RWE Pembroke Abstraction Supporting Information

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Attention: RWE Generation UK plc (RWE)
Company: Jacobs UK Ltd
Prepared by: Kevin Thatcher, Isabel Lee-Elliott, Oliver McLaren Roberts and Rachel Wilson
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1180 Eskdale Road
Winnersh, Wokingham
Reading RG41 5TU
United Kingdom
T +44 (0)118 946 7000
F +44 (0)118 946 7001
www.jacobs.com

1.1 Introduction

Jacobs UK Ltd was contracted to undertake additional work to provide supporting information for RWE in support of their Abstraction licence Renewal for Pembroke Power Station. This work is to satisfy the request of Natural Resources Wales (NRW) for additional information and data analysis to support the Abstraction licence Renewal. This document draws together this supporting information into one place and Table 1 below provides a summary of the requested information along with links to the sections of the document that address the concern.

Table 1 Additional information

NRW Key Issue	Information requested by NRW	Location in Document
1	Provision of raw entrapment data and transparently presented calculations of annual estimates of impingement and entrainment from the raw entrapment data	Section 1.2
2	Provision of annual entrapment estimates using arithmetic means rather than geometric means	Section 1.3
3	Provision of uncertainty/variability in annual entrapment estimates to account for sampling resolution and scaling uncertainties	Section 1.4
4	Provision of updated EAVs for the entrapment data	Section 1.5 Section 1.6
5	Provision of post-hoc power analysis of the monitoring data	Section 1.7
6	Provision of species-specific trend analysis	Section 1.8
N/A	Assessment of whether entrapment at the power station in combination with increased water temperatures within the Haven as a result of the power station operation, affects populations of any fish species, the wider fish community or indirectly bird or marine mammal species through prey losses.	Section 1.9

1.2 Key Issue 1: Raw Entrapment Data

Impingement and entrainment data for each year is provided with the annual monitoring reports submitted annually to NRW for approval and can be found in the appendices of the fish monitoring reports:

- Appendix C of the fish reports provides a detailed overview of all of the statistical analysis undertaken for each data set (intertidal fish, subtidal fish, impingement, entrainment, ichthyoplankton).
- Appendix D of the fish report provides the data for each data set as follows:

- D.1: Ichthyoplankton data as average abundance per 10^6m^3 water sampled
- D.2: Entrainment overall abundance per 10^6m^3 water sampled as total abundance and by species
- D.3: Intertidal fish as total abundance by species by season
- D.4: Subtidal fish as total abundance by species by season
- D.5: Impingement as an annual abundance as well as abundance and biomass per survey in graphic form.

Appendix B of the entrapment pressure reports provide full transparency on how the data are treated and the process by which the scaling to annual abstraction is completed:

- B.1.3. presents how the entrainment values are calculated.
- B.2.3 presents how the impingement values are calculated.

Earlier on in the environmental monitoring programme this detail was fully provided and can be found within the body of the report. In 2016 it was moved to the above mentioned appendices, in accordance with NRW, to permit the main body of the report to be focused and smaller in size. An example of the calculations is provided below.

Raw Abundance (main catch and trash)

Species	14/01/2019	15/01/2019	21/01/2019	22/01/2019	04/02/2019	05/02/2019	18/02/2019
Pogge	0	0	0	0	0	0	1
Lesser sandeel	0	0	0	0	0	0	0
Raitt's sandeel	0	0	1	0	0	0	0
Sandeel	0	0	0	0	0	0	0

Abundance +1 (to allow for geometric mean calculation

Species	14/01/2019	15/01/2019	21/01/2019	22/01/2019	04/02/2019	05/02/2019	18/02/2019
Pogge	1	1	1	1	1	1	2
Lesser sandeel	1	1	1	1	1	1	1
Raitt's sandeel	1	1	2	1	1	1	1
Sandeel	1	1	1	1	1	1	1

Geometric mean calculated for month (cells highlighted where greater than 1)

Species	Jan	Feb
Pogge	1	1.25992105
Lesser sandeel	1	1
Raitt's sandeel	1.189207115	1
Sandeel	1	1

False 1 returned to 0

Species	Jan	Feb
Pogge	0	1.25992105
Lesser sandeel	0	0
Raitt's sandeel	1.189207115	0
Sandeel	0	0

Abstraction data for month and typical daily figure

Total monthly abstraction (m3)	91,099,727	76,792,586
Typical daily abstraction (m3)	2,897,333	2,711,444

Factor catch to monthly abstraction (no. fish divided by typical daily flow and then scaled to monthly abstraction)

Species	Jan	Feb
Pogge	0	36
Lesser sandeel	0	0
Raitt's sandeel	37	0
Sandeel	0	0

1.3 Key Issue 2: Arithmetic and Geometric Mean

Both geometric and arithmetic means were calculated and then subsequently visualised within R (R Core Team, 2024[1]) utilising the tidyverse package (Wickham *et al*, 2019[2]).

Figure 1 shows the geometric as well as arithmetic mean of both total abundance and biomass fish (per 10^6 m^3) each month during the previous three reported monitoring years (2020 – 2022). While it is evident that both versions of the mean accurately visualise the variation in catch size throughout each year (e.g. peak abundance observed during winter months) there is a notable discrepancy between the raw values reported. The seasonal and temporal (within and between year) variations in overall impingement is not unexpected as the susceptibility of fish is strongly influenced by the abundance and distribution of species and size classes within the vicinity of the cooling water intake.

The geometric mean exhibits a far more stable behaviour, while the arithmetic are more erratic as point events influence the arithmetic mean in a greater capacity. Due to the inherent `patchy` and random nature of the impingement sampling design there is a significant chance of outlier data to be produced during surveys throughout the year – this volatility introduces skew into the data set. As a result, the overarching trend, is more accurately represented by a geometric mean.

The method adopted in the entrapment reports is to represent the 'typical' values entrapped by using the geometric mean rather than the arithmetic mean in calculations as it better represents the central tendency. It has been shown that screen-catch data has a characteristic positive skew, therefore the use of the arithmetic mean in scaling catches is biased (Turnpenny *et. al*., 1983[3]). Furthermore many fish species swim in groups (schools) which are randomly distributed within the environment and fish themselves are randomly distributed within the groups. As a result, seine net , trawl and impingement catches are often not normally distributed, rather they exhibit random contagious distributions (probability distribution that exhibits a clustering effect). In ecology this distribution frequently occurs due to the uneven distribution of resources such as food or because of mutual attraction (e.g. fish school for protection from predators).

It is therefore common practise to use the geometric mean when investigating abundance and fluctuations in fish populations (Hutchings *et al*., 1983[4]). Owing to the contagious distribution of fish species observed within the impingement, intertidal as well as subtidal surveys carried out at Pembroke, where appropriate the geometric mean has been used to determine indices of abundance. This provides a more representative estimate of population abundance which can then be compared temporally.

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[1] R Core Team. (2024). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.

[2] Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T., Miller, E., Bache, S., Müller, K., Ooms, J., Robinson, D., Seidel, D., Spinu, V., Yutani, H. (2019). Welcome to the tidyverse. Journal of Open Source Software, 4(43), 1686.

[3] Turnpenny, A.W.H., Utting, N.J., Milner, R.S. and Riley, J.D. (1983). The effect of fish impingement at Sizewell A Power Station, Suffolk, on North Sea fish stocks. Central Electricity Generating Board, Sizewell Public Inquiry Support Document No. TPRD/L/3270/R88, 28 pp.

