TITLE: Glass Eel Tidal Population Severn Estuary. An analysis of recruitment, exploitation and escapement targets

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Abstract

This analysis uses fishery sampling data to determine whether there are enough glass eel entering the Bristol Channel and Severn estuary to meet the pristine escapement target of the Eel Management Plan EMP [Ref 1] and to compare this with Defra's proposal for a Non Detriment Finding for the South West glass eel fishery.

While information on numbers of glass eels entering large estuaries is limited, the CEFAS Publication, Dynamics of Glass Eels in the Bristol Channel 2012-2013; Walmsley et al. (2018) [ref 16] describes a comprehensive approach to the collection of fishery sample data for the Hinkley Point Nuclear Power Station. From these data, used in conjunction with data from Admiralty charts, an estimate of a single tidal population of glass eels can be calculated.

The estimate of glass eel abundance is conservatively based on a maximum depth of 8 m (the depth of survey data at the transect of the estuary), four waves of migration (tidal cycles) and a varying number of tides contributing to the glass eel stock during each tidal cycle. This estimate of abundance is compared with the catch data to obtain a measure of the effectiveness of the fishery.

An analysis of the fishery effectiveness combined with data for escapement as a function of stocking data indicates that the impact of the glass eel fishery on silver eel output is between 6.3% – 0.2%.

The approach to the analysis is conservative. The results are scrutinised and discussed in relation to the parameters (natural mortality, tidal volume and number of tides per tidal cycle) used in the estimate and in the context of glass eel fisheries operating elsewhere.

A conclusion is that there is a high probability that the recruitment supports an escapement to the seas of at least 40% of the silver eel biomass relative to the pristine estimate of escapement and that the fisheries are not preventing the Severn RBD [Ref 1] from meeting its EU escapement target.

The Bristol Channel/Severn estuary fishery is therefore one of the few glass eel fisheries that can be claimed to be sustainable. This conclusion is at odds with that of the EMP 2015 and 2018 evaluations, however it is consistent with the artisan nature of the fishery which is restricted to the use of handheld dip nets. The latter is in contrast to the industrial fisheries of continental Europe upon which the body of eel management expertise has been built.

On a separate matter, if the analysis is correct the obvious question is; "if there are enough glass eel entering the Severn RBD to theoretically meet the pristine escapement target, why is it failing to do so?" The authors propose a number of reasons as to why this might be the case and a mitigation plan.

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1 Introduction

The principal glass eel fisheries in the UK are freshwater fisheries, found typically in the lower regions of the rivers discharging into the Bristol Channel such as the lower Severn, Parrett, Usk, Wye and Taw. There are some additional fisheries associated with the estuarine environment. These estuarine fisheries are estimated to amount to 20% of the total fishery. With the exception of the river Parrett, all the glass eel fishing in the UK use the artisan hand dip net (not a scoop net) that date back to time immemorial.. They are passive not active fisheries as described in other regions of the EU. In 1907 Herr Lubbert made an investigation to obtain glass eel from the UK after failing to collect glass eels from the Elbe near Cuxhaven. Glass eels were first translocated from the Severn fishery to Germany in 1908. Gloucester Journal 25/04/1908 [ref 17]

Little work has been done to estimate the glass eel populations across this estuary, but fortunately, data has been collected to study in part the impact of the Hinkley Point C nuclear infrastructure project on the glass eel population (Walmsley et al.,2018 [Ref **16]**. This is referred to in this paper as the CEFAS Survey (Centre for Environment, Fisheries and Aquaculture Science). This is a rich dataset that defines the glass eel population of the Bristol Channel. It is probably the most comprehensive large-scale sampling exercise carried out in any European estuarine environment.

2 Background

This study concerns the phase from when the glass eels arrive at the continental shelf, enter the tidal part of the Severn Estuary and then migrate into the lower reaches of the river basin through the selective tidal process.

