems. It is impractical to tag representative samples from all river systems and in our recommendations, we have identified a subset of ‘sentinel’ river systems in each area, to act as representative or populations to assess overall impacts.

Allis and twaite shad

Allis shad are rare, and there is little evidence of any spawning population around Wales. Twaite shad are known to spawn in the Severn, Wye, Usk and Tywi, and mature adults are known to utilise the Bristol Channel, and probably the Celtic sea for feeding. There is anecdotal, but not confirmed, evidence of possible spawning in in the Dwyfor (Lleyn Peninsula). Immature fish migrate to sea and feed for several years prior to first spawning. Both life stages are therefore potentially exposed to MRE impacts in their sea phase.

The evidence presently available suggests that impacts are more likely in the Bristol Channel and MRE deployed in South and West Wales. However, given the lack of information on marine distribution of immature fish, the possibility of some impacts in other resource zones such as Anglesey, cannot be completely precluded and we have recommended a systematic eDNA survey to clarify distribution for these and other species. The limited data available suggest a wide range of depth utilisation so depth of device deployment is not material to assessments of risk.

Fish spawning in each river should be treated as individual populations; tagging recommendations can be found in ‘Acoustic tracking in Wales – designing a programme to evaluate Marine Renewable Energy impacts on Diadromous fish (Clarke *et al, 2021b).*

Sea lamprey and river lamprey

The data on general distribution, life cycle and swimming depths suggest that both sea and river lamprey are likely to encounter MRE devices and therefore be at risk. This is to some extent mitigated by the lack of fidelity to individual river systems, which may increase the size of impacted population units. The literature suggests that sea lamprey migrate long distances and use oceanic areas as well as coastal waters, which would reduce MRE risk. Some depth utilisation data are available which suggest they use a wide range of depths, although it is unclear whether they prefer surface or seabed. Understanding of migration paths remains limited.

A key point for both species is that they spend a significant part of their marine lives attached to and feeding on host species. As a consequence, their risk is directly related to the movement, distribution and behaviour of the host – they inherit the same risks.

European eels

Eels are potentially exposed to MRE developments as silver eels migrate to spawn, and as glass eels migrating to coastal waters and rivers. They may also be exposed as yellow eels residing in coastal waters. This is of particular importance as given the extended period of the yellow eel stage, even a very low annual mortality may have significant impacts on survival. They are widely distributed around Wales and it is likely that both juvenile and adult life stages will interact with MRE devices.

There is some information on behaviour, swimming depths and speeds but we have not found evidence describing distribution of any life stage in the Welsh marine environment. Further information is needed on both juvenile and adult life stages.

The panmictic nature of the population has implications for management of MRE devices. It could be argued that as the population is widely spread throughout Europe, localised developments will have limited effect. However, the status of eel stocks remains critical. Annual recruitment indices of glass eel to European waters in 2017 remained low, at 1.6% of the 1960–1979 level in the North Sea series, and 8.7% in the "Elsewhere Europe" series. ICES (2017) advised that "when the precautionary approach is applied for European eel, all anthropogenic impacts (e.g., recreational and commercial fishing on all stages, hydropower, pumping stations, and pollution) that decrease production and escapement of silver eels should be reduced to – or kept as close to – zero as possible".

European smelt

The distribution of European smelt in Wales is limited to the north, with the only known spawning site being at Llanrwst in the river Conwy, although they are also caught in the River Dee trap. It is therefore unlikely that they would need to be considered in EIA for southern resource areas, although this would depend on confirmation of the absence of a population in Milford Haven. It is clearly possible that smelt could be impacted by both tidal stream and tidal range resource areas, during the marine feeding stage; we have therefore made some recommendations in 'Acoustic tracking in Wales – designing a programme to evaluate Marine Renewable Energy impacts on Diadromous fish (Clarke, *et al, 2021b).* as well as for eDNA surveys to establish whether they are likely to be found in those areas.
In the absence of other information, the population spawning at Llanrwst should be considered to be a discrete population. If adults are found to utilise the resource zones, work should be undertaken to estimate population size alongside impacts of MRE.

5. Identified methodologies to study presence and duration, migration routes, speed swim depth and river fidelity of diadromous species

This section describes the various survey techniques which could be used to fill the evidence gaps. These include capture methods, tag types and tagging methods (including tag burden and best practice for applying acoustic tags), cameras, active acoustics, eDNA and stable isotopes.

We have focussed most attention on methods which we believe to be practical. Other methods are mentioned with a brief explanation as to why they are not considered further.

5.1. Capture methods for different species and life stages.

Many fish survey techniques require fish to be captured. Additionally, both mark-recapture and telemetric tagging studies require the capture of sufficient fish in good condition to tag. We have therefore summarised the main methods available.

5.1.1. Atlantic salmon and sea trout

Ideally to look at a life cycle, juvenile salmonids / smolts would be captured, tagged and followed throughout their lives until final river return. For sea trout this can be effectively achieved by tagging smolts to look at initial migration and maiden returns, and by tagging adults, either during their upstream spawning migration or as kelts, to look at post spawning migration and returns. Both smolt and adult data can be combined to get an overall picture of the marine life cycle.

For Atlantic salmon, smolts can be captured, acoustically tagged and tracked, enabling their emigration paths and exposure to resource areas to be identified and quantified. Survival rates at sea prior to adult return are currently poor (of the order of 2% for Welsh fish), and very large numbers would have to be tagged to get suitable return data. Unlike sea trout, salmon spawning survival is low, so tagging of kelts is probably impractical. Adult salmon could potentially be captured at sea and tagging of fish within resource areas could provide data on the origin of affected fish. However, there is not an obvious tagging strategy to establish impacts on returning adult Atlantic salmon.

There are a range of fixed and mobile in-river trap designs for smolts. Fixed designs include Wolf traps which effectively sieve fish out as they fall over raised areas such as weirs, dropping them into channels which flow into an offline holding box. There are currently no fixed facilities within Wales for trapping of smolts.

Modified eel fyke nets have been deployed successfully on the River Dee and the River Tawe (Figure 4). This approach could be applied to the majority of Welsh rivers and has the advantage of low cost. Fyke nets are also flexible as they can be moved between rivers and from tributaries to lower reaches. However, the utility of fyke nets is restricted during periods of higher flows.

Rotary screw traps have been utilised in a range of studies including within Scottish rivers, various locations in England, and on the River Dee in Wales. They have the advantage that they can be operated during higher flows than fyke nets but are significantly more expensive and more difficult to deploy.

For practical purposes, trapping of adult salmonids has a number of purposes in respect of assessing marine renewable Impacts.

- For both species, adult trap catches can be used as a basis for assessing population strength including providing baseline estimates during the pre-construction phase.

- The capture of adult sea trout (which can be multiple spawners) enables tagging with acoustic and/or archival tags which may then enable the fish to be tracked at sea. This approach does not have the same use for Atlantic salmon because of the low survival rates following spawning.

- Sea trout tagged with data storage (archival) tags may be recaptured by in-river traps, enabling tag retrieval and extraction of data.

Sea trout can be captured during their upstream migration phase or during and after spawning. Upstream capture is ideally undertaken using fixed permanent trap facilities. These facilities are limited in Wales to upstream in-scale traps on the River Dee at Chester and the River Tawe at Panteg (Figure 3). Both sites have large well developed trap facilities. The Dee facility is at head of tide on Chester Weir and has been managed as an index river with a good data record going back many years. Panteg is located midway up the catchment. For Panteg there are some records based on trapping over a 10-year period in the 1990s, associated with the construction of the River Tawe barrage.

Given the lack of permanent facilities elsewhere, for tagging operations, alternative methods of capturing adult sea trout need to be considered and include the use of temporary in-scale traps, electrofishing and fyke nets.

Portable temporary traps have been used to capture sea trout with good success in the past on various Welsh rivers. However, no traps are available, so the traps and screens would need to be constructed. Swansea University have recently caught numbers of large trout in fyke netting operations designed to catch downstream migrating smolts. Electrofishing has also been used to capture adult sea trout kelts in some studies. GWCT regularly use this approach and have a bespoke boat fishing set up which has been used successfully to catch sea trout kelts for tagging on the Rivers Tamar and Frome and their estuaries during their post-spawning downstream migration.

GWCT also deployed two Rotary Screw Traps (RST) for downstream trapping post-spawning sea trout kelts, but they do not recommend this method as it was difficult to maintain safety on the trap and resulted in a very low number of captured individuals.

At sea sampling: adults

The difficulty with capturing adults at sea is that (i) the fish may already have passed the area of interest and (ii) the origin of fish captured is unknown at the point of tagging. To overcome this, some studies have used fish captured in-river, tagged them and relocated them back to sea. Examples of these studies include studies of the impact of Cardiff Bay and Swansea Bay barrages.

Adults can be captured at sea using a range of netting techniques. Fixed, drift or trammel nets can be deployed and are relatively flexible, though fixed or drift nets in particular tend to damage fish.

Trap nets can be deployed (e.g., jumper nets, bag nets, T-nets). These can provide fish in good condition and have been demonstrated to work in past studies around Wales including the River Tywi (Clarke *et al.,* 1991) and Swansea Bay. They can be used on open beaches or in shallower water to catch Atlantic salmon and sea trout as they migrate. However, they are highly labour intensive and commercial fisheries using this gear in Scotland have historically caught marine mammals such as seals, which look to enter the nets in search of trapped fish.

Seine nets may also be a valuable source of fish particularly where existing commercial or semi commercial net fisheries exist, and the fish can be purchased on the water. This is a low-cost approach which can provide fish in excellent condition. However, these fisheries are limited in estuaries which limits the value of this approach as the fish are likely to have already passed the resource areas.

At sea sampling: smolts

Both Atlantic salmon and sea trout smolts can be caught at sea using drift, trammel or fixed nets of appropriate sizes. Research fishing using trawls has also been undertaken by government bodies, to establish the distribution of Atlantic salmon smolts during sea migrations. These methods are potentially useful for presence /

absence information but may damage fish and do not tend to provide fish in a taggable condition. The origin of the smolts is also unknown. Tagging juvenile Atlantic salmon or sea trout in river is therefore preferred.

