HINKLEY POINT C PERMIT VARIATION

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Technical Brief: TB019

Investigation of the relationship between impingement at HPB and abstraction within the Bristol Channel.

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Executive summary

The Environment Agency has examined data from the Routine Impingement Monitoring Programme (RIMP) at Hinkley Point B power station (HPB). We reviewed whether this data can help us to understand how future cooling water abstraction may affect fish populations over the next sixty years.

The RIMP measured the number and size of fish trapped on the intake screens, from 1981 to 2017. The programme start coincided with a period where abstraction in the Bristol Channel began to decrease as earlier power stations closed. Abstraction volumes are expected to fall further in 2023 with the closure of HPB, and then rise again to mid-1990s levels when HPC enters operation. By 2030, Pembroke and HPC are expected to be the only remaining active abstractions.

This paper investigates the relationship between the fish population measured by the RIMP and abstraction within the Bristol Channel. Our analyses show:

- It may not be possible to detect a reduction in fish abundance smaller than 50%. There is substantial variability within the data, even during years when the total abstraction volume does not change. Consequently, it is not possible to conclude whether the abstraction volume in the Bristol Channel has affected population abundance, or not.
- The change in overall fish abundance (all species combined) over time is too weak to conclude whether fish abundance increased or decreased between 1981 and 2017.
- Of 106 species analysed individually (91 fish and 15 invertebrates), only five showed a strong correlation between number impinged and time:
    - Decreasing trends in European eel and hake.
    - Increasing trends in spider crab, Atlantic herring, and Dover sole.

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Introduction

Chapter 3, section 3.3 of ‘HPC-DEV024-XX-000-RET-100031 - Revised Predictions of Impingement Effects at Hinkley Point C – 2018 TR456 Edition 2 Version 10’ (TR456), discussed power station cooling water abstractions in the Bristol Channel. Power station abstraction volumes from 1950 to 2025 are noted, in context with the data collected during the Routine Impingement Monitoring Programme (RIMP), from 1981-2017.

TR456 chapter 4, section 4.1 and chapter 11 review the results from impingement monitoring programmes. The 37-year RIMP, designed to assess long term changes in fish populations at Hinkley Point rather than to provide an unbiased estimate of HPB impingement, takes place for six hours once a month (72 hours per annum). However there were a few exceptions when sampling did not take place, due to staff shortages and power station maintenance.

Several results are highlighted in TR456 regarding the marine species, stating that:

- There has been a significant rise in total fish abundance over the observation period with a 54% increase in fish numbers excluding European sprat (*Sprattus sprattus*), or more than 100% increase with European sprat included.
- 29 out of 89 species analysed display a statistically significant trend in abundance over the period, with 19 showing an increasing and 10 a decreasing trend:
    - exponential increases in the numbers of Atlantic herring (*Clupea harengus*), Dover sole (*Solea solea*), European sprat, fivebeard rockling (*Ciliata mustela*), thin lipped grey mullet (*Liza ramada*);
    - declines in the number of European eel (*Anguilla anguilla*), dab (*Limanda limanda*), poor cod (*Trisopterus minutus*) and Norway pout (*Trisopterus esmarkii*).

Appendix E of TR456 uses a Mann-Kendall (MK) analysis to identify temporal trends in fish abundances. The MK test used is a Seasonal MK, which corrects for seasonal (actually monthly) autocorrelation. TR456 then overlays locally estimated scatterplot smoothing (LOESS) curves over the trend data. A summary for five dominant species is provided in TR456 chapter 1, section 1.12.3 with a significant increasing trend for all species - thin lipped grey mullet, flounder, five-bearded rockling, sand goby (*Pomatoschistus minutus*) and the brown shrimp (*Crangon crangon*). The dataset is also used to consider the impact of increasing and decreasing abstractions within the wider Bristol Channel on the assemblage. This historical analysis is then used to predict future impacts of the proposed HPC station abstraction. From this analysis, TR456 concludes that if the mortality rate was unsustainable the population would show a decline.

TR456 predicts that the equivalent abstraction rate of HPC due to embedded mitigation of the low velocity side entry (LVSE) intake heads and the fish return and recovery system (FRR) will be less than the unmitigated HPB abstraction rate. Therefore the impingement effects on these species will drop compared with the baseline put forward as part of the Development Consent Order (TR456).

The aim of this review is to consider the validity of the RIMP dataset as a predictor of future impacts of the proposed HPC power station on the Bristol Channel fish assemblage, and as a detector of the impacts from HPB during its operation. This will be examined by:

- Reviewing historic power station abstraction in the Bristol Channel.
- Undertaking a trend analysis of the abundance of the assemblage, as a whole as well individual species recorded in the RIMP dataset.
- Investigating whether there is a relationship between fish abundance and historic cooling water abstraction in the Bristol Channel.
- Investigating what size of change the RIMP data could detect.

Review of abstraction in the Bristol Channel, 1940-2030

Power station abstraction (and its associated impact on entrained and impinged organisms) began in 1950 in the Bristol Channel (Table 1, adapted from TR456 Table 5; Figure 1). At its peak, there was more power station abstraction in the Bristol Channel than in any other estuary in Europe (Henderson, 2018).

Table 1 Bristol Channel power station abstraction, 1950-2085

Station	Opens	Closes	ElectricalPower output	Estimated CW flow (m^3s^{-1})	Station type
Uskmouth A	1950	1981	228 MW	8	Coal
Uskmouth B	1959	1995	363 MW	12.7	Coal
Aberthaw A	1960	1995	384 MW	13.5	Coal
Berkeley	1962	1989	276 MW	25.8	Magnox
HP A (2 units)	1965	1999	470 MW	44	Magnox
Oldbury (2 units)	1967	2011	424 MW	39.6	Magnox
Aberthaw B	1971	2025	1560 MW	54.8	Coal
HP B (2 units)	1976	2023	960 MW	33.7	AGR
Uskmouth B	2001	2014	393 MW	12.7	Coal
Pembroke	2012	N/A	2000 MW	40	CCGT
HP C reactor 1	2024	2084	1600 MW	66	EPR
HP C reactor 2	2025	2085	1600 MW	66	EPR

Figure 1 Locations and unmitigated abstraction volumes of power station intakes 1950-2030, Bristol Channel (Google Earth, 2020). N.B.: abstraction volume size does not indicate area of abstraction impact

Abstraction steadily increased from 0 cubic metres per second (m^3s^{-1}) in 1950 to 232 m^3s^{-1} in 1976 (Figure 2). The early stations began to close in 1981, reducing abstraction by 54% to 101 m^3s^{-1} in 2011. When HPC reactors become operational, abstraction will again increase by 34% to 149 m^3s^{-1}. The RIMP monitoring began at HPB in 1981 and continued until 2017, beginning when abstraction began its steady decline in the area.