2.1 Eel Management Plan

The Eel Management Plan (EMP [Ref **1**]) sets targets for the escapement of silver eels as a biomass per hectare of the River Basin District. This value is 40% of the best estimate of the eel population for the pristine environment, to be ~5.6 $kgha^{-1.}$ (being 40% of 14 $kgha^{-1}$) (Alan Walker Pers. Comm. - July 2019 meeting). This value is slightly larger than the Severn EMP value of ~12 $kgha^{-1}$, to take account of the additional area (20,000 ha) of the Severn RBD that has been included in this analysis.

This study seeks to estimate the quantity of glass eels entering the Severn River Basin District (RBD) from the Bristol Channel/Severn Estuary, evaluate the potential of this recruitment to result in the target escapement of silver eels and to determine the effect of the Glass Eel fishery. The assessment is made on the basis of a whole zone approach. The Severn estuary, an important habitat for the estuarine and transitional population, is 55,000 ha, the additional river basins of the Severn RBD included here (20,000 ha) now gives a total wetted area of 75,000 ha.

3 Estimating glass eel abundance

3.1 Method

The method is based on a model of the migration whereby a shoal of glass eels enters the Bristol Channel and progresses up the Severn Estuary.

- A transect is established across the entry to the estuary.
- The density of this shoal is measured by sampling across this transect
- The effective area of the transect is estimated (conservatively) as the length (shore to shore) x the sampling depth (8m)
- The volume of water passing through the transect on a tide is the effective area x tide speed x time (Tidal Volume)
- The mass of glass eels passing through the transect on a tide is the density x Tidal Volume

A limitation of the data is that the total extent of the shoal of glass eels within the Bristol Channel was not measured and therefore the degree of synchronisation of the sampling and migration periods is unknown. Thus, the total mass of the glass eels has to be estimated from the net migration rate through the transect over the sampling period of some 52 days (~98 tides) (the number of days between Feb 19th and Apr 11th, 2013; when the most extensive survey was undertaken).

Physical data

Data from the sampling strategy of CEFAS Survey in conjunction with estimates of tidal flow has been used to make an overall stock assessment. Though the principal transect for the data collection was from Lavernock to Hinkley point, three cross sectional areas of the estuary were chosen; Lavernock Point to Hinkley Point, Lavernock Point to Brean Down and from Newton to Sand Point (**Figure 1**). This was to make the Welsh parallel data more inclusive and to test the sensitivity of the data to different cross sections. The chart datum and tidal information is taken from Admiralty charts approved by MCA for fishing vessels under 24 metres (**Table 1**).