5.1.2. Allis shad

Allis shad are rarely caught around Wales, and there are no practical current options for targeted capture because of extremely low abundance.

5.1.3. Twaite shad

Twaite shad are multiple spawners which in Wales are known to spawn in the rivers Usk, Wye, Severn and Tywi. The ‘Unlocking the Severn’ project has successfully used a combination of rod fishing and trapping to catch and tag adult fish prior to spawning, typically in May (Davies *et al.*, 2020). The trapping facility comprises a cage structure at the top of a fish pass and is continuously operated, using an entrance gate to trap fish one at a time as they enter the structure. They are then immediately removed from the trap, tagged and released before trapping recommences.

This work has focussed on catching migrant adults early in their river entry, because the focus has been on their freshwater migration. Survival of fish tagged in this way to return to the sea has been demonstrated by Breine *et al, (2017)* and in the Bristol Channel is some 70% (Davies *et al.*, 2020; Bolland pers. comm). Tagged fish have to survive predation in the river and spawning stress, as well as tagging, so this appears to be a good success rate. This is a viable strategy, which could be applied to any of the rivers in question. It has the advantage that by the time fish reach the sea immediate tagging losses are likely to be complete, and the fish would be expected to be behaving normally. However, capturing fish after spawning, using fyke nets, rod captures or downstream traps, could also be considered, to reduce spawning losses after tagging.

Juvenile fish could be caught by similar methods to those used for catching Atlantic salmon and sea trout smolts. However, they are not large enough to tag by the time they reach the sea. Data on the availability of these life stages will need to be derived from eDNA studies, or targeted netting or trawl surveys in the vicinity of resource areas.

5.1.4. Sea and river lamprey

Transformers could be caught in traps or nets within the river. The relatively small size of transformers limits tagging options. The juvenile migratory stage is considered too small to tag and adults die after spawning. In-river capture therefore has limited value, though adults are often captured in in-scale traps and can be captured by methods such as fyke netting.

OSPAR, 2009, states: ‘Sea lampreys are caught so infrequently at sea, and so little is known about their maritime distribution that a targeted marine monitoring system is not feasible’.

Investigation using tagging techniques is limited by the relatively small size of transformers as they migrate to sea.

Understanding of migration paths and depth utilisation also remains limited. Investigation using tagging techniques is limited by the relatively small size of transformers as they migrate to sea.

For these species we recommend initial eDNA surveys of resource areas to establish presence/absence and seasonal distribution. If these prove positive developments specific catch surveys, such as high-speed plankton nets, could be considered.

5.1.5. European eels

From January 2021, no authorisation to fish eels and elvers will be given in Wales and the cross-border rivers (except in the Severn). However, for scientific purposes, permission could be granted (NRW, pers comm.).

Glass eels can be sampled using artificial substrate traps (R. Frome, pers comm.). The units are either anchored on the bottom or can be suspended just above the bed of an estuary or an inshore area. The traps are serviced as required, from daily to weekly, but care has to be taken when lifting the units to make sure all of the glass eels are captured, as they can jump free if the unit is not quickly surrounded by a retention bag.

Juvenile eels, entering rivers from the sea as elvers, can be caught using dip nets. They are too small for normal acoustic tags, and at this stage they have already passed the resource zones. Options to identify presence or absence in resource areas include eDNA studies alongside active surveys such as high-speed plankton nets. Quantitative estimates would be difficult, though intensive surveys during peak periods could yield sensible data.

Eels migrate to sea in the autumn as silver eels, often after many years developing within the river. They can be captured with baited traps or eel fyke nets; working with experienced local fishermen under dispensation would be the method of choice to catch fish for tagging.

5.1.6. European smelt

European smelt can be captured using a range of methods, including seine nets, baited traps, fyke nets and beam and otter trawls. They are also caught in the Dee trap. There are licenced fisheries for this species in the UK. If available, contacting local commercial fishermen would be the preferred approach. Alternatively pilot studies would be needed to establish viability and the best method using baited traps, fyke nets and seine nets. They are caught in the fixed trap on the River Dee every year and are known to spawn on the Conwy at Llanrwst. Therefore, there is potential for the species to be captured and tagged then; however, this would require a trial.

6.2. Tagging Methods

6.2.1. Marker tags (Carlin, Floy, VIE tags, dye markers)

There are a wide range of external marker tags available for fish including tags such as Carlin, floy, dye marks and VIE tags. They are generally used for mark/recapture studies and population estimates and they may also be used to identify acoustic or radio tracked fish when they are captured in traps or by fishermen. The selection of tag type depends on the species and life stage to be tagged. There is some disadvantage in using these tags within acoustic or radio tracking studies, as they may make the fish more visible and vulnerable to predation as well as providing increasing the risk of disease. However, they still have value in studies which require the return of the tag for data recovery, such as archival tags.

6.2.2. Transponding (PIT) tags

Passive Integrated Transponder (PIT) tags are widely used to study fish survival, movement and behaviour. The most commonly used full duplex tag size is small at 12 mm x 2 mm. The PIT tags are encapsulated in glass, weigh only 0.1 g and each tag has a unique identifiable code. Given their small size they are suitable for studying small fish such as Atlantic salmon and trout parr 1+ and even larger fry (0+) (Vollset *et al*., 2020). Being small, they are relatively easy to implant, and a small team can tag several hundred fish in a day. In juveniles they are generally implanted into the peritoneal body cavity through a small incision with a scalpel or a dedicated injector which does not require suturing. They are cheap at ca. £2 per tag.

Unlike radio and acoustic tags, PIT tags have no battery, and are not limited by battery life. They are activated by PIT tag readers and will remain detectable as long as the glass capsule is intact, but within a very short range (<1m).

For the purpose of the studies planned in this report, PIT tag technology is of limited value. The automated detection technology is geared towards in-river use, where fish can be detected at close range by the readers. For some species, PIT tags could be used in conjunction with an adipose fin clip and acoustic tags. However, using PIT tags alongside acoustic tags can identify the recapture of individuals, when the acoustic transmitting tags have run out of battery or if the acoustic tag has been expelled.

6.2.3. Radio tags

Radio telemetry for fish is not widely used in marine studies, because of rapid signal attenuation in seawater. In rivers the technology can be used to examine and improve the functionality and efficiency of fish passes, to detect fish passages at weirs and for spawning surveys. Radio tagging studies may also provide information on site fidelity to natal rivers.

6.2.4. Acoustic tagging

Acoustic tags emit a ‘ping’ which contains a unique ID code. Depending on frequency, sound travels well in both river and marine environments, so they can be used for studies spanning both environments. Acoustic tags are detected by passive fixed hydrophones (receivers), which can detect tags in both freshwater or seawater (typically at a range of 200 - 500 m). In marine studies receivers are typically deployed as fixed lines, fences or in matrix arrays.

A separate report as part of this project (Clarke *et al.,* 2021b) contains further details on acoustic tracking systems, including system selection, tag types, receivers, and costs, as well as tagging proposals and monitoring array designs.

Tag battery life varies, typically from a few months to a number of years, and is determined by battery size (which translates to tags size), power output of the tag, and ping rate which can be programmed to vary. For example, the Unlocking the Severn (UtS) group, who are focussed on in-river movements, have their tags (Innovasea V9) set to a 1 minute average ping rate from April - June/July, then a 10 minute rate. This tag specification (pulse rate combination) allows for 3 years of life, and around [30%] of those tagged survive a second spawning round and provide data for two or more years. Matching study requirements with tag parameter selection is therefore extremely important.

Acoustic tags are now a well-established technology, with four main manufacturers producing tracking systems. Commercially available tag and detection systems are primarily manufactured by four manufacturers: Innovasea, Thelmabiotel, Lotek and Sonotronics. Most deployed systems in the marine environment use the 69 kHz system, which has been adopted as it provides the wider detection range. However other frequencies are available at 180 kHz or 307 kHz (Innovasea) and 416 kHz (Lotek), frequencies less impacted by ambient noise but with a reduced detection distance.

It is possible to implant electronic (acoustic) transmitters in fish and track their movements over increasingly long periods of time. Such studies can provide information on individual fish distribution, migration rates, marine residency patterns, as well as population-level survival rates. They can also enable identification of critical marine habitats and periods (Chaput *et al.,* 2018).

With closely spaced receivers fine scale tracking can also be undertaken. With high frequency systems theoretical accuracy of less than 1 m can be achieved in three dimensions (Leander *et al.*, 2019). Such an approach could be of particular value in looking at avoidance behaviour around turbines and turbine transit survival or survival during migration into and out of tidal lagoons.

6.2.5. Acoustic sensor tags

These are acoustic tags combined with one or several sensors. In addition to the identification and timing of the presence of a tagged fish, when the fish is detected by an acoustic receiver, additional information is also broadcast, such as information on the fish itself (position in the water, activity) and/or on the environment (temperature, pressure, salinity). The tags broadcast real time information to the detecting receiver (e.g., pressure=depth). This can be of particular value because unlike literature estimates, the data will represent the depth of the animal in the array or development area i.e., the area that is important for consenting. The tags utilise the same receivers/arrays which are used for standard acoustic pinger tags.

The number of additional sensors is limited by the size of the tag; smaller tags being able to include only one sensor, most of the time measuring pressure. The bigger tags can include many additional sensors at the same time, for example temperature, pressure, salinity, activity (movement) and tilt.

Predator tags are an interesting recent development with potential utility in looking at mortality rates in tidal lagoons such as the proposed Swansea bay tidal lagoon. Once the tagged fish is ingested by a predator, the stomach secretes acid, the biologically inert polymer coating is digested, and the tag immediately changes its identification code (Halfyard *et al.*, 2017). The new code is transmitted by the tag until the end of tag life. The time from prey ingestion to the time of the change of ID, is largely a function of temperature and typically ranges between 3-5 hours after ingestion. However, predator tags do not transmit data once out of water so are of limited use for evaluating bird predation.

Therefore, using acoustic tags it is now possible to get not only spatial and temporal information on the fish location, but also information on its ecology and its behaviour in the water column. Information like the preferred temperature and swimming depth can be studied.

However, the parameters of the sensors are not recorded on the tag, and it does not provide temporal data series. The tag transmits one sensor value at the same time as its detection by a receiver. If there are several sensors included in the tag, the first transmission provides the first sensor value, the second transmission the second sensor value, etc. It is generally possible to program the frequency and order of transmission of each sensor.

