Acoustic tracking in Wales – designing a programme to evaluate Marine Renewable Energy impacts on Diadromous fish.

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Author Name: David Clarke[1], Claudia Allen[1], Céline Artero[2], Lorna Wilkie[3], Ken Whelan[3], Dylan Roberts[2]
Author Affiliation: [1]Swansea University, [2] Game and Wildlife Conservation Trust, [3] Atlantic Salmon Trust

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Cefndir
Mae'r adroddiad hwn yn rhan o ddarn o waith ehangach a gomisiynwyd gan Cyfoeth Naturiol Cymru (CNC) i nodi sut i gasglu data ar ddosbarthiad a symudiadau rhywogaethau pysgod allweddol o amgylch defnydd morol adnewyddadwy yng Nghymru, er mwyn mynd i'r afael â bylchau mewn tystiolaeth a nodwyd.

Mae'r adolygiad yn canolbwyntio ar wyth rhywogaeth ymfudol, gan gynnwys eogiaid yr Iwerydd, brithyllod y môr, gwangen a herlod, llysywen bendoll yr afon a'r môr, llysywod Ewropeaidd a brwyniaid.

Diffiniwyd prif fylchau mewn tystiolaeth fel a ganlyn: Presenoldeb / absenoldeb mewn meysydd adnoddau dynodedig, llwybrau mudo camau bywyd gwahanol, a hyd presenoldeb a / neu amser preswylio mewn meysydd adnoddau. Roedd bylchau mewn gwybodaeth eilaidd yn cynnwys y canlynol: gwybodaeth benodol am rywogaethau / cyfnodau bywyd am ddyfnder nofio, cyflymder nofio a ffyddlondeb tuag at safle i afonydd gwreiddiol. Mae'r wybodaeth yn ofynnol er mwyn galluogi CNC i wneud penderfyniadau sy'n seiliedig ar dystiolaeth mewn perthynas â datblygiadau morol, rheoli ardaloedd morol gwarchodedig a phoblogaethau pysgod ymfudol a warchodir.

Dull gweithredu
Comisiynwyd yr adolygiad mewn dwy ran, y gyntaf yn edrych i nodi'r dulliau gorau sydd ar gael i ddarparu tystiolaeth ar gyfer y rhywogaethau a nodwyd a'r bylchau mewn tystiolaeth, gyda'r ail ran yn cynnwys dylunio araeau olrhain acwstig sy'n canolbwyntio ar y meysydd adnoddau a datblygiadau hysbys o amgylch Cymru. Mae'r adroddiad hwn yn ystyried ail ran cwmpas y prosiect. Mae wedi'i baratoi gan bartneriaeth sy'n cynnwys Prifysgol Abertawe, Ymddiriedolaeth Eogiaid Iwerydd a'r Ymddiriedolaeth Anifeiliaid Hela a Bywyd gwyllt.

Dewisiadau offer ac amledd
Mae systemau tagio acwstig sy'n defnyddio tagiau 69 kHz a derbynyddion acwstig yn systemau datblygedig, gyda thagiau hynod ddibynadwy a all bara rhai blynyddoedd a derbynyddion cedyrn y gellir eu defnyddio am hyd at flwyddyn mewn amodau delfrydol. Daw'r adroddiad i'r casgliad mai offer 69 kHz yw'r dull o ddewis ar gyfer arolygon morol er y gallai systemau amledd uchel eraill fod â defnydd mewn astudiaethau mân effaith tyrbin.

Dyluniadau araeau
Mae dyluniadau wedi'u cynhyrchu sy'n cwmpasu meysydd adnoddau amrediad llanw a llif llanw yng ngogledd, de-orllewin a de Cymru. O ystyried maint y meysydd hyn a chost derbynyddion acwstig, dyluniwyd araeau ar gyfer y meysydd mwy hyn fel gridiau breision, gyda derbynyddion sydd fel arfer ar gyfnodau o 5 km. Yn y meysydd adnoddau hyn, lle mae cynigion datblygu hysbys, nod y dyluniadau yw darparu data meintiol ar argaeledd ac amseroedd preswylio yn yr ardal ddatblygu uniongyrchol.

Costau araeau
Mae costau araeau'n cynnwys costau cyfalaf a chostau gwaith cynnal a chadw. Mae costau cyfalaf yn seiliedig ar gostau cyfredol a gafwyd gan wneuthurwyr, gyda'r cyfrifiadau'n cael eu gwneud gan ddefnyddio costau Innovasea; mae'r rhain wedi'u defnyddio gan mai offer Innovasea sy'n cael eu defnyddio gan fwyaf ac oherwydd bod y costau hyn yn arwain at y ffigurau uchaf (ac felly ceidwadol).

Cyfrifwyd costau gwaith cynnal a chadw yn seiliedig ar y rhagdybiaeth y gellir defnyddio wyth derbynnydd bob dydd a gellir adfer, gwasanaethu a dychwelyd chwech i'w safle a ddyrannwyd iddynt. Tybiwyd mai cost llong ymchwil yw £1,000 y dydd gan gynnwys tanwydd a chriw ac mae 10% wrth gefn wedi'i gymhwyso i gostau cyfalaf i gyfrif am golledion offer a mân gostau megis batris newydd ac atgyweiriadau mwrio. Manylir ar gostau yn Nhabl 2.

Tagio - defnydd o afonydd gwarchodol a chyfyngiadau rhywogaethau
Gyda nifer o rywogaethau wedi'u dosbarthu ar draws llawer o systemau afonydd, mae'n amlwg nad yw'n bosibl nac yn synhwyrol tagio samplau cynrychiadol o bob system. Y dull gweithredu a fabwysiadwyd yn yr adroddiad yw dewis afonydd ‘gwarchodol’ i gynrychioli’r ardal, gan gynnwys afonydd sydd, gyda’i gilydd, yn caniatáu tagio’r holl rywogaethau sydd o ddiddordeb. Mae'r afonydd a ddewiswyd yn cynnwys: afon Dyfrdwy ac afon Conwy yng ngogledd Cymru, afon Teifi ac afon Dyfi yng ngorllewin Cymru ac afon Tywi, afon Tawe, afon Wysg ac afon Gwy yn ne Cymru.

Nid yw'n bosibl tagio'n acwstig bob cam o fywyd pob rhywogaeth. Disgrifir mathau o dagio addas ar gyfer pob rhywogaeth yn adran 3.10. Ystyrir llyswennod gwydr, gwangen ifanc a llysywen bendoll ifanc i gyd yn rhy fach i'w tagio. Mae eogiaid yr Iwerydd aeddfed a rhywogaethau llysywen bendoll yn rhywogaethau problemus hefyd oherwydd, yn sgil hanes eu bywyd, byddai angen eu dal a'u tagio yn y môr ac felly ni fyddai eu hafon wreiddiol yn hysbys.

Cyfleoedd partneriaeth a chyllido
Mae amrywiaeth o gyfleoedd partneriaeth a ellir eu defnyddio i ddatblygu'r gwaith hwn. Mae gan reoleiddwyr eraill ddiddordeb uniongyrchol gan gynnwys y Sefydliad Rheoli Morol yn ogystal ag Asiantaeth yr Amgylchedd, a Natural England sydd eisoes yn cydweithredu ar olrhain gwangen ym Môr Hafren. Mae cyfleoedd partneriaeth eraill yn cynnwys y sector prifysgolion, a’r trydydd sector, gan gynnwys cyrff megis cymdeithasau genweirio, ymddiriedolaethau afonydd, a grwpiau sectoraidd fel Ynni Morol Cymru. Mae gan ddatblygwyr cynllun rôl allweddol hefyd.

Mae cyfleoedd cyllido'n heriol ar hyn o bryd oherwydd bod y rhan fwyaf o gyllid Ewropeaidd wedi'i dynnu'n ôl. Mae cronfeydd ymchwil eraill ar gael i roi cynnig amdanynt, a chyflwynwyd cynnig Cyngor Ymchwil yr Amgylchedd Naturiol i ariannu olrhain arae ym Môr Hafren. Mae sicrhau cyllid o'r ffynonellau hyn yn hynod gystadleuol ac ansicr.

Mae'r model cyllido a argymhellir yn yr adroddiad hwn yn rhagweld y bydd y llywodraeth yn cefnogi adnodd strategol craidd o arbenigedd ac offer, a ategir gan gynigion cyllido eraill, efrydiaethau ymchwil a chyfraniadau datblygwyr.

Executive summary

Background
This report is part of a wider piece of work commissioned by Natural Resources Wales to identify how to collect data on the distribution and movements of key fish species around marine renewable deployments in Wales, to address identified evidence gaps.

The review focuses on eight diadromous species, including Atlantic salmon, sea trout, twaite and allis shad, river and sea lamprey, European eel and European smelt.

Primary evidence gaps were defined as: presence / absence in designated resource areas, migration routes of different life stages, and the duration of presence and / or residence time in resource areas. Secondary information gaps included: species / life stages specific information on swimming depth, swim speed and site fidelity to natal rivers. The information is required to allow Natural Resources Wales to make evidence-based decisions in relation to marine developments, management marine protected areas and protected diadromous fish populations.

Approach
The review was commissioned in two parts, the first looking to identify the best available methods to provide evidence for the identified species and evidence gaps, the second part comprising the design of acoustic tracking arrays focused on the resource areas and known developments around Wales. This report looks at the second part of the project scope. It has been prepared by a partnership including Swansea University, The Atlantic Salmon Trust (AST), and the Game and Wildlife Conservation Trust (GWCT).

Equipment and frequency choices
Acoustic tagging systems using 69 kHz tags and acoustic receivers are well developed systems, with highly reliable tags which can last for some years and robust receivers which can be deployed for up to a year in ideal conditions. The report concludes that 69 kHz equipment is the method of choice for marine surveys although other high frequency systems could have utility in fine scale studies of turbine impact.

Array designs
Designs have been produced covering tidal range and tidal stream resource areas in North, South West and South Wales. Given the scale of these areas and the cost of acoustic receivers, arrays for these larger areas have been designed as coarse grids, with receivers typically at 5 km intervals. Within these resource areas, where there are known development proposals, the designs aim to provide quantitative data on availability and residence times in the immediate development area.

Array costings
Array costs include both capital and maintenance costs. Capital costs are based on the current costs obtained from manufacturers, with the calculations undertaken using Innovasea costs; these have been used as Innovasea equipment is most

widely used and because these costs result in the highest (and hence conservative) figures.

Maintenance costs have been calculated based on the assumption that eight receivers can be deployed each day and six can be retrieved, serviced and returned to their allocated site. The cost of a Research Vessel (RV) has been assumed to be £1,000 per day including fuel and crew and 10% contingency has been applied to capital costs to account for losses of equipment and minor costs such as battery replacements and mooring repairs. Costs are detailed in Table 2.

Tagging – use of sentinel rivers and species limitations
With multiple species distributed across many river systems it is clearly not possible or sensible to tag representative samples from every system. The approach adopted in the report is to select 'sentinel' rivers to represent the area, including rivers which, taken together, allow tagging of all the species of interest. The rivers selected include the: Dee and Conwy in North Wales, the Teifi and Dyfi in West Wales, and the Tywi, Tawe, Usk and Wye in South Wales.

It is not possible to acoustically tag all life stages of all species. Suitable tag types for each species are described in section 3.10. Glass eels, juvenile shad and juvenile lamprey are all considered too small to tag. Adult Atlantic salmon and lamprey spp. are also problematic species because due to their life history they would have to be captured and tagged at sea and therefore their river of origin would be unknown.

Partnerships and funding opportunities
There are a range of partnership opportunities which can be used to develop this work. 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.

1. Background and scope

Swansea University, the Atlantic Salmon Trust, and the Game and Wildlife Conservation Trust, have been commissioned by Natural Resource Wales (NRW) to review methods on how to collect data on distribution and movements of key fish species around marine renewable deployments in Wales in order to inform monitoring and licencing discussions. The review focuses on eight diadromous species, including Atlantic salmon, sea trout, twaite and allis shad, river and sea lamprey, European eel and European smelt.

The review was asked to consider primary and secondary evidence gaps. Primary evidence gaps were defined as:

i) presence /absence in designated resource areas,
ii) migration routes of different life stages and
iii) duration of presence and/or residence times in resource areas.

Secondary information gaps included species/life stage specific information on swimming depth, swim speed and site fidelity to natal rivers.

The information is required to allow NRW to make evidence-based decisions in relation to marine developments, management of Marine Protected Areas and protected diadromous fish populations.

An initial review of available monitoring methods and how they might best be used together (Clarke *et al.,* 2021a) has been completed. The report concluded that a combination of methods, including eDNA studies and acoustic tracking with ID only tags and sensor tags, was needed. Archival tags and satellite tags could also add value for some species and situations. Used together these techniques can provide NRW with evidence to support assessment of Marine Renewable Energy (MRE) developments around Wales.

A second part of the work requested was the design and costing of the installation and operation of acoustic tracking arrays and associated tagging programmes. This report comprises the second element of the review and includes the design, deployment and operation of passive acoustic detection arrays, together with tagging options to collect information on the target species. The key deliverables are:

- size and configuration of arrays
- tagging effort
- data analysis requirements to deliver an effective evidence base
- capital and annual maintenance costs
- potential partners
- future funding options.

The proposed arrays (hubs) are required to be capable of detecting both the finer scale movement and wider scale distribution of targeted species in the areas of interest. The hubs will facilitate data collection on tagged diadromous fish and would have the ability to detect other acoustically tagged animals of interest. The objective of running these arrays is to improve the primary and secondary evidence gaps previously specified in the monitoring report and with respect to the spatial and temporal distribution of tagged fish.

2. The resource areas

Resource areas for Marine Renewable Energy are set out in the Welsh National Marine Plan (WNMP; Welsh Government, 2019) for tidal range, tidal stream, and wave energy (Figure 1). It is considered that tidal stream and tidal range technologies are more likely to impact fish or fisheries, and the proposed array designs focus primarily on the tidal stream and tidal range areas currently identified. Designs are also provided for ‘hotspots’ in areas which are subject to existing consent or current application or plans.

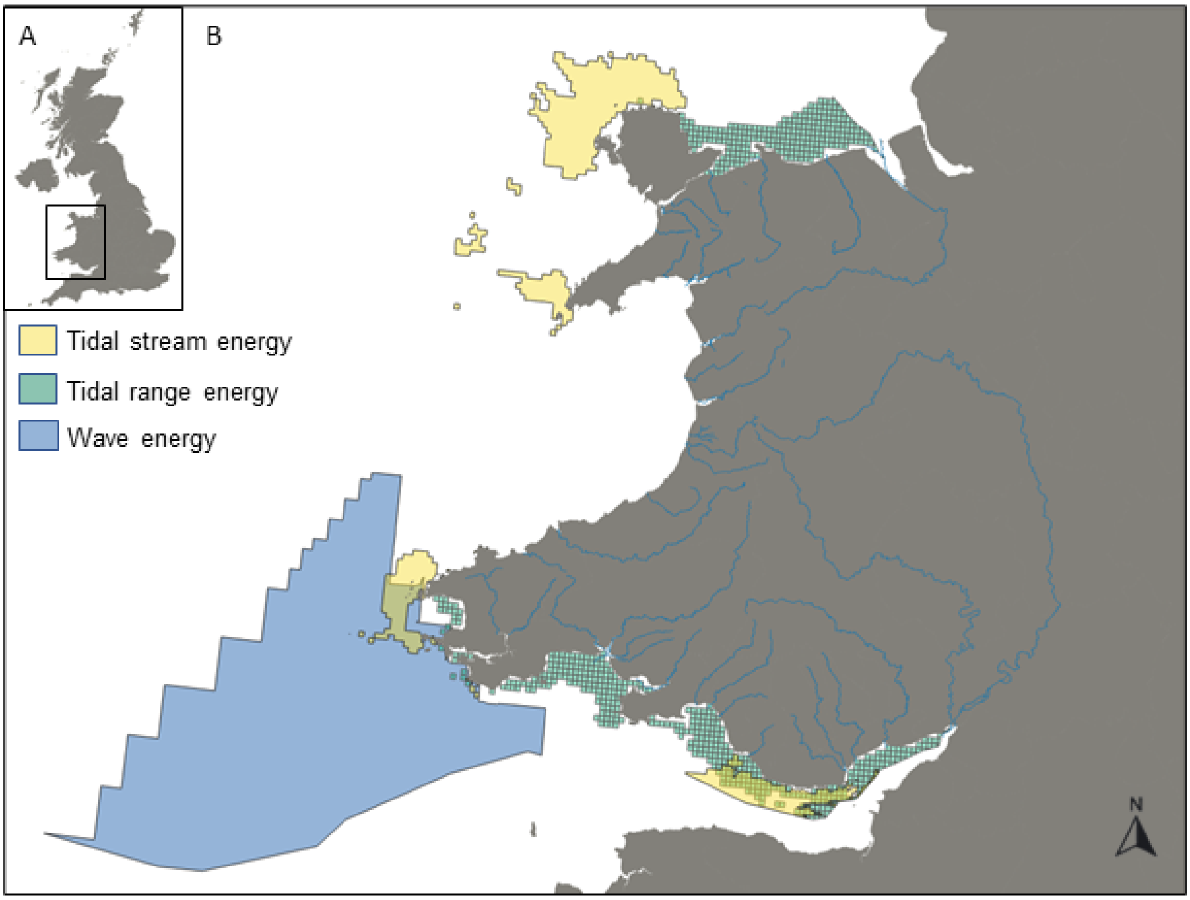

Figure 1. Map of the three types of marine energy resource areas along the Welsh coastline. Including wave energy (blue), tidal stream energy (yellow) and tidal range (green).