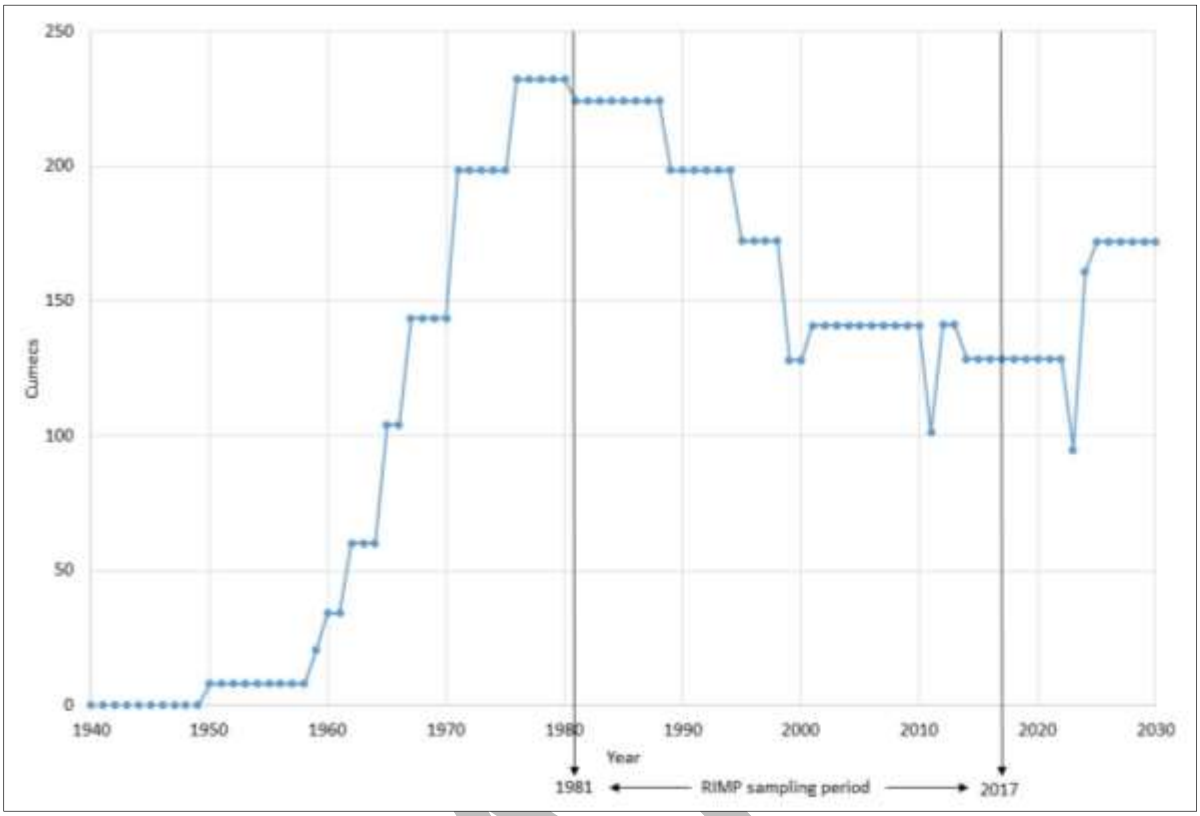


Figure 2 **Abstraction volume of Bristol Channel power stations, 1940-2030**

Abstractions rates for the power stations (Figure 2) have not been adjusted to account for the effects that any embedded mitigation may have on fish mortality (e.g. Pembroke employs an acoustic fish deterrent system and fish return and recovery system). In TR456, it was estimated the Low Velocity Side Entry (LVSE) intake head designed for HPC will effectively reduce impingement by 0.646 to a commensurate level of 85 m^3s^{-1} compared to an unmitigated value of 132 m^3s^{-1}. However, Technical Brief: TB006 predicts the LVSE intake head will increase impingement by 1.394 in the absence of a behavioural cue, such as an acoustic fish deterrent to encourage fish to avoid the intake head, effectively increasing impingement commensurate to 184 m^3s^{-1} (EA, 2019b). HPC will also include the mitigation of a Fish Return and Recovery System (FRR) which will reduce the impingement impact for the more robust species. The HPC intake design will also incorporate a ‘capped’ intake design, reducing the impingement further for pelagic species.

This examination does not consider the additional abstraction of the Tidal Lagoon Swansea Bay development, which is currently due for power generation to commence in 2023 (Tidal Lagoon Power, 2020).

Investigation of the relationship between impingement at HPB and abstraction within the Bristol Channel

It is not possible to consider the impact of HPB abstraction upon the fish assemblage of the Bristol Channel, as no studies of the assemblage were conducted prior to HPB being in operation, and no form of control and impact monitoring has been conducted. However, it is possible to review whether the changes in wider abstraction volumes around the Bristol Channel have influenced the numbers of fish captured at HPB (and by proxy the fish abundance within the Bristol Channel) by using the RIMP data.

TR456 states that the overall abstraction volume within the Bristol Channel has reduced in recent years, but no change or trend is observed in impingement at HPB from the RIMP, and therefore this level of abstraction has not affected the fish populations. This assertion was based on a trend analysis of the RIMP data.

The relationship between RIMP data for two species and the abstraction volumes within the Bristol Channel has therefore been investigated. The species were chosen as they represent species which were recorded regularly and abundantly through the RIMP, and also represent examples of key clupeid and gadoid species in the Bristol Channel.

This investigation has been conducted to identify whether changes in abstraction around the Bristol Channel can be detected by the RIMP dataset in terms of the number of fish impinged (and by proxy the fish abundance within the Bristol Channel). This analysis assumes that HPB impingement matches changes in population abundance exactly and that HPB provides an efficient and representative sample of the fish population in the Bristol Channel. This assumption is inherently incorrect as the sampling frequency of the HPB impingement data will limit the representativeness of the data, and species and life stages within the population will have different vulnerabilities to impingement at HPB but is a necessary one for the analysis.

The investigation has attempted to answer the following questions:

- Can changes in abstraction around the Bristol Channel and their effects upon fish abundance be detected by the RIMP dataset?
- Given the variability in the RIMP dataset, what level of effect on fish abundance would need to be occurring from abstraction to be detectable by the RIMP dataset?

Can changes in abstraction around the Bristol Channel and their effects upon fish abundance be detected by the RIMP dataset?

EA method for abstraction analysis and trend analysis

All data for all years has been used in this approach, summed for each year (EA, 2019).

We estimated the annual impingement at HPB, and calculated the associated uncertainty, using 37 years of RIMP monitoring data. For each species:

1. Impinged fish counts in each 6-hour RIMP sampling window (*n*=443) were raised to a daily (24-hour) count by multiplying by 4.
2. RIMP sampling was only conducted at 2 of the 4 drum screens at HPB, therefore the daily counts from step 1 were multiplied by 2 to estimate daily impingement at full capacity.
3. The counts were summed within each calendar year and then multiplied by 30.4375 (i.e. 365.25 (days) divided by 12 (months)) to obtain an annual impingement count. The occasions where sampling was completed more or less than once in a month were amended to ensure 12 sampling dates each year. Where two samples were taken in one month, the maximum sampling effort was taken (*n*=1). Where 11 samples were taken in a year (*n*=2), the missing month was interpolated as the average of the two adjacent months.
4. The 37 annual counts were then resampled with replacement (bootstrapped) within each year, over 100,000 iterations. 95% confidence intervals were derived from the resulting bootstrap distribution using the bias-corrected and accelerated (BCa) method for the confidence intervals (Efron, 1987). The resulting estimate of impingement uncertainty, over the 37 year period, accounts for inter-annual variability but not sub-annual variability.
5. The mean and 95% confidence estimates of impingement derived from the bootstrapping procedure to obtain an annual estimate of impingement at HPB.