[4] Hutchings, J.A. (1996). Spatial and temporal variation in the density of northern cod and a review of hypotheses for the stock's collapse. Canadian Journal of Fisheries and Aquatic Science. 53, 943 – 962.

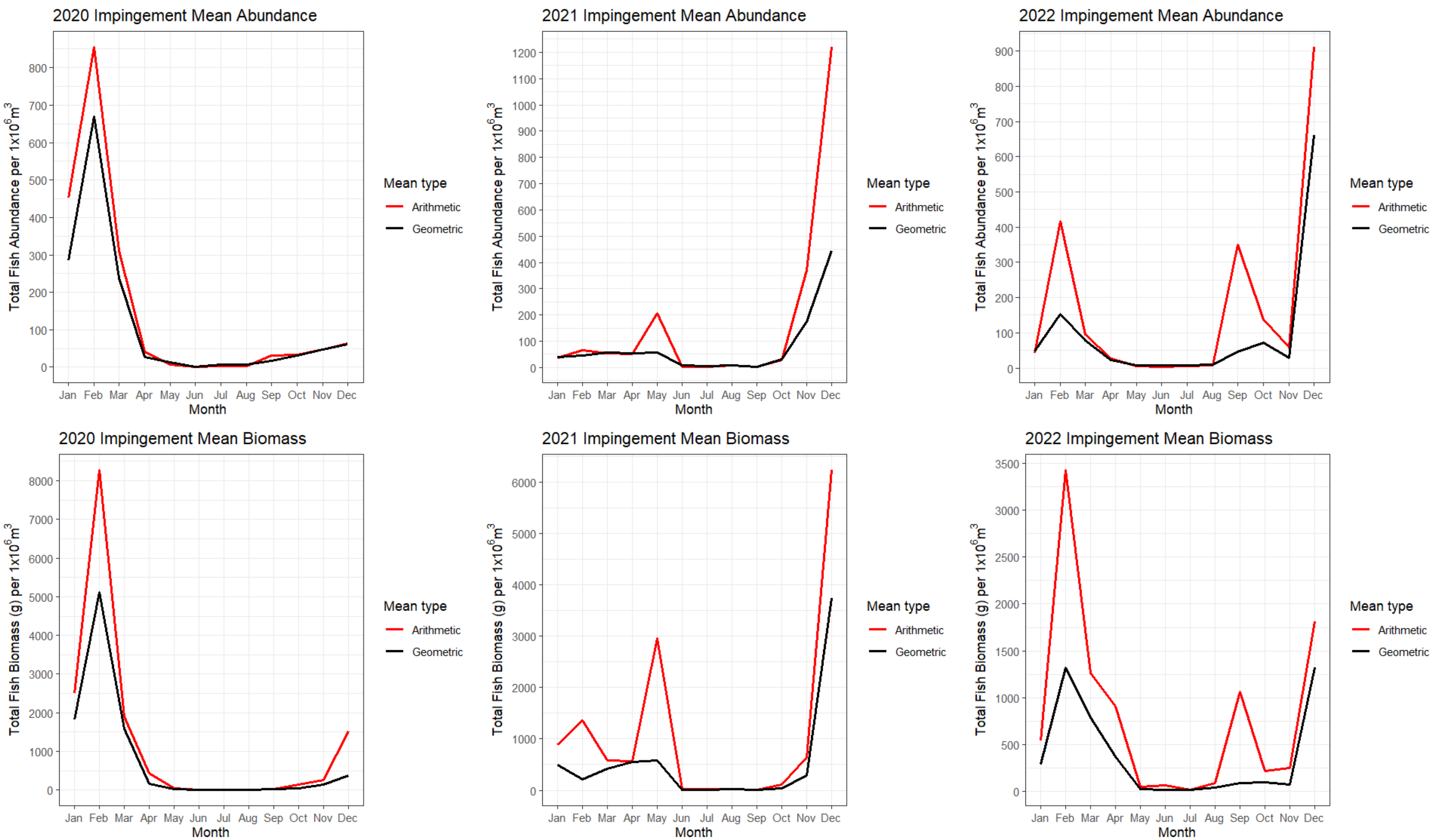

Figure 1. The geometric and arithmetic mean of total monthly abundance and biomass recorded per $10^6 m^3$ of water abstracted during impingement surveys between 2020-2022.

1.4 Key Issue 3: Uncertainty/Variability

Additional analyses in this report were all undertaken on the basis of reviewing data observed since 2019, when the Pembroke monitoring annual reports were last reviewed and approved by NRW. This only allows for the analysis of two years of data as, due to the Covid-19 pandemic sampling was not conducted in the same manner as in previous or subsequent years. Population data is inherently variable as has been observed in the Pembroke data set collected to date. Entrapment catches can vary by orders of magnitude each month and through the years have been highly variable.

Uncertainty analysis is a process that models variation and uncertainty in a real world system by using parameters that have been derived from the real world. Consequently the main requirement of uncertainty analysis is to have identified and quantified as many of the uncertainty parameters as possible and this will require as large a data set as possible (Carstensen, 2016[5]). In order to complete a viable assessment of variability, sensitivity and uncertainty within a time-series data set it then follows that a data set which is representative of the full range of variation with time will be required. Looking at any form of variability or uncertainty in a data set with a small number of data points (in this case two) would be unlikely to produce a meaningful analysis. Whilst this is the case, the signposting document that accompanies this document provides a review of the bootstrap method in the context of the impingement data as an example (in Appendix B).

The annual reports provided across the monitoring programme include confidence intervals on the graphics to show the levels of variability in the data points provided. This was introduced following consultation with NRW who felt that an understanding of the variability was needed when interpreting the data. Whilst the uncertainty is not provided in the extrapolated abundance data, it is provided in the analysis that is used to assess entrapment pressure. There will be inherent uncertainty in the scaling of the entrapment data as assumptions are made (as agreed with NRW previously) when the data are scaled. The fundamental point here is that regardless of the scaling method, the data are showing no significant effects at the community level, therefore the conclusion relating to no effect on the conservation objectives of the SAC remain.

1.5 Key Issue 4: EAV Review

A review of recent literature published has been conducted with respect to the Equivalent Adult Value (EAV) life table parameters. Particular focus has been given to if the literature is relevant to the Milford Haven/Irish Sea area and identify whether any data are available that may be used to update the original 2013/2016 life tables created for the Pembroke Equivalent Adult Value (EAV) analysis. This Technical Memorandum presents the literature and a summary of the findings.

1.5.1 Methods

Literature searches were undertaken for the following species:

- Bass (*Dicentrarchus labrax*)
- Herring (*Clupea harengus*)
- Sprat (*Sprattus sprattus*)
- Sandeel (*Ammodytes*)
- Sand goby (*Pomatoschistus minutus*)

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[5] Carstensen, J., Lindegarth, M., 2016 Confidence in ecological indicators: A framework for quantifying uncertainty components from monitoring data. Ecological Indicators, 67(306-317).

- Plaice (*Pleuronectes platessa*)
- Whiting (*Merlangius merlangus*)

These species were originally selected as they had adequate input parameter data available in the literature.

Information relating to any of the following were searched for according to each species or group, as applicable:

- Lifespan
- Spawning duration
- Lifestages - duration of
- Ageing - length at age/stage, growth rate
- Natural mortality
- Fishing mortality
- Fecundity
- Sex ratio
- Percent maturity

Information was collated within the Tables 2 to 8 in the Results section.