6.2.6. Archival tags

Archival tags, also named data storage tags, have been used extensively to study large-scale movement and behavioural patterns of marine animals. Rapid advances in archival tag technology (smaller size, increased memory capacity and lower cost) allowed gathering information on a wide variety of open ocean animals including fish.

Archival tags are light (1.3-20 g) and are most often implanted or secured externally on the dorsal part of the fish. Archival tags can record abiotic parameters such as pressure, ambient light, external water temperature and magnetic field but also fish parameters like internal body temperature, heart rate, swimming velocity and the tilt of the fish. The measurement of environmental temperature, light levels as well as magnetic field, environmental parameters widely measured and recorded around the ocean, are used to geolocate the individuals.

Archival tags record these various parameters, at a programmed rate (few seconds to several minutes), over periods of deployment up to ten years. This level of data intensity allows determining an animal's fine and large-scale behavioural patterns, migratory routes and physiology response, all in relation to the surrounding environment.

The main limitation of archival tags is that they must be recovered to obtain the recorded data. This limitation restricts their use to fish that have a sufficiently large fishery associated with them to ensure their eventual capture and return; or animals that return to specific sites such as rivers, with high fidelity.

Some archival tags are embedded in a float and in some cases designed with a release mechanism (for external attachment) to allow the tag to drift at the death of the animal and be found on beaches. Depending on the tagged species, the rate of archival tags found by the public on beaches can reach 20% of the tags deployed.

6.2.7. Pop-up satellite archival tags (PSATs)

To overcome the issues of data retrieval of archival tags, Pop-up satellite archival tags (PSATs) have been developed. PSATs are archival and satellite tags combined in the same package. Their major advantage is that instead of having to retrieve the animal carrying the tag to get the data, these devices send the data via satellite. They have been deployed with a high level of success on a variety of marine animals around the globe including Atlantic salmon and eels.

Pop-up satellite archival tags are designed to track the large-scale movements and behaviour of animals that do not spend enough time at the oceans' surface to allow the use of traditional satellite tags. One advantage of using PSATs is that no human intervention is required to recover the data. However, as it is a heavy tag (30 to 80g), only fish of sufficient size can be tagged, limiting the use of PSATs to larger adult Atlantic salmon, sea trout or eels.

Attachment methods for pop-up satellite archival tags to a fish consists of the insertion of a small anchor in the dorsal part of the fish. The anchor is made of surgical material that does not harm the fish and is connected to a monofilament “attachment strap” that loops around a metal pin at the base of the tag. The metal pin is connected to a battery that is programmed to switch on at a specific date and time, causing electrolysis and dissolving the attachment pin. The tag floats to the surface and starts transmitting a summary of the recorded data via satellite. The battery power is sufficient for the tag to transmit for up to two weeks. All records are maintained in non-volatile memory (memory that retains its contents when power is turned off), thus, should a PSAT happen to be recovered, fine-scale records will be accessible and not only a summary.

The results of the processed data provide the migration path taken by the study animal, depth and temperature preferences, as well as oceanographic data in the form of depth-temperature profiles.

6.3. Tagging limitation and tag burden

To ensure that reliable and meaningful results are obtained from studies following the movements of tagged fish, the tagging procedure itself should not alter the natural behaviour of fish. This is particularly important when extrapolating data on individual fish to populations as a whole and where crucial management decisions rely on the study results (Jepsen *et al.,* 2008).

In 1983 and again in the 2nd edition of the “Fisheries Techniques” book in 1996, Winter *et al.,* (2005) recommended that fish should not be tagged with a transmitter that weigh more than 1.25% in water or 2% in air of the fish’s body weight. Since then, researchers have used this general “rule of thumb”, called the “2% rule” to argue that tagging does not impact the fish. However, Thorstad *et al.,* (2013) stated that this was not a valid argument as some small tags can have an effect on the fish behaviour and in other cases larger tags can be used without tagging effect (Jepsen *et al.,* 2005).

Several experiments looking at the impact of a tag >2% of the fish body weight on mortality, swimming performance and growth concluded that there were no significant differences on the tested parameters between the tagged and the untagged individuals (Moore *et al.,* 1990; Brown *et al.,* 1999; Anglea *et al.,* 2004; Bégout *et al.,* 2003; Lacroix *et al.,* 2004; Brown *et al.,* 2006; Rechisky and Welch, 2010; Ostrand *et al.,* 2011; Ammann *et al.,* 2013; Smircich and Kelly, 2014; Newton *et al.,* 2016; Klinard *et al.,* 2018). However, other experiments showed that tags >2% of the fish body weight, sometimes even tags >1.5% of the fish body weight, can increase the mortality, decrease the swimming speed or slow the growth of some fish species (Adams *et al.,* 1998; Lefrancois *et al.,* 2001; Winter *et al.,* 2005; Brown *et al.,* 2006; Welch *et al.,* 2007; Jepsen *et al.,* 2008; Chittenden *et al.,* 2009; Knudsen *et al.,* 2009; Brown *et al.,* 2010; Lacroix *et al.,* 2014; Watson *et al.,* 2019).

Because of these mixed observations, in their review, Jepsen *et al.,* (2005) stated that the "2% rules" should not be generalised. The size of the tag used in a study should depend on the objectives of the study itself, the tagging method (internal or external) and the species and life stage of the species. As an example, long-term impact of a tag could be considered irrelevant for a short duration tracking study lasting just 10 days.

Another difficulty with the experiments conducted on tag burden is that fish in the studies are kept in a safe tank when in telemetry study of wild fish, fish are immediately released in their natural environment with potential predators, current, etc. that could have a higher impact during their recovery period than in a tank in a laboratory. Also, after a surgery, fish behaviour may be disturbed so observations made 24 hours after tagging may not reflect a natural behaviour (Bridger and Booth 2003).

6.4. Tagging best practice

Most of the experiments considering the best tagging method recommended an internal insertion of the tag instead of external attachment (Adams *et al.,* 1998; Baras and Jeandrain, 1998; Bégout *et al.,* 2003).

External tags can change the streamlined body shape that many fish species possess, disturb balance and, at worst, cause loss of equilibrium if the tag is too heavy compared to the mass of the fish (Jepsen *et. al*, 2015). Therefore, fish swimming capacity can be reduced with an external tag (McCleave & Stred, 1975; Lewis and Muntz, 1984; Mellas and Haynes, 1985; Peake *et al.,* 1997; Steinhausen *et al.,* 2006; Lefrancois *et al.,* 2001; Janak *et al.,* 2012). Sometimes, external tags impact the feeding of fish and therefore their growth (Ross and Mc Cormick, 1981; Greenstreet & Morgan, 1989; Baras, 1992).

However, external attachment holds certain benefits compared to the surgery implantation, such as speed of application, and it may be the only option for fishes with a body shape unsuitable for surgical implantation, or when using tags with sensors recording the external environment (Jepsen *et al*., 2015).

When internally inserting a tag, careful attention should be given to the material used as sensitivity differs between species. Tagging is regulated by the Home Office which deliver individual and project licences to allow this practice.

6.5. Species and life stage tagging methods

6.5.1. Atlantic salmon

With the development of telemetry methodology, the tag burden limitation for Atlantic salmon have been tested by several scientists. As conditions and animal characteristics differed between experiments, care should be taken when transposing the results of one experiment to a telemetry study. Indeed, most of the experiments that tested the limit of the percentage of a tag size and weight compared to the fish body length or weight, used fish from hatcheries and not wild individuals. Hatchery fish might react differently to the tag burden and Bridger and Booth (2003) highlighted that care should be taken when extrapolating experiments with hatchery fish to wild fish.

Only one study has been done on wild Atlantic salmon species, where Brown *et al.* (2006) compared the survival of tagged and untagged Chinook with a tag burden of 5.6 % and recorded a higher mortality on tagged Chinook salmon individuals. However, in a follow-up experiment conducted in 2010 with Chinook salmon from a hatchery with a similar tag burden (5.7 %) there was no difference in mortality in tagged Chinook salmon (Brown *et al.,* 2010).

Mortality

Adams *et al.* (1998) observed a higher predation rate of surgically tagged juveniles of Chinook Atlantic salmon compared to untagged control groups and advised against the tagging of individuals under 12 cm (tag burden > 4.6% of fish body weight) but stated that tagging had no effect on individuals larger than 12 cm. Ammann *et al.* (2013), Anglea *et al.,* (2004) and Rechisky & Welch (2010), who tagged bigger Chinook salmon individuals, concluded in the same way that a tag burden inferior to 5.6 %, 6.7 % or 7.6% of fish body weight, respectively, can be effectively used in Chinook salmon larger than 14 cm. Also, Brown *et al.,* (2010) confirmed that tagging Chinook salmon < 10 cm (tag burden >8.2% of fish body weight) increased their mortality and the tag expulsion rates.

Tag expulsion

Tag expulsion does not necessarily induce a mortality as fish can expel a foreign body through the skin or by intestine encapsulation and anal expulsion (Marty & Summerfelt 1986). However, it can bias the interpretation of a telemetry study if the rate of tag expulsion is unknown. For Atlantic salmon, tag expulsion is reported in several studies, even for light passive integrated transponder (PIT) tags (Foldvick & Kvingedal, 2018; Moore *et al*., 1990; Knudsen *et al*., 2009). The expulsion rate varies depending on the species and is related to the tag: body mass ratio (Jepsen *et al.*, 2008; Brundsen *et al*., 2019). Lacroix *et al*., (2004) reported that 100% of the Atlantic salmon > 14 cm tagged with dummy transmitters had expelled their tags after 217 days of observation (tag burden >16%). Such a high tag burden also induced up to 60% mortality.

Growth rate

After the implantation of a tag in Atlantic salmon some scientists also mentioned a lower growth rate that generally returns to normal after several days (Lacroix *et al*., 2004; Knudsen *et al.*, 2009; Ostrand *et al.*, 2011). This effect on Atlantic salmon growth is size dependent; growth of <11 cm individuals decreased significantly for a few days (tag burden <4% of fish body weight) but this effect was not observed for larger individuals (Chittenden *et al.*, 2009; Brown *et al.*, 2010).