3. Acoustic systems description and recommendation

3.1. Overview

Acoustic telemetry comprises attaching or inserting an acoustic tag to an animal that will then be detected and decoded when in range of passive listening receivers. Unlike radio tags, acoustic tags require the fish to remain in water to be detected by a receiver.

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. It is possible to implant acoustic transmitters in fish and track their movements over increasingly long periods of time; up to 10 years with larger tags. 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).

Acoustic tags are detected by passive fixed hydrophones (receivers), which can detect tags in both freshwater and seawater. In marine studies receivers are typically deployed as fixed lines, fences or in matrix arrays.

Four main manufacturers produce tracking systems: Innovasea, Thelmabiotel, Lotek and Sonotronics. Detailed discussions with each manufacturer were undertaken to understand their commercial product range, as well as products under development in order to provide the most appropriate recommendations.

Most studies use simple ‘pinger’ tags, operating at 69 kHz, which broadcast a signal coded using pulse position modulation (PPM) identifying the individual fish. These ‘pulse trains’ may last a few seconds and typically contain some 8-10 pings.

More recently tracking systems have also been produced at 180 kHz and 307 kHz (Innovasea) and 416 kHz (Lotek). These higher frequency systems have a reduced detection range (<200 m) but are less impacted by ambient noises. They also use different coding systems (digital binary phase shift key based systems) with very short signals - microseconds in the case of the Lotek system. This allows improved position fixing accuracy (+/- 1 m in 3 dimensions) in fine scale studies.

Manufacturers can provide tags with sensors such as temperature, pressure, acceleration, and other parameters. These sensor tags send additional information such as pressure (depth) added to the pulse train, which is collected when the tags are detected by a receiver. They have value in delivering the secondary information gaps, for example identifying swimming depth and speed of tagged fish within the resource areas. However, they only provide instantaneous values and are not capable of storing data or download historical information to the receivers. Further information is provided in Clarke *et al.,* 2021a.

The range of receivers and tags produced by Innovasea, Thelmabiotel, Lotek and Sonotronics are summarised together with current costs in Annex A, B and C; Data storage tags (DST) and satellite tags are described in Annex D and E.

3.2. Tag range

Detection range is determined by a combination of factors, including frequency and tag output. Sound attenuation increases with frequency, significantly reducing detection range at higher frequencies. For example, a V7 Innovasea tag (69 kHz, 137 dB) can be detected up to 500 m away from a receiver on ideal conditions when the maximum range of a V5 Innovasea tag (180 kHz, 143 dB) will be 200 m (see Appendix B for detailed detection range value of each tag).
Local conditions such as background noise, biofouling, tides, waves, wind condition, nature of substrate or turbidity also reduce the detection range. Therefore, before finalising array configuration some basic range tests are strongly advised to confirm design assumptions.

3.3. Tag size

A general principle of tagging studies is that researchers aim to use the smallest / lightest tag available, consistent with the project aims, to reduce tag burden on the tagged animals. For smaller fish this may require compromises between tag size, power output (range), frequency and tag life.

Tag size and consequent tag burden is limited by the size of the emitter and its battery size. Lower frequencies require larger emitters; for example, the smallest diameter emitter for 69 kHz is approximately 6 mm in diameter. Higher frequency systems can use emitters with smaller diameter; Innovasea offers a V3 (3 mm diameter, <0.3 g in air). Lotek JSATS are the smallest tag available with the L-AMT-1.416 weighing only 0.28 g.

However, in the marine environment these small high frequency tags have shorter range (less than 200 m; Appendix B) because of range limitations caused by attenuation. This limitation makes them unsuitable for large marine arrays, although they may be useful for studying behaviour close to deployed MRE devices.

3.4. Battery / Tag life

Battery life of acoustic tags is determined by the battery storage, tag power output, the interval between pings, the temperature in which the tag is stored and operated, and the time between manufacture and activation.

Smaller tags have smaller batteries, therefore a shorter battery life, for a given set of characteristics. Therefore, studies involving the tagging of smaller fish, e.g., juvenile Atlantic salmon, may involve more compromises than those looking at adult fish with large tags.

Transmitter batteries, like all batteries, are subject to discharge over time in addition to depletion associated with baseline tag operations, even when the tag is not activated. This is a particular issue for smaller tags. For example Innovasea V7 tags have a recommended pre-activation shelf life of two months at a recommended storage temperature of 20 to 25°C in a dry location. Holding transmitters significantly longer than the recommended deployment window introduces several factors that need to be considered.

Battery consumption during baseline operations when tags are not activated is less predictable than when tags are active and pinging. To add certainty to study results, when tagging takes place, it is recommended that a tag life control study is performed in parallel, with a subset of tags, holding the tags in a similar environment/temperature to the fish for the expected duration of the tag's life. Test tags are then monitored over time, making note of when each battery stops transmitting.

3.5. Tag collision and false detections

For 69 kHz tags the ID pulse train comprises a series of 'pings' over some 3-5 seconds. However, if multiple tags are in an area, the signals can collide resulting in a false signal. This can also happen with echoes - e.g., from a harbour wall, anthropogenic or natural background noise. This is largely eliminated by the coding system which contains a 'checksum' to identify false values. However false, apparently valid, detections can still be generated, particularly if a large number of fish are in the same area, e.g., in studies of movements around impoundments or weirs.

This can be overcome in a number of ways. To avoid repeat clashes in the same area Innovasea tags pseudo randomises pulse train intervals, varying the gap between pulse trains i.e., the ping intervals, so that a 30 seconds interval rate can in reality be 15 to 45 seconds interval. Other frequencies may also be used to avoid clashes; Thelmabiotel offers tags on frequencies from 69-77 kHz and their receivers can be programmed accordingly.

Recently developed high frequency tags use a different coding technique with extremely short signal lengths. That minimises the risk of collisions and these tags are promoted for ‘high residence’ work where many fish may be in the same area at the same time.

3.6. Frequency choices

Acoustic detection at a specific frequency is affected by several factors, including salinity, background noise, turbidity, biofouling, nature of the ground etc. It is therefore necessary to have prior information on the environment where the acoustic system will be deployed, to choose the most adapted frequency.

3.6.1. 69 kHz

The commercial systems currently in widespread use were initially developed using the 69 kHz frequency, which was considered to represent the best available option for marine studies with a good balance between background noise and attenuation. Research uptake was extensive (though largely limited to fisheries as this frequency is within the hearing range of many marine mammals). This frequency is now widely used, facilitating wider collaborations, and improving the chance of detection of a tagged fish. With the 69 kHz frequency, the detection range would normally be between 100 m and 1 km in the marine environment, depending on the power output of the tag and the local conditions where the receivers are deployed. Most researchers in the UK use Innovasea V7 or V9 tags (or the Thelmabiotel equivalent) with typical ranges in reasonable conditions being 200-500 m, though this reduces in highly turbid or noisy conditions.

3.6.2. 180 kHz

The Innovasea 180 kHz system allows smaller tags ranging from the V4 (0.42 g in air), to the V9 (3.7 g in air). These have a reduced tag burden for smaller fish. The signal from the higher frequency 180 kHz tags is, however, more quickly attenuated in sea water, and therefore range is limited compared to 69 kHz for any given power output. With the 180 kHz frequency, the detection range is typically between 50 to 200 m, in marine environments depending on the local conditions where receivers are deployed.

3.6.3. 307 / 416 kHz

High frequency 307 / 416 kHz frequency systems are also available from Innovasea and Lotek. These systems use a binary phase shift, keying system with very short ID pulses (microseconds). They are designed for high accuracy (+/- 1 m) positioning in noisy environments and are ideal for studies of movements around weirs etc. Tags can be built in very small tag sizes; Innovasea offers a V3 (3 mm diameter, <0.3 g in air, 70 days of battery life at a 10 s ping rate).

Lotek developed Juvenile Atlantic Salmon Acoustic Telemetry System Acoustic Micro Transmitter (JSATS AMT L-AMT-1.416) are the smallest tag commercially available at the present time (0.28 g, 48 days of battery life at a 10 s ping rate). They work at 416 kHz frequency and are hence subject to significant attenuation, although Lotek claim that the emitter they use is extremely efficient at providing a high output, and hence a usable range (100 m plus) for fine scale studies, even in marine environments.

3.7. Acoustic receivers

All four manufacturers produce passive receivers that work on 69 kHz and there is a degree of compatibility between the systems with some tags detectable across different manufacturers equipment types. This compatibility is only partial and there is both convergence and divergence occurring in development paths (see section 3.6).

At higher frequencies systems are divergent, with Innovasea offering equipment which operates at 180 kHz and 307 kHz; the Lotek JSATS system operates at 416 kHz.

Passive receivers are the data collection workhorses of acoustic tracking studies. There are a number of key elements of functionality which vary between receivers, with progressively increases cost:

- Basic receivers which have no transponding capability (e.g., Innovasea VR2W)
- Receivers which can undertake some basic communication with a surface unit (e.g.: location, battery status, limited detection information). These receivers are also capable of other functions such as emitting a regular signal for range testing and synchronisation of clock times. (e.g., Innovasea VR2Tx)
- Receivers with inbuilt acoustic release capability (Innovasea VR2AR, Thelmabiotel TBR 800)
- Receivers with real time connectivity (Thelmabiotel TBLive)
- Innovasea VR4 (designed for long term deeper water deployments) with up to six-year battery life; dual frequency (69/180 kHz) option; and full acoustic download capability.
- Other functions include rechargeable batteries for some units, programmable reception frequencies etc.

Most data are downloaded from receivers by retrieving the receiver and communicating with it via a portable computer fitted with a Bluetooth connection.

However, alongside the receivers, manufacturers have their own ‘deck box’ systems for communicating with receivers via an underwater modem (e.g., Innovasea VHTX), typically performing a range of functions (communicate and download data of a receiver). The deck box can also detect tags via their own transducer, enabling it to act as an active tracking system.

More complex receivers (e.g., Innovasea Fathom Live receiver, or Thelmabiotel TBLive) transmit recorded detections in real time. These are typically cable based systems that can be deployed onshore or mounted in a floating system with solar panels and radio/satellite links to download data. At the most advanced level are drones, such as the wave glider system, which can be used for active tracking and / or be programmed to visit sites remotely and download receivers such as the Innovasea VR4.

3.8. Acoustic systems compatibility

The 69 kHz tags are coded according to a number of different algorithms or tag ‘protocols’. The separation time between the first two pings in the code train identifies the tag protocol, enabling the receiver to select the correct algorithm to decode and identify the tag. Receivers are set to a map code; each map code includes a series of tag protocols that the receiver is capable of decoding.

There is a degree of compatibility between manufacturers, with some 69 kHz receivers able to detect and decode data from tags made by other manufacturers. This is summarised in Figure 2 below (sourced from European Tracking Network, 2020). Thus, as an example from the table, A69-1303 tags have been produced by all manufacturers and would be detectable by any receiver set at Map 114 or lower. However, they would not be detected by a receiver set to Map 115. An Innovasea A69-1601 tag would be detected by receivers set to Map 113 and above but would only be decoded by Innovasea receivers.

This is a complex issue and a current area of contention, driven by both technical and commercial considerations. Innovasea have recently adopted an encoded set of tag protocols which renders their newer tags incompatible with the receiver equipment of other manufacturers. In parallel Lotek and Thelmabiotel are working on open tag protocols; OPI (plain tags) and OPS (sensor tags), which will enable their equipment to work together. These are currently undergoing initial trials.

Tag Protocols

Old name	Thelma	Sonotronics	Lotek	MAP-110*	MAP-112*	MAP-113*	MAP-114*	MAP-115*
	OPi	OPi	OPi	-	-	-	-	-
	OPs	OPs	OPs	-	-	-	-	-
R64K	A69-1303	A69-1303	A69-1303	A69-1303	A69-1303	A69-1303	A69-1303	-
S256	A69-1105	A69-1105	A69-1105	A69-1105	A69-1105	A69-1105	-	-
R04K	A69-1206	A69-1206	-	A69-1206	A69-1206	-	-	-
R256	A69-1008	-	-	A69-1008	-	-	-	-
*Unique code sets **NON**-compatible between manufacturers*								
	HS256	ACT	Lotek MAP			A69-9006	A69-9006	A69-9006
	DS256				A69-9005			
	R01M				A69-9004	A69-9004	A69-9004	A69-9004
	S64K				A69-9002	A69-9002	A69-9002	A69-9002
					A69-9001	A69-9001	A69-9001	A69-9001
						A69-1602	A69-1602	A69-1602
					A69-1601	A69-1601	A69-1601	A69-1601

N.B. Protocols of the same colour are **compatible**. For example, Thelma A69-1303 protocol equipment is compatible with all other equipment using A69-1303, **except** for Vemco/Innovasea MAP-115, where this protocol is no longer supported.

OPi and OPs are new Open Protocols, available for **ALL** manufacturers and supported by the ETN. OPi for ID tags and OPs for sensor tags.

*Vemco/Innovasea protocol sets

Figure 2. Tag protocol compatibility within the European Tracking Network.

3.9. Receiver system choices

The scope of this study is entirely marine. In saltwater attenuation of the signal increases with frequency (Figure 3) resulting in reduced range as the frequency of tag and detection systems increases. For marine applications, manufacturers developed the 69 kHz frequency systems as they provide a good balance between range, background noise levels and tag size. Most systems deployed in marine situations use 69 kHz systems, primarily manufactured by Innovasea or Thelmabiotel.

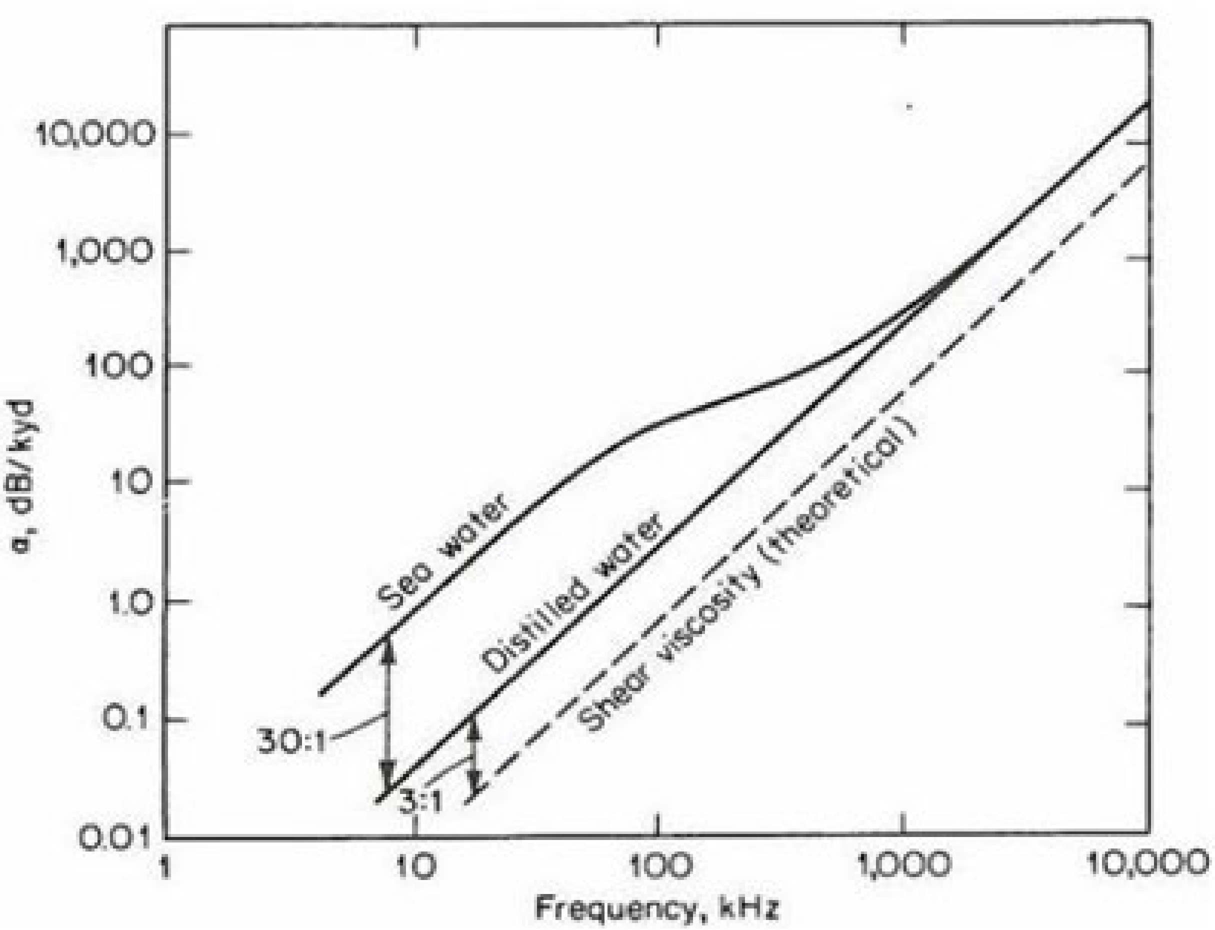

Figure 3. Signal attenuation in salt water.