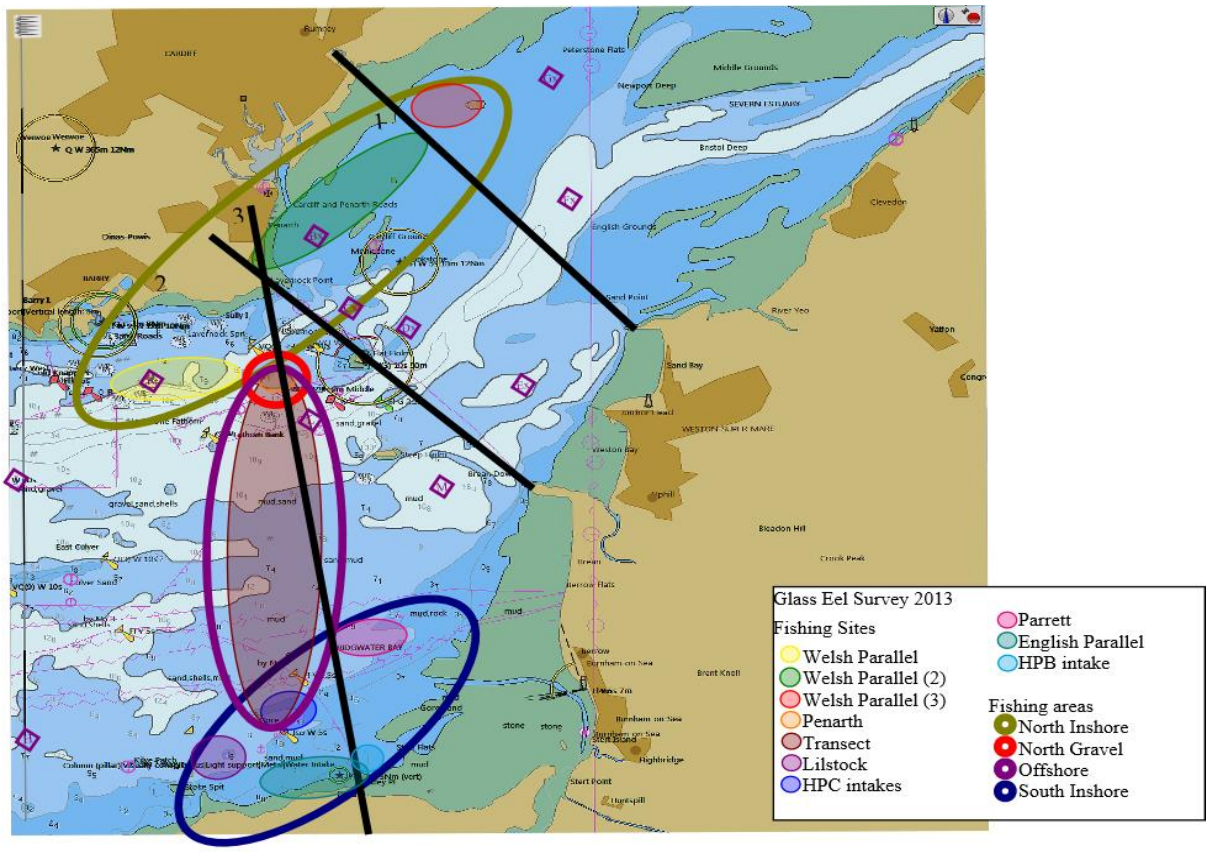

Figure 1 – Location of CEFAS Surveys and The Transects used in the Assessment

The cross-sectional area is based (conservatively) on a maximum 8 metre trawls depth with a mean tidal flow measured across the 6 hours of flood tide. The more representative cross-sectional area that could have been calculated based on chart datum and a volume estimated using tidal curve diagrams and additional local tidal stream data has not been used.

This is a conservative approach for the following reasons. On the Spring tides the tidal currents are in excess of 4 knots (2 metres/sec). The water is very turbulent, and mixing is extensive. Not only because of the extensive mixing but also because the glass eels have to return to the bottom of the estuary to benefit from the selective tidal transport mechanism, it is highly unlikely that the glass eels are just limited to the top 8 metres of the sampling area.

Table 1 - Parameters used to estimate total volume of a single tide

Parameter	Transect		
	Newton to Sand Point	Lavernock Point to Brean Down	Lavernock Point to Hinkley
Distance NM datum (km)	12.96	12.04	20.37
Calculated (km)	12.96	11.11 Excl. Flat Holme	20.37
Distance MHWS[1] (km)	13.89	12.04	20.37
Depth (m)	8	8	8
Cross sectional area (m^2) [calculated distance * depth]	103,680	88,880	162,976
Tidal Velocity (ms^{-1})	1.23	1.34	1.13
Time (seconds) [6 hours]	21,600	21,600	21,600
Tidal Volume (m^3)	2,764,782,305	2,567,628,012	3,983,832,281

[1] Mean High Water Springs

The mean tidal volume of the three transects is: 3,105,414,100 m^3.

3.2 Glass eel density - single tide estimate

Mean glass eel density was estimated from the CEFAS Survey in 2012 and 2013 (Walmsley et al.,2018) [Ref 16]. In 2013 two surveys were undertaken between Feb 19th – Mar 4th at 11 locations and between Apr 5th – Apr 11th at 7 locations. In 2012 one survey was carried out between Feb 17th – Mar 5th at 11 locations.

The mean glass eel density at each site on each sampling occasion was determined (**Table 2**, **Table 3**, Table 4).