1.5.2 Results

The following tables present data found for each species. If certain parameters are not shown this indicates that no new data were available or the parameter was not applicable (e.g. fishing mortality for non-commercially exploited species in this sea area).

Table 2 Summary of data found for bass (RAG system for the outcome column shows data within (green) and outside (amber) the original life tables)

	More recent/relevant Reference(s)	Notes/brief summary of parameter	Outcome
Spawning duration	Lincoln, H. Robins, P.E., Wilmes, S-B., Pérez-Mayol, S., Moore A., Simpson S., Goward-Brown A., Heney, C., Malham S., Morales-Nin B., Hold N. and McCarthy, I.D. (2024). Predicting potential spawning areas of European bass, *Dicentrarchus labrax*, in the Irish and Celtic seas, Fisheries Research, Volume 270	Estimate bass spawning in the Irish and Celtic Seas between April and May for 2014 and 2019.	A narrower range which lies within the spawning times reported for the UK, i.e. January-May, but only for selected years.
	Graham, J. A., Watson J.W., Garcıa Garcia, L.M., Bradley, K., Bradley, R., Brown, M., Ciotti, B.J., Goodwin, D., Nash, R.D.M., Roche, W.K., Wogerbauer, C. and Hyder K (2023) Pelagic connectivity of European sea bass between spawning and nursery grounds. Front. Mar. Sci. 9:1046585. doi: 10.3389/fmars.2022.1046585	Feb-June (based on references therein)	Similar length spawning duration as the Pembroke lifetable.

	More recent/relevant Reference(s)	Notes/brief summary of parameter	Outcome
Ageing	ICES (2016). Report of the second Inter-Benchmark Protocol for sea bass in the Irish Sea, Celtic Sea, English Channel, and southern North Sea (IBPBass2), 1 December 2015–31 March 2016, by correspondence. ICES CM 2016/ACOM:31. 190 pp.	Gives length composition and length of age for population. E.g. French data up to 2014 in the western English Channel	The data from this report show some variation from the Pembroke lifetable lengths at age (e.g. in 2014 post 11 years), which were derived from Welsh waters (note data are 10 years old).
Natural Mortality	ICES (2018). Report of the Data Evaluation meeting for the Benchmark Workshop on Sea Bass (DEWKBASS), 10–12 January 2017, Copenhagen, Denmark. ICES CM 2017/ ACOM:32. 139 pp. https://doi.org/10.17895/ices.pub.19290410	Adopted M=0.24 for all age groups for assessment purposes	As this paper uses one value for M, this differs from the Pembroke life table values.
Fishing Mortality	ICES (2023). Seabass (*Dicentrarchus labrax*) in Divisions 4.b–c, 7.a, and 7.d–h (central and southern North Sea, Irish Sea, English Channel, Bristol Channel, and Celtic Sea). In Report of the ICES Advisory Committee, 2023. ICES Advice 2023, bss.27.4bc7ad-h. https://doi.org/10.17895/ices.advice.21840747	Gives a value of total F (averaged 2020 to 2022) for ages 4 to 15 of 0.105.	As this paper uses one value for F, this differs from the Pembroke life table values.
Percent maturity	ICES (2018). Report of the Benchmark Workshop on Seabass (WKBASS), 20–24 February 2017 and 21–23 February 2018, Copenhagen, Denmark. ICES CM 2018/ACOM:44. 283 pp.	Estimated length at 50% maturity (L50% = 40.65 cm. Ages at 100% maturity also presented.	Ages at 100% maturity differ slightly from the Pembroke lifetable values.

Table 3 Summary of data found for sprat (RAG system for the outcome column shows data within (green) and outside (amber) the original life tables)

	More recent/relevant Reference(s)	Notes/brief summary of parameter	Outcome
Lifespan	Henderson, P.A. and Henderson, R. C. (2017) Population regulation in a changing environment: Long-term changes in growth, condition and survival of sprat, *Sprattus sprattus* L. in the Bristol Channel, UK, Journal of Sea Research, Volume 120, Pages 24-34	Lifespan of Bristol Channel / Bridgewater Bay sprat limited to 3 years.	This differs from the 5 years presented in the Pembroke lifetable.
	Moore, C., Lynch, D., Clarke, M. Officer, R, Mills, J. Louis-Defour, J. and Brophy, D. (2019). Age verification of North Atlantic Sprat Fisheries Research vol. 213 (144-150	Celtic seas ecoregion population dominated by ages 0 to 2.	As above

	More recent/relevant Reference(s)	Notes/brief summary of parameter	Outcome
Fishing mortality	ICES (2023). Sprat (*Sprattus sprattus*) in Subarea 6 and Divisions 7.a-c and 7.f-k (West of Scotland, southern Celtic Seas). In Report of the ICES Advisory Committee, 2023. ICES Advice 2023, spr.27.67a-cf-k. https://doi.org/10.17895/ices.advice.21975368	No assessment of fishing mortality rate due to lack of reference data.	N/A
Fecundity	Henderson, P.A. and Henderson, R. C. (2017) Population regulation in a changing environment: Long-term changes in growth, condition and survival of sprat, *Sprattus sprattus* L. in the Bristol Channel, UK, Journal of Sea Research, Volume 120, Pages 24-34	Total fecundity reduction calculated from length / weight reduction. Reduction of 1+ population modal length to 110mm total fecundity = 12,163 eggs. Reduction of biomass (13g to 9g) of 120mm+ fish total fecundity 14,884 eggs.	Slight difference in total fecundity from the Pembroke lifetables.

Table 4 Summary of data found for herring (RAG system for the outcome column shows data within (green) and outside (amber) the original life tables)

	More recent/relevant reference(s)	Notes/brief summary of parameter	Outcome
Lifespan duration	Jennings, S., and Beverton, R. J. H. 1991. Intraspecific variation in the life history tactics of Atlantic herring (Clupea harengus L.) stocks. - ICES J. mar. Sci., 48: 117-125.	Reproductive lifespan (Manx stock) 9 years. Max 12 years.	This used data from Beverton (1963, within reference) Based on report findings in Milford Haven therefore no new information.
Lifestages - length at age	Fischbach, V., Finke, A., Moritz, T., Polte, P. and Thieme, P. (2023). A staging system for Atlantic herring (*Clupea harengus*) larvae based on external morphology and skeletal development. Limnology and Oceanography Methods Volume21, Issue7. 357-376	Yolk sac length towards end of stage 8.9 mm.	Data show 8.9 mm (Vs 10mm in Lifetable parameters). However, according to the varying habitat conditions and spawning biology, herring stocks in the Northern hemisphere show differences in larval development. It has been shown that larvae from different spawning ecotypes such as autumn and spring spawner herring show differences in growth rates characterized by, for example, the length at a certain stage (Gamble *et al.* 1985; Johannessen *et al.* 2011). This dataset is from Baltic herring.