69 kHz systems remain the system of choice because of tag range, and at least in Europe, the widespread use of 69 kHz receivers by other research groups, which provides the opportunity for additional detections in other areas. This recommendation is primarily based on cost as the reduced range of higher frequency systems would greatly increase the number of receivers required for the same level of detection and would also increase the maintenance costs. The 69 kHz system also has the advantage of maturity, known tag reliability, and the widest range of tag and equipment availability.

The array designs in this report are therefore based on the use of a 69 kHz system.

The higher frequency / fine scale systems such as the LOTEK JSATS system may however, have accuracy advantages and may have specific marine applications for geographically restricted (fine scale) studies, such as evaluating collisions and movements in close proximity to structures.

3.10. Tag Choices

From the information already discussed; matching study requirements with tag types and tag parameter selection is extremely important (Table 1).

Ideally for most marine studies tags would have long range (500 m or more), a rapid ping rate to reduce the chance of a fish swimming past a receiver undetected and have a small tag burden. Where the fish are large, tags such as the Innovasea V16 (16 mm diameter, 36 g in air) can output signals at high power, with a range of up to 1 km and a life of up to 10 years, allowing fish to be studied for many years. These large tags (or somewhat smaller versions) can provide a relatively ideal solution for large fish such as yellow or silver eels (Thorstad *et al.,*2013).

In most situations, unless the fish is large, that combination is not practical, and researchers have to compromise or use more complex programmable tag functions to match reasonable tag burden with project goals. For example, the Unlocking the Severn (UTS) group, whose primary focus is in-river movements of twaite shad, have their tags (Innovasea V9) set to a 1-minute average ping rate from April - June/July, then a 10-minute rate for the rest of the year (to preserve tag life but provide a chance of detection). This allows the fish movements to be observed in detail in-river, while still enabling at sea detection in arrays such as those in Swansea Bay and the Taw Torridge estuary (Davies *et al*., 2020).

For marine studies most researchers in Europe currently use tags in the 6 – 9mm range. The lightest 69 kHz tags are the V7-2L supplied by Innovasea (1 g in air, 0.7 g in water) and the LP6 developed by Thelmabiotel (1.2 g in air, 0.7 g in water). These tags can be supplied with different battery sizes and programmable power output settings, and V7-2L will last for approximately 132 days at a constant 60 second ping rate and 253 days at a 180 second ping rate, respectively. Tags of this size are widely used by Atlantic Salmon Trust and Swansea University for tagging salmon and sea trout smolts but are also suitable for tagging other small fish.

V9 tags are currently being used by the ‘Unlocking the Severn’ project to tag twaite shad in the River Severn and by Swansea University to tag adult sea trout in the River Tawe. These are programmed to allow a tag life of ca 3 years, hence allowing the fish to be followed at multiple spawnings.

Some life stages in Table 1 are too small to be tagged. These include juvenile twaite shad, sea and river lamprey and glass eel.

Satellite and DST options are also described for adult sea trout and silver eels. These are not directly linked to the deployment of arrays but are potentially part of the wider solution (Clarke et al 2021a) and are included for completeness.

Table 1. Limitations of tag type per species life stage.

Species and life stage	Tag type	Experimental objective	Justification	Tagging limitation
Salmon smolt	Innovasea V7-2L, equivalent or smaller	Determining emigration routes, use and presence in MRE/hotspots	Smallest tag available at 69 kHz	Smolts > 14 cm
Salmon smolt	Innovasea V7-2LP	Determining swimming depth	Smallest sensor tag available at 69 kHz	Smolts > 14.5 cm
Salmon adult	Innovasea V9, equivalent or smaller	Determining emigration routes, use and presence in MRE/hotspots	Tag size adapted to fish size	Salmon > 25 cm
Sea trout smolt	Innovasea V7-4L, equivalent or smaller	Determining emigration routes, use and presence in MRE/hotspots	Smallest tag available	Smolts > 14 cm
Sea trout smolt	Innovasea V7-4LP	Determining swimming depth	Smallest sensor tag available at 69 kHz	Smolts > 14.5 cm
Sea trout adult	Innovasea V9, equivalent or smaller	Determining emigration routes, use and presence in MRE/hotspots	Tag size adapted to fish size	Sea trout > 25 cm
Sea trout adult	G5 Data storage tag	Determining swimming behaviour	Most accurate DST available	Sea trout > 32 cm
	Satellite tag	Determining precise migration route outside of acoustic arrays	Smallest PSATs available	Sea trout > 80 cm
Shad juvenile	None		Too small to tag with current available acoustic tags.	
Shad adult	Innovasea V9, equivalent or smaller	Determining emigration routes, use and presence in MRE/hotspots	N/A	Shad > 25 cm

Species and life stage	Tag type	Experimental objective	Justification	Tagging limitation
Shad adult	Innovasea V7-2LP	Determining swimming depth	Smallest sensor tag available at 69 kHz	Shad > 23 cm
Sea lamprey juvenile	None		Too small to tag with current available acoustic tags.	
Sea lamprey adult	Innovasea V7 or V9 acoustic tags or sensor tags subject to size	Determining swimming depth	Tag size adapted to fish size	Sea lamprey >30cm
River lamprey - juvenile	None		Too small to tag with current available acoustic tags.	
River lamprey adults	Innovasea V7-2LP	Determining swimming depth	Too small to tag with current available acoustic tags.	
Silver eels	Up to Innovasea V16, equivalent or smaller	Determining emigration routes, use and presence in MRE/hotspots	Tag size adapted to fish size	Eels > 37 cm (for V9)
Silver eels	Satellite tag	Determining precise migration route outside of acoustic arrays	Smallest PSATs available	Eels > 80 cm
Yellow eels	Up to V16 depending on Eel size	Determining extent of inshore habitat utilisation during prolonged growth phase.	Tag size adapted to fish size	Eels > 37 cm (for V9)
European smelt	Innovasea V7-2L, equivalent or smaller	Determining emigration routes, use and presence in MRE/hotspots	Smallest tag available	Smelts > 18 cm

4. Array design strategies

The main information gaps for all of the species include detailed understanding of migration paths, information on the proportion of the stock likely to be affected by specific developments and detailed information on interactions with devices and the extent of avoidance behaviour. As detailed in Clarke *et al*, 2021b, information on avoidance behaviour and possible interactions with devices at a fine scale is likely to require the use of fine scale tagging systems combined with split beam and multibeam active acoustic technology.

Our primary array design focuses on the identification of the main migration paths, particularly in the resource areas, together with quantification of proportional presence of populations in areas of specific development proposals. Fine scale tracking and active acoustic designs would only be required where these results suggest that the development could pose a population scale risk.

Various approaches have been used by others to design receiver deployments to look at migration paths. Generally, designs are constrained by cost and logistics, given the limited range of the tag and receiver combinations which can be used for fish of interest. Broadly approaches fall into two categories, fence lines or grid arrays.

The fence line approach generally comprises a line, or lines of receivers, typically extending from the coast across the anticipated migration path. These studies generally aim to produce an efficient fence line in order to quantify the proportion of the tagged fish passing through the area and to identify factors such as distance from shore, use of particular pathways etc. However, maintaining an efficient line in a dynamic marine environment is particularly difficult.

An alternative approach is to design a grid covering the area of interest. This approach does not necessarily seek full efficiency but relies on the fact that the fish have to pass multiple receivers rather than a single fence line in order to transit the area of interest. In this scenario the expectation is that the majority of tagged fish will be detected again, thereby signalling migration paths.

A third approach, used by Swansea University to look at the proportion of twaite shad tagged by UTS in the River Severn, combines both approaches. In this design the area of interest is enclosed by a fixed receiver fence which is designed to provide a high degree of efficiency. The area within the fence is populated with a more widely spaced grid of receivers, enabling the detection of fish which have crossed the outer receiver fence. Detections within the inner receiver grid allow the efficiency of the outer fence to be estimated, both as fish enter the bay and as they depart.

In effect, the approach is similar to a mark recapture experiment. The advantage of this approach is that the inner grid provides confidence in the data provided by the outer fence and the combined approach enables estimation of both the proportion of tagged fish entering the area of interest, as well as information on residence times, tidal state, and detailed movements within the bay.

Where ‘fence lines’ or receiver rings are proposed we have generally assumed a spacing of 600 m for designs. Based on our own experience these would be reasonably efficient for most V7 and V9 tags or equivalent; essentially it assumes a tag detection range of 300 m. Some V7 tags, however, may have shorter ranges. These will still be detected if they approach fence lines at an oblique angle, and our general approach (below) allows for inefficiency. However, the fence line separations could be reduced if required and resources allowed.

The proposed acoustic array designs use a combination of approaches, with a coarse grid approach used to cover the main resource areas and a combined fence and grid approach covering specific development areas (hotspots). The approach seeks to quantify availability and residence times in the development zones, while providing broader qualitative information on migration paths in the wider resource areas. Wider migrations are expected to be picked up through movements between resource areas and specific targeted receiver deployments where natural features constrain migration paths (e.g. Ramsay Sound, Bardsey). Four additional ‘gates’ have been included to provide additional information on movement up and down the west coast. Outside Wales, other arrays (e.g. Compass), may provide data on wider migrations.

The array designs cover the following resource areas and developments:

- North Wales tidal range area
- North Wales tidal stream area including Minesto, Morlais and Bardsey.
- South West Wales, including Transition Bro Gwaun and Ramsey Sound.
- South Wales; Bristol Channel covering the Pembrokeshire wave and tidal stream areas, including the Milford Haven Marine Energy Test area – META.

An overview of locations is shown in Figure 4 below.

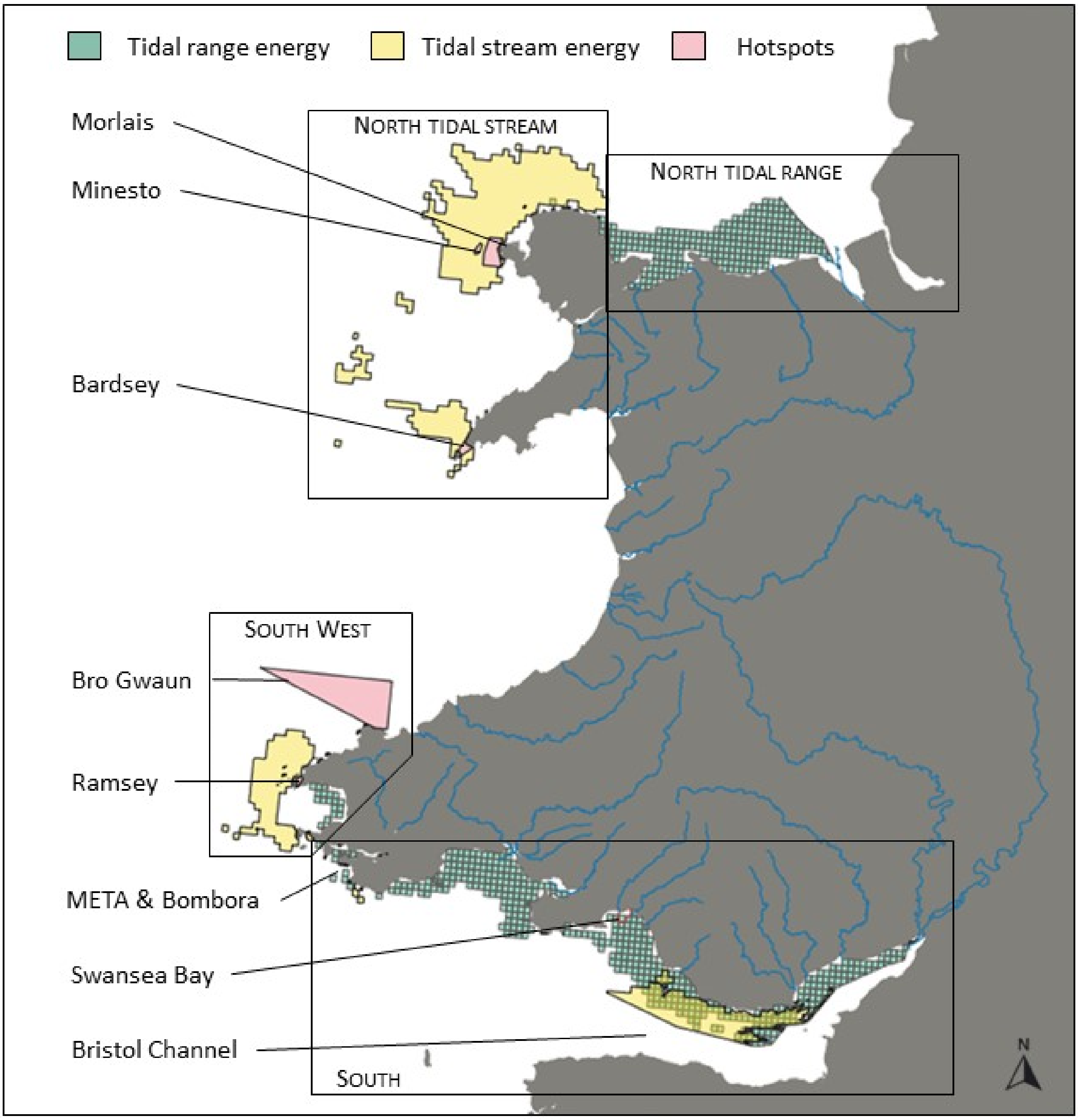

Figure 4. Tidal stream and tidal range Marine Resource Areas of Wales and general location of deployment areas for array designs.

4.1. Overall design

The main factors limiting array design are the logistics, and cost of procuring, deploying and managing receivers. In essence cost is balanced against effectiveness. We have used the following general design principles, modified in some instances to reflect local circumstances:

- Coarse grid spacing for resource areas, ca 5 km apart.
- ‘Fence lines’ around development areas 600 m apart
- Grids within development areas 1000 m apart.

- Receivers deeper than [50 m] are deployed on acoustic releases
- 4 ‘gates’ up the West Wales coast (600 m apart)
- Two to three receivers at the mouth of ‘sentinel’ rivers where fish are being tagged (see section 5).

The complete array (Figure 5) has:

- A grid with 5 km spacing arrays covering all the tidal range and tidal stream resource areas
- A grid with 5 km spacing array to complete the Bristol Channel area [although not fully an NRW responsibility, completion of the grid is needed to properly understand migration in the Bristol Channel area].
- Four acoustic *gates* along the coastline of west Wales. Each gate is composed of six receivers at 600 m spacing, allowing detection of fish 4 km away from the coast. With many species expecting to stay within the nearshore and follow the coastline, these receivers aim to provide evidence of directionality for species such as twaite shad, salmon and sea trout migrating up or down the west coast.
- Seven ‘hotspots’ arrays to cover actual developments generally composed of a 600 m spacing outer ring and a 1 km spacing inner array (in noisy and turbid environment more closely spaced receivers have been included), providing quantitative data for areas where device deployments exist or are expected.

Two to three receivers will also be required in the river mouths of each of the proposed sentinel rivers where tagging will take place (Dee, Conwy, Dyfi, Teifi, Tywi, Tawe, Usk, Wye and Severn). These are critical to confirm the number of tagged fish emigrating to sea. These are included in Figure 5 below and are incorporated in tagging costs.