Swimming performance

Finally, tag burden relating to swimming speed and swimming performance of Atlantic salmon were also investigated. Once again, observations differ between experiments. Burst speed was showed to be significantly lower for > 12 cm tagged fish (5.6% of tag burden) compared to control fish (Adams *et al*.*,* 1998) whereas Anglea *et al.,* (2004) or Chittenden *et al*. (2009) did not find any impact of a tag burden < 6.7% on swimming performance of juvenile Chinook and Coho Atlantic salmon, respectively.

McCleave and Stred (1975), and later Lacroix *et al.,* (2004), looked at Atlantic salmon smolts swimming performance with and without tags. Both observed reduced swimming performance in tagged smolts, but that diminished with time after surgery. A study of Moore *et al*. (1990), with 2.2% tag burden in Atlantic salmon smolts did not highlight any impact on swimming behaviour.

The migration route of adult Atlantic salmon has been followed using pop-up satellite tags (PSAT). Satellite tags do not appear to impact the survival or growth rate of adult Atlantic salmon (Hedger *et al.*, 2017) and were successfully deployed in adult Atlantic salmon by Strøm *et al*. in 2017 and 2018ab, Lacroix (2014) among others.

Overall, tag burden studies have shown that Atlantic salmon smolts can be monitored by internally inserting acoustic and/or DSTs tags, provided the total weight of the tag is <8% of the smolt’s body weight, for fish >14 cm fish. The total weight of the tag should be less than <4% of the smolts body weight for fish <14cm in length. External satellite tags can also be used on the biggest individuals (>65 cm) to precisely track their migration routes at sea or study their vertical behaviour.

6.5.2. Sea trout

Similar tag burden issues to those for Atlantic salmon were found in experiments conducted on Brook trout (Smircich and Kelly 2014), steelhead trout (Welch *et al.*, 2007), Cutthroat trout (Zale *et al.*, 2005) and wild brown trout (Jepsen *et al*., 2008). No information was specifically found on the tag burden limitation on sea trout in the literature. Nevertheless, smolt and adult individuals have been successfully tracked using acoustic tags in several rivers and coastal areas e.g., in UK, France, Norway, Holland (Aarestrup *et al*., 2003; Thorstad *et al*., 2004; Flaten *et al.*, 2016; Lauridsen *et al*., 2017). Kristensen *et al*. (2018, 2019) also collected information on sea trout migration at sea using data storage tags. Also, due to similarities in physiology between the two species it is likely that the relationship between body size and tag burden will be similar.

Sea trout can be monitored by internally inserting acoustic and/or DSTs tags with the same limitations that for Atlantic salmon. External satellite tags can also be used on the biggest individuals (>65 cm) to precisely track their migration routes at sea.

6.5.3. Twaite shad

No experimental information was found on the tag burden of twaite shad. However, Bolland *et al*., (2019) and Davies *et al.,* (2020) have successfully tagged, externally and internally, twaite shad with a 1.3% tag burden. These studies have demonstrated good survival rates, consistent with expectations from population age structure.

We therefore recommend tagging adult twaite shad by internally inserting acoustic tags with total weight of the tags <2% of the shad body weight.

6.5.4. Sea and river lamprey

The literature found on lamprey *spp* tagging mostly refers to the insertion of PIT tags. Insertion of PIT tags do not affect the survival of juvenile Pacific lampreys if individuals are maintained in an 8°C tank after surgery (Mueller *et al.,* 2006). Simard *et al.* (2017) had a similar conclusion when inserting a 12 mm PIT tag in metamorphosing juvenile sea lamprey. Tag retention is reported to be better when 1 stitch is done to close the incision (Mueller *et al.,* 2006). Meeuwing *et al.* (2006) looked at survival of Pacific lamprey larvae after insertion of a PIT tag and showed a relationship between larva length and the probability of tag retention, however survival of tagged lamprey did not differ from the untagged ones.

Lamprey can also be tagged with radio-tags. Keefer *et al.*, (2009) looked at the migration behaviour of Pacific Lamprey (*Lampetra tridentata)* in the Columbia river basin (USA) during several months. Size limit of the lamprey was determined by the length of the girth at the dorsal fin; and only fish with girth >9 cm at the dorsal fin were internally radio-tagged (tag weight: 4.5 g in water). No conclusion was made on the survival rate of the radio-tagged fish, but a difference of behaviour was highlighted compared to PIT-tagged lamprey.

Finally, Mueller *et al*., (2019) evaluated the effect of a new micro acoustic tag insertion on juvenile Pacific lamprey (>12 cm, tag burden <4.8% of the lamprey body weight) and did not determine any impact on their swimming ability or survivability.

Lamprey can be monitored at different life stages, or juvenile phase by internally inserting PIT or micro-acoustic tags with total weight of the tags <4.8% of the lamprey body weight.

6.5.5. European eels

None of the experiments reviewed in this study reported any increasing mortality nor growth rate decrease with tagging (Hirt-Chabbert and Young, 2012), but authors mentioned some tag loss:

- Winter *et al*. 2005 did not report any mortality during their experiment comparing the insertion of PIT (0.033 g) and dummy transponders (26.5 g in air) into > 680 g European eels (tag < 3.9% of eel body weight). However, they found that 38% of acoustically tagged eels had a lower activity level than the control group.
- Similarly, Thorstad *et al.,* (2013b) inserted G5 DST tags (Cefas Technology Limited, 9 g in air) into >520 g silver eels (tag <1.73% of eel body weight) and did not report any impact on the mortality or growth of the individuals for 6 months. However, 12% of tagged eels started to expel their tag after 6 months.
- Mueller *et al*. (2017) had the same results than Thorstad *et al*., (2013b) when pit tagging (0.033 g) juveniles of American eels (1.7 to 7.5 g), with tag representing <1.95% of the eel weight. However, the tag retention rate fell to only 50% after 38 days of experiment.

To follow the migration of eels toward their spawning sites, scientists externally attach satellite tags. Even if the presence of the satellite tag impacts the swimming behaviour of European eel with an increase of oxygen consumption and increase in oxygen transportation cost (Burgerhout *et al.*, 2011), individuals can be tracked for several months with this device (e.g., Aarestrup *et al.*, 2008; Righton *et al*., 2016).

With regards to the literature, eels can be monitored by internally inserting acoustic and/or archival tags with total weight of the tags <3.9% of their body weight, though some tag loss may be expected. External satellite tags can also be used on the biggest individuals to follow the eel's migration further away at sea.

6.5.6. Tag availability and recommendations for each species.

The main 69 kHz tags currently used are 7-9 mm in diameter with weights varying from 1.2 g to 4.5 g (see Clarke et al, 2021b for detail of all tag types, drawn from all manufacturers). Table 3 combines tag weights for frequently used tag types with acceptable tag burden for each species at different life stages, to identify the minimum acceptable fish weight in each case. For European smelts, literature does not provide indication on the acceptable tag burden, so a tag burden <4% as Atlantic salmon smolts was considered.

Table 3. Minimal weight (g) of diadromous species required when inserting the different acoustic tags available on the market in 2021.

	Innovasea 69kHz			Thelma biotec 69 kHz			Lotek 69 kHz			
Species	**V7-2L**	**V8-4L**	**V9-6L**	**LP6**	**LP7**	**MP9**	**8-SO**	**11-SO**	**11-28**	**16-25**
Atlantic salmon >14cm (tag burden <8%)	17.5	25	36.3	15	22.5	45	68.8	82.5	125	325
Atlantic salmon <14cm (tag burden <4%)	35	N/A	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A
Sea trout >14cm (tag burden <8%)	17.5	25	36.3	15	22.5	45	68.8	82.5	125	325
Sea trout <14cm (tag burden <4%)	35	N/A	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A
European eels (adults) (tag burden <3.9%)	35.9	51.3	74.4	30.7	46.1	92.3	141	169.2	256.4	666.7
Allis and twaite shad (tag burden <2%) (adults)	70	100	145	60	90	180	275	330	500	1300
Sea and river lamprey (tag burden <4.8%) (adults)	29.1	41.7	60.4	25	37.5	75	114.6	137.5	208.3	541.7
European smelt (tag burden <4%)	37.5	50	N/A	30	45	N/A	N/A	N/A	N/A	N/A

6.6. Cameras (visual, freshwater lens, baited cameras)

Cameras are important tools used in marine exploration to assess species abundance, diversity and behaviour (Mallet and Pelletier, 2014). They are a highly repeatable sampling method which can be used over broad temporal (hours to years) and spatial (metres to kilometres) scales. Recent advancements in aspects such as battery life, video quality, underwater housings, cost and data storage have increased the application of these methods in challenging environments (Bicknell *et al.*, 2016; Jones, 2020).

Baseline surveys of both the near and far field areas to establish the presence / absence of marine animal groups such as fish both prior and post implementation of tidal turbine infrastructures may be undertaken by using non-destructive /non-extractive baited remote underwater video (BRUV) techniques. The inclusion of bait with optical underwater cameras has been shown to help with overcoming the problem of low fish counts associated with fish passing un-baited systems by chance. Furthermore, recent methodological research into BRUVs using clear optical chambers have expanded their working window so they may be applied to low visibility and dynamic environments associated with renewable developments (Jones *et al.*, 2020).

For the evidence gaps covered by this report, the primary value of camera systems is the provision of information on presence as part of baseline surveys. However, this method may be biased toward benthic feeding species and cannot provide quantitative data on abundance.

The primary value of visual cameras is in monitoring near field behaviour around turbines, including turbine strikes, where in daylight and clear water visual they are the method of choice. However, such conditions are rarely found around Wales. We therefore recommend limiting use to fine scale observations of movements around turbines, where they may help with species identification in combination with multibeam methods such as acoustic cameras.

6.8. eDNA sampling

As animals move through water, they leave tiny traces of their DNA behind. eDNA analyses amplify this DNA (or parts of it) to enable the various genetic codes (and hence the species) present to be identified.

As with most techniques, use of eDNA has both strengths and weaknesses. With the correct sampling strategy, it can be used to determine the presence of target species in an area including seasonality of presence and relative abundance (Ratcliffe *et al*., 2021).

However, there are some significant limitations on the technique.