	More recent/relevant reference(s)	Notes/brief summary of parameter	Outcome
	Worsøe Clausen, L., Stæhr, K-J., Rindorf, A., and Mosegaard, H. (2015). Effect of spatial differences in growth on distribution of seasonally co-occurring herring Clupea harengus stocks. Journal of Fish Biology, 86(1), 228–247. https://doi.org/10.1111/jfb.12571	*Presents Adult length at age for north sea spring spawning herring. Length slightly smaller than life table*	This study is from the North sea. Lifetable uses Milford Haven data, therefore not as relevant.
	Campbell, N. and Pert, C. (2022) Herring in the Firth of Clyde - setting the total allowable catch for 2022: consultation	Length at age	**Study** covers the Firth of Clyde – Pembroke Lifetable based on Milford Haven.
	Sswat, M., Stiasny M. H., Jutfelt, F., Riebesell, U. and Clemmesen, C. (2018). Growth performance and survival of larval Atlantic herring, under the combined effects of elevated temperatures and CO2. PLoS One. Jan 25;13(1):e0191947. doi: 10.1371/journal.pone.0191947. PMID: 29370273; PMCID: PMC5785030.	Mean SL of 9.6 mm ± 0.5 SD at 2 Days post hatch	In agreement with Pembroke lifetable length.
Natural mortality	ICES (2022). Herring Assessment Working Group for the Area South of 62° N (HAWG). ICES Scientific Reports. https://doi.org/10.17895/ices.pub.10072	Same Natural mortality as used for he lifetables previously - remain unchanged)	N/A
Fishing mortality F	ICES (2021) Herring Assessment Working Group for the Area South of 62° N (HAWG). VOLUME 3 | ISSUE 12	*Fishing mortality up to 2020 are presented.*	2020 F values are different to the Pembroke Lifetable values and would result in a decrease in the calculated EAV (note this would be only for the relevant years).
Sex ratio	Alemland, O. W. (2015). Phenotypic plasticity in Atlantic herring (*Clupea harengus*) juveniles reared at two different salinities. Masters Thesis, University of Bergen.	*The sex ratio in the fish examined from the parental fish population groups was close to 1:1 in both the Atlantic and Baltic catches*	In agreement with Pembroke lifetables.
Proportion mature	ICES (2022). Herring Assessment Working Group for the Area South of 62° N (HAWG). ICES Scientific Reports. Report. https://doi.org/10.17895/ices.pub.10072	Irish Sea stocks proportion mature @ age 2 in 2021 is 0.95 compared to 0.8 in life table	2021 values are different to the Pembroke Lifetable values and could result in a slight decrease in the calculated EAV (note this would be only for the relevant years).

Table 5 Summary of data found for sand goby (RAG system for the outcome column shows data within (green) and outside (amber) the original life tables)

	More recent/relevant Reference(s)	Notes/brief summary of parameter	Outcome
Lifestages - length at age	Re, P. and Meneses, I. (2008). Early Stages of Marine Fishes Occuring in the Iberian Peninsula.	Yolk sac absorption @3.5mm - this is in Iberia though so warmer sea area	Different sea area and not a new reference.
	Arula, T., Laur, K., Simm, M. and Ojaveer, H. (2015). Dual impact of temperature on growth and mortality of marine fish larvae in a shallow estuarine habitat, Estuarine, Coastal and Shelf Science,Volume 167, Part B. 326-335.	Growth rates of goby (*Pomatoschistus* spp.) larvae were high (0.23-0.35 mm d-1). High mortality rates primarily resulted from a rapidly increasing and high (>18 °C) water temperature that masked potential food-web effects	Not speciated, Baltic Sea and potential high temperature effects may mean these rates not representative of Milford Haven. Rates are higher than used in EAV/life tables
Life stages (duration)	Kvarnemo, C. (1994). Temperature differentially affects male and female reproductive rates in the sand goby: Consequences for operational sex ratio. *Proc. R. Soc. Lond. B, 256*, 151–156 cited in Asnicar, D.; Ašmonaitė, G.; Birgersson, L.; Kvarnemo, C.; Svensson, O.; Sturve, J. Sand Goby—An Ecologically Relevant Species for Behavioural Ecotoxicology. Fishes 2018, 3, 13.	Egg development is relatively slow, especially early in the breeding season when water temperatures are low, a parental male will normally stay with his eggs for a considerable time (approximately 2–4 weeks in 8–12 °C, 1-2 weeks in 12-18 °C)	These values are based on older literature and the upper end of the duration is only likely at lowest temperatures so the value of 18 days used in the Pembroke lifetable would likely be appropriate for Milford Haven.
Natural mortality	Arula, T., Laur, K., Simm, M. and Ojaveer, H. (2015). Dual impact of temperature on growth and mortality of marine fish larvae in a shallow estuarine habitat, Estuarine, Coastal and Shelf Science, Volume 167, Part B. 326-335.	Mortality rates of goby (*Pomatoschistus* spp.) larvae were high (0.57–1.05). high mortality rates primarily resulted from a rapidly increasing and high (>18 °C) water temperature that masked potential food-web effects	Baltic Sea and potential high temperature effects may mean these rates not representative of Milford Haven.
Sex ratio	García-Berro, A., Yliportimo, J., Lindström, K. and Kvarnemo, C. (2019). Understanding resource driven female-female competition: ovary and liver size in sand gobies. R Soc Open Sci. 2019 Sep 11;6(9):190886. doi: 10.1098/rsos.190886. PMID: 31598312; PMCID: PMC6774974.	Differences in the operational sex ratio (OSR, ready-to-mate males to females) of *P. minutus* was female-biased in the Baltic Sea population, compared to the North Sea, and that female–female competition for mating opportunities is stronger in the Baltic population.	The ratio is dependent on resource availability e.g. food therefore conditions not necessarily reflective of Milford Haven.

Table 6 Summary of data found for sandeel (RAG system for the outcome column shows data within (green) and outside (amber) the original life tables)

	More recent/relevant Reference(s)	Notes/brief summary of parameter	Outcome
Spawning duration	MacDonald, A., Speirs, D. C., Greenstreet, S. P. R., Boulcott, P. and Heath M. R. (2019). Trends in Sandeel Growth and Abundance off the East Coast of Scotland. Frontiers in Marine Science 6.	Hatch end dates varied by 20 days over the 10-year period between 2000-2009 and were correlated with the date of the seasonal minimum of sea bottom temperature.	No update needed - temperature regime not specific to Irish Sea/Milford Haven
Ageing – Duration of Lifestages	Perrichon, P., Bjelland, R., Durif, C. M.-F., Uglenes Fiksdal, I., Johnsen, E, Berit Skiftesvik, A., Cresci, A., Browman, H. I. and Sørhus, E. (2023). Early ontogeny of the lesser sandeel (*Ammodytes marinus*) Developmental Dynamicshttps://doi.org/10.1002/dvdy.634	Egg: (1 month - 27 days post fertilization) embryonic period	The Pembroke life table assumed 26 days for *A. tobianus* (warmer temperatures). Paper gives general "one month".
	Perrichon, P., Bjelland, R., Durif, C. M.-F., Uglenes Fiksdal, I., Johnsen, E, Berit Skiftesvik, A., Cresci, A., Browman, H. I. and Sørhus, E. (2023). Early ontogeny of the lesser sandeel (*Ammodytes marinus*) Developmental Dynamicshttps://doi.org/10.1002/dvdy.634	Larvae (39 days post hatch) (66 cumulative days. Larval phase durations between 2000 and 2002 were 54–107 days, 63–126 days, and 72–145 days, respectively	The Pembroke lifetable assumes 27-87 days, which encompasses this value.
	Perrichon, P., Bjelland, R., Durif, C. M.-F., Uglenes Fiksdal, I., Johnsen, E, Berit Skiftesvik, A., Cresci, A., Browman, H. I. and Sørhus, E. (2023). Early ontogeny of the lesser sandeel (*Ammodytes marinus*) Developmental Dynamics https://doi.org/10.1002/dvdy.634	Juvenile 120 days (unclear if total or post hatch)	88 days+ was assumed for the Pembroke life table so this is still valid (need to clarify if the 120 days in the paper is post fertilization or post hatch).
Growth rates	MacDonald, A., Speirs, D. C., Greenstreet, S. P. R., Boulcott, P. and Heath M. R. (2019). Trends in Sandeel Growth and Abundance off the East Coast of Scotland. Frontiers in Marine Science 6.	0.468 mm day^{-1} in 2000 to 0.338 mm day^{-1} in 2002.	Pembroke lifetable rates are within this range. An average growth rate was used in the Pembroke lifetables.