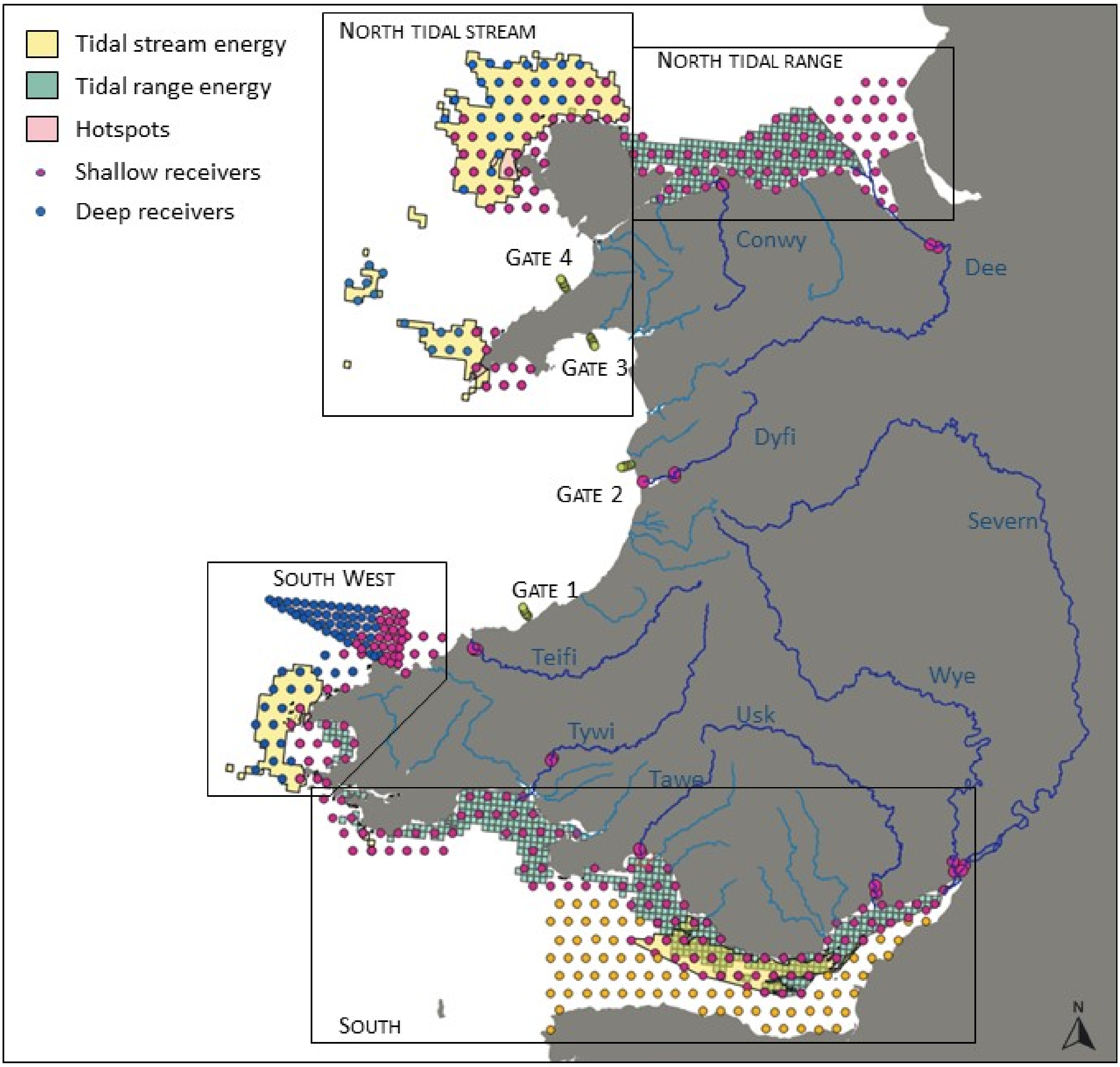

Figure 5. Overview of acoustic array designs covering key Marine Energy Resource areas and developments around Wales. The large pink circles represent the river receivers.

4.2. North Wales tidal range area

We are not aware of detailed locations for tidal range schemes in North Wales at present and have not, therefore, included 'hotspots' in this area. Receivers are deployed at 5 km intervals, to provide general migration data for fish tagged in the Dee and Conwy. The grid has been continued in English waters in order to gain a more robust understanding of movement direction from any species leaving the River Dee (Figure 6).

If a tidal range scheme is proposed, we would recommend adding a ‘hotspot’ based on 69 kHz receivers to collect baseline data; subject to results (i.e., fish being found to be present) we would add a fine scale system at or after construction to look at behaviour in the immediate vicinity of the structure and turbines, with receivers deployed both within and outside the impoundment. (This could potentially be a high frequency system such as JSATS or Innovasea HR).

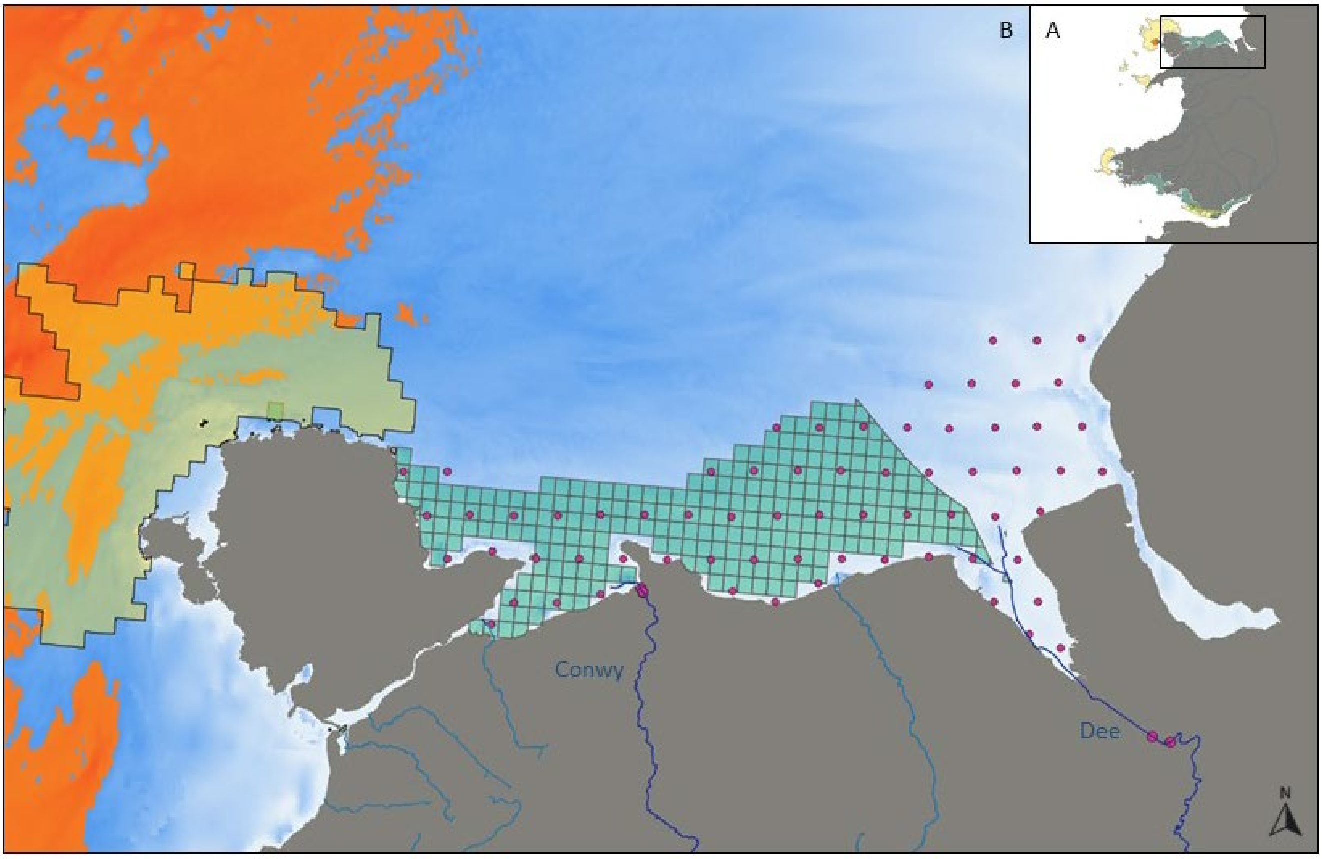

Figure 6. Location of the North Wales resource area (A) and proposed acoustic receiver array for the tidal range resource area in North Wales (B). Pink circles represent receivers located shallower than 50 m.

4.3. North West Wales tidal stream area

The tidal stream area has followed default assumptions with a 5 km grid, although the coarse grid has been extended beyond the resource area boundary to the shoreline to pick up fish travelling close inshore. There are currently three development areas in this zone, Morlais, Minesto and Bardsey sound (Figure 7).

The three known development areas have been treated as hotspots and surrounded with a fence line at 600 m intervals with receivers deployed inside the fence line to enable assessment of the efficiency of the fence line and correct for any inefficiencies. This approach is intended to allow quantification of the number of fish from tagged migratory fish populations entering the immediate development areas (primarily from the Dee, Conwy and Dyfi - see section 5).

The denser receiver distributions in the hotspots will allow quantitative estimates of availability in the areas.

If data from this approach showed that use of the area was at a level which created concern, a fine scale array could be employed covering an area of (say) 500 m x 500 m in the immediate vicinity of the turbines to look at avoidance behaviour and potential turbine strikes. For this type of deployment of 69 kHz receivers in a 100 m interval grid around the turbine, or High Frequency (HF) receivers in a 50 m grid are recommended. Deploying an HF system would improve near field accuracy but would require different tags and receivers; HF receivers would not be suitable for wider area tracking because of range limitations. No fine scale array has been included in the hotspots design at this stage.

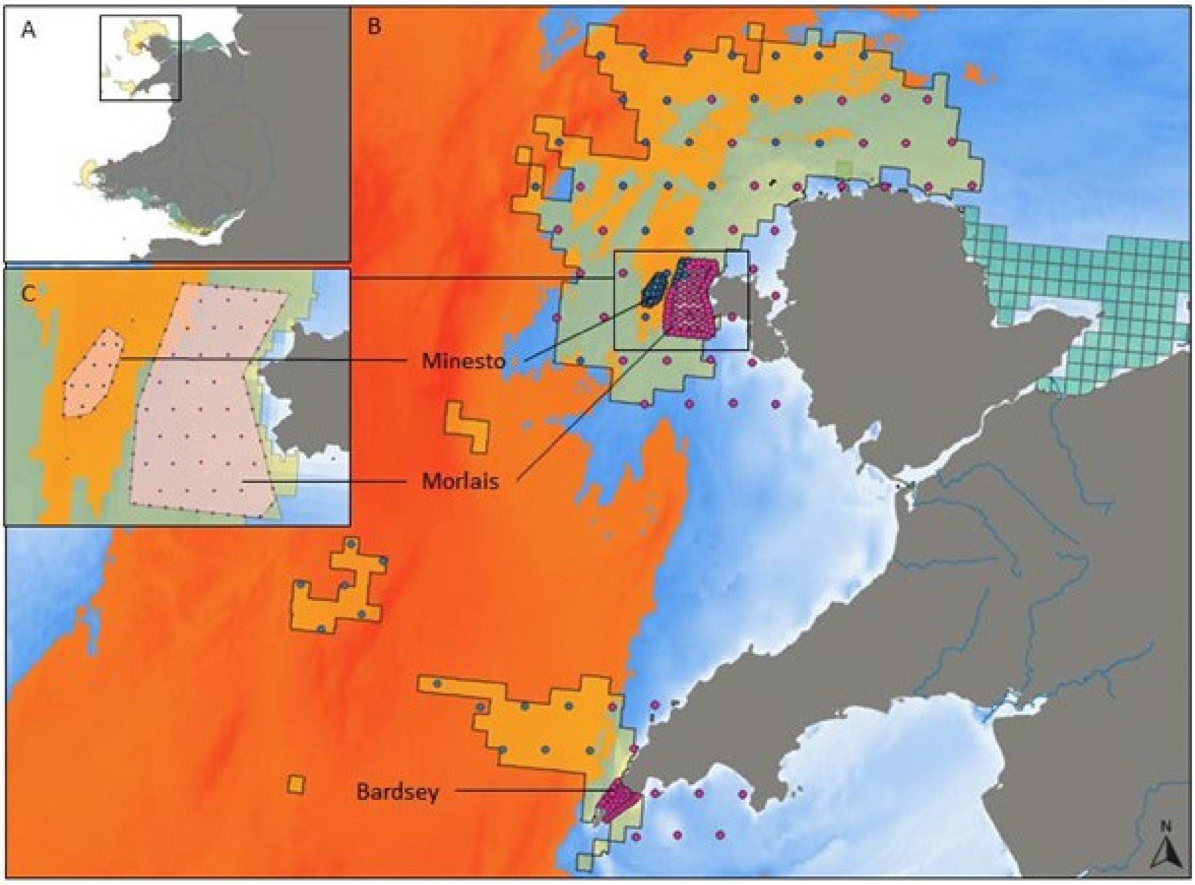

Figure 7. Location of the North West Wales resource area (A), proposed receiver arrays for the North west tidal stream resource area and Morlais, Minesto and Bardsey hotspots (B) and detailed array design for Morlais and Minesto hotspots (C). Pink circles represent receivers located shallower than 50 m and blue circles receivers located deeper than 50 m.

4.4. South West Wales tidal range and tidal stream area

The South West Wales area (Figure 8) includes multiple resource types, with known potential developments including:

- Transition Bro Gwaun (TBG) (a community led turbine development),
- Ramsey sound (existing consented location with a failed turbine; turbine replacement planned by Cambrian Offshore with funding from the TIGER project)

At present the TBG development shows a large area, although the initial development is planned as a single turbine. We have assumed there are secondary plans to extend the initial development and have therefore provided for a 2.5 km coarse grid, following the approach taken for the North Wales tidal stream area. The exact location of the proposed turbine is not known, but once it is determined we would add a hotspot. The design and costing for that would probably be similar to that previously outlined for Minesto.

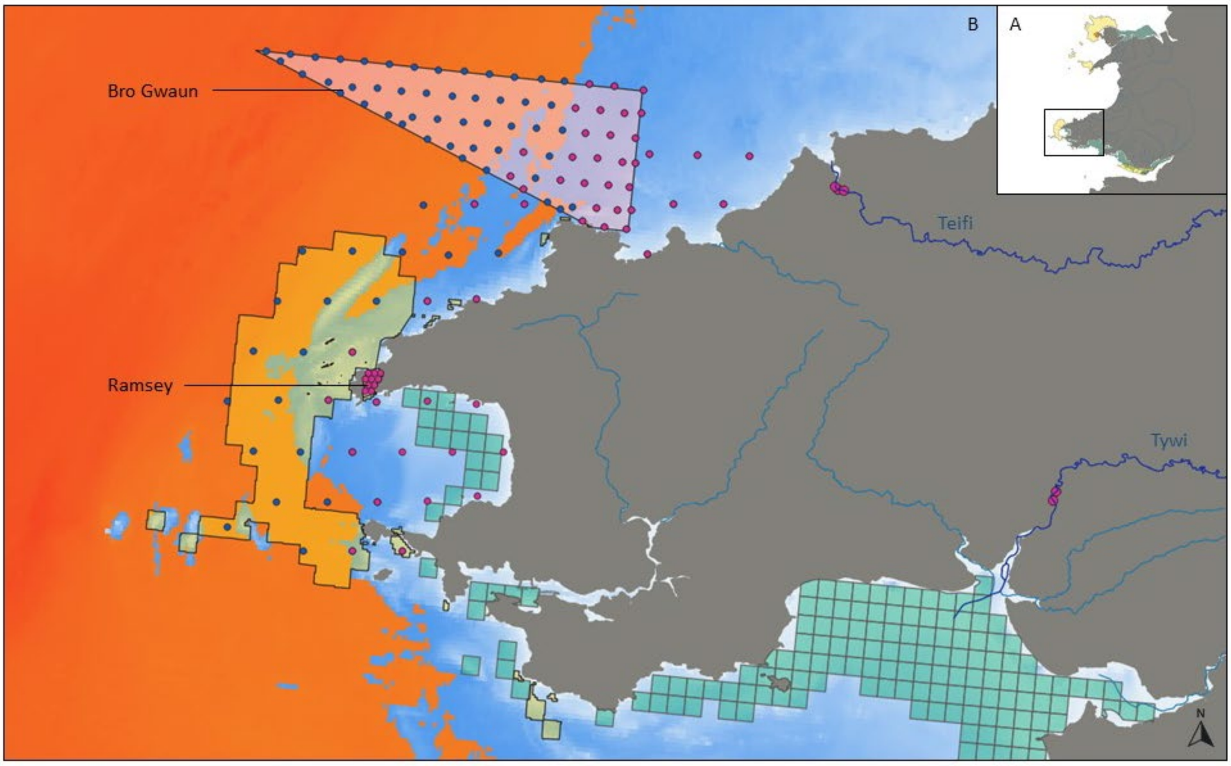

Figure 8. Location of the South West resource area (A) and proposed receiver arrays of the tidal stream and tidal range Marine Resource area and Transition Bro Gwaun (Tidal stream), Ramsey Sound (Tidal stream), developments (B). Pink circles represent receivers located shallower than 50 m and blue circles receivers located deeper than 50m.

The consented turbine for Ramsey is in the channel between the island and mainland. In addition to the hotspot itself, the natural geography makes this a good location to site receivers looking for fish migrating up and down the coastline. The design for this location includes a fence at 400 m intervals at each end of the Channel with a number deployed within the channel itself; this reduced interval reflects high tidal velocities and an expectation of reduced range.

4.5. South Wales tidal range and tidal stream areas

This area includes both tidal range and tidal stream areas. The design includes 5 km spacing to identify migration paths from rivers such as the Severn, Wye, Usk and Tawe (see section 5). For that reason, we have added receivers covering the whole of the inner Bristol channel as an option, though they are costed separately. These are also at 5 km intervals (Figure 9).

There are three hotspot locations:

- The Marine Energy Wales Marine Energy Test Area (META) in Milford Haven
- Bombora (test wave deployment planned for Summer 2021
- Swansea Bay Tidal Lagoon

The Swansea Bay hotspot is currently being investigated by researchers at Swansea University. This has receivers at 600 m intervals in an outer ring, plus a number of receivers deployed within the ring, and has successfully demonstrated the approach used in these designs for development ‘hotspots’.

The META and Bombora sites are covered by a 2 km grid. The tidal stream resource area in south west of Wales is covered by a 5 km grid.