A linear model was then fitted to the logged yearly data. Using this approach, one can determine whether there is a potential trend in yearly impingement abundance through time. This approach has been used for multiple peer-reviewed publications that have previously analysed data collected from the RIMP programme (Henderson & Seaby, 1999; Henderson & Henderson, 2017; Henderson, 2019).

Examples for Atlantic cod and European sprat are shown in Figure 3 and Figure 4 where annual impingement data from the RIMP (calculated using steps 1 to 3 of the methodology presented above) is plotted against annual abstraction volumes in the Bristol Channel.

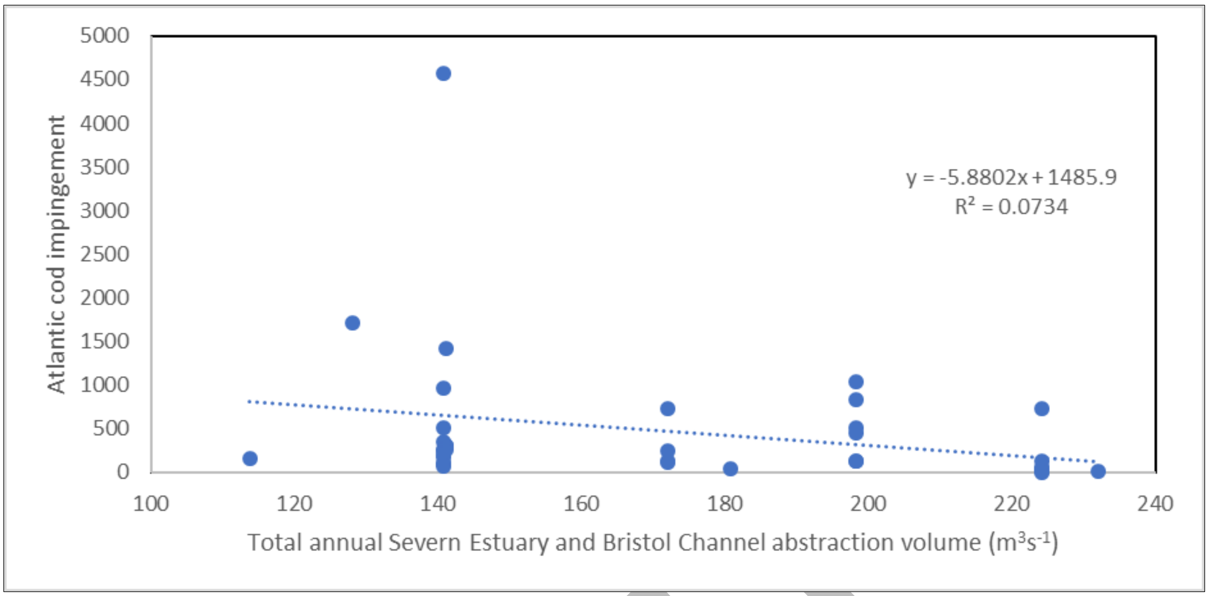


Figure 3 Relationship between Bristol Channel total abstraction volume and Atlantic cod RIMP data

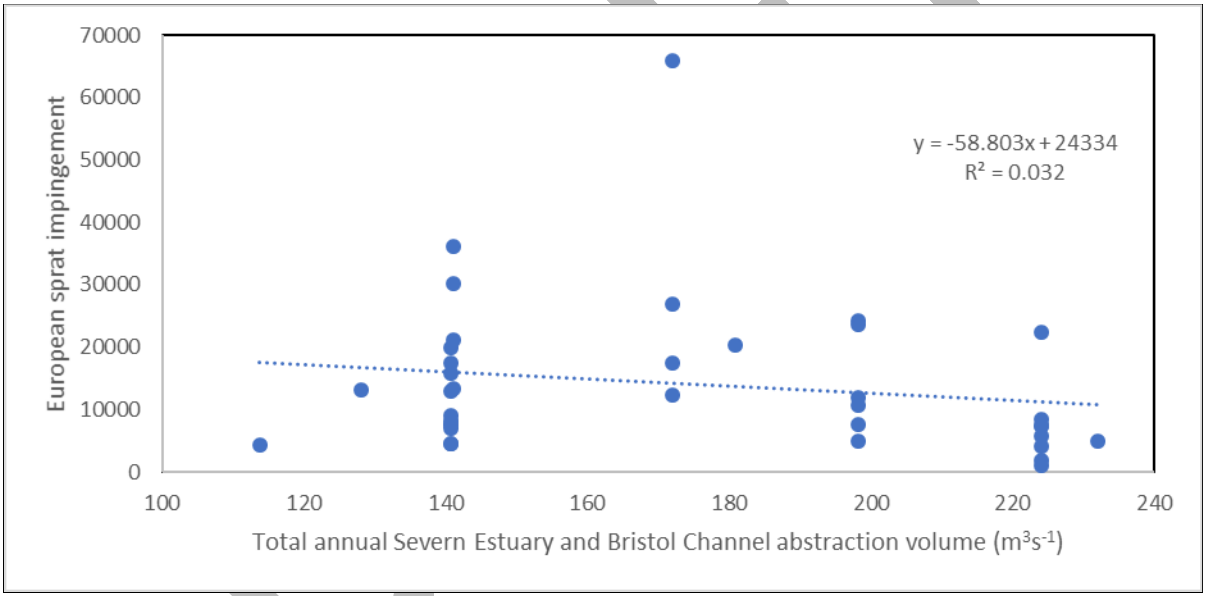


Figure 4 Relationship between Bristol Channel total abstraction volume and European sprat RIMP data

These figures show a weak negative relationship between impingement at HPB and abstraction volume around the Bristol Channel, indicating as abstraction volume decreases, impingement increases. Using this relationship it could be concluded that the reduction in total abstraction volume would lead to an increase in impingement at HPB (and thus represent an increase in population abundance), and that the abstraction does in fact have an effect upon population abundance (greater abstraction = lower abundance).

However, the strength of the fit is weak given the substantial variability within impingement at HPB during years of consistent abstraction volume. Furthermore, there may be other factors which may be influencing the trends in fish abundance in the Bristol Channel, such as climate change and warming water temperatures. It is therefore not possible to conclude whether or not total abstraction volume in the Bristol Channel has any significant effect upon population abundance or not, given the trends shown in impingement against total abstraction and the variability within the impingement data.