	More recent/relevant Reference(s)	Notes/brief summary of parameter	Outcome
Yolk sac/Larval length at age	Perrichon, P., Bjelland, R., Durif, C. M.-F., Uglenes Fiksdal, I., Johnsen, E, Berit Skiftesvik, A., Cresci, A., Browman, H. I. and Sørhus, E. (2023). Early ontogeny of the lesser sandeel (*Ammodytes marinus*) Developmental Dynamicshttps://doi.org/10.1002/dvdy.634	Authors state newly hatched larvae measured 5.93 ± 0.41 mm, which is consistent with the size reported in the literature (ca. 5.5 mm at hatching).	The Pembroke lifetable assumed 5 mm +-1mm - The paper indicates a small increase in length (approximately 0.5 mm) from the lifetable value. However, EAV table starts at 7 mm so post hatching length.
Juvenile length at age	Perrichon, P., Bjelland, R., Durif, C. M.-F., Uglenes Fiksdal, I., Johnsen, E, Berit Skiftesvik, A., Cresci, A., Browman, H. I. and Sørhus, E. (2023). Early ontogeny of the lesser sandeel (*Ammodytes marinus*) Developmental Dynamicshttps://doi.org/10.1002/dvdy.634	79.6 ± .9.0 mm after 8 months	Length in paper consistent with Pembroke EAV length at age.
Juvenile/adult Length at age (1 year)	Laugier, F., Feunteun, E., Pecheyran, C. and Carpentier, A. (2015). Life history of the Small Sandeel, *Ammodytes tobianus*, inferred from otolith microchemistry. A methodological approach, Estuarine, Coastal and Shelf Science, Volume 165, 2015, Pages 237-246, ISSN 0272-7714, https://doi.org/10.1016/j.ecss.2015.05.022.	The definitive length of fish, almost reached at one year of age, was estimated from otoliths at 118.33 ± 7.15 mm	Upper length of *A tobianus* (125.5mm) in the paper is similar to length at end of lifestage used for the Pembroke lifetable (128mm).
Adult length at age	van Deurs, M., Koski, M. and Rindorf, A. (2014). Does copepod size determine food consumption of particulate feeding fish?, ICES Journal of Marine Science, Volume 71, Issue 1, Pages 35–43, https://doi.org/10.1093/icesjms/fst090	2005-2010 Age 1 (around 120mm+) Age 2 (between 140 and 160mm)	Although paper is more recent than 2013 it uses North Sea data until 2010. Length points are within the range of those used in the Pembroke lifetables (which are 128mm and 160mm at one and two years old, respectively).
Natural mortality	MacDonald, A., Speirs, D. C., Greenstreet, S. P. R., Boulcott, P. and Heath M. R. (2019). Trends in Sandeel Growth and Abundance off the East Coast of Scotland. Frontiers in Marine Science 6	1st year mortality rates range from 0.2373-0.9996 y^{-1}.	This is from 4 years-worth of data over 20 years ago from north east Scotland where commercial fishing exists. Pembroke lifetables use higher natural mortality rates of 0.03 d^{-1} (paper rates equate to 0.007 d^{-1}). However, there may be density effects owing to

	More recent/relevant Reference(s)	Notes/brief summary of parameter	Outcome
			commercial fishing that affects the rates.
Natural mortality	ICES (2017). Report of the Benchmark on Sandeel (WKSand 2016), 31 October - 4 November 2016, Bergen, Norway. ICES CM 2016/ACOM:33. 319 pp. https://doi.org/10.17895/ices.pub.7718	Age 0- 0-0.925 Age 1- 0.571-0.586 Age 2- 0.437-0.491 Age 3- 0.317-0.419 Age 4- 0.311-0.409	Although these annual rates are different from the lifetable rate, those natural mortality rates reported by ICES for North Sea stocks reduces the effect of positive density effects that may be introduced where commercial fishing is significant.
Percent maturity	Wright, P.J., Christensen, A., Régnier, T., Rindorf, A., and van Deurs, M. (2019). Integrating the scale of population processes into fisheries management, as illustrated in the sandeel, *Ammodytes marinus*, ICES Journal of Marine Science, Volume 76, Issue 6, Pages 1453–1463, https://doi.org/10.1093/icesjms/fsz013	100% mature at ~120mm to 150mm (from graph)	This dataset is from different areas of the North Sea and demonstrate the range in length that 100% maturity is achieved. Pembroke lifetable assumes 100% maturity at 2 years old (160mm) (30% mature at one year (128mm). The age of the fish at length are not displayed in this reference.

Table 7 Summary of data found for plaice (RAG system for the outcome column shows data within (green) and outside (amber) the original life tables)

	More recent/relevant Reference(s)	Notes/brief summary of parameter	Outcome
Spawning duration	Sauger, C., Quinquis, J., Berthelin, C., Lepoittevin, M., Elie, N., Dubroca, L. and Kellner, K. A. (2023). Quantitative Histologic Analysis of Oogenesis in the Flatfish Species *Pleuronectes platessa* as a Tool for Fisheries Management. Animals 13, 2506. https://doi.org/10.3390/ani13152506	Spawning duration in English Channel from December to February	Lifetable information states spawning usually takes place from January to late April/early May with peak spawning occurring from late-February to early-March. However, it can vary by year.
Fishing mortality	ICES (2023). Plaice (*Pleuronectes platessa*) in Division 7.a (Irish Sea). In Report of the ICES Advisory Committee, 2023. ICES Advice 2023, ple.27.7a.	Total F = 0.071 for ages 3 to 6 averaged 2020 to 2022.	This value for F differs from Pembroke lifetables (0.22).

	More recent/relevant Reference(s)	Notes/brief summary of parameter	Outcome
Maturity	Sauger, C., Quinquis, J., Berthelin, C., Lepoittevin, M., Elie, N., Dubroca, L. and Kellner, K. A. (2023). Quantitative Histologic Analysis of Oogenesis in the Flatfish Species *Pleuronectes platessa* as a Tool for Fisheries Management. Animals 13, 2506. https://doi.org/10.3390/ani13152506	Categorise size at maturity as 20.6cm. Also presents 50% maturity	These maturity values at lengths differ from the Pembroke lifetable age and length at maturity.