There are no acoustic releases receivers in this area as all sites are less than 50 m in depth.

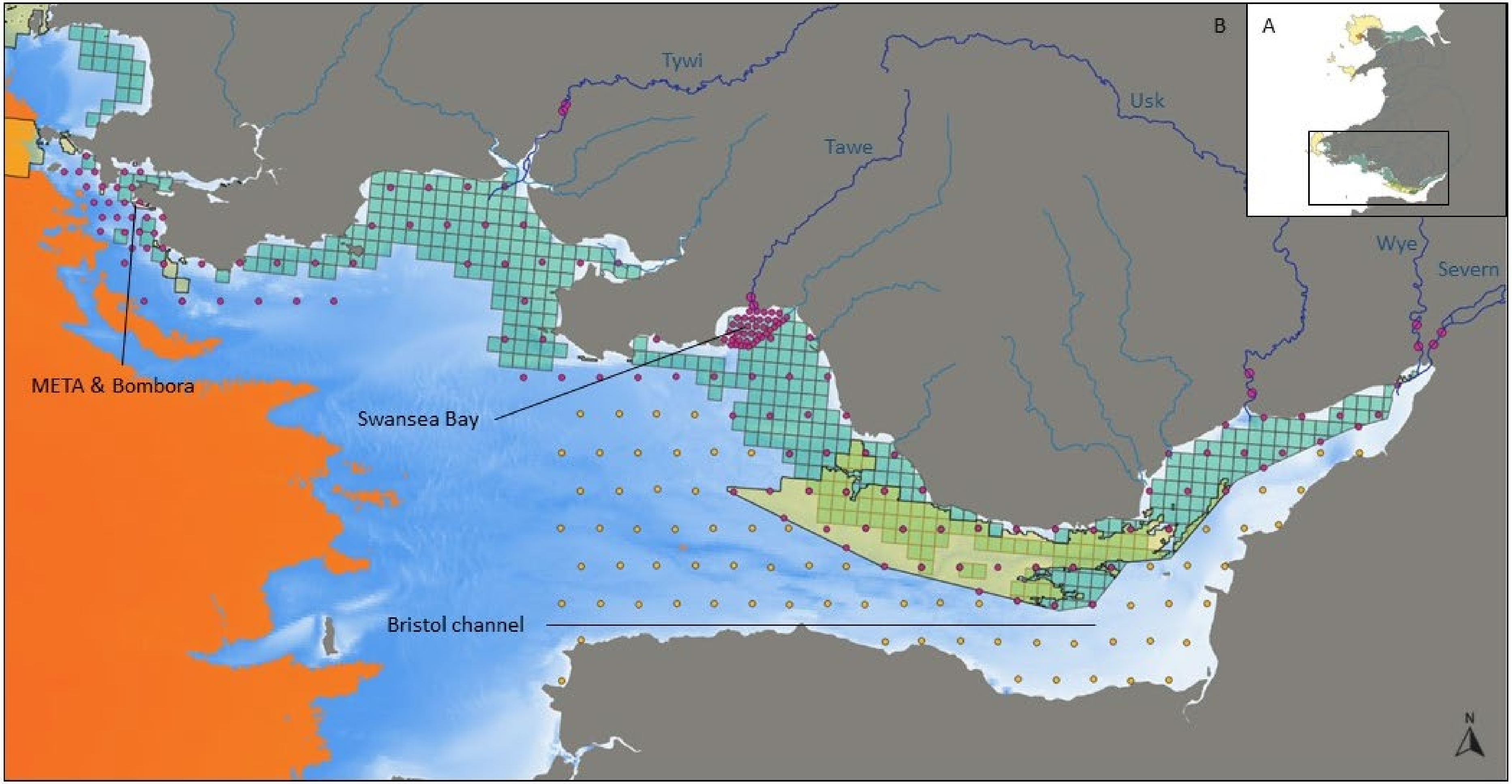

Figure 9. Location (A) and proposed acoustic array for the tidal range and tidal stream resource areas and the hotspots of Swansea Bay, META and Bombora (B). Pink circles represent receivers located shallower than 50 m, orange circles are extra receivers to complete the Bristol Channel

4.6. Acoustic gates

In addition to the main arrays, four ‘gates’ have been included along the West Wales coast to provide information on north/south species migration along the west coast of Wales. Each gate is composed of 6 receivers, spaced at 600 m intervals, and deployed perpendicular to the coast, extending some 4 km offshore (Figure 5).

These gates are intended to complement the deployment of arrays off Pembrokeshire, in Ramsey Sound, and in Bardsey sound. They are situated at the following locations 1) north of the Afon Teifi, near Tresaith; 2) North of the River Dyfi, 3) at the mouth of the river Dwyfor, and 4) at Trefor. These locations are shown in Figure 5.

4.7. Array Costing

The costs included in this section comprise the cost of procuring deploying and maintaining the receiver arrays. Section 5 describes tagging costs. Core staff time is required for array maintenance, tagging and reporting; these costs are included in section 6 (combined costs), where the overall costs for tagging fish and managing the array are bought together.

Costs and designs are derived from extensive experience of the partners in deploying and managing arrays.

Equipment costs

The vast majority of the acoustic tracking equipment deployed in the UK is sourced from Innovasea and to ensure compatibility with existing equipment Innovasea equipment would be advantageous to ensure that fish tagged in Wales would also be detected at existing tagging/tracking programmes elsewhere in the UK and ROI. Equipment costs in the array costings are therefore based on Innovasea equipment and prices which provides conservative (safe) figures, as Innovasea equipment is the most costly. This does not, however, mean that other manufacturers equipment should be ruled out; this would need to be considered at procurement and some comparative trials may also be necessary, and depend on the precise tracking project objectives.

Ideally all receivers would include acoustic releases (the Innovasea receiver with this capability is the VR2AR). However, VR2AR are costly - approximately double the cost of VR2Tx. Our default assumption is therefore the use of VR2Tx. While VR2W receivers are slightly less expensive, VR2Tx have acoustic modem capability allowing boat-based staff to contact the receivers and locate them while deployed. This is important functionality in marine situations, though VR2W may be worth considering for in-river deployments e.g., to check numbers reaching the sea.

For practical reasons (ability to recover) acoustic releases are necessary for all depths greater than 50 m. Where the array design includes receivers at these depths, VR2AR are assumed.

Maintenance and Consumables

Costs for deployment, maintenance, and retrieval are included for a 12-month period, based on initial deployment, data recovery at three-month intervals, and final recovery of equipment. Service intervals are based on experience of biofouling and loss rates in Welsh waters. These intervals could potentially be extended with experience in different locations, but in our experience regular recovery periods reduce difficulty. Research Vessel (RV) costs are assumed to be £1000 per day including staff and fuel.

Mooring costs are the cost of purchasing the various mooring components. Data download costs comprise the cost of data QA and loading into databases. The cost of analysis and reporting which is included in the core staff element within the combined costs section.

Costings have assumed £1000 per day RV costs, deployment and recovery of 6 VR2TX per day and deployment and recovery of 8 VR2AR per day. They assume basic mooring costs. These are reasonable for the large majority of deployments, but specific areas in close proximity to devices may need heavier duty mooring arrangements.

A laptop with Bluetooth is needed for download and storage of data, but no other specialist IT equipment is required; we have therefore assumed this is already available.

Expected losses

Based on experience of the different organisations, receiver loss rates of between 5-10% per annum are to be expected and replacement should be planned for in budgets. Costings include an upper estimate of 10% which will also cover minor costs such as replacement batteries and mooring repairs.

One off purchases

There are a number of one-off costs for receiver maintenance such as purchase of deck-boxes and hydrophones. A minimum of two deck boxes (VR-100) would be required (one each for north/south Wales). These are priced at £4515 each. Compatible directional hydrophones (£508 each) would also be required.

Overall costs are presented in Table 2 below, based on the designs presented and broken down by for each of the resource area and hotspots. The total figures for each location include purchase costs and maintenance costs for 12 months.

These are clearly options; some areas could be prioritised, and a pool of receivers could be deployed in different locations in different years to address data needs over time. We have separately provided NRW with a spreadsheet to allow cost assumptions to be changed and enable costs to be recalculated quickly, or to enable rapid estimation of the cost of additional designs (e.g., for new developments). This contains current equipment costs obtained from manufacturers and can be updated as these costs change.

The total cost for all areas and hotspots, including deployment and 12 months maintenance is £1,889,571.

Table 2. Array cost breakdown.

	Site	# VR2TX	Capital cost VR2TX	#VR2AR	Capital cost VR2AR	Deployment	Maintenance	Retrieval	Moorings	Loss contingency	Data download	Total
Acoustic barrier (West Wales gates)	Acoustic barrier	24	£34,080	0	£0	£3,000	£11,952	£3,984	£1,992	£3,408	£240	£58,656
Tidal range north	Tidal range north	67	£95,140	0	£0	£8,375	£33,366	£11,122	£5,561	£9,514	£670	£163,748
North west	Minesto	0	£0	22	£62,766	£2,200	£8,250	£2,750	£814	£6,277	£220	£83,277
North west	Morlais	65	£92,300	8	£22,824	£8,925	£35,370	£11,790	£5,691	£11,512	£730	£189,142
North west	Bardsey	40	£56,800	0	£0	£5,000	£19,920	£6,640	£3,320	£5,680	£400	£97,760
North west	Tidal Stream	46	£65,320	38	£108,414	£9,550	£37,158	£12,386	£5,224	£17,373	£840	£256,265
South west	Tidal stream south West	8	£11,360	16	£45,648	£2,600	£9,984	£3,328	£1,256	£5,701	£220	£80,097
South west	Tidal stream coast	10	£14,200	4	£11,412	£1,650	£6,480	£2,160	£1,126	£2,561	£140	£39,729
South west	Ramsey	17	£24,140	0	£0	£2,125	£8,466	£2,822	£1,411	£2,414	£170	£41,548
South west	Tidal range	7	£940	0	£0	£875	£3,486	£1,162	£581	£94	£70	£7,208
South west	Bro Gwaun	26	£35,500	48	£119,826	£8,050	£30,948	£10,316	£3,934	£15,533	£740	£224,847
South	Tidal range south	102	£132,060	0	£0	£12,750	£50,796	£16,932	£8,466	£13,206	£930	£235,140
South	Tidal stream south	34	£48,280	0	£0	£4,250	£16,932	£5,644	£2,822	£4,828	£340	£83,096
South	Bristol channel	70	£99,400	0	£0	£8,750	£34,860	£11,620	£5,810	£9,940	£700	£171,080
South	Swansea	39	£55,380	0	£0	£4,875	£19,422	£6,474	£3,237	£5,538	£390	£95,316
South	Bombora & META	25	£36,920	0	£0	£3,125	£12,450	£4,150	£2,075	£3,692	£250	£62,662

5. Tagging strategy

5.1. Approach

Clarke *et al*., (2021a) recommended that eDNA should be used to confirm or rule out the likely presence of key species in the resource areas. This approach would focus in particular on twaite and allis shad, sea and river lamprey, eels and European smelt, where distribution in the marine environment is uncertain. Such an approach will inform more detailed studies, such as the tagging and acoustic tracking assessments outlined in this chapter.

Where it is uncertain if a particular species is likely to be affected by marine energy units located in these areas, an initial pilot study is recommended. Based on the results of these studies, it will offer an opportunity to pause and review the results before considering if scaling up the tagging programme is required.

To define the tagging strategy, 'sentinel' rivers have been identified in each of the resource areas on the basis of known availability and abundance of juvenile and adult fish, together with existing capture facilities and proximity to resource areas. These rivers (Table 3, Figure 10) are also likely to contribute significant numbers of diadromous fish to local tidal stream and tidal range areas.

Exceptions to this include the tagging of yellow eels where they inhabit the lower estuaries or inshore zones, adjacent to key resource areas. In recent years it has become apparent that yellow eels may spend extended periods of time in estuaries and in nearshore areas (Walker *et al*., 2013). We recommend that yellow eels should be captured in the lower estuaries or along shorelines adjacent to the major rivers as recommended in Table 3.

In the case of Atlantic salmon, sea trout and twaite shad (the latter along the south Wales coast) we recommend starting with more extensive tagging and acoustic tracking studies. As less is known about the occurrence in the resource areas of silver eels, yellow eels, and European smelt, tagging programmes for these species should be initiated on a pilot basis. Trials could also be undertaken to establish the viability of capturing and tagging river and sea lamprey adults at sea. Results from these pilot programmes can then inform the nature and the extent of future tracking studies.

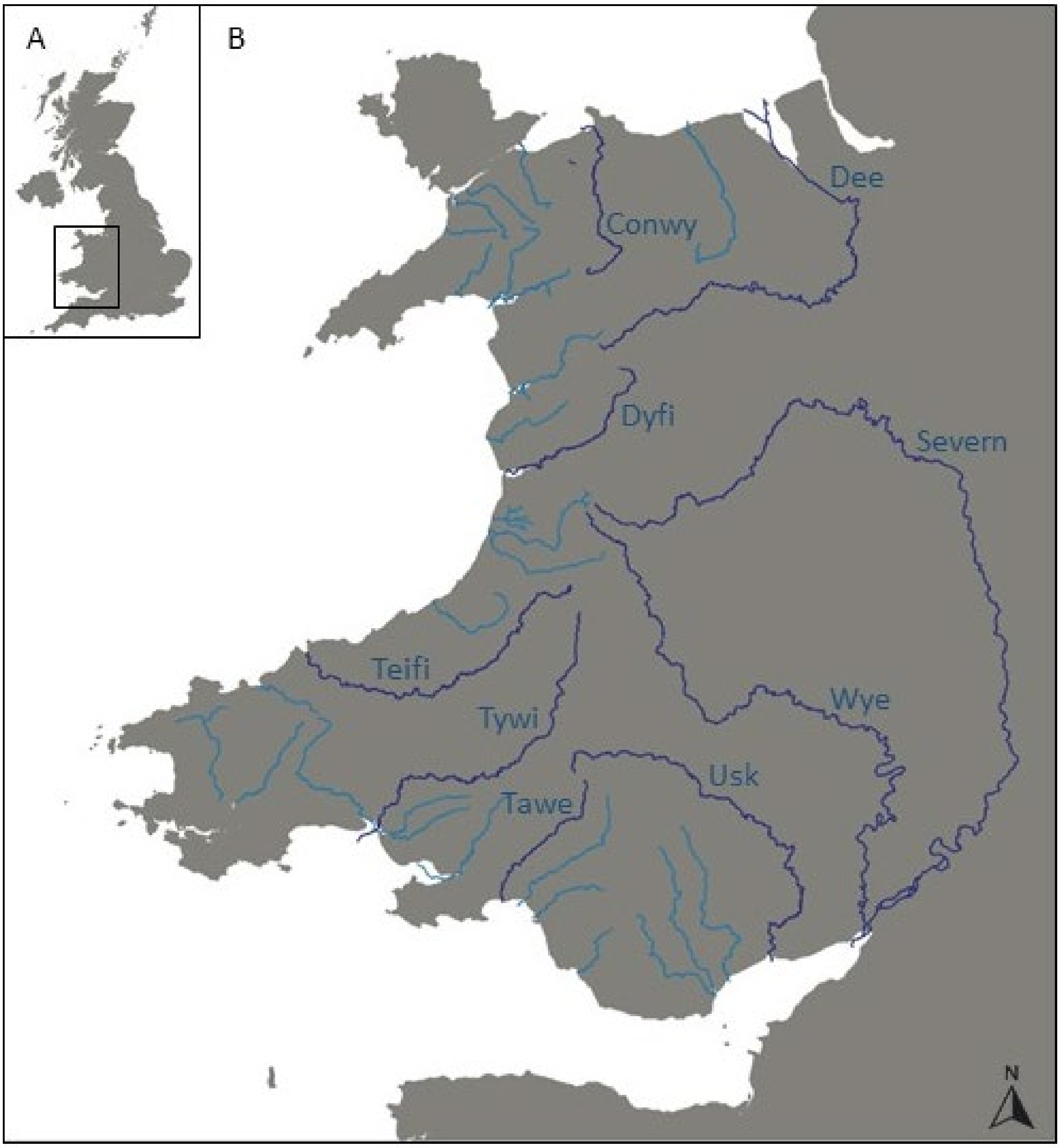

Figure 10. Map of the major river systems in Wales for fish tagging (light blue) and proposed sentinel rivers (dark blue).

5.2. Sourcing fish to tag

Fixed fish trapping facilities offer the best opportunities for capturing migrating juvenile and adult fish. All potential migratory fish trapping sites in Wales were reviewed and consideration given to what form of trapping might be hosted at these sites (Clarke *et al* 2021a). Only two permanent trapping sites are currently in place on the Dee and the Tawe. Both units at present only offer the possibility of trapping upstream migrating fish. The possibility of installing permanent facilities for trapping downstream migrating salmon and sea trout smolts, sea trout kelts and migrating silver eels at both of these sites should be reviewed.