Given the variability in the RIMP dataset, what level of effect on fish abundance would need to be occurring from abstraction to be detectable by the RIMP dataset?

The abundance of individual fish species between years is highly variable, controlled by a range of natural factors (such as water temperature or food availability) and anthropogenic factors (such as fishing effort or water quality) which vary year-on-year. This variability is clear within the RIMP dataset. The presence of a chronic pressure, such as abstraction, which remains relatively constant for a number of years at a time, is unlikely to influence the year-on-year variability in fish abundance. Instead it would cause an overall depression of fish abundance whilst the pressure is occurring. The other factors would cause the year-on-year fluctuations in impingement. Considering the variability within impingement numbers from the RIMP, the effect size (as % reduction in fish abundance) that could be detected from the RIMP has been investigated by conducting *a priori* statistical power analysis.

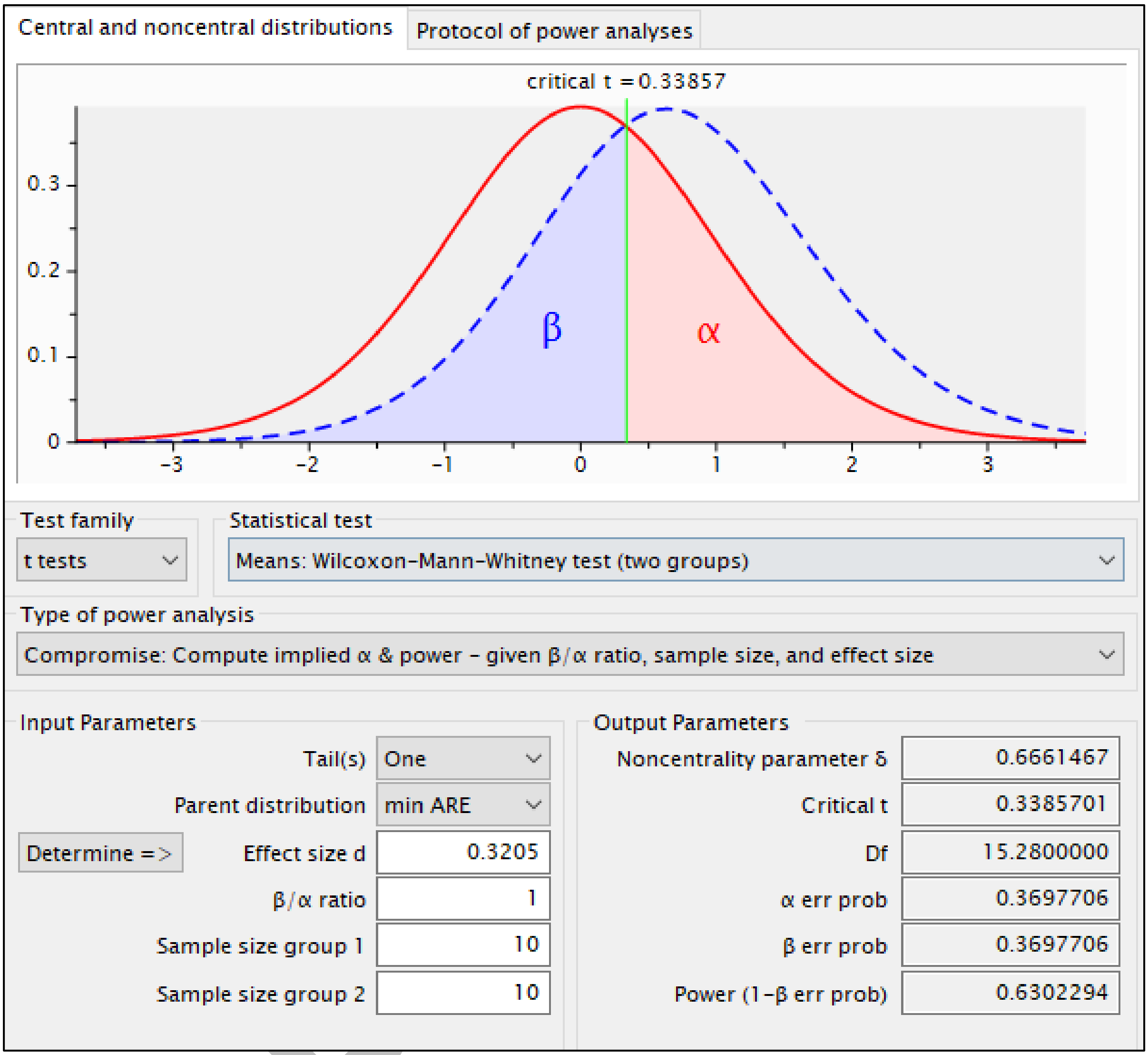
Taking an assumed 10-year baseline and 10-year impact dataset (summarised in Table 2 below) and non-normally distributed data (requiring a non-parametric statistical test), the RIMP data would be able to detect a 50% reduction in Atlantic cod abundance with associated levels of 63% confidence and power, and a 50% reduction in European sprat abundance with associated levels of 87% confidence and power. Figure 5 and Figure 6 show the analysis parameters.

When testing for significant differences between datasets, convention is to use a confidence level for rejection of the null hypothesis of 95% (p=0.05), and a confidence level of <80% (p=0.2) is rarely used. Therefore, setting a confidence level for rejection of the null hypothesis of 95% (p=0.05), then a 50% reduction in Atlantic cod and European sprat abundance would not be detectable from the dataset. The null hypothesis of no significant difference would therefore be unable to be rejected, and would be accepted. This would present an issue for use of the data in identification of impacts, as if a 50% reduction in the abundance of these species occurred, then the data would not be able to identify the change.

Furthermore, the impact of the historic abstractions from the stations in the Bristol Channel in terms of their effect size is not known, though they are likely to be much lower than 50% given their abstraction volumes, and so would be even harder to detect. It may therefore not be possible to use the RIMP dataset to determine whether an effect is occurring with an acceptable level of confidence and power.