Table 8 Summary of data found for whiting (RAG system for the *outcome* column shows data within (green) and outside (amber) the original life tables)

	More recent/relevant Reference(s)	Notes/brief summary of parameter	Outcome
Lifespan duration	Henderson, P.A. (2019). A long-term study of whiting, *Merlangius merlangus* (L) recruitment and population regulation in the Severn Estuary, UK. ,Journal of Sea Research, Volume 155	Bristol channel most individuals reach a maximum of 6 years.	This value differs for from Pembroke lifetables (8 years maximum).
Natural mortality	Henderson, P.A. (2019). A long-term study of whiting, *Merlangius merlangus* (L) recruitment and population regulation in the Severn Estuary, UK. ,Journal of Sea Research, Volume 155	1.15% day^{-1}	This rate equates to an M value of 4.20 which differs from the Pembroke lifetable value.
Fishing mortality	ICES (2023). Whiting (*Merlangius merlangus*) in Division 7.a (Irish Sea). In Report of the ICES Advisory Committee, 2023. ICES Advice 2023, whg.27.7a. https://doi.org/10.17895/ices.advice.21864330	F = 0.77	This rate differs from the Pembroke lifetable value.

1.5.3 Discussion

The literature review Tables 2 to 8 presented in the Results section indicate that much of the more recent data (where they are available) are within the range of those utilised within the Pembroke lifetables. However, some new data did differ and a high level sensitivity analysis could be undertaken on the following species and parameters, to determine whether the associated EAVs may be subject to change:

- Bass (length at age, natural mortality, fishing mortality and percent maturity)
- Sprat (lifespan and fecundity)
- Herring (proportion mature, fishing mortality)
- Sandeel (duration of lifestages)

- Plaice (fishing mortality and maturity)
- Whiting (Lifespan duration, natural mortality and fishing mortality)

It should be noted that some parameters are expected to change annually. e.g. fishing mortality, some data may be less relevant/reliable (e.g. laboratory-derived vs environmental) and average values for some parameters have been used in the original lifetables so even though the more recent literature may indicate values would be different, the overall lifetable and EAV outputs are not expected to change the magnitude of calculated annual adult equivalents. As outlined in Section 1.4, EAV estimates derived from the created lifetables fell within 95% confidence of average EAV estimates derived from multiple data scenarios. Therefore a single newer value is likely to fall within this range once the average and reliability of the data are taken into account, and overall the original lifetables are considered fit for purpose.

A high level worked example of this is shown for herring in Table 9, where some updated fishing mortality and proportion mature values were used in place of the original lifetable values. The EAVs generated from the new data were between 5.5 and 13.4% lower than the original figures. However, the EAVs as a percentage of the extrapolated annual abundance were essentially the same and therefore conclusions drawn are still valid.

Table 9 Herring parameter changes and overall change in EAV/reduction of extrapolated abundance

	Extrapolated abundance (original)	Extrapolated EAV (original)	Extrapolated EAV reduced by 5.5%	Extrapolated EAV reduced by 13.4%	EAV as % reduction of extrapolated abundance @ 5.5%	EAV as % reduction of extrapolated abundance @ 13.4%	Original EAV as % reduction of extrapolated abundance
Herring	103,345	14	**13.2**	**12.1**	**100.0**	**100.0**	>99.9
Clupeids as herring	167,927	1,182	**1,117.0**	**1,023.6**	**99.3**	**99.4**	99.3

1.6 Existing Sensitivity Analysis

Although conceptually sound, EAVs are dependent on a large number of age-specific life history parameters. In some cases these parameters are poorly known, particularly for early life stages. To determine the potential effect of different input parameters derived from literature on age-specific EAVs, a local sensitivity analysis was conducted when the tables were created. This allowed the uncertainty associated with each input parameter to be estimated and provided a means for computing confidence limits for EAVs. However, this process was limited to species and input parameters for which multiple data sets exist in literature.

During the literature review process, multiple data sets representing the same input parameter were identified for commercial species and species of scientific interest. This data was evaluated to identify the most geographically relevant and plausible values for each of the lifetable parameters to generate the species-specific lifetables developed. This process is not strictly empirical and requires application of professional judgement.

To assess the effect of different data sets on EAV estimates a 'one-factor-at-a-time' (OAT) local sensitivity analysis was conducted (Daniel, 1973[6]; Morris, 1991[7]). Each input parameter was varied one at a time either within a range of likely values or using point estimates reported in literature. This analysis demonstrated that EAV estimates derived from the created lifetables fell within 95% confidence of average EAV estimates derived from multiple data scenarios reported in literature. This indicates that the Pembroke lifetables provide an accurate reflection of species specific life history parameters and subsequent EAVs.

[6] Daniel, C. (1973). One-at-a-time plans. Journal of American Statistics Association, 68: 353 – 360.

[7] Morris, M.D. (1991). Factorial sampling plans for preliminary computational experiments. Technometrics, 33; 161 – 174.

The majority of life history parameters can be measured with relative ease, however there is no standardised methodology for sampling and when drawing upon data from literature with conflicting information, experimental design and linguistic imprecision can introduce uncertainty. All lifetables created and used in the assessments were reviewed by industry experts (Dr Andrew Turnpenny (THA) and Steve Colclough (SC[2]), Professor Peter Miller (University of Bristol) and Dr Beatriz Roel (Cefas)) to get their view of the most appropriate parameters to be used.

The recent literature review has shown only a small number of new datasets with general values falling within the range of the original lifetables and associated outputs. With the rigorous sensitivity analysis implemented in the original lifetable construction process and the use of professional judgement and peer reviewed parameters (which could be averages of data points) it is considered that the Pembroke lifetables are still valid and fit for purpose.

1.7 Key Issue 5: Power Analysis

The observed or post-hoc statistical power is based on the effect size estimate derived from a dataset. As observed power differs from the true power of a sampling design to detect a significant effect using it as a tool to indicate power for outcomes already observed is not only conceptually flawed but also analytically misleading (Zhang *et al*, 2019[8]). Low power will likely be indicated from results concluding non-significant effects (Hoeing & Hiesey, 2001[9]) undermining the ability to detect true negatives (concluding there is no effect, when there is no effect) from false negatives (concluding there is no effect, when there actually is an effect, or a Type II error). Therefore, a comprehensive simulation-based power analysis (following Weiser *et al*, 2021[10]) was conducted to determine the estimated power of each data set / sampling design to detect change in abundance across a range of annual trends.

Abundance data from the previous ten years of impingement, as well as subtidal and intertidal fisheries was utilised in the calculation of the key metrics (as per Weiser *et al*, 2021[11]) that were subsequently input into the TrendPowerTool (https://rconnect.usgs.gov/TrendPowerTool/). The outputs, of which, provide estimates on the ability of each data set to detect varying levels of annual change. Raw abundance was pooled by survey for impingement, by site for intertidal fisheries, and Catch per Unit Effort (CPUE) was pooled per site for subtidal fisheries. Each of the 40 annual impingement surveys were treated as an individual site.

1.7.1 Impingement

The estimated statistical power of the impingement dataset increases with increasing annual change (Figure 2). Effectively, the data set can detect an inter-annual change in the populations between 7.5%-10% with an estimated power of 0.8, detecting a lower percentage change in abundance diminishes the estimated power. In order for the sampling design to produce a dataset that could detect smaller annual variation (at acceptable power values, ≥0.8) in population trend, an increase in the number of individual surveys would be required. For instance, the model estimated that 200 surveys (per year over 10 years) would need to be conducted per annum (currently 40) in order to detect an annual change in abundance of 3% with a power ≥0.8.

[8] Zhang Y, Hedo R, Rivera A, Rull R, Richardson S, Tu XM. (2019). Post hoc power analysis: is it an informative and meaningful analysis? Gen Psychiatry 32(4).

[9] Hoenig J. M., and Heisey, D. M. (2001). 'The Abuse of Power: The Pervasive Fallacy of Power Calculations for Data Analysis', The American Statistician, 55(1), pp. 19–24.