- DNA collected can be transported by tidal movement, in these cases the technique cannot identify fine scale distribution of species.
- Determining absence is difficult and would require a threshold detection level to be agreed which constitutes absence for practical purposes.
- It cannot distinguish between different life stages (e.g., silver eels and glass eels).
- The presence of DNA from the target species does not guarantee local presence as the DNA might have been transported by currents or from predators predating on the target species.

Nevertheless, eDNA analysis is potentially a very powerful screening tool which can provide baseline data to identify the species which are important in an environmental impact assessment of a particular area and also those which are unlikely to be present and can therefore be excluded from further assessments. One of the main strengths of the technique is the relative simplicity of collecting samples and the non-invasive nature of sampling.

6.7. Active acoustics

Active acoustic technology is widely used in fishery surveys to underpin stock assessments and quota allocation. This includes annual abundance surveys in areas such as the Celtic Sea and Bristol Channel for species such as Atlantic herring (C*lupea harengus* L.) Boarfish, Sprat (*Sprattus sprattus*) Mackerel and horse Mackerel. Typically, these surveys are conducted with equipment such as the Simrad EK60 scientific echosounder with transducers mounted below the hull. Multiple operating frequencies are then used for trace recognition (e.g., for herring 18, 38, 120 and 200 kHz; O'Donnel *et al.*, 2020), in combination with confirmatory trawl data to aid calibration, with the results from one frequency used to generate abundance estimates. While these are powerful techniques for assessing the abundance of shoaling species, the tools are of less value in identifying more dispersed species, and identification of migratory species such as salmon remains difficult (O' Donnel, pers comm).

In addition to the advancements in optical camera technology, the rise in hydroacoustic methods such as multibeam sonars and dual frequency imaging sonar 'acoustic cameras' also allow for data collection in areas heavily restricted by reduced visibility conditions such those found around Wales and other dynamic coastal environments (Gordon Jr., 1983; Jones, 2020; Moursund *et al.*, 2003). These include the acoustic camera technology such as ARIS, used as fish counters in freshwater rivers. However, these are very limited in range, and are probably only useful for fine scale studies of avoidance behaviour and the effect of potential collisions.

While marine deployment is technically challenging, multibeam and acoustic cameras deployed in close proximity to marine turbines are likely to be important tools in monitoring impacts and avoidance behaviour in operational turbine deployments. Detailed coverage of this issue is beyond the scope of this report but is being covered in detail in a separate report for Welsh Government (Clarke *et al.,* 2021). However, they are of limited value for the evidence gaps within the direct scope of this report.

6.8.1. Analytical Techniques

There are two main techniques used in eDNA studies, quantitative (q)PCR (including digital droplet, ddPCR) analyses and metabarcoding, based on next generation sequencing (NGS). Both techniques have strengths and weaknesses (Harper *et al*., 2018; Holman *et al*., 2019).

qPCR requires amplification of genetic material using assays (primer pairs and often species-specific probes) specifically designed for the species being examined. qPCR approaches are regarded as capable of detecting lower concentrations of DNA than metabarcoding. However, this approach can only look at one or a small number of species at one time.

Metabarcoding, amplifies specific regions of a gene that is shared among many species and DNA variants within the region is used to discriminate among species present in the sample. For example, the fish specific 12S-V5 primers will amplify the 12S variable region 5 and identify a wide range of fish species (Miya *et al*., 2020). Primers can be chosen to enable us to look at all species of interest. Metabarcoding can, however, be less sensitive than qPCR analysis. Table 4 identifies some fishery specific references for metabarcoding and qPCR primers.

Table 4. Key references for fisheries metabarcoding and qPCR.

Species	**Metabarcoding**	**qPCR**
Atlantic salmon (*Salmo salar*)	Mynott & Marsh, 2020	Atkinson, *et al.,* 2018 Gargan *et al*., 2020
Sea trout (*Salmo trutta*)	Hanfling *et al* 2016	Gustavson *et al.,* 2015
European eel (*Anguilla Anguilla*)	Mynott & Marsh, 2020	Weldon *et al.,* 2020
Allis shad (*Alosa alosa*)	Mynott & Marsh, 2020	UCD,Area 52 research group unpublished
Twaite shad (*Alosa fallax*)	Mynott & Marsh, 2020	[UTS, papers in prep]
European smelt (*Osmerus eperlanus*)	N/A	{Under development - Natural England}
Sea lamprey (*Petromyzon marinus*)	Mynott & Marsh, 2020	Zancolli *et al.,* 2018 Gustavson *et al.,* 2015 Bracken *et al.,* 2019
River lamprey (*Lampetra fluviatilis*)	Mynott & Marsh, 2020	N/A

Both methods can be compared with existing genetic sequence databases to identify the species present, and species will only be identified if they are included in reference databases (Bohmann *et al*., 2014). In practice, provided that both the samples, and resulting eluted DNA are correctly stored with appropriate controls in place, samples can be used for both qPCR and metabarcoding, and can be re-used in future as new techniques and primers etc develop. Metabarcoding can therefore be used to identify the broad range of species present in a group, with qPCR analysis undertaken to target species of particular interest (Ratcliffe *et al*., 2020).

6.8.2. Sampling strategies

Effective sampling strategies and laboratory practice are a key element of eDNA studies. Essentially all that is required is a water sample representative of the location. However, the sensitivity of the techniques requires stringent methods to avoid cross contamination between samples, sample replication and positive/negative control samples. Good training of sampling staff is also important. Once collected, properly preserved samples can be used for a wide range of purposes. For example, samples taken from resource areas can be used to identify the presence of cetaceans, seabirds, and fish.

Various sampling strategies can be used with varying degrees of simplicity or sophistication.

At the simplest end of the spectrum, water samples can be obtained using simple, sterile, water bottles (Miskin bottles or similar). These samples are transported to the laboratory to be filtered or may be filtered on site/aboard ship with portable filtering equipment (Ratcliffe *et al*., 2020). This approach has the benefit of simplicity, but sample volumes are limited, and the sample is instantaneous, so limited to a single point in time. To cover a larger area and time period effectively, the study will require a higher number of samples.

A more rigorous approach involves fitting surface buoys with sampling equipment, which undertakes the analysis in situ (Hansen *et al.,* 2020). This reduces the use of expensive ship time and ensures consistency of sample timing, but the length of deployments is limited by the capacity of the buoy to carry reagents, and the necessity of filter changes. The equipment is also costly and with longer deployments there is risk of equipment loss and damage.

Recently, Natural England have successfully trialled an automated sampler which takes large volume samples over one or more tidal cycles (Mynott and Marsh, 2020). Samplers are submerged for ~24 hours, with the ability to filter ~50 L of water over this period. The pilot study looked at 6 sampling locations along the South Coast of England between October 2019 and February 2020. Effectively, this provides an integrated sample across the tidal cycle, covering a reasonably large area (i.e., the area over which the tide has passed during the period in question). They then applied a metabarcoding approach to their samples and identified 74 fish species, including several species of particular relevance to this review such as allis and twaite shad, eels and Atlantic salmon, and some of which had not been previously recorded in the area. In addition, this study investigated temporal variation across the sampling period and haplotype diversity (which can be used to look at gene flow between metapopulations).

Figures 3 and 4, courtesy of Applied Genomics, use the AVS Dev Tide Modelling Tool to illustrate the area coverage which can be obtained by deployment of six samplers on spring and neap tides, respectively. For each of the modelled tidal excursion areas, the area in yellow indicates water movement at the sea surface and the area in green indicates water movement at 1 metre above the benthos, where the sampler water inlet is assumed to be placed.

Figures 3 and 4 show indicative sample areas on spring and neap tides.

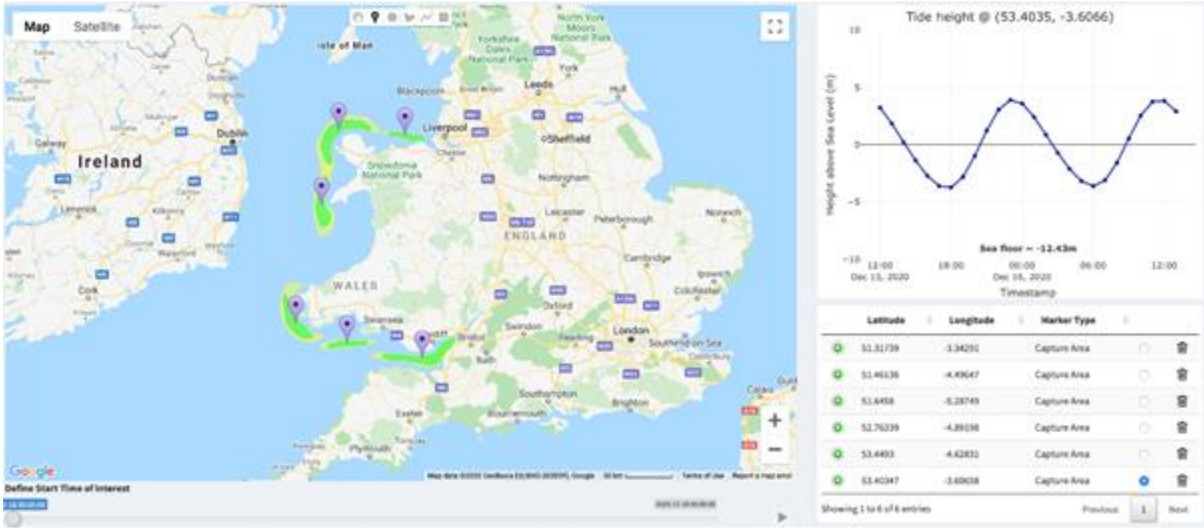

Figure 3. Spring tides (modelled using data from 15th December 2020).