Table 2 - Mean glass eel density (eel m^{-3}) by date and fishing location in 2012

Date	English Parallel	Hinkley Point B	Hinkley Point C	Lilstock	Parrett	Penarth	Transect N - S	Transect S - N	Welsh Parallel 1	Welsh Parallel 2	Welsh Parallel 3
17-02			0.0008								
18-02											
19-02								0.0008			
20-02				0.0016							
21-02					0.0010						
22-02											
23-02		0.0045	0.0013								
24-02							0.0012				
25-02	0.0071										
26-02									0.0007		
27-02						0.0006					
28-02								0.0008			
29-02								0.0014			
01-03		0.0022	0.0015								
02-03	0.0019										
03-03										0.0015	
04-03										0.0078	0.0016
05-03										0.0013	0.0012

Table 3 - Mean glass eel density (eel m^{-3}) by date and fishing location in 2013 from Feb 19 - Mar 4th.

Date	English Parallel	Hinkley Point B	Hinkley Point C	Lilstock	Parrett	Penarth	Transect N - S	Transect S - N	Welsh Parallel 1	Welsh Parallel 2	Welsh Parallel 3
19-02			0.0057								
20-02							0.0013				
21-02				0.0053							
22-02		0.0045									
23-02					0.0033						
24-02	0.0064										
25-02									0.0025		
26-02						0.0065					
27-02								0.0027			
28-02										0.0054	
01-03											0.0171
02-03			0.0055								
03-03	0.0113										
04-03		0.0099									

Table 4 - Mean glass eel density (eel m^{-3}) by date and fishing location in 2013 from Apr 5th – Apr 11th.

Date	English Parallel	Hinkley Point B	Hinkley Point C	Lilstock	Parrett	Penarth	Transect N - S	Transect S - N	Welsh Parallel 1	Welsh Parallel 2	Welsh Parallel 3
05-04	0.0037										
06-04							0.0014				
07-04					0.0014						
08-04			0.0011								
09-04		0.0028									
10-04								0.0017			
11-04						0.0033					

The second survey in 2013 was conducted at 7 of the 11 sites (no sampling was carried at Welsh Parallel 1-3 & Lilstock) to account for this the mean glass eel density for the second period was adjusted as follows:

Mean glass eel density Period 2 (2013) at all 11 sites = Mean glass eel density Period 1 at all 11 sites * (Mean glass eel density Period 1 at 7 sites / Mean glass eel density Period 2 at 7 sites)

Equation 1

Mean glass eel density Period 2 (2013) at all 11 sites = 0.00623663 * (0.0063087 / 0.00220007) = 0.00217495 eel m^{-3}

The mean glass eel density at each site on each sampling occasion was used to estimate the overall mean per survey period. (**Table 5**)

Table 5 - Overall mean glass eel density per survey period

Survey period	Mean glass eel density (eel m^{-3})
2012 Feb 17th - Mar 5th	0.002035587
2013 Feb 19th - Mar 4th	0.006236632
2013 Apr5th - Apr 11th	0.002174946

For 2013 the overall mean was the mean of the two-sampling periods 0.004205789 (eel m^{-3}).

Note that this mean is conservatively based on the average of the two periods and is not weighted by the respective days of sampling.

For 2012, as only one survey was undertaken the mean was estimated using the ratio between the overall mean and the mean estimated from survey 1 (Feb 19th - Mar 4th) at the same locations fished in 2013 (i. e Welsh Parallel 1 – 3 have been excluded):

Mean glass eel density 2012 period 2 = Mean glass eel density 2012 period 1 * Mean glass eel density 2013 period 2 / Mean glass eel density 2013 period 1. Equation 2

Mean glass eel density 2012 period 2 = 0.002035587 * 0.002174946 / 0.006236632 = 0.000709885 eel m^{-3}

This gives an overall mean glass eel density for 2012 of 0.001372736 eel m^{-3}.

The overall mean density of glass eel for 2012 and 2013 for a single tide was estimated at 0.001372736 and 0.004205789 (eel m^{-3}), respectively.