Where it is not possible to utilise existing trapping facilities, the use of fyke nets may offer the simplest and most cost-effective way to trap most migratory species from the donor rivers. However, where Rotary Screw Traps (RSTs) are in use, or where Wolf grids / Wolf traps can be easily and cost effectively inserted into a suitable location, the use of these units should also be considered and reviewed. In some instances, electro-fishing might be considered as a method for collecting fish, such as sea trout kelts, for tagging but in general this is an expensive and labour-intensive method of fish capture.

The final choice of trapping sites and the design of suitable fish traps will be dependent on the availability of experienced, trained, licensed staff locally, ease of access to trapping sites, safety concerns and logistics relating to the insertion, servicing, and removal of the fish traps.

5.3. Tag types and options

Clarke *et al.* (2021a) have reviewed tagging options and tag burden for different species in more depth. This section briefly summarises the main conclusions.

5.3.1. Salmon and sea trout

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.

Salmon

Salmon smolts, can be tagged using Innovasea, V7-2L tags (or Thelmabiotel equivalent). These tags are suitable for smolts greater than 14 cm in length.

Adult Salmon are more problematic. Salmon smolt return rates are low and therefore very large numbers (1000+) would be required to generate quantitative data. The use of salmon kelts is not recommended, as the numbers of these are likely to be low, as is the overall return rate as second spawners (Niemela *et al*., 2006). This leaves the option of tagging adults at sea, where the origin of the tagged fish is unknown. Tagging returning adult fish in RA could provide data on origins of impacted fish but would not provide quantitative residence time / potential impacts.

Sea trout

Sea trout smolts are on average larger than salmon smolts (16 cm to 20 cm). V7-4L tags have a larger battery and are slightly longer and heavier than V7-2L tags but the extended life with the right programming allows tracking of the fish at .0+ and 1+ returns to the river. These tags are recommended for sea trout smolts.

Sea trout kelts and adult sea trout can be tagged with V9 tags or equivalent. These are well within the acceptable tag burden and have an active life of as much as 3 years, depending on the ping rate used.

Consideration might also be given to the use of satellite, data storage and sensor tags on sea trout kelts (to provide data on location, temperature, and swimming depth). Experience from the SAMARCH Project (https://samarch.org/) has shown that tagging sea trout kelts with a number of different tag types has added greatly to the information that can be collected from individual fish (e.g., acoustic plus DST tags). This is particularly true in the case of fish which return to spawn on several separate occasions to their river of origin. Costings do not include these tags as they are not relevant to array costs, though they may provide valuable information on movements of sea trout around the MRE sites and out to sea.

Sea trout may well prove to be one of the most important sentinel fish for use in assessing the effects of marine energy units around the coast of Wales. They are long-lived, multiple spawners and frequently inhabit areas close in-shore. Combining sea trout smolt and adult tagging can give a good overall picture of the life cycle.

5.3.2. European eels

Yellow eels may be caught in the lower estuaries / nearshore areas at the mouths of the larger rivers, using baited fyke nets or un-baited nets. Local commercial fishermen may have knowledge of where eels are encountered on a regular basis in these areas and consideration should be given to including the skills of these individuals in the teams seeking to tag yellow eels. Experience has shown that fyke nets containing a catch of eels can quickly attract marine predators. For this reason, the nets will need to be serviced on a frequent basis. We recommend the use of V9 tags on the yellow eels captured in this manner.

Silver eels can be trapped in fyke nets or Wolf traps, primarily during dark, moon-less nights in October and November. We recommend the use of V9 and also some V9 sensor tags on these fish. There are major studies underway to assess the migration patterns of eels in the open ocean and if funding was available, it is recommended that a small number of pop-off, satellite tags should also be used in tagging silver eels (Økland *et al*., 2013 & Righton *et al*., 2016). As in the case of large sea trout kelts, this will provide more detailed information on movements around the MRE areas and further out to sea. Costs of satellite tags are additional to array costings.

5.3.3. Twaite shad

Spawning populations of shad are found in the Severn, Usk, Wye and Tywi. No spawning populations of shad have been confirmed to date from mid-Wales or North Wales. Ongoing research in this area has shown that adult spawning shad, caught on rod and line, can be effectively tagged, and tracked using V9 tags. A similar approach is recommended in assessing the migration patterns of the twaite shad across the marine resource areas in South Wales. In addition to the shad which are being tagged in the Severn (Unlocking the Severn Project), it is recommended that a small number of additional adult shad (50) are tagged in either the Usk or the Wye and in the Tywi. This will allow comparison with the more extensive marine dataset derived from the Severn, to determine if the impacts are likely to be similar on all rivers.

5.3.4. European smelt

Although smelt have been caught in the River Dee, the only known spawning population of smelt recorded to date in Wales is in the estuary of the River Conwy. It is recommended that some 50 adult spawning smelt are captured by netting in the estuary of the Conwy and fitted with V7 tags. It is also recommended that an additional receiver is placed in the estuary of the Conwy to confirm that the tagged fish leave the estuary and are not a semi-resident stock of smelt.

5.3.5. River and sea lamprey

Juvenile lamprey are too small to tag using physical tags. The only adult lamprey, which are available for tagging in rivers, are adults returning to spawn. Since these fish die after spawning, they will not provide a source of tagged fish to assess their movements around the Marine Resource Areas. If the eDNA profiling recommended in this report shows the presence of lamprey in the vicinity of the turbine sites, consideration should be given to carrying out trawl surveys for adult lamprey to determine tagging options.

Table 3. Proposed initial tagging strategy for each species and river system. Tagging costs for two rivers related to each area North tidal range (Dee and Conwy); north west tidal stream (Dyfi and Teifi), south west tidal stream (Tywi and Tawe) and south tidal stream/range (Wye and Usk)

	Dee # tags	Dee Cost £	Conwy # tags	Conwy Cost £	Dyfi # tags	Dyfi Cost £	Teifi # tags	Teifi Cost £	Tywi # tags	Tywi Cost £	Tawe #tags	Tawe Cost £	Severn # tags	Severn Cost £	Wye # tags	Wye Cost £	Usk # tags	Usk Cost £	Total # fish tagged	Total cost per species £
Atlantic salmon smolt	100 V7	22500	100 V7	22500	100 V7	22500	100 V7	22500	100 V7	22500	100 V7	22500	N/A	N/A	100 V7	22500	100 V7	22500	**800**	**180000**
Atlantic salmon smolt	20 V7P	4500	20 V7P	4500	20 V7P	4500	20 V7P	4500	20 V7P	4500	20 V7P	4500	N/A	N/A	20 V7P	4500	20 V7P	4500	**160**	**36000**
Sea trout smolts	100 V7	22500	100 V7	22500	100 V7	22500	100 V7	22500	100 V7	22500	100 V7	22500	N/A	N/A	100 V7	22500	100 V7	22500	**800**	**180000**
Sea trout smolts	30 V7P	6750	30 V7P	6750	30 V7P	6750	30 V7P	6750	30 V7P	6750	30 V7P	6750	N/A	N/A	30 V7P	6750	30 V7P	6750	**240**	**54000**
Sea trout kelts	50 V9	11250	50 V9	11250	50 V9	11250	50 V9	11250	50 V9	11250	50 V9	11250	N/A	N/A	50 V9	11250	50 V9	11250	**400**	**90000**
Silver European eels	25 V9	5625	25 V9	5625	25 V9	5625	25 V9	5625	25 V9	5625	25 V9	5625	N/A	N/A	25 V9	5625	25 V9	5625	**200**	**45000**
Yellow European eels	25 V9 inshore	5625	N/A	N/A	25 V9 inshore	5625	N/A	N/A	25 V9 inshore	5625	N/A	N/A	N/A	N/A	25 V9	5625	N/A	N/A	**100**	**22500**
European smelt	N/A	N/A	50 V7	11250	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**50**	**11250**
Twaite shad adults	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	50 V9	11250	N/A	N/A	100 V9 - UTS tagging	N/A	50 V9	11250	50 V9	11250	**250**	**33750**
Total # fish tagged per river	350	N/A	375	N/A	350	N/A	325	N/A	400	N/A	325	N/A	100	N/A	400	N/A	375	N/A	**3000**	**N/A**
Total cost per river £	**N/A**	**78750**	**N/A**	**84375**	**N/A**	**78750**	**N/A**	**73125**	**N/A**	**90000**	**N/A**	**73125**	**N/A**	**0**	**N/A**	**90000**	**N/A**	**84375**	**N/A**	**652500**

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6. Combined costings

The life of a programme of this nature covering all areas and species described above is likely to be between 3 and 5 years. Some costs are 'one off' and some annual. This section provides illustrative estimates of staff costs and combines these with the firmer estimates from previous sections to provide an overall cost figure.

6.1.1. Staff time

The programme as a whole would require a full-time manager / lead scientist to plan and coordinate work, and lead data analysis, together with three full time technicians (assuming all work was to be undertaken). These core staff would provide the resource for the majority of the programme including much of the tagging operations, planning and preparing array equipment for deployment, data analysis and reporting.

Tagging operations may also represent significant cost. The biggest cause of failure for tagging and tracking studies is the inability to capture the target species. These costs are difficult to estimate in advance because they are highly variable according to local circumstance, available facilities, and local conditions.

For example, tagging adult sea trout migrating upstream on the River Dee has a high probability of success, with a low marginal cost because the cost of trapping operations is already largely covered. In comparison tagging 100 sea trout smolts on the River Tawe requires up to 5 weeks continuous night work for 3 staff from a pool of 6 (approximately 0.6 Full Time Equivalents (FTE)). Adding 100 salmon smolts to that number does not, however, significantly increase that cost as the fish are caught alongside each other and the main effort is in deploying and servicing the fyke nets rather than the tagging itself. Additionally, these costs were incurred during the COVID pandemic and may be substantially reduced in normal circumstances by utilising volunteer support from local angling associations, rivers trusts and University students or postgraduates. The costs may also be substantially reduced if the fish are caught quickly, which is certainly possible. Tagging also requires a license form the Home Office (HO) and at a minimum one HO licenced tagger is required for any operation, together with one other trained member of staff.

For costing purposes, a reasonable staff cost estimate could be assumed to be 70 days' work per 100 fish. For all tagging in table 3 this equates to 8.7 FTE.

6.1.2. Illustrative staff costs

Realistic staff costs are not easy to provide, because of the range of practical issues and operational choices described above. The costs provided below should therefore be considered illustrative.
Assuming a lead scientist / manager costs approximately £60k per annum and a technician £30k per annum (approximate Swansea university costs including overheads), the core team of lead scientist and three technicians would cost ca. £150k per annum.

Provided the tagging was spread out seasonally and over two to three years it is reasonable to assume that around 4 FTE of the 8.7 FTE tagging effort could be provided by the core team with the balance from seasonal workers and volunteers. Indicatively 2 FTE (£60k) of additional effort is assumed, spread over the period (ie not an annual cost) with 2.7 FTE assumed to be volunteer effort.

This would result in indicative staff costs of £510k for 3 years and £810k for 5 years.

6.1.3. Illustration of Total costs assuming 3 and 5 years programmes.

The cost of purchasing deploying and running arrays in each of the three areas, together with the capital cost of tags is summarised in Table 4 below. Headline costs for all areas and all species, including capital equipment, maintenance and staff £4.3m (3 years) and £5.9m (5 years). It is important to note that although tag numbers and costs are indicative for the full three or 5 year period, they would be expected to change as data is collected and the programme evolves.

These costs are significant, but bearing in mind the multi-species/multi location nature of the programme, they are proportionate to studies being undertake elsewhere (e.g. SAMARCH 7.8m€ over 5 years; AST's Moray Firth Tracking Programme - £2m over 3 years for a single species in a single area). We would expect significant spin off benefits with researchers taking advantage of array deployments to look at marine species such as European sea bass, ray, skate etc.

Table 4. Table showing the combined capital costs (receivers and moorings), maintenance (deployment, maintenance, retrieval and data download and loss contingency) and capital tagging costs (tag purchase costs per river) for 3 and 5 year programmes. Annual and temporary staff time have been included.

Area	**Capital array Cost**	**Annual array maintenance**	**Capital tagging cost**	**Annual staff**	**Temporary staff**	**Total cost**
North	£524,174	£266,018	£241,875	N/A	N/A	N/A
South West	£271,334	£122,095	£163,125	N/A	N/A	N/A
South	£394,450	£252,854	£247,500	N/A	N/A	N/A
West Wales gates	£36,072	£22,584	**N/A**	**N/A**	**N/A**	N/A
Totals	**£1,226,030**	**£663,551**	**£652,500**	**£150,000**	**£60,000**	N/A
3-year programme	**£1,226,030**	**£1,990,653**	**£652,500**	**£450,000**	**£60,000**	**£4,379,153**
5-year programme	**£1,226,030**	**£3,317,755**	**£652,500**	**£750,000**	**£60,000**	**£6,006,235**

7. Funding Sources

Currently there are an increasing number of marine renewable energy initiatives across Europe. All of these face similar challenges in relation to assessing the potential environmental impacts associated with a wide array of ocean energy devices. In Scotland (Orkney and Shetland Islands) and in Ireland (Galway Bay) renewable energy hubs have been established to research, develop, coordinate, and promote marine energy resources. There is a growing awareness that the establishment of co-operative research and development initiatives are fundamental to dealing with many of the challenges the new industry faces in relation to assessing and mitigating environmental impacts.

The approach being adopted in Smart Bay (Galway) involves up-front Government funded research and development, twinned with site-specific industry investment. Additional research funding is leveraged from both national and international research programmes.

The authors anticipate that the diadromous fish research programme, outlined in this report and Clarke *et al.* (2021a) would initially be centrally funded. This funding would create a core pool of expertise and equipment, which would be used to carry out pilot tagging and tracking of the key migratory species' in the eight sentinel river systems highlighted in this review. Core support would be used to carry out the broad screening of the MRE areas, using the novel eDNA techniques described in the first part of this work (Clarke *et al.,* 2021a).

Developer contributions are also important. Consent monitoring conditions would require developers to monitor and make available data to fine tune the assessment of migratory fish behaviour in the specific areas in which they have a commercial interest. A developer could, for example, fund the array and receivers in their own ‘hotspot’ area, within the wider array and tagging framework funded centrally.

In parallel with the funding of baseline Resource Area array maintenance and tagging the research teams would be charged with seeking out partnerships with other research bodies, research funds and marine energy development companies within the UK and internationally.

NERC has in the recent past funded a significant Marine Renewable Energy (MRE) research programme (2011 to 2015), with a budget of £2.4 million, jointly funded by NERC and Defra. The overall aim of the research programme was to understand the environmental benefits and risks of up-scaling marine renewable energy schemes on the quality of marine bio-resources and biophysical dynamics of open coasts. NERC continues to take an active interest in funding research in this area. An example of this is the current bid by Swansea University, working with Cardiff and Plymouth Universities, for £1.5m of funding over 3 years from the NERC Sustainable Management of Marine Resources Programme, to carry out tracking work in the Bristol Channel.

Funding opportunities are challenging at the present time, because of the withdrawal of the European Regional Development Fund (ERDF). This support funded schemes such as the EU Interreg Programmes. However, replacement collaborations and research funds are opening up at present, but full details have yet to be agreed and published. The recently concluded UK/ EU trade deal will give UK researchers and businesses continued access to Horizon Europe funding on equivalent terms as EU counterparts, including eligibility to lead projects. This may also open up the possibility of potentially including North American partners in any future Horizon Europe bid, under the 2013 (EU / USA / Canada) Galway Agreement.

The funding model recommended in this report envisages government developing a core strategic resource of both expertise and equipment, which is supplemented by other funding bids, as outlined above and utilising a wide range of support mechanisms, such as research studentships and developer contributions.