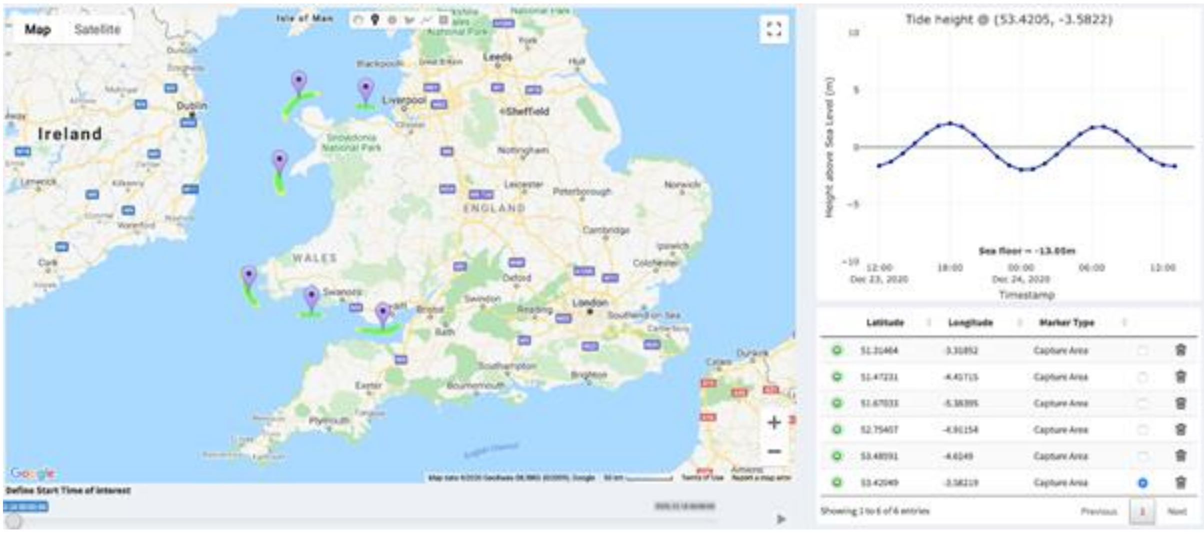

Figure 4. Neap tides (modelled using data from 23rd December 2020).

6.8.3. Wider benefits

Although beyond the technical scope of this report, once collected, properly preserved samples can be used for a wide range of purposes. For example, samples taken from resource areas can be used to identify the presence of cetacean and seabird species, as well as fish. As demonstrated by Natural England (Mynott & Marsh, 2020), metabarcoding of large volume samples can also demonstrate the presence of a wide range of fish species, including those subjected to special protection measures.

6.9. Stable isotopes; from Trueman *et al.,* (2012)

Effective tagging of any type in the marine area is limited by the size of the studied animal (see tag burden paragraph), the species, and ability to capture individuals.

Organisms, plants, or animals, comprise in their tissues elements such as isotopes that are natural chemical tags. Stable isotope analysis is based on the principle 'you are what you eat.' Stable isotope ratios vary among food webs and are incorporated into an animal's tissue via its diet (Hobson, 1999). Therefore, composition of fish reflects that of their environment. It is thus sometimes possible to infer the whereabouts of an animal moving between food webs so natural chemical tags are an attractive complement to genetic and tagging studies.

In practice, however, while such techniques can provide information on movements at a strategic level, they require extensive baseline data about stable isotopes ratios in the wider environment and are unlikely to provide the level of precision required to attribute individuals to small areas such as resource zones, or back to individual river systems.

7. Feasibility conclusions

7.1. Existing literature

We have undertaken a review of the literature based on the species of concern and the primary and secondary evidence gaps. We have also spoken with experts, where appropriate. This has led to the following conclusions.

7.2. Species

7.2.1. Atlantic salmon and sea trout (*Salmo salar* and *Salmo trutta*)

Both Atlantic salmon and sea trout are widely distributed around Wales, being found in all major river systems. As a consequence, they are likely to pass through Marine Renewable Energy (MRE) resource areas as both juveniles and emigrating adults. Sea trout could also reside within the MRE areas. They show strong fidelity to natal rivers and, as a result, management requires consideration of stocks (and hence impacts of developments) on a river-by-river basis. Sea trout are generally considered to be more at risk because of their multiple spawning trait; this means that they can be exposed to potential impacts on multiple occasions, resulting in cumulative impacts (see for example Swansea Bay modelling undertaken by Tidal Lagoon Power Ltd).

We can confidently infer presence (not absence) within hotspots in some cases (e.g., Swansea Bay), and it is probable that all resource areas have some salmonids present at certain times. There is no scientific evidence to confirm this, and it is possible that migration paths and feeding areas do not coincide with some resource areas. Confirmatory studies, using eDNA (as part of a wider strategy – see below) and targeted surveys (e.g., drift nets for adults, trawling or fine mesh drift nets for smolts) are recommended to confirm presence or absence.

Both species can be acoustically tagged as smolts and adults to obtain data describing migration paths, presence or absence and quantitative availability within MRE development areas. For sea trout, which are likely to be most at risk, acoustic tagging of all life stages is possible to obtain quantitative data in RA. For salmon both smolts and adults can be tagged, and smolts will provide quantitative data. However natural salmon survival rates at sea are low (ca 2%), so to obtain adult return data, very large numbers of smolts would have to be tagged. Unlike sea trout, multiple spawning rates in salmon are also low, so tagging upstream migrating adults is not a practical option, although tagging of well mended adult kelts in lower reaches of rivers might be possible. Tagging of adults at sea could be undertaken, but the origin of the tagged fish would be unknown.

Options and costs for implementing this are considered in a separate report.

7.2.2. Eels (*Anguilla anguilla*)

Eels are widely distributed in rivers around Wales. Potential impacts of MRE devices include impacts on returning juveniles (glass eels or elvers), yellow eels, which may use the marine environment during their extended growth phase, and silver eels during their spawning migration to the Sargasso Sea. As with Atlantic salmonids there is little data on key migration pathways or marine movements around Wales.

For juvenile eels there are no practical tagging options. eDNA and targeted surveys e.g., with high-speed plankton samplers or artificial substrate traps are the only way of determining presence / absence, depth distribution and densities and quantifying potential impacts.

Yellow eels and silver eels can be fitted with acoustic tags. Eels can spend many years in rivers and estuaries, and even low levels of annual mortality may have a significant cumulative effect. Understanding the marine habitat use (near shore / estuarine) of yellow eels is, therefore, particularly important.

7.2.3. Allis and twaite shad (*Alosa alosa* and *Alosa fallax*)

There is no current evidence of spawning populations of allis shad in Welsh rivers although there is published data of hybridisation with twaite shad (ISFC, 2010). There are spawning populations of twaite shad in the Severn, Usk, Wye, and Tywi.

Literature data on marine movements in Welsh waters are very limited. There are some data on movements in the Bristol Channel area (Davies *et al.*, 2020) and some unpublished quantitative data for the Swansea Bay development area (Swansea University SEACAMS). Swimming speeds are available from flume studies and migration speeds could be obtained from the unpublished data.

Acoustic tagging of twaite shad juveniles is not practical because of size. Acoustic tagging of adults has been successful and is continuing through the ‘Unlocking the Severn’ project, providing a current opportunity for marine tracking in the Bristol Channel. However, for broad scale migration knowledge is limited and we recommend that they be included in any eDNA studies, and that acoustic tracking is extended to include adult populations in the Usk, Wye and Tywi.

7.2.4. European smelt/sparling (*Osmerus eperlanus*)

The distribution of this species in Wales is limited to the North, specifically the Conwy, where they spawn in the Llanrwst area and have been captured in the Dee trap. Information on marine distribution around Wales is limited, and it is unclear whether migrations are limited to estuaries, or whether they inhabit offshore areas. Adults are potentially large enough for acoustic tags, although pilot studies would be needed to establish the viability of tracking. We recommend that eDNA studies are used to establish presence or absence in the tidal range and tidal stream resources areas, and if they are found to be present, this is followed up with targeted surveys and acoustic tracking.

Centralised investment in eDNA studies to establish presence/absence in resource areas (and indeed other locations) followed by more targeted survey work, would seem to be a sensible approach at this stage, to try and identify whether they are present in RA.

7.2.5. River and sea lamprey (*Lampetra fluviatilus* and *Petromyzon marinus*)

Although thought to be widely distributed in rivers around Wales, information about marine migration is virtually absent. Both species spawn in rivers with ammocoetes living in sediments for some years before emerging as ‘transformers’ and migrating to sea. They then feed by attaching themselves to other fish. The adults return to freshwater to breed and die after spawning.

Both river and sea lamprey may be at risk as transformers and as adults. However, their wider use of marine habitat around Wales needs clarifying, and river lamprey may be primarily located in adjacent estuaries and near shore areas. Their feeding habitat makes assessment difficult as they may inherit the risks of their hosts.

Juvenile stages emigrating from rivers are too small for acoustic tags. While it is possible to tag adults returning to rivers this will not provide information on sea movements as they die after spawning. Tagging sub-adults in the estuaries/near shore or adults at sea may be possible but would rely on accidental catches in marine fisheries so is likely to be impractical. We therefore recommend an initial eDNA survey, followed by targeted surveys, if river or sea lamprey are recorded in the area. To locate different life stages, targeted surveys should include a variety of netting and trawling techniques.

7.2.6. Primary evidence gaps

The primary evidence gaps identified in the scope of work included presence or absence in resource areas, migration routes of different life stages, and duration of presence and/or residence time in the resource areas.

For most species of interest, the broad distribution on an international scale is well described. There is also a reasonable understanding of distribution in river systems around Wales, based on catch reports, survey data, fish counters and traps, as well as anecdotal evidence. For most species there is some general information on spawning migration timings and the time of emigration.

However, specific evidence describing their marine distribution around Wales is scarce and unclear.

For salmonids it is possible to infer the likelihood of presence in RA, at least for a part of the year, primarily because of the widespread nature of riverine populations.

Some information is available describing movements of twaite shad in the Bristol channel, most of which is as yet unpublished. We have not found useful evidence of marine distribution data around Wales for eels, sea or river lamprey, or European smelt.

With the limited exception of Swansea Bay for twaite shad and sea trout, there is no quantitative data describing residence times in resource areas or the proportion of populations which may be at risk.

We have therefore made recommendations to address these evidence gaps.

7.2.7. Secondary Evidence gaps

The secondary evidence gaps include fidelity to natal rivers and species/life stage specific data on swimming speeds and swimming depth.

For all species except European smelt, there is literature evidence covering fidelity to natal river.

Data on swimming speed is incomplete for most species with a wide range of data types. These range from flume studies of burst speed and sustained swim speeds, which may have value for near field escape, to migration speeds over short and long distances. The latter are very variable depending on factors such as tide or holding periods.