[10] Weiser E.L., Diffendorfer J.E., Lopez-Hoffman L., Semmens D., Thogmartin W.E. (2021). TrendPowerTool: A lookup tool for estimating the statistical power of a monitoring program to detect population trends. Conservation Science and Practice.

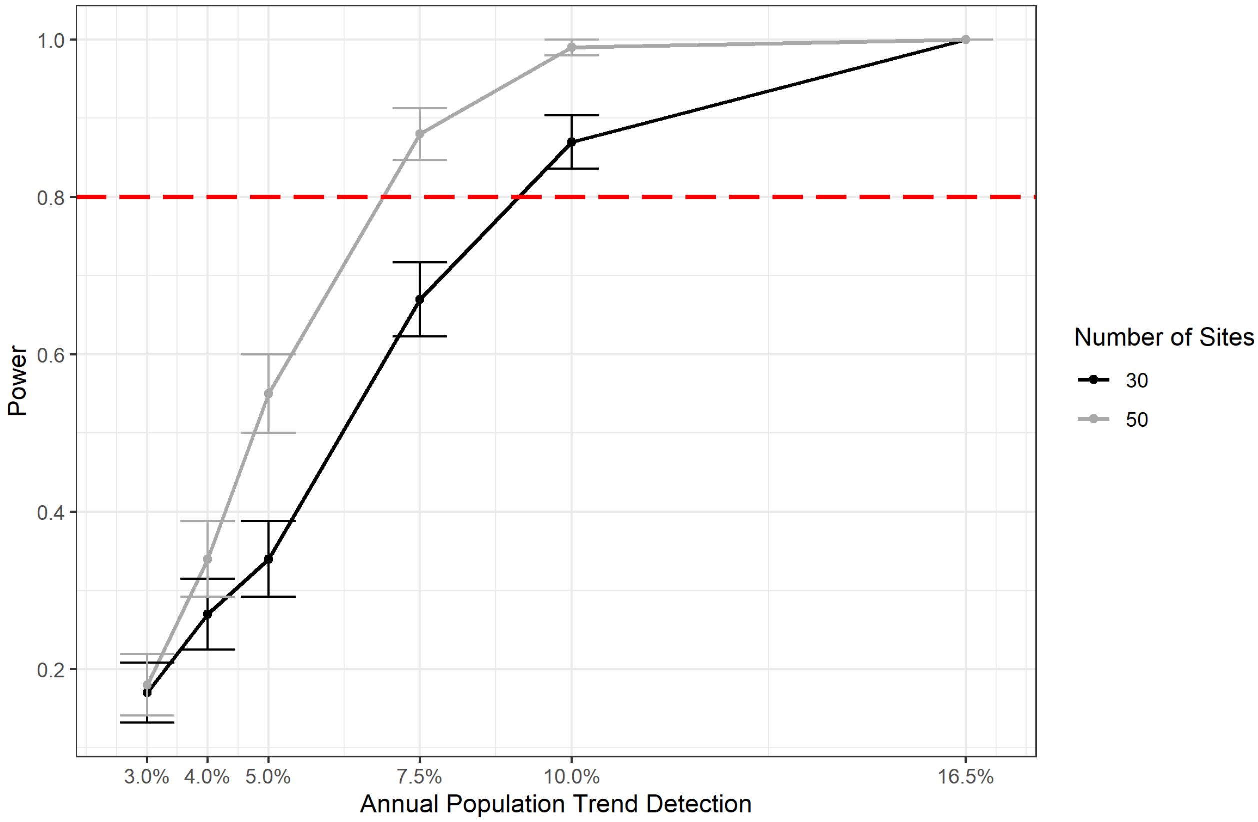

Figure 1. Estimated statistical power of the last ten years of impingement data to detect population change. The TrendPowerTool estimates power for either 30 or 50 sites annually, as 40 impingement surveys are conducted a year both are displayed. Error bars represent the standard error of the estimated power.

1.7.2 Subtidal and Intertidal Fisheries

The sampling design of both the subtidal and intertidal fisheries surveys are sufficient to detect an 7.5% change in abundance (CPUE in the case of subtidal fisheries) per annum (Figure 23). Similar to the Impingement dataset, the lower the variation in the abundance the lower the estimated power values. The model estimated that 200 sites (per year over 10 years) would be required to be surveyed per annum (currently 28) for both the subtidal and intertidal fisheries sampling design to support a detection of 3% change per annum with a power ≥0.8.

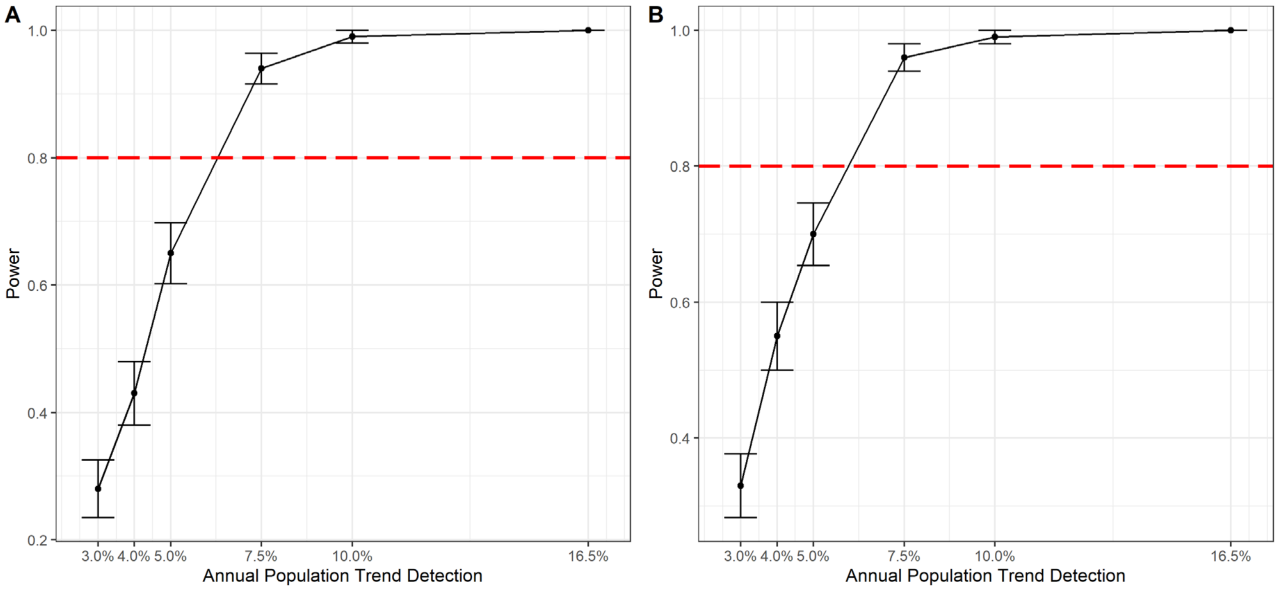

Figure 2. Estimated statistical power of the last ten years (2013-2022) of both the subtidal (A) as well as intertidal (B) fisheries datasets to detect population change. Error bars represent the standard error of the estimated power.