Table 2 Summary statistics for 2008-2017 RIMP data for Atlantic cod and European sprat

	Atlantic cod	European sprat
Mean	839.2	18,505.6
Standard deviation	1,308.9	8,971.9



Test family: t tests

Statistical test: Means: Wilcoxon–Mann–Whitney test (two groups)

Type of power analysis: Compromise: Compute implied α & power – given β/α ratio, sample size, and effect size

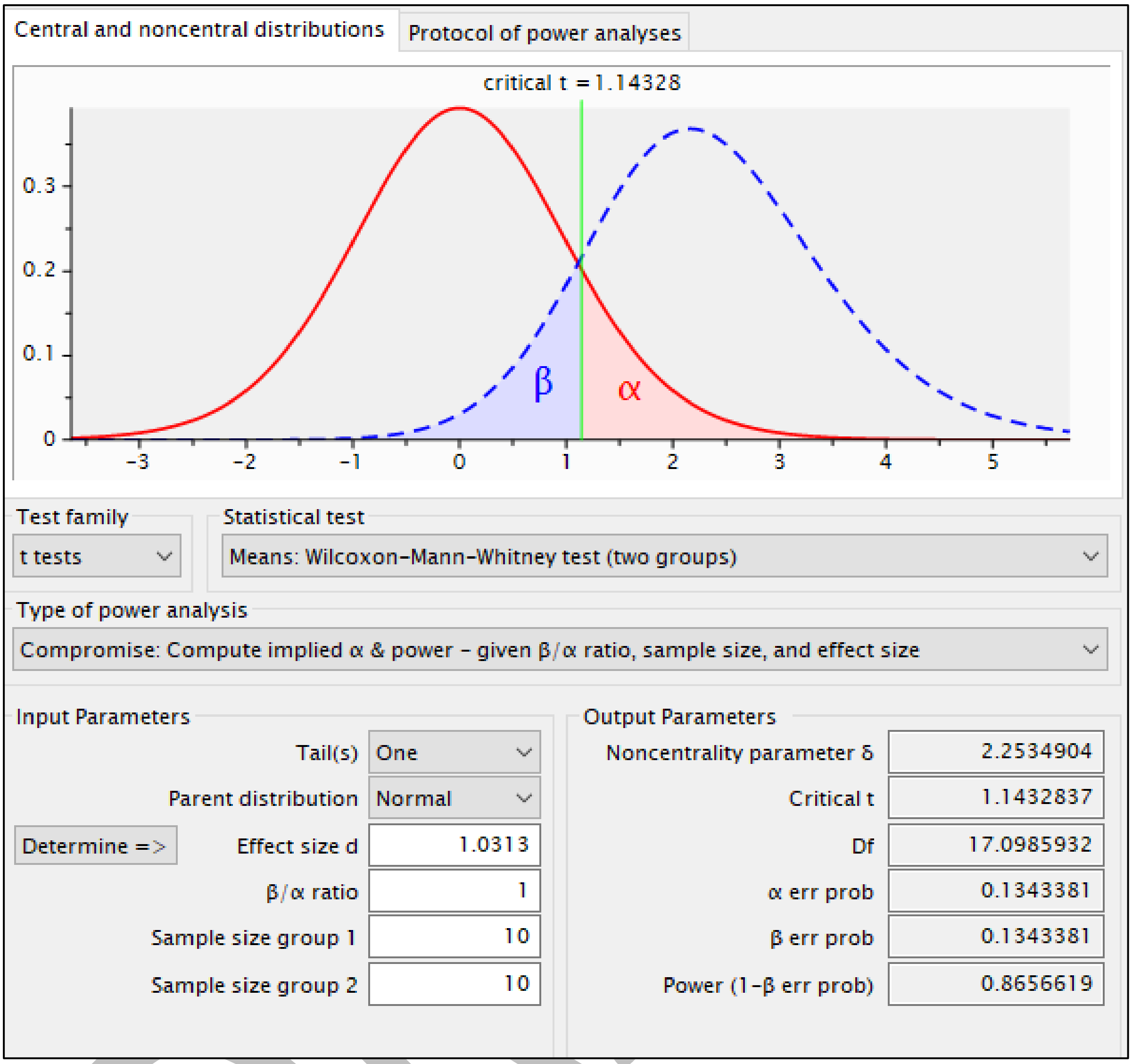
Input Parameters

Tail(s): One
Parent distribution: min ARE
Effect size d: 0.3205
β/α ratio: 1
Sample size group 1: 10
Sample size group 2: 10

Output Parameters

Noncentrality parameter δ: 0.6661467
Critical t: 0.3385701
Df: 15.2800000
α err prob: 0.3697706
β err prob: 0.3697706
Power (1−β err prob): 0.6302294

Figure 5 ***A priori*** **statistical power analysis outputs for assessing reduction in abundance of Atlantic cod from RIMP data**



Test family: t tests

Statistical test: Means: Wilcoxon-Mann-Whitney test (two groups)

Type of power analysis: Compromise: Compute implied α & power - given β/α ratio, sample size, and effect size

Input Parameters

Tail(s): One

Parent distribution: Normal

Effect size d: 1.0313

β/α ratio: 1

Sample size group 1: 10

Sample size group 2: 10

Output Parameters

Noncentrality parameter δ: 2.2534904

Critical t: 1.1432837

Df: 17.0985932

α err prob: 0.1343381

β err prob: 0.1343381

Power (1-β err prob): 0.8656619

Figure 6 ***A priori*** **statistical power analysis outputs for assessing reduction in abundance of European sprat from RIMP data**

Trend analysis of RIMP data, 1981-2017

While the substantial variability in the impingement dataset makes it difficult to draw conclusions about impacts of HPB abstraction on population abundance, it is possible to examine the dataset for species trends.

Summary of approach taken in TR456

TR456 Appendix E details the approach to identify trends in the RIMP data. The Mann-Kendall (MK) test is used to identify significant positive and negative trends across taxa. TR456 then applies a LOESS to data that have already returned a significant MK result.

Concerns with approach taken in TR456

The MK test is used to identify significant positive and negative trends across taxa, however this is not what the MK test is actually doing. From one sampling event to the next, the MK test works by assigning a score of +1 if there is an increase in species abundance, a score of -1 if there is a decrease and a score of 0 for no change. These values are summed for all sampling events. A test statistic and p value are generated to test the hypothesis of the sum being different from 0.

The scale of change is inconsequential. As such, the test does not detect increases or decreases in abundance, but is simply a measure of the regularity of changes. For example, a time series with 4 sampling events, with three small abundance increases (e.g. starting at 100 individuals at t=0, changing to t1=101; t2=102; t3=103), but one massive decrease (t4=10) would be scored as an overall positive trend by the MK test (i.e. 1+1+1-1 = +2). Therefore, there is potential for the MK test to provide an inaccurate (and potentially misleading) indication of the degree and direction of abundance change.

An MK analysis is only really suitable for the identification of monotonic trends over time. An MK analysis that investigates a trend that starts at, say X, then rises to 2X, then falls back to X at the end of the data will not show as 'significant' under the MK test. TR456 acknowledges this by doing two things to lessen the risk of missing a trend:

1. MK test is run over the whole data set from 1981-2017. This MK analysis has the greatest potential to miss a trend/change over time. The risk is lessened somewhat given that in TR456 their data is split into two chunks: 1981-1999 and 2000-2017.
2. LOESS curves are also laid over that data.

In principle, LOESS curves should identify overarching, non-linear (non-monotonic) trends, in addition to pulse-like, shorter-term peaks and troughs. Such events would likely be missed by MK analyses. However, TR456 only applies LOESS to data that have already returned a significant MK result. TR456 does not justify why only 'significant' data were included. It seems that the very point of using the LOESS smoothers is overlooked when it is applied only to data that has already shown a 'significant' monotonic trend using MK analysis. Not using LOESS smoothers on all data runs a risk of missing non-linear and/or non-monotonic changes in abundances of fish species.