Links to potential partnerships/funders:

- Smartbay
- Renewable energy world
- Scottish Government renewable and low carbon energy – marine
- Renewables-atlas
- Horizon Europe

- NERC offshore energy
- Denmark Clean Energy Innovation and Design
- UK-EU Research deals (Science Buisness)
- Galway Agreement, 2013
- NERC MRE Research Funding
- Shetland Renewables
- OREF
- MEECE
- ORJIP OE

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9. Appendices

Appendix A: Inventory and cost of acoustic receivers available from different providers

Brand	Receiver's name	Frequency (Hz)	Battery life (months)	Detection range (m)	Price (£)	Price	Comments
Lotek	WHS 2000 R Code	69	6	200	935	1620 $ CAD	N/A
Lotek	WHS 4350 JSATs	416	6	100	2034	3525 $ CAD	N/A
Lotek	WH 6000 OPI/S	69	6	1000	946	1600 $ CAD	N/A
Thelma	TBR 700	63-77	9	500	9800	9800 (NOK)	Can detect 3 different frequencies at the same time
Thelma	TBR 700 L	63-77	18	500	11300	11300 (NOK)	Can detect 3 different frequencies at the same time
Thelma	TBLive Receiver	63-77	18	500	15000	15000(NOK)	Can detect 3 different frequencies at the same time
Thelma	TBLive Link	63-77	N/A	N/A	13000	13000 (NOK)	Can detect 3 different frequencies at the same time
Thelma	TBLive software	63-77	N/A	N/A	3000	3000 (NOK)	Can detect 3 different frequencies at the same time
Thelma	TBR 800 Release	63-77	18	500	20000	20000 (NOK)	Can detect 3 different frequencies at the same time
Thelma	TBR 800	63-77	18	500	TBD	TBD (~12000 NOK)	Can detect 3 different frequencies at the same time
Innovasea	VR2W	69	15	500	1172	2030 $ CAD	N/A
Innovasea	TX	69	14	500	1420	2460 $ CAD	N/A
Innovasea	AR	69	14	500	2853	4945 $ CAD	N/A
Innovasea	Real time	69	external battery: 1	500	4125	7150 $ CAD	N/A
Innovasea	VR2W	180	8	200	1255	2175 $ CAD	N/A
Innovasea	HR2	180	6	200	2815	4880 $ CAD	N/A
Innovasea	real time	180	external battery: 1	200	8500	7150 $ CAD	modem + receiver + com
Innovasea	HR3	307	6	100	2816	4880 $ CAD	N/A
	VR4	69 - 180	60 - 120	200-500	13755	23 835 $ CAD	N/A
Innovasea	VR100	69 - 180	rechargeable	N/A	4515	7826 $ CAD	tracking device

Brand	Receiver's name	Frequency (Hz)	Battery life (months)	Detection range (m)	Price (£)	Price	Comments
Innovasea	VR100-300	69 -180 - 307	rechargeable	N/A	4515	7826 $ CAD	tracking device
Innovasea	directional hydrophone	69	N/A	500	1116	1935 $ CAD	tracking device
Innovasea	mulltidirectional hydrophone	69	N/A	500	508	880 $ CAD	tracking device
Innovasea	directional hydrophone	180	N/A	200	1116	1935 $ CAD	tracking device
Innovasea	mulltidirectional hydrophone	180	N/A	200	508	880 $ CAD	tracking device
Innovasea	directional hydrophone	307	N/A	100	1116	1935 $ CAD	tracking device
Innovasea	mulltidirectional hydrophone	307	N/A	100	508	880 $ CAD	tracking device
Sonotronics	USR-14	30-150	N/A	N/A	N/A	N/A	Narrow band receiver
Sonotronics	MANTRAK	N/A	N/A	N/A	N/A	N/A	Manual tracking unit for active tracking
Sonotronics	UDR	30-90	N/A	N/A	N/A	N/A	Narrow band Dive Receiver Unit
Sonotronics	AVAR	30-100	Externally powered but also with a small NiMH battery for 12-hour deployments	N/A	N/A	N/A	Autonomous Vehicle Acoustic Receiver
Sonotronics	DH-4- Directional hydrophone	30-100	N/A	N/A	N/A	N/A	Active Tracking
Sonotronics	TH2 - Towed Omni Directional Hydrophone	30-100	N/A	N/A	N/A	N/A	Active Tracking
Sonotronics	*Mini*surt Mini submersible ultrasonic receiver/trasmitter	69-83	AA battery	N/A	N/A	N/A	N/A
Sonotronics	SUR-3 (BT)	30-90	D-Cell Batteries	N/A	N/A	N/A	N/A

Appendix B: List and specifications of acoustic tags available from four major providers: Lotek, Thelma Biotel, Innovasea and Sonotronics

Brand	Tag name	Frequency (Hz)	Tag length (mm)	Tag diameter (mm)	Tag weight in air (g)	tag weight in water (g)	Battery life at a specific frequency	Power output (dB)	Approximative detection range (m)	Comments
Lotek	MM-R-8-SO	69	38	8.5	5.5	3.4	202 days at 60 sec Fz	146	300-400	no sensors on R-code tags
Lotek	MM-R-11-SO	69	38	11	6.6	3.1	202 days at 60 sec Fz	147	300-400	no sensors on R-code tags
Lotek	MM-R-11-28	69	56	12	10	3.9	1011 days at 60 sec Fz	147	300-400	no sensors on R-code tags
Lotek	MM-R-11-45	69	72	12	14	6.1	1573 days at 60 sec Fz	147	300-400	no sensors on R-code tags
Lotek	MM-R-16-25	69	57	16	26	14.9	2043 days at 60 sec Fz	151	300-400	no sensors on R-code tags
Lotek	MM-R-16-33	69	64	16	29	16.5	2785 days at 60 sec Fz	151	300-400	no sensors on R-code tags
Lotek	MM-R-16-50	69	80	16	35	19.4	4457 days at 60 sec Fz	151	300-400	no sensors on R-code tags
Lotek	JSATs AMT 1.416	416	10.7	5.4	0.28	N/A	87 days at 20 sec Fz	158	100-200	possibility to have pressure sensor
Lotek	JSATs AMT 1.421	416	11.1	5.5	0.32	N/A	131 days at 20 sec Fz	158	100-200	possibility to have pressure sensor
Lotek	JSATs AMT 1.527	416	12	6.5	0.47	N/A	229 days at 20 sec Fz	158	100-200	possibility to have pressure sensor
Lotek	JSATs AMT 5.1B	416	13	7	0.6	N/A	327 days at 20 sec Fz	158	100-200	possibility to have pressure sensor
Lotek	JSATs AMT 5.2	416	16	7	1.1	N/A	568 days at 20 sec Fz	158	100-200	possibility to have pressure sensor
Lotek	JSATs AMT 8.2	416	23	9	3.5	N/A	1522 days at 20 sec Fz	158	100-200	possibility to have pressure sensor
Lotek	JSATs AMT 14-12	416	45	14	8	N/A	3114 days at 20 sec Fz	158	100-200	possibility to have pressure sensor
Thelma	LP6	63-77	14.5	6.3	1.2	0.7	70 days at 30 sec Fz	137	50-100	possibility of temperature, pressure, activity
Thelma	2LP6	63-77	22	6.3	1.9	1.2	139 days at 30 sec Fz	137	50-100	possibility of temperature, pressure, activity
Thelma	LP7	63-77	17	7.3	1.8	1.1	101 days at 30 sec Fz	139	100	possibility of temperature, pressure, activity or tilt sensor
Thelma	MP7	63-77	20.6	7.3	2.3	1.5	69 days at 30 sec Fz	141	100	possibility of temperature, pressure, activity or tilt sensor
Thelma	2LP7	63-77	23.2	7.3	2.7	1.8	180 days at 30 sec Fz	139	100	possibility of temperature, pressure, activity or tilt sensor
Thelma	LP9L	63-77	24	9	4	2.5	330 days at 30 sec Fz	142	500	possibility of temperature, pressure, activity, tilt or salinity sensor

Brand	Tag name	Frequency (Hz)	Tag length (mm)	Tag diameter (mm)	Tag weight in air (g)	tag weight in water (g)	Battery life at a specific frequency	Power output (dB)	Approximative detection range (m)	Comments
Thelma	MP9	63-77	24.4	9	3.6	2.1	137 days at 30 sec Fz	146	500	possibility of temperature, pressure, activity, tilt or salinity sensor
Thelma	MP9L	63-77	29.4	9	5.2	3.3	210 days at 30 sec Fz	146	500	possibility of temperature, pressure, activity, tilt or salinity sensor
Thelma	LP13	63-77	27.9	12.7	9.19	5.5	570 days at 30 sec Fz	150	1000	possibility of temperature, pressure, activity, tilt or salinity sensor
Thelma	2LP13	63-77	38.7	12.7	13.8	8.7	1140 days at 30 sec Fz	150	1000	possibility of temperature, pressure, activity, tilt or salinity sensor
Thelma	MP13	63-77	33.3	12.7	11.5	7.1	420 days at 30 sec Fz	153	1000	possibility of temperature, pressure, activity, tilt or salinity sensor
Thelma	HP16	63-77	70	16	29	14.9	960 days at 30 sec Fz	158	1000	possibility of temperature, pressure, activity, tilt or salinity sensor
Innovasea	V6	69	-	-	-	-	-	-	-	will be developed soon
Innovasea	V7-2L	69	19.5	7	1.5	0.7	220 days at 90 sec Fz	137	500	possibility of temperature, pressure and predation sensors
Innovasea	V7-4H	69	21.5	7	1.8	0.9	220 days at 90sec Fz	141	500	possibility of temperature, pressure and predation sensors
Innovasea	V8-4L	69	20.5	8	2	1	165 days at 90 sec Fz	144	500	possibility of temperature, pressure and predation sensors
Innovasea	V9-1L	69	24	9	3.6	2	550 days at 90sec Fz	146	500	possibility of temperature, pressure and predation sensors
Innovasea	V9-2H	69	27.5	9	4.5	2.7	550 days at 90sec Fz	151	500	possibility of temperature, pressure and predation sensors
Innovasea	V13-1L	69	36	13	11	6	845 days at 60sec Fz	147	500	possibility of temperature, pressure and predation sensors
Innovasea	V5-1H	180	12.7	4.3	0.65	0.38	90 days at 30 sec Fz	143	200	possibility of predation sensor
Innovasea	V5-2H	180	12.7	5.7	0.77	0.46	110 days at 30 sec Fz	143	200	possibility of predation sensor
Innovasea	V7-2L	180	19	7	1.2	0.6	78 days at 30 sec Fz	137	200	possibility with temperature, pressure and predation sensors

Brand	Tag name	Frequency (Hz)	Tag length (mm)	Tag diameter (mm)	Tag weight in air (g)	tag weight in water (g)	Battery life at a specific frequency	Power output (dB)	Approximative detection range (m)	Comments
Innovasea	V7-4H	180	22	7	1.5	0.8	117 days at 30 sec Fz	143	200	possibility with temperature, pressure and predation sensors
Innovasea	V9-2H	180	24.1	9	3.67	2.1	635 days at 30 sec Fz	143	200	possibility with temperature, pressure and predator sensors
Innovasea	V3	307	15	4	< 0.3		70 days at 10 sec Fz	141	100	possibility of predation sensor
Sonotronics	PT-1	69-83	15	7.1	N/A	0.6	7 days	N/A	300-750	Coded tags
Sonotronics	PT-2	69-83	18	7.1	N/A	1	12 days	N/A	300-750	N/A
Sonotronics	PT-3	69-83	28	7.8	N/A	1	21 days	N/A	300-750	N/A
Sonotronics	PT-4	69-83	24	9	N/A	2.3	90 days	N/A	300-750	N/A
Sonotronics	IBT-96-1	69-83	22/30	8	N/A	1.4	21 days	N/A	750+	Coded tags
Sonotronics	IBT-96-2	69-83	25/33	9.5	N/A	2.5	60 days	N/A	750+	N/A
Sonotronics	IBT-96-6-I/E	69-83	42/45	11	N/A	3.9	8 months	N/A	750+	N/A
Sonotronics	IBT-96-9-I/E	69-83	47/50	11	N/A	4	9 months	N/A	750+	N/A
Sonotronics	CT-82-I-I/E	32-40, 69-86	38/49	15.6	N/A	6	60 days	N/A	1000	Coded tracking tags
Sonotronics	CT-82-2-I/E	32-40, 69-86	53/54	15.6	N/A	9.5	14 months	N/A	1000	N/A
Sonotronics	CT-05-36-I/E	32-40, 69-86	63/64	15.6	N/A	10	36 months	N/A	1000	N/A
Sonotronics	CT-05-48-I/E	32-40, 69-86	79/80	15.6	N/A	12	48 months	N/A	1000	N/A
Sonotronics	CHP-87-S	32-40, 69-83	54	15.6	N/A	9	7 months	N/A	3000	High powered version of CT
Sonotronics	CHP-87-L	32-40, 69-83	80	15.6	N/A	12	18 months	N/A	3000	N/A
Sonotronics	CHP-87-XL	32-40, 69-83	99	33.5	N/A	34	4 years	N/A	3000	N/A
Sonotronics	ART-01	32-40, 69-83 150 MHz nominal RF	80	15.6	N/A	12	12 months	N/A	1000	Acoustic and radio transmitter
Sonotronics	ART - 09	32-40, 69-83,150 MHz	55	11	N/A	4.5	9 months	N/A	1000	Acoustic and radio transmitter

Brand	Tag name	Frequency (Hz)	Tag length (mm)	Tag diameter (mm)	Tag weight in air (g)	tag weight in water (g)	Battery life at a specific frequency	Power output (dB)	Approximative detection range (m)	Comments
		nominal RF								
Sonotronics	CTT-83-2-I/E	35-83	53	15.6	N/A	9	14 months	N/A	1000	Temperature telemetry
Sonotronics	CTT-83-3-I/E	35-83	63	15.6	N/A	10	36 months	N/A	1000	Temperature telemetry
Sonotronics	IBTT-08-9-I/E	69-83	40/43	11	N/A	4.2 / 5.2	9 months	N/A	750+	Mini temperature telemetry tag
Sonotronics	PTT-2	69-83	18	7.1	N/A	1.2	12 days	N/A	750+	Smallest telemetry transmitters
Sonotronics	PTT-3	69-83	19	7.8	N/A	1.2	21 days	N/A	750+	Smallest telemetry transmitters
Sonotronics	DT-97-L	35-83	66	15.6	N/A	11	12 months	N/A	3000	Depth tags
Sonotronics	IBDT-97-1	69-83	25	9.5	N/A	1.6	20 days	N/A	500	Mini depth tags
Sonotronics	IBDT-97-2	69-83	34	9.5	N/A	2.5	45 days	N/A	500	Mini depth tags
Sonotronics	IBDT-96-9	69-83	52	11	N/A	4.5	9 months	N/A	750	Mini depth tags
Sonotronics	AT-82 -2-I/E	35-83	53/54	15.6	N/A	9.5	24 months	N/A	1000	Activity tags
Sonotronics	IBT-AT-6-I/E	69-83	42/45	11	N/A	3.9	12 months	N/A	1000	Mini activity tags

Appendix C: Tag price list

Brand	Tag name	Price / unit (£)	Price / unit (seller currency)	Price / unit with sensor (except depth)	Price / unit with depth sensor	Comments
Lotek	MM-R-8-SO	154	265 $ CAD	N/A	N/A	N/A
Lotek	MM-R-11-SO	154	265 $ CAD	N/A	N/A	N/A
Lotek	MM-R-11-28	154	265 $ CAD	N/A	N/A	N/A
Lotek	MM-R-11-45	154	265 $ CAD	N/A	N/A	N/A
Lotek	MM-R-16-25	154	265 $ CAD	N/A	N/A	N/A
Lotek	MM-R-16-33	154	265 $ CAD	N/A	N/A	N/A
Lotek	MM-R-16-50	154	265 $ CAD	N/A	N/A	N/A
Lotek	JSATs AMT 1.416	127	215 $ CAD	N/A	245-440 $ CAD	N/A
Lotek	JSATs AMT 1.421	128	216 $ CAD	N/A	246-440 $ CAD	N/A
Lotek	JSATs AMT 1.527	128	217 $ CAD	N/A	247-440 $ CAD	N/A
Lotek	JSATs AMT 5.1B	129	218 $ CAD	N/A	248-440 $ CAD	N/A
Lotek	JSATs AMT 5.2	129	219 $ CAD	N/A	249-440 $ CAD	N/A
Lotek	JSATs AMT 8.2	130	220 $ CAD	N/A	250-450 $ CAD	N/A
Lotek	JSATs AMT 14-12	131	221 $ CAD	N/A	251-450 $ CAD	N/A
Thelma	LP6	161	1930 (NOK)	3000 (NOK)	4000 (NOK)	1 NOK = £ 0.085
Thelma	2LP6	161	2020 (NOK)	3000 (NOK)	4000 (NOK)	Possibility to reprogram the tags if it was not possible to deploy them on time.
Thelma	LP7	152	1800 (NOK)	3000 (NOK)	4000 (NOK)	Possibility to estimate the battery life even if the tag stayed on a shelve
Thelma	MP7	152	1845 (NOK)	3000 (NOK)	4000 (NOK)	N/A
Thelma	2LP7	152	1890 (NOK)	3000 (NOK)	4000 (NOK)	N/A
Thelma	LP9L	169	1890 (NOK)	3500 (NOK)	4000 (NOK)	N/A
Thelma	MP9	169	1900 (NOK)	3500 (NOK)	4000 (NOK)	N/A
Thelma	MP9L	169	1945 (NOK)	3500 (NOK)	4000 (NOK)	N/A
Thelma	LP13	169	1950 (NOK)	3500 (NOK)	4000 (NOK)	N/A
Thelma	2LP13	169	2080 (NOK)	3500 (NOK)	4000 (NOK)	N/A
Thelma	MP13	169	2015 (NOK)	3500 (NOK)	4000 (NOK)	N/A
Thelma	HP16	169	2450 (NOK)	3500 (NOK)	4510 (NOK)	N/A
Innovasea	V6	N/A	N/A	N/A	N/A	N/A