Power is usually desired to be at least 0.8 (Cohen, 1988[11]; Stefano, 2003[12]), although values of power as low as 0.5 are sometimes considered acceptable (Murphy and Myors 2004[13]). In practice, it is often difficult to obtain power much greater than 0.8 (i.e., a very large sample size is necessary) (Morrison, 2007[14]). The impingement, subtidal and intertidal fisheries data sets all support a detection of 7.5%-10% change in the abundance per annum at an estimated power ≥0.8. The current sampling regime has been agreed with NRW and is able to confidently detect acceptable levels of change (7.5-10% per annum) to reach a robust and reliable decision in this case.

1.8 Key Issue 6: Species Specific Trend Analysis

Within the fish and entrapment pressure reports, focus is given to individual species of concern, and this reflects the data being analysed as well as focus areas for NRW. These species are reviewed in terms of trends in annual abundance and are provided for all years of monitoring so shifts in abundance can be seen. More detailed analyses of individual fish species is provided in the annual fish report, again with the focus on species being driven by what is seen in the data.

Species reviewed include the following:

- Sprat;
- Sand smelt;
- Gobies;

[11] Cohen, J. (1988). Statistical Power Analysis for the Behavioral Sciences. Lawrence-Erlbaum. Hillsdale, N.J.

[12] Stefano, J. D. (2003). How much power is enough? Against the development of an arbitrary convention for statistical power calculations. Functional Ecology 17:707–709.

[13] Murphy, K. R. and Myors, B. (2004). Statistical Power Analysis: a Simple and General Model for Traditional and Modern Hypothesis Tests. Lawrence Erlbaum. Mahwah, N.J.

[14] Morrison, L. W. (2007). "Assessing the Reliability of Ecological Monitoring Data: Power Analysis and Alternative Approaches," Natural Areas Journal 27(1), 83-91.

- Herring;
- Bass;
- Lesser-spotted dogfish;
- Gadoids; and
- EPAA species

Examples of the analysis contained in the reports are shown in Figure 4 below for sprat, sand smelt and poor cod. The analysis of trends in abundance for the species of concern are within Section 5 of the entrapment pressure report with wider analysis of the species within the fish report.

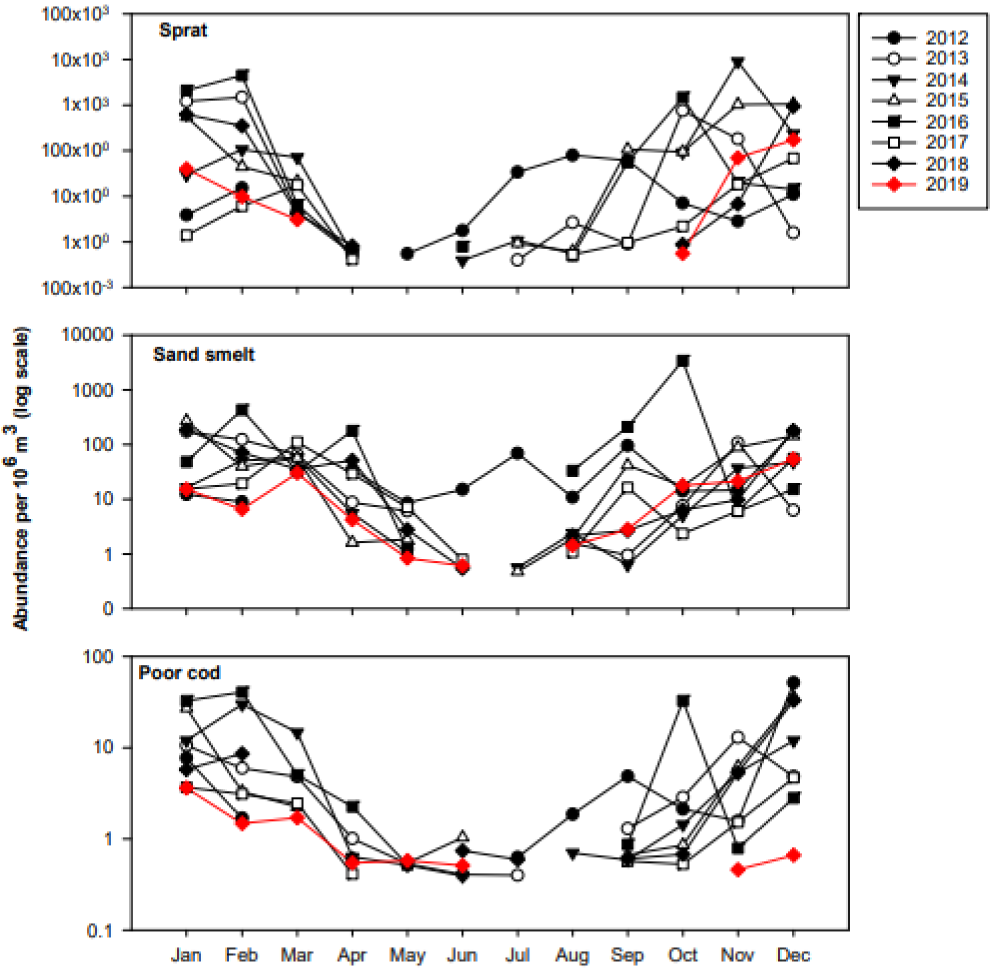

Figure 4. Geometric mean monthly abundance (per $10^6 m^3$ of sprat, sand smelt and poor cod which each contributed >10% to the total abundance impinged between 2012 and 2019 combined. Taken from Entrapment Pressure report.

The annual reports acknowledge that species populations, including fish communities, within the Haven vary in time and space, partly in reflection of the variable habitats and dynamic environment of the estuary; stochastic events and the great variation in survival and recruitment of species also plays a major role (NRW, 2017[15]). As such, 'boom and bust' species such as sprat and sand smelt have demonstrated dramatic increases and decreases during the monitoring programme as a result of natural variability in environmental factors, spawning and recruitment success and other factors relating to their population dynamics. Equally, species that are infrequently recorded may disappear altogether for a period of time, whilst new ones might arrive in the Haven particularly as species ranges extend northwards as a result of climate change. Importantly, it is expected to see short-term changes to the fish communities within Milford Haven, but it is the relative long-term stability (e.g. cyclical patterns) and persistence of species populations and functional guilds that should inform any assessment of the impacts of any pressure of which power station operation is one.

The observed changes in fish communities remain in line with expected variation, based upon the knowledge from previous years, as well as from historical data, unpublished data from NRW fish monitoring and general appreciation of the complex estuarine fish community dynamics in the Pembrokeshire Marine SAC. There is no evidence to date of an ecologically significant change in the fish community since monitoring began, in terms of abundance or diversity of the core species.

1.9 In-combination

It is noted that NRW in correspondence has requested that the impacts of the renewal licence be considered in combination with the increased water temperature within the Haven as a result of the power station discharge. The HRA assessment undertaken has accounted for the influence of temperature as it is inherently built into the baseline data that forms part of the assessments. The operation of the station is already regulated as part of the Environmental Permit, for which annual reports are prepared and discussed. There is, however, reference to power station operation in the in-combination section of the Report to Inform Appropriate Assessment (Section 9.1).

[15] Natural Resources Wales (2017). Pembrokeshire Marine / Sir Benfro Forol Special Area of Conservation. Advice provided by Natural Resources Wales in fulfilment of Regulation 35 of the Conservation of Habitats and Species Regulations 2010 (as amended). Cardiff, Wales. 131 pp. [Online]. Available at: https://naturalresources.wales/media/682013/pembrokeshire-marine-reg-35-report.pdf [Accessed March 2018].