Availability of data on depth distribution varies considerable between species. For salmon and sea trout data are available from sensor / DST tagging, and demonstrate a wide range of depth use with an overall bias toward surface layers. Data are also available for European eels. Marine depth utilisation data for European smelt are lacking and data is poor or incomplete for other species (sea and river lamprey, which may inherit the risks of their hosts),

7.3. Monitoring techniques

We have looked at the applicability of a wide range of monitoring techniques. These have included targeted capture surveys such as plankton surveys, trawling or netting, traditional tagging methods, transponding tags, radio tags, acoustic tags, data recording (archival) and sensor tags, and eDNA monitoring.

For the primary evidence gaps, the main techniques which are likely to be of value include eDNA, acoustic tagging and tracking. For life stages where tracking is impractical, targeted surveys would need to be designed, using appropriate capture methods. These would need to be specific to the species/evidence gap and tailored to local circumstances.

7.3.1. eDNA

eDNA is a valuable technique which, although it has significant limitations, could be deployed as part of an overall monitoring package. Metabarcoding can provide information on the presence in a general area of a wide range of species using a single survey, and targeted Sanger sequencing/qPCR can be used to confirm or rule out the likely presence of key species in the resource areas, as well as establishing relative seasonal abundance throughout the year.

This evidence can then be used to inform next steps – e.g., whether to undertake or require more detailed surveys, including larval or fishing surveys and acoustic tagging studies, depending on species.

7.3.2. Acoustic tracking

Where fish are large enough to be implanted with acoustic tags, acoustic tracking can be used to establish migration paths and to quantify the extent that fish from specific populations are present within specific resource zones. This is evaluated in more detail in a separate report where we have been requested to design arrays for each of the resource zones.

There are currently three main tracking technologies available for this type of study. These include the 69 kHz tracking systems pioneered by Innovasea, 180 kHz systems and high frequency and high residence systems at much higher frequencies with 307 and 416 kHz.

For most marine studies of this type the 69 kHz system is the preferred option because it has the greatest range, and because most marine arrays currently in operation use the 69 kHz system. The system is well proven with highly reliable tags and receivers. The primary limitation is tag size which is driven by the acoustic emitter to a minimum of 6 to 7 millimetres in diameter. The 180 kHz system allows smaller tags to be used but is heavily attenuated in salt water and therefore has shorter range in the marine environment.

Recently, high frequency and high-resolution systems have come on to the market. These have very short pulses and ping frequently, typically once every one or two seconds. These systems allow extremely accurate continuous location of the fish and are worth considering for detailed studies in the immediate vicinity of structures such as tidal lagoons or turbines, for example to evaluate turbine collisions. However, tag life and range limit their wider application at the present time.

7.3.3. Data storage and sensor tags

Various tag types are available including depth, temperature, predator and various types of movement sensors.

The primary limitation on these tags is the mechanism for retrieving the data which is either based on tag recovery (data storage) requiring the death of the fish or instantaneous communication with receivers (sensor tags). The former enables detailed information about fish history based on data storage but requires the fish to be recaptured and the tag removed, or the tag to be found and returned; the latter only provides the measurement while the tag is in contact with the receiver. However, if more extensive arrays are deployed, focused on resource areas, sensor tags could provide valuable behavioural data targeted to MRE applications.

The primary use of these tags within the scope of this review is to provide data on depth distribution of fish and swim speeds. However, archival tags recording temperature and pressure can also provide information on their migration routes.

7.3.4. Tag burden and tags for different species

Tag burden should be kept to a minimum to avoid interfering with the natural behaviour of the fish. The smallest 69 kHz tags available at present are Thelma LP6 and Innovasea V7. Although general rules have typically been applied to tag burden for all species, our literature review suggests that tag burden should be species and size specific. Table 3 recommends acceptable tag burdens for each species based on the available literature.

8. Recommendations

Our overall recommendation is for a layered monitoring approach, using a number of complementary techniques. The core approach is based on the use of eDNA studies to establish presence or absence in RA of key/protected species (not limited to fish), supplemented by acoustic tracking where practical to establish migration paths, quantitative availability, and residence times in resource zones. Where this is not practical, because particular life stages are too small to tag, or because there is no obvious capture technique in an appropriate location, we advocate targeted survey techniques such as high-speed plankton sampling, with the survey design and method depending on the species/location.

8.1. Stage one; screening study using eDNA

- A strategic and comprehensive marine eDNA survey is recommended to establish presence or effective absence of key fish (and other) species in each resource zone. This should be centrally funded as a two-year, comprehensive survey, to make data available to all developers, to provide a consistent baseline identifying the species which need to be covered by EIA in each resource zone. We recommend using automated samplers to collect eDNA across full tidal cycles, with [3] replicate samples spread across each area every two weeks. As eDNA screening is an emerging technology, such a study could include an initial, short pilot phase to test and refine these field techniques across a number of RA's.
- Laboratory analysis should include metabarcoding and Sanger sequencing/qPCR for the target species to get a broad view of the species present, while ensuring maximum sensitivity for key species.
- Total cost is estimated at £400k for a 12-month period; including all deployment costs, equipment hire, laboratory analysis and reporting. The majority of this cost is sample collection. A two-year sampling period would be preferable to understand inter annual variation and provide additional confidence in 'absence' conclusions.
- The laboratory analysis could be extended to cetaceans, bird species and seals to improve value for money.
- Where key species are detected, but the life stage is unclear, further targeted surveys should be designed and executed to identify the life stages present.
- Our view is that this approach will provide key information to both regulators and developers, avoiding wasted time and cost for both by identifying where species are *not* present, while ensuring that developers EIA do not miss important species.
- We are aware that various countries undertake observer surveys of by-catch on commercial vessels, which picks up many of these species. If available, this data should be analysed to complement eDNA work.

The benefit of making such an investment is that:

- it may enable certain species to be ruled out of Environmental Impact Assessment (EiA) requirements for developers in particular locations. This could considerably reduce survey and planning costs.

- looking at a wider suite of species, particularly those requiring statutory protection will provide reassurance that unexpected impacts will not occur.

8.2. Stage two; migration routes and quantitative data

- Where eDNA or other definitive data confirm the presence of key species in the development area, acoustic tracking studies should be carried out to establish quantitative presence of key species. The most cost-effective way to carry this out would be deploying arrays and tagging/tracking multiple species at the same time. RA with actual development proposals could be prioritised.
- Deploying lower density arrays across wider resources areas alongside detailed studies of hotspots will allow qualitative data to be collected to identify key migration routes.
- For some species or life stages, acoustic tracking is unlikely to be practical, as a consequence of the fish size at the time when impact may occur. This includes glass eels/elvers, juvenile lamprey and juvenile twaite shad. For these species' bespoke surveys [high speed plankton samplers/baited camera/acoustic camera studies] will need to be designed.
- Ideally NRW would have a wider understanding of migration routes. For larger fish (> 330 g), such as sea trout kelts, use of archival tags and back cast modelling to geolocate the fish could be considered.

8.3. Swimming speed and depth

- Literature information is available for swimming speeds of most species and life stages; where gaps exist data may be derived from existing tracking data, or flume-based studies can be commissioned.
- Although some literature data are available, swimming depth information is less extensive. Sensor or archival tags may be used to generate these data where needed in most cases. Sensor tags download instantaneous data to passive receivers and are generally smaller than archival tags. Archival tags provide more comprehensive data but are limited to larger fish; the tag also has to be physically recovered from the fish or found on e.g., beaches to retrieve the data. In the SAMARCH study the recovery rate of DST tags from 250 sea trout kelts is 23%.

8.4. Avoidance and aggregation behaviour

Although not directly within the scope of this review, avoidance behaviour (or fish aggregation around structures) is a key element for determining the likelihood and nature of impacts with marine turbines. This is the subject of a separate review being undertaken by Swansea University. For fish, fine scale tagging and array technology may be the only practicable method.

8.5. Partnerships and funding opportunities

Although funding is not directly discussed in the body of the current report, funding options have been considered within the contract (Clarke et al., 2021b). UK and Welsh government departments have an interest, as well as regulators such as the Marine Management Organisation, Environment Agency, and Statutory Nature Conservation Bodies incl. Natural England who are already collaborating on twaite shad tracking in the Bristol Channel. Other partnership opportunities include the university sector, and the third sector, including bodies such as angling associations, rivers trust's, and sectoral groups such as Marine Energy Wales. Scheme developers also have a key role to play.

Funding opportunities are challenging at the present time because of the withdrawal of most European funding. Other research funds are available to bid for, and a NERC bid has been submitted to fund a tracking array in the Bristol Channel. Securing funding from these sources is highly competitive and uncertain.

The funding model recommended in this report envisages government supporting a core strategic resource of both expertise and equipment, which is supplemented by other funding bids, research studentships and developer contributions.

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11. Appendices

Appendix A. Current knowledge of diadromous fish presence in Welsh river systems.

Table 5. Known species presence in Welsh rivers.

Rivers are split into North/South Species considered include Atlantic salmon (SL), sea trout (ST), Eels (E), sea lamprey (Sla), river lamprey (RLa) European smelt (SM), twaite shad (TS) and allis shad (AS). Species in bold show good locations to catch the species.

River	Species Present (breeding populations)	Trap sites	Possible trap sites for smolts/kelts	Morphological data and contacts	Habitat Regulations or other designation (all Annex 2)
South	South	South	South	South	South
Severn	SL,ST, E, RLa , Sla,**TS**	N/A	N/A	N/A	Severn Estuary SAC (estuary downstream of Frampton-on-Severn) - TS, RLa , Sla Annex 2 features os the Severn Estuary ST, SL, RLa , Sla, TS, AS, E - as part of assemblage
Usk	**SL, ST**, E, **Sla, RLa**, **TS**	N/A	Brecon weir Larinier,	N/A	Usk SAC UK0013007 SL, RLa, Sla, TS are primary reasons for this designation, AS are a qualifying feature.
Wye	SL, ST, E, **Sla, RLa, TS**	Eel trap on Llangorse lake	N/A	N/A	Wye SAC UK0012642 SL, RLa, Sla, TS are primary reasons for this designation, AS are a qualifying feature.