Results of EA approach for trend analysis

Using steps 1-7 outlined in the method section above, an examination of the total fish dataset provides an indication of the variation through time (Figure 7). While the dataset does indicate an increasing trend, the high year to year variation is indicated in the low coefficient of determination (R^2=0.20).

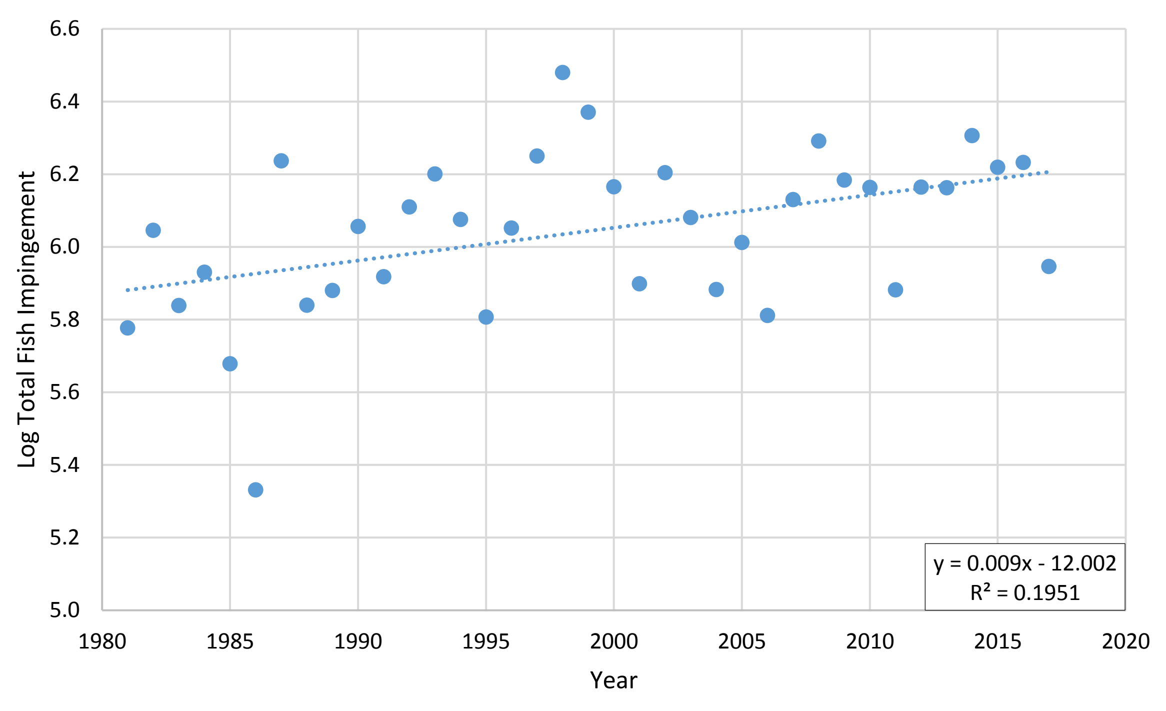


Figure 7 **Log total impingement of fish in RIMP dataset, 1981-2017**

Using the same method, all 106 species recorded in the RIMP dataset (91 fish and 15 invertebrates) were examined individually. The species patterns roughly fall into three types:

- Species that are seen infrequently with no increasing or decreasing trend (such as rock cook (*Centrolabrus exoletus*); lobster (*Homerus gammarus*); European perch (*Perca fluviatilis*).
- Species that are caught frequently with no increasing or decreasing trend (including European sprat; whiting (*Merlangius merlangus*); thin lipped grey mullet (*Liza ramada*); flounder (*Platichthys flesus*); hooknose/pogge (*Agonus cataphractus*).
- Five species showed an increasing or decreasing trend with a strong correlation (R^2>0.4). European eel, consistent with other datasets across the species' population range, are subject to a decreasing trend between 1980 and 2017 (Figure 8). It is likely that this overall trend would have been observed, regardless of changes in abstraction pressure in the locality, and we would not therefore seek to draw any conclusions on the influence of abstraction on this species' RIMP data. Apart from 2012 and 2014, hake (*Merluccius merluccius*) (Figure 9) is not present from 1980 onwards in the dataset, while the spider crab (*Macropodia rostrata*) is absent until 2002 (Figure 11). Atlantic herring (Figure 10) and Dover sole (Figure 12) both exhibit increasing trends in the dataset.