3.3 Migration Period

Catch data suggests the migration period extends over four tidal cycles (**Figure 2**). A tidal cycle represents a period of 14 days from one spring tide to the next, a total of 27 tides.

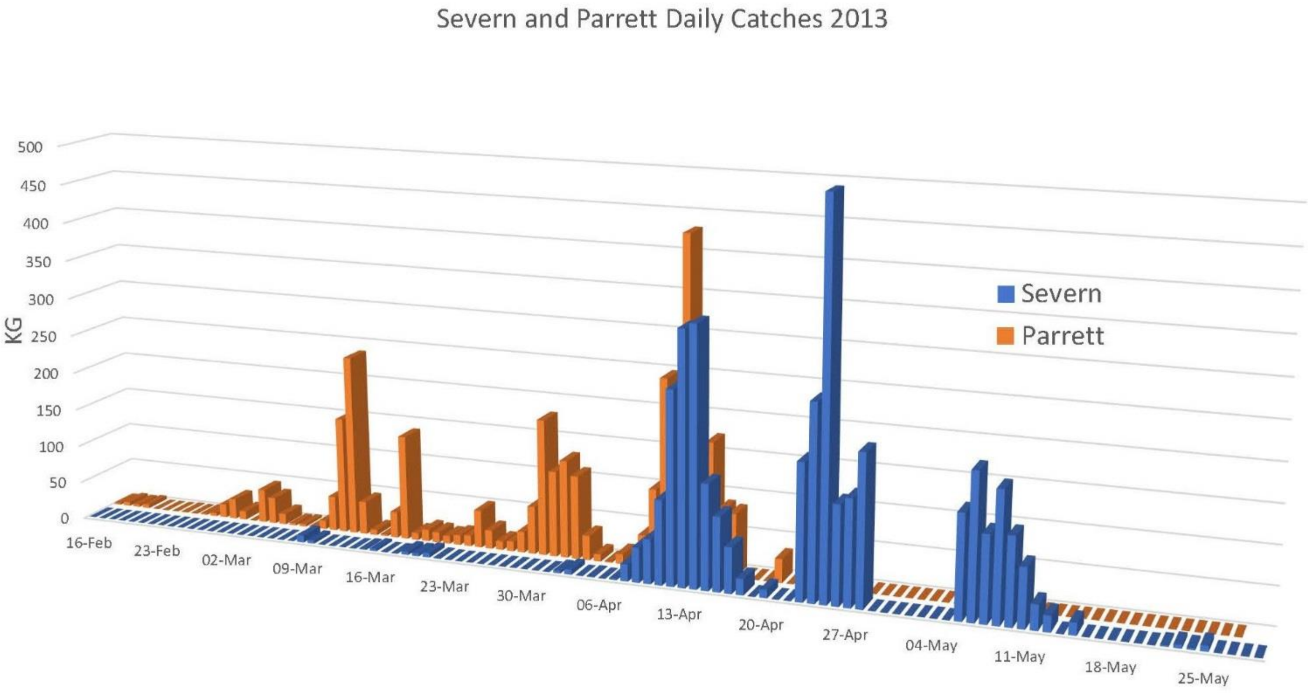

Figure 2 - Catch of glass eel in the rivers Parrett and Severn in 2013

3.4 Estimation of glass eel abundance entering the Bristol Channel prior to exploitation

Estimates of abundance are dependent on the tidal volume (3,105,414,100 m^3), the mean abundance of glass eel per tide (0.001372736 eel m^{-3} (2012) and 0.004205789 eel m^{-3} (2013)) and the migration period (four tidal cycles; neap-spring / spring - neap cycles). A major unknown is how many of the 27 tides in a tidal cycle contribute to the population.