River	**Species Present (breeding populations)**	**Trap sites**	**Possible trap sites for smolts/kelts**	**Morphological data and contacts**	**Habitat Regulations or other designation** **(all Annex 2)**
Rhymney	SL, ST, E, Sla, RLa	N/A	N/A	N/A	N/A
Taff/Ely	SL, ST ,E, Sla, RLa	Radyr (u/s)– need work owned by CC and is confined space.	N/A	Taff data available from NRW	N/A
Ogmore	SL, ST, E, Sla, RLa	No fixed sites	N/A	N/A	N/A
Neath	SL, ST, E, **Sla, RLa**	No fixed sites	N/A	N/A	N/A
Afan	SL, ST, E , RLa	Afan weir (u/s)	Afan pass - possible to convert to smolt trap	Afan camera data available from NRW	N/A
Tawe	**SL, ST**, E, Sla, RLa	Panteg (u/s), Barrage in fish pass facility (u/s)	N/A	N/A	N/A
Loughor	SL, ST, E, RLa	No fixed sites	N/A	N/A	N/A
Gwendraet h	SL, ST, E, RLa	No fixed sites	N/A	N/A	N/A
Tywi	**SL, ST**, E, **RLa, Sla,TS**	No fixed sites (Brianne trapping facilities in headwaters decommissioned 30+ years ago	N/A	Acoustic monitoring data available from NRW	River Tywi SAC Tywi UK0013010 TS are an Annex 2 species that are a primary reason for site section, AS, RLa , Sla are a qualifying feature. Carmarthen bay and Estuaries SAC

River	Species Present (breeding populations)	Trap sites	Possible trap sites for smolts/kelts	Morphological data and contacts	Habitat Regulations or other designation (all Annex 2)
					TS are an Annex 2 species that are a primary reason for site section,, AS, RLa , Sla are a qualifying feature.
Taf	SL,ST,E, Sla, RLa	No fixed sites	N/A	N/A	N/A
Cleddau (W and E)	SL,ST,E, Sla, RLa	No fixed sites	Possible trapping sites at larrinier pass at Haverford west town weir at head of tide. Possibly good fyke netting locations below Canaston weir at DCWW raw water intake. Both locations near head of tide.	N/A	Cleddau SAC SAC UK0030074 RLa are an Annex 2 species that are a primary reason for this designation, Sla are a qualifying feature. Pembrokeshire marine SAC TS,AS, RLa Sla are a qualifying feature of this designation.
North	North	North	North	North	North
Nevern	SL, ST, E, RLa	No fixed sites	Net fishery	N/A	N/A
Teifi	**SL, S, T**, E, **Sla, RLa**	No fixed sites	Net fishery	Acoustic monitoring data available from NRW	Afon Teifi/ River Teifi **Designated Special Area of Conservation (SAC)** UK0012670**.** Annex 2 species that are a primary reason for the designation include: SA, RLa , Sla Cardigan Bay SAC UK0012712 RLa, Sla are the annex two species present as a qualifying feature but not a primary reason for site selection.
Aeron	SL,ST,E	No fixed sites	N/A	N/A	N/A

River	Species Present (breeding populations)	Trap sites	Possible trap sites for smolts/kelts	Morphological data and contacts	Habitat Regulations or other designation (all Annex 2)
Ystwyth	SL,ST,E, Sla, Rla	No fixed sites	N/A	N/A	N/A
Rheidol	SL,ST,E	No fixed sites	N/A	N/A	N/A
Clarach	ST, SL, E	No fixed sites	N/A	N/A	N/A
Dyfi	**ST, SL**, E, Sla, RLa, TS	No fixed sites	Net fishery	N/A	N/A
Dysinni	ST, SL, E, RLa	No fixed sites	Net fishery	N/A	N/A
Mawddach	ST, SL, E, Sla, RLa,TS(low numbers)	No fixed sites	Possible trap sites used for broodstock for hatchery. Net fishery		N/A
Artro	ST, SL, E	No fixed sites			N/A
Dwyryd	ST, SL, E, Sla	No fixed sites			N/A
Glaslyn	ST, SL, E, Sla RLa , TS	No fixed sites	Net fishery, Tidal Doors.		N/A
Dwyfawr	ST, SL, E, Sla, RLa – records of shad in the Dwyfor	No fixed sites	Easier to fyke than neighbouring rivers.		N/A
Llyfni	ST, SL, E, Shad (unknown species) RLa	No fixed sites	Fyke site below gauging weir		N/A

River	Species Present (breeding populations)	Trap sites	Possible trap sites for smolts/kelts	Morphological data and contacts	Habitat Regulations or other designation (all Annex 2)
Gwyrfai	SL, ST, E, TS, Sla, Rla	No fixed sites	Good fyke sites above tide limit	During TRAC survey we caught Smelt at Bellan	Afon Gwyrfai SAC SL are an Annex 2 species and a primary reason for site selection.
Seiont	ST, SL, E, Sla, Rla	No fixed sites	Pen Llyn, Llanberis		N/A
Ogwen	ST, SL, E, Rla	No fixed sites	Have to go high up for fyke sites		N/A
Conwy	SL, ST, E Sla, RLa , **SM**	Conwy Falls fish pass. Lledr fish trap (basket fishery location)	Possible to use fish pass at falls for trapping (smolts and potentially adults) Net fishery		N/A
Clwyd	ST, SL, RLa, E	Two hydro power schemes on Elwy with Larinier fishpasses	Poss sites for fyke netting identified		N/A
Dee	**ST, SL**, E, Rla, Sla, **SM**	Chester trap, RST sites and sites for fyke nets for smolts, upper and lower river. Baskets in fish pass for river	Fish counter site at Manley Hall	Data from Ian Davidson	River Dee and Bala lake SAC Annex 2 species that are a primary reason for the designation include: SL. Annex 2 species that are a qualifying species are: RLa Sla Dee Estuary SAC

River	Species Present (breeding populations)	Trap sites	Possible trap sites for smolts/kelts	Morphological data and contacts	Habitat Regulations or other designation (all Annex 2)
		lamprey being trialled this winter.			RLa , Sla are a qualifying feature of this designation.

Appendix B. Primary statutory protection of each species.

Table 6. Statutory protections for each species

Species	Statutory protection
Atlantic salmon *(Salmo Salar)*	The species are an Annex II feature of the Habitat Regulations and are listed for the following sites: Afon Gwyrfai a Llyn Cwellyn SAC, Afon Eden; Cors Goch Trawsfynydd SAC, River Dee and Bala lake SAC, Afon Teifi SAC, River Usk SAC, and River Wye SAC. Atlantic salmon are listed as part of the migratory fish assemblage sub feature of the Severn Estuary Ramsar. In addition, salmon are a listed as a Section 7 species in the Environment (Wales) Act 2016 (formerly UKBAP species). Atlantic salmon are also listed in the Convention for the protection of the marine environment of the north-east Atlantic as a Threatened and/or declining species within the OSPAR region.
Sea trout (Salmo trutta)	Sea trout listed as part of the migratory fish assemblage sub feature of the Severn Estuary SAC and Ramsar and are also listed as a Section 7 species in the Environment (Wales) Act 2016 (formerly UKBAP species).

Species	Statutory protection
Allis shad *(Alosa alosa)*	The species are an Annex II feature of the Habitat Regulations and are listed for the following sites: Pembrokeshire Marine SAC, River Tywi SAC and Carmarthen Bay and Estuary SAC, River Usk SAC and River Wye SAC. Allis shad are listed as part of the migratory fish assemblage sub feature of the Severn Estuary Ramsar and are also listed as a Section 7 species in the Environment (Wales) Act 2016 (formerly UKBAP species). Allis shad are also listed in the Convention for the protection of the marine environment of the north-east Atlantic as a Threatened and/or declining species within the OSPAR region.
Twaite shad *(Alosa fallax)*	The species are an Annex II feature of the Habitat Regulations and are listed for the following sites: Pembrokeshire Marine SAC, River Tywi SAC and Carmarthen Bay and Estuary SAC, River Usk SAC, River Wye SAC, and Severn Estuary SAC. Twaite shad are listed as part of the migratory fish assemblage sub feature of the Severn Estuary Ramsar and are also listed as a Section 7 species in the Environment (Wales) Act 2016 (formerly UKBAP species).
Sea lamprey *(Petromyzon marinus)*	The species are an Annex II feature of the Habitat Regulations and are listed for the following sites: River Dee and Bala lake SAC, Dee Estuary SAC, River Tefi SAC, Cardigan Bay SAC, Pembrokeshire Marine SAC, River Tywi SAC and Carmarthen Bay and Estuary SAC, River Usk SAC, and River Wye SAC. Sea lamprey are listed as part of the migratory fish assemblage sub feature of the Severn Estuary SAC and Ramsar and are also listed as a Section 7 species in the Environment (Wales) Act 2016 (formerly UKBAP species). Sea lamprey are also listed in the Convention for the protection of the marine environment of the north-east Atlantic as a Threatened and/or declining species within the OSPAR region.
River lamprey *(Lampetra fluviatilis)*	The species are an Annex II feature of the Habitat Regulations and are listed for the following sites: River Dee and Bala lake SAC, Dee Estuary SAC, River Tefi SAC, Cardigan Bay SAC, Pembrokeshire Marine SAC, River Tywi SAC and Carmarthen Bay and Estuary SAC, River Usk SAC, and River Wye SAC. River lamprey are listed as part of the migratory fish assemblage sub feature of the Severn Estuary SAC and Ramsar and are also listed as a Section 7 species in the Environment (Wales) Act 2016 (formerly UKBAP species).

Species	Statutory protection
European smelt/Sparling (*Osmerus eperlanus*)	European smelt are listed as a Section 7 species in the Environment (Wales) Act 2016 (formerly UKBAP species).
European eel *(Anguilla Anguilla)*	European eel are listed in the Convention for the protection of the marine environment of the north-east Atlantic as a Threatened and/or declining species within the OSPAR region and as a Section 7 species in the Environment (Wales) Act 2016 (formerly UKBAP species). Furthermore, eels are listed as in the International Union for Conservation of Nature Red List of Threatened Species Red list as Critically endangered.