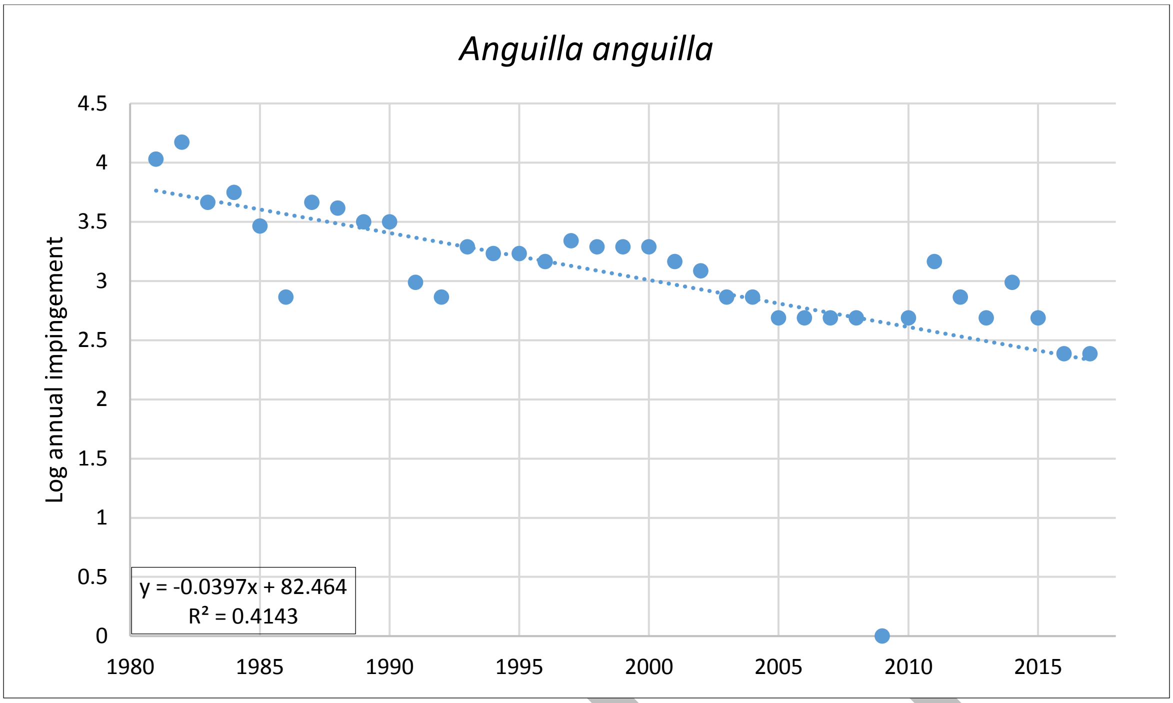


Figure 8 Log total impingement of European eel

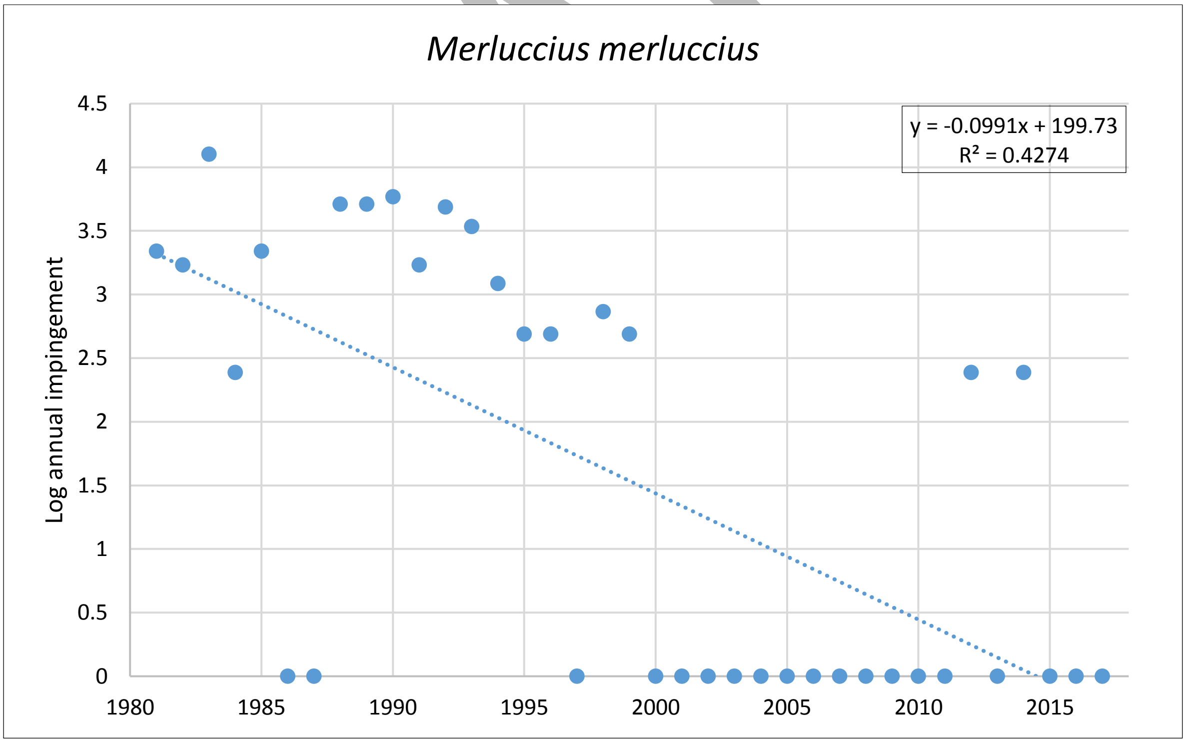


Figure 9 Log total impingement of Hake

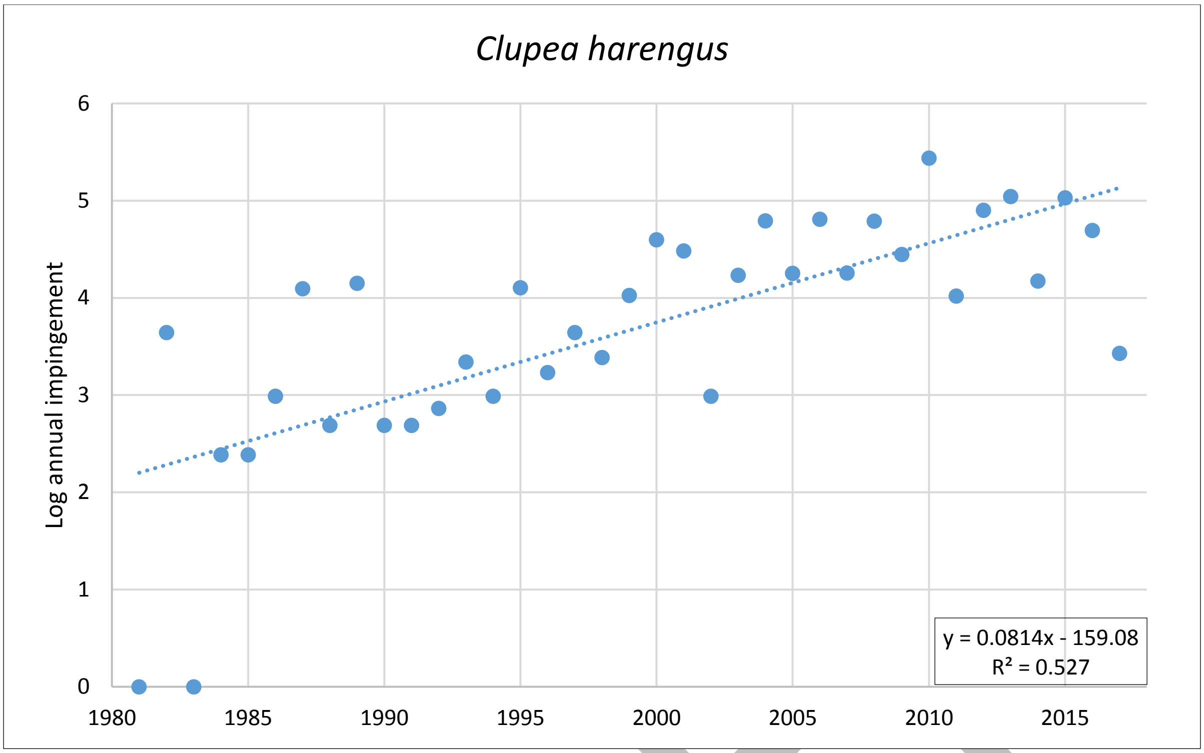


Figure 10 Log total impingement of Atlantic herring

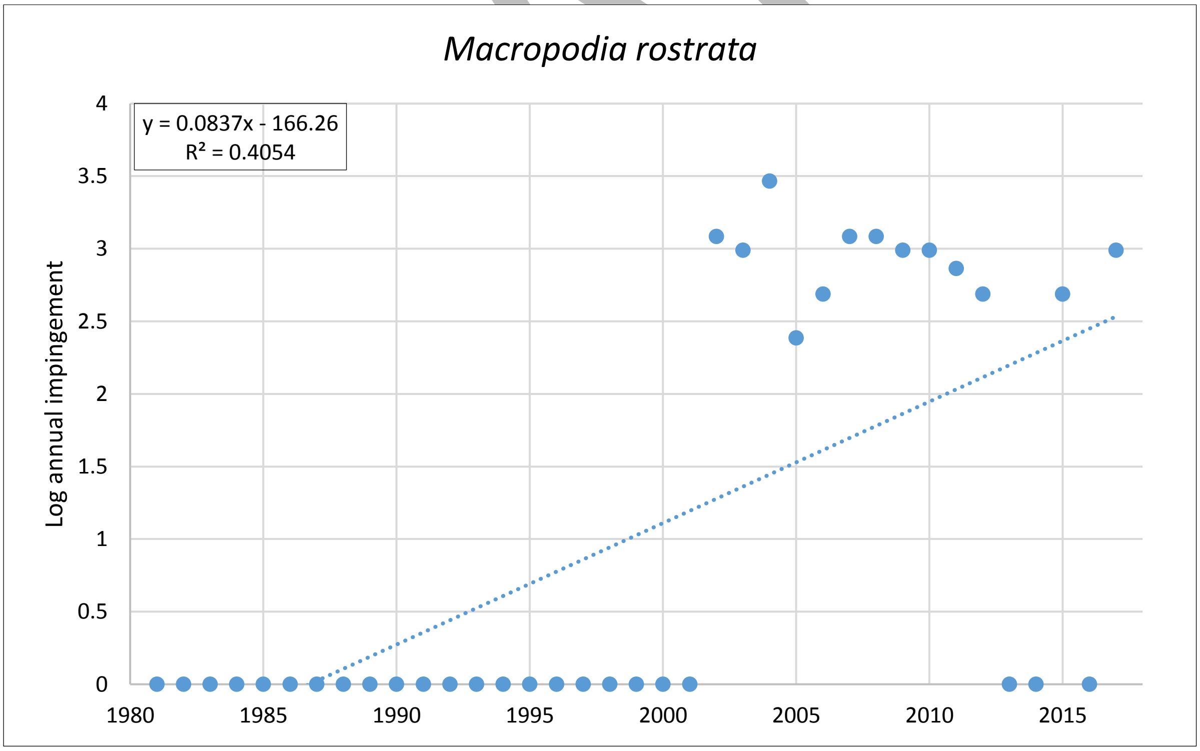


Figure 11 Log total impingement of Spider crab

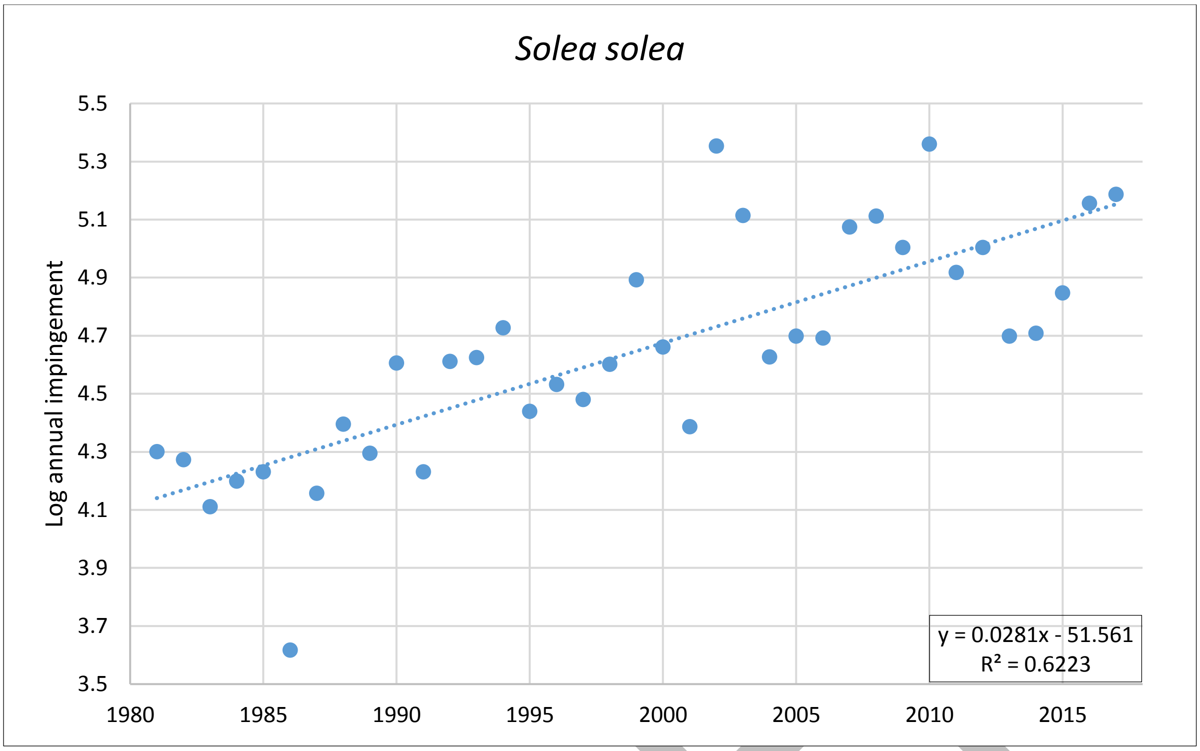


Figure 12 Log total impingement of Dover sole

The results for overall fish abundance in this paper (Figure 7) do not corroborate the results in TR456, of an increase of 154% in overall fish abundance. TR456 also records exponential increases in the numbers of Atlantic herring, Dover sole, European sprat, five-bearded rockling, grey mullet and brown shrimp. TR456 does not explore the potential relationship of the 54% reduction in Bristol Channel power station abstraction over the period when RIMP sampling was active with increased fish abundance noted in TR456.

While we saw temporal increases for herring (Figure 10) and Dover sole (Figure 12), we found no relationships for five-bearded rockling, grey mullet or brown shrimp. The lack of trend over time for European sprat is consistent with independent peer-reviewed results (Henderson & Henderson, 2017) and does not corroborate the exponential increase noted in TR456. The lack of long term trend in whiting abundance noted in this paper is consistent with independently peer-reviewed results (Henderson, 2019).

Conclusions

Initial conclusions are that there may be a relationship between fish abundance and abstraction but it is very weak. The RIMP data can only detect very large changes in fish abundance (>50%) with acceptable confidence and power so would be too weak a sampling resolution to identify the effects of smaller abstractions (such as Aberthaw, Uskmouth, etc.).

The approach taken in TR456 to investigate trends does not provide an opportunity to explore the year on year variability. TR456 notes 29 species with a statistically significant trend during the sampling period. The approach taken in this report which is consistent to other peer reviewed approaches, indicates only five species with an increasing or decreasing trend through time. Herring and Dover sole are the only two species that our approach confirms as increasing. TR456 also notes more than 100% increase in total fish abundance between 1981 and 2017, however our analyses indicate that the annual variability over the sampling period results in poor correlation between time and abundance. Therefore the increase in total fish abundance cannot be confirmed.

The substantial annual variability in the dataset means that it is not possible to confirm that mortality rates similar to those we are predicting for HPC would have been shown as a decline in the HPB RIMP dataset. Furthermore, due to our predictions of much higher impingement effect of HPC compared to HPB (EA 2019b, EA 2019c), it is not possible to conclude that the lack of trends the historic RIMP dataset implies that the impact of HPC upon some marine species will be negligible.

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