Brand	Tag name	Price / unit (£)	Price / unit (seller currency)	Price / unit with sensor (except depth)	Price / unit with depth sensor	Comments
Innovasea	V7-2L	225	390 $ CAD	455 $ CAD	605 $ CAD	N/A
Innovasea	V7-4H	225	390 $ CAD	455 $ CAD	605 $ CAD	N/A
Innovasea	V8-4L	225	390 $ CAD	N/A	N/A	N/A
Innovasea	V9-1L	225	390 $ CAD	460 $ CAD	780 $ CAD	N/A
Innovasea	V9-2H	225	390 $ CAD	460 $ CAD	780 $ CAD	N/A
Innovasea	V13-1L	225	390 $ CAD	460 $ CAD	780 $ CAD	N/A
Innovasea	V5-1H	211	365 $ CAD	N/A	N/A	N/A
Innovasea	V5-2H	211	365 $ CAD	N/A	N/A	N/A
Innovasea	V7-2L	211	365 $ CAD	455 $ CAD	605 $ CAD	N/A
Innovasea	V7-4H	211	365 $ CAD	455 $ CAD	605 $ CAD	N/A
Innovasea	V9-2H	211	365 $ CAD	N/A	780 $ CAD	N/A
Innovasea	V3	194	335 $ CAD	N/A	N/A	N/A
Sonotronics	PT-1	234.31	325 $ USD5	N/A	N/A	N/A
Sonotronics	PT-2	234.31	325 $ USD5	N/A	N/A	N/A
Sonotronics	PT-3	234.31	325 $ USD5	N/A	N/A	N/A
Sonotronics	PT-4	234.31	325 $ USD5	N/A	N/A	N/A
Sonotronics	IBT-96-1	212.68	295 $ USD5	N/A	N/A	N/A
Sonotronics	IBT-96-2	212.68	295 $ USD5	N/A	N/A	N/A
Sonotronics	IBT-96-6-I/E	216.29	300 $ USD5	N/A	N/A	N/A
Sonotronics	IBT-96-9-I/E	216.29	300 $ USD5	N/A	N/A	N/A
Sonotronics	CT-82-I-I/E	126.17	175 $ USD5	N/A	N/A	N/A
Sonotronics	CT-82-2-I/E	126.17	225 $ USD5	N/A	N/A	N/A
Sonotronics	CT-05-36-I/E	216.29	300 $ USD5	N/A	N/A	C/A
Sonotronics	CT-05-48-I/E	216.29	300 $ USD5	N/A	N/A	N/A
Sonotronics	CHP-87-S	234.31	325 $ USD5	N/A	N/A	N/A
Sonotronics	CHP-87-L	234.31	325 $ USD5	N/A	N/A	N/A
Sonotronics	CHP-87-XL	288.39	400 $ USD5	N/A	N/A	N/A
Sonotronics	ART-01	360.48	500 $ USD5	N/A	N/A	N/A
Sonotronics	ART - 09	360.48	500 $ USD5	N/A	N/A	N/A
Sonotronics	CTT-83-2-I/E	187.45	260 $ USD5	N/A	N/A	N/A
Sonotronics	CTT-83-3-I/E	234.31	325 $ USD5	N/A	N/A	N/A
Sonotronics	IBTT-08-9-I/E	252.34	350 $ USD5	N/A	N/A	N/A
Sonotronics	PTT-2	252.34	350 $ USD5	N/A	N/A	N/A

Brand	Tag name	Price / unit (£)	Price / unit (seller currency)	Price / unit with sensor (except depth)	Price / unit with depth sensor	Comments
Sonotronics	PTT-3	252.34	350 $ USD5	N/A	N/A	N/A
Sonotronics	DT-97-L	360.48	500 $ USD5	N/A	N/A	N/A
Sonotronics	IBDT-97-1	324.43	450 $ USD5	N/A	N/A	N/A
Sonotronics	IBDT-97-2	324.43	450 $ USD5	N/A	N/A	N/A
Sonotronics	IBDT-96-9	324.43	450 $ USD5	N/A	N/A	N/A
Sonotronics	AT-82 -2-I/E	288.39	400 $ USD5	N/A	N/A	N/A
Sonotronics	IBT-AT-6-I/E	288.39	400 $ USD5	N/A	N/A	N/A

Appendix D: DST inventory and costs from available manufacturer

Brand	Tag name	Frequency (Hz)	Tag length (mm)	Tag diameter (mm)	Tag weight in air (g)	tag weight in water (g)	Temp	Pressure	Heart rate	Acceleration	DST memory	Battery life at a specific frequency	Power output (dB)	Approximative detection range (m)	Comments	Price / unit (£)	Price / unit (seller currency)	comments
Innovasea	ADST V9TP-L	69	43	9	6	N/A	-5/35 +-0.5	max 136 +-1	N/A	N/A	360 days at 120sec Fz	468 days at 120sec Fz	146	500	no buoyancy	512	890$ CAD	N/A
Innovasea	ADST V9TP-H	69	43	9	6	N/A	-5/35 +-0.5	max 136 +-1	N/A	N/A	360 days at 120sec Fz	201 days at 120sec Fz	151	500	no buoyancy	512	890$ CAD	N/A
Innovasea	ADST V9TP-L buoyancy	69	65	13	8.5	0	-5/35 +-0.5	max 136 +-1	N/A	N/A	360 days at 120sec Fz	468 days at 120sec Fz	146	500	N/A	512	890$ CAD	N/A
Innovasea	ADST V9TP-H buoyancy	69	65	13	8.5	0	-5/35 +-0.5	max 136 +-1	N/A	N/A	360 days at 120sec Fz	201 days at 120sec Fz	151	500	N/A	512	890$ CAD	N/A
Innovasea	ADST V13TP-L	69	43	13	11.5	N/A	-5/35 +-0.5	max 136 +-1	N/A	N/A	360 days at 120sec Fz	749 days at 60sec Fz	149	500	no buoyancy	512	890$ CAD	N/A
Innovasea	ADST V13TP-H	69	43	13	11.5	N/A	-5/35 +-0.5	max 136 +-1	N/A	N/A	360 days at 120sec Fz	244 days at 60sec Fz	154	500	no buoyancy	512	890$ CAD	N/A
Innovasea	ADST V13TP-L buoyancy	69	75	16	14.2	0	-5/35 +-0.5	max 136 +-1	N/A	N/A	360 days at 120sec Fz	749 days at 60sec Fz	149	500	N/A	512	890$ CAD	N/A
Innovasea	ADST V13TP-H buoyancy	69	75	16	14.2	0	-5/35 +-0.5	max 136 +-1	N/A	N/A	360 days at 120sec Fz	244 days at 60sec Fz	154	500	N/A	512	890$ CAD	N/A
Cefas TL	G5 standard	N/A	31	8	2.7	1.3	-10/60 +-0.1	max 200 +- 0.4%	N/A	N/A	240 days at 120sec Fz	N/A	N/A	N/A	smaller tag under development	240	N/A	price for 50 units
Cefas TL	G5 standar	N/A	31	16	N/A	0	-10/60 +-0.1	max 200 +- 0.4%	N/A	N/A	240 days at	N/A	N/A	N/A	smaller tag under	265	N/A	price for 50 units

Brand	Tag name	Frequency (Hz)	Tag length (mm)	Tag diameter (mm)	Tag weight in air (g)	tag weight in water (g)	Temp	Pressure	Heart rate	Acceleration	DST memory	Battery life at a specific frequency	Power output (dB)	Approximative detection range (m)	Comments	Price / unit (£)	Price / unit (seller currency)	comments
	d + float										120sec Fz				development			
Cefas TL	G5 long-life	N/A	36.5	12	6.5	2.5	-10/60 +-0.1	max 200 +- 0.4%	N/A	N/A	730 days at 60sec Fz	N/A	N/A	N/A	N/A	230	N/A	price for 50 units
Cefas TL	G5 long-life + float	N/A	36.5	24	N/A	0	-10/60 +-0.1	max 200 +- 0.4%	N/A	N/A	730 days at 60sec Fz	N/A	N/A	N/A	N/A	255	N/A	price for 50 units
Cefas TL	G5 pDST	N/A	71.5	15	18	14	-10/60 +-0.1	max 200 +- 0.4%	N/A	N/A	730 days at 10sec Fz	N/A	N/A	N/A	with release mechanism	320	N/A	price for 50 units
Cefas TL	G5 pDST + float	N/A	71.5	21	32	0	-10/60 +-0.1	max 200 +- 0.4%	N/A	N/A	730 days at 10sec Fz	N/A	N/A	N/A	with release mechanism	350	N/A	price for 50 units
Cefas TL	G7 + float	N/A	62	15	16.7	6	-10/60 +-0.1	max 200 +- 0.4%	N/A	N/A	730 days at 10sec Fz	N/A	N/A	N/A	N/A	520	N/A	price for 50 units
Cefas TL	G7	N/A	62	30	31	0	-10/60 +-0.1	max 200 +- 0.4%	N/A	N/A	730 days at 10sec Fz	N/A	N/A	N/A	N/A	550	N/A	price for 50 units
STAR ODDI	DST-nano T	N/A	17	6	1.3	1	5/45 +-0.2	N/A	N/A	N/A	420 days at 600sec Fz	N/A	N/A	N/A	no buoyancy	239	275 €	price for 50 units
STAR ODDI	DST-nano T + float	N/A	94.1	6	N/A	-0.35	5/45 +-0.2	N/A	N/A	N/A	420 ays at 600sec Fz	N/A	N/A	N/A	N/A	259	298 €	price for 50 units
STAR ODDI	DST-centi T	N/A	46	15	19	12	5/45 +-0.1	N/A	N/A	N/A	3285 days at 600sec Fz	N/A	N/A	N/A	no buoyancy	170	195 €	price for 50 units
STAR ODDI	DST-centi T + float	N/A	174.5	16	N/A	-2	5/45 +-0.1	N/A	N/A	N/A	3285 days at 600sec Fz	N/A	N/A	N/A	N/A	200	230 €	price for 50 units
STAR ODDI	DST-milli T	N/A	39.4	13	12	7	5/45 +-0.1	N/A	N/A	N/A	1825 days at 600sec Fz	N/A	N/A	N/A	no buoyancy	182	209 €	price for 50 units

Brand	Tag name	Frequency (Hz)	Tag length (mm)	Tag diameter (mm)	Tag weight in air (g)	tag weight in water (g)	Temp	Pressure	Heart rate	Acceleration	DST memory	Battery life at a specific frequency	Power output (dB)	Approximative detection range (m)	Comments	Price / unit (£)	Price / unit (seller currency)	comments
STAR ODDI	DST-milli T + float	N/A	116.5	13	N/A	-1	5/45 +- 0.1	N/A	N/A	N/A	1825 days at 600sec Fz	N/A	N/A	N/A	N/A	202	232 €	price for 50 units
STAR ODDI	DST-micro TD	N/A	25.4	8.3	3.3	1.9	-1/40 +- 0.2	1/150 +- 0.6%	N/A	N/A	912 days at 1800sec Fz	N/A	N/A	N/A	no buoyancy	263	302 €	price for 50 units
STAR ODDI	DST-micro TD + float	N/A	102.5	9	N/A	-0.5	-1/40 +- 0.2	1/150 +- 0.6%	N/A	N/A	912 days at 1800sec Fz	N/A	N/A	N/A	N/A	283	325 €	price for 50 units
STAR ODDI	DST-milli TD	N/A	39.4	13	13	7	-1/40 +- 0.1	max 100 +- 0.6%	N/A	N/A	912 days at 120sec Fz	N/A	N/A	N/A	no buoyancy	263	302 €	price for 50 units
STAR ODDI	DST-milli TD + float	N/A	102.5	13	N/A	-1	-1/40 +- 0.1	max 100 +- 0.6%	N/A	N/A	912 days at 120sec Fz	N/A	N/A	N/A	N/A	283	325 €	price for 50 units
STAR ODDI	DST-centi TD	N/A	46	15	19	12	-2/40 +- 0.1	max 100 +- 0.6%	N/A	N/A	3285 days at 600sec Fz	N/A	N/A	N/A	no buoyancy	312	369 €	price for 50 units
STAR ODDI	DST-centi TD + float	N/A	174.5	16	N/A	-2	-2/40 +- 0.1	max 100 +- 0.6%	N/A	N/A	3285 days at 600sec Fz	N/A	N/A	N/A	N/A	351	404 €	price for 50 units
STAR ODDI	DST-milli HRT	N/A	39.5	13	11.8	N/A	5/45 +- 0.2	N/A	100-800	N/A	255 days at 600sec Fz	N/A	N/A	N/A	no buoyancy	395	454 €	price for 50 units
STAR ODDI	DST-micro-HRT	N/A	25.4	8.3	3.3	N/A	5/45 +- 0.2	N/A	100-800	N/A	105 days at 600sec Fz	N/A	N/A	N/A	no buoyancy	395	454 €	price for 50 units
STAR ODDI	DST-centi HRT	N/A	46	15	19	N/A	5/45 +- 0.2	N/A	80-800	N/A	570 days at 600sec Fz	N/A	N/A	N/A	no buoyancy	447	514 €	price for 50 units
STAR ODDI	DST-milli HRT ACT	N/A	39.5	13	12	N/A	5/45 +- 0.2	N/A	80-800	+-2mg	31 days at 120 sec Fz	N/A	N/A	N/A	no buoyancy	485	558 €	price for 50 units
STAR ODDI	DST-centi	N/A	46	15	19	12	5/45 +- 0.2	N/A	100-800	+-4mg	570 days at	N/A	N/A	N/A	no buoyancy	485	558 €	price for 50 units

Brand	Tag name	Frequency (Hz)	Tag length (mm)	Tag diameter (mm)	Tag weight in air (g)	tag weight in water (g)	Temp	Pressure	Heart rate	Acceleration	DST memory	Battery life at a specific frequency	Power output (dB)	Approximative detection range (m)	Comments	Price / unit (£)	Price / unit (seller currency)	comments
	HRT ACT										600 sec Fz							
STAR ODDI	DST-tilt	N/A	46	15	19	12	-1/40 +- 0.1	max 100 +- 0.6%	N/A	N/A	1460 days at 600sec Fz	N/A	N/A	N/A	no buoyancy	512	588 €	price for 50 units
STAR ODDI	DST-tilt + float	N/A	174.5	16	N/A	-2	-1/40 +- 0.1	max 100 +- 0.6%	N/A	N/A	1460 days at 600sec Fz	N/A	N/A	N/A	N/A	542	623 €	price for 50 units
STAR ODDI	DST-compass magnet	N/A	46	15	19	12	-1/40 +- 0.1	max 100 +- 0.6%	N/A	N/A	1095 days at 600sec Fz	N/A	N/A	N/A	no buoyancy	655	753 €	price for 50 units

Appendix E: Satellite tag inventory and cost from main providers

Brand	Tag name	Tag length (mm)	Tag diameter (mm)	Tag weight in air (g)	Battery life at a specific frequency	Memory space (MB)	Location	Depth sensor (m)	Temperature sensor (°C)	Light sensor ($W.cm^{-2}$)	dry/wet sensor
Wildlife Computers	Survivorship PAT-355	124	38	60	60 days	N/A	Argos	0/1700 +-0.5	-40/60 +-0.1	$5.10^{-12}/5.10^{-2}$	YES
	Mark report PAT-376	127	28	40	730 days	N/A	Argos	NO	-40/60 +-0.1	NO	YES
	MiniPAT-348	124	38	60	800 days	64	Argos	0/1700 +-0.5	-40/60 +-0.1	$5.10^{-12}/5.10^{-2}$	YES
	TDR-Mk9-286C	72	17	34	2920 days	64	light level	0/200 +-0.1	-40/60 +-0.1	$5.10^{-12}/5.10^{-2}$	NO
	TDR-Mk9-286D	72	17	34	2920 days	64	light level	0/200 +-0.1	-40/60 +-0.1	$5.10^{-12}/5.10^{-2}$	NO
Microwave telemetry	PSAT PTT 100	167	40	78	360 days	N/A	Argos	0/1250 +-5	-4/40 +-0.2	$< 4.10^{-5}$	NO
	X-tag	122	33	45	360 days	N/A	Argos	0/1250 +-5	-4/40 +-0.2	$< 4.10^{-5}$	NO
Desert Star System	SeaTag-MOD	175	25	130	N/A	N/A	Magnetic	0/2000 +-0.1	-20/50 +-0.0	N/A	NO
	SeaTag-3D	199	10	60	N/A	N/A	Argos	YES	YES	YES	NO
	SeaTag-GEO	170	15	37	N/A	N/A	Argos	NO	YES	YES	NO
	SeaTag-LOT	178	15	42	N/A	N/A	Argos	NO	YES	YES	NO

Brand	Tag name	Other sensors	Comments	Price / unit (£)	Price / unit (seller currency)
Wildlife Computers	Survivorship PAT-355	NO	no possible time series or graphs	1435	$ 2000
	Mark report PAT-376	tilt	No depth sensor	1076	$ 1500
	MiniPAT-348	Activity, acceleration	N/A	2834	$ 3950
	TDR-Mk9-286C	NO	External or internal fixation	682	$ 950
	TDR-Mk9-286D	Conductivity	External or internal fixation	682	$ 950
Microwave telemetry	PSAT PTT 100	NO	N/A	2719	$ 3800
	X-tag	NO	N/A	3005	$ 4200
Desert Star System	SeaTag-MOD	Acceleration, Magnetometer	N/A	1610	$ 2250
	SeaTag-3D	Magnetometer	N/A	1290	$ 1800
	SeaTag-GEO	Magnetometer	No depth sensor	870	$ 1215
	SeaTag-LOT	NO	No depth sensor	643	$ 899