The accuracy of the immigration calculation depends on the efficacy of the Selective Tidal Stream Transport mechanism. Data from Prouzet et al. (2009) [Ref 13) indicates that the migration speed may be equal to the displacement of the tide. There is a lag phase of one / two series of spring tides when the glass eels are first observed on the Parrett to when they appear on the Severn which is compatible with the migration speeds indicated by Prouzet et al.(2009). The separation distance between the two rivers is 100 kilometres. The authors have taken the worst-case situation for the migration speed in the estuary but recognise that it could be considerably faster. This is discussed in more detail in Appendix 2.

Prouzet et al. (2009) also showed, in normal hydroclimatic conditions when the tides progress through the estuary, that the daily glass eel runs remain distinct from other shoals. They assumed non accumulation of different runs of glass eels issued from two (or more) consecutive rising tides.

Also, the site most extensively sampled during the Cefas survey in 2013 (period 1), South Bank Inshore, when sampling was conducted over a 14-day period, (27 tides) there is a suggestion of recruitment taking place over the neap spring tidal cycle (Figure 3).

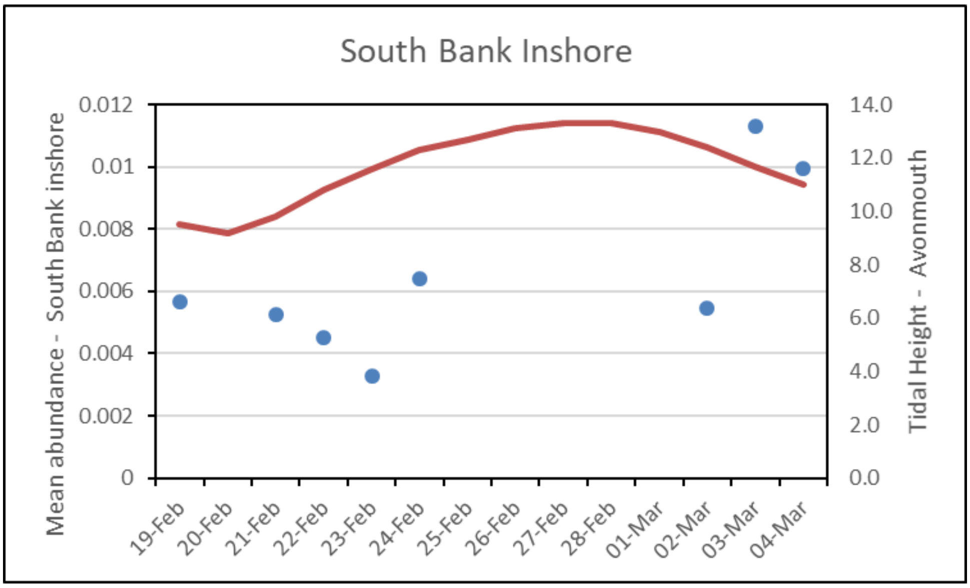

*Figure 3 - Trend in mean abundance of glass eel between Feb 19 – Mar 4th, 2013 **(blue circles)** at the fishing area South Bank Inshore (CEFAS, unpublished) and tidal height **(red line).***

3.4.1 Effective Number of Transport Tides per Cycle

As noted above, glass eel migrate by selective tidal stream transport (see review by Harrison et al.,2014, [Ref 12]) i.e. glass eels migrate upstream on the flood tide and stem displacement on the ebb either by moving to the bottom or to the sides of the channel. It is possible that on the ebb tide some may get swept downstream to the transect line and therefore there is a risk of double accounting.

To understand the sensitivity of the estimate of abundance to possible double accounting, estimates were determined as a function of the effective number of tides per 14 day tidal cycle (spring - neap – spring - neap tides) of 27 tides (Table 6). The abundance is estimated for an effective number of tides in the range 1 to 5, for the other 26-22 tides in the tidal cycle no recruitment is assumed. The number of glass eel per kg is 3000.

This is discussed further in 4.c) and Appendix 2. Estimate of Glass Eel Abundance from Migration Rate.

Table 6 - Estimate of total glass eel abundance (kg) entering the Bristol Channel assuming 1 - 5 tides per tidal cycle of 27 tides.

Parameter	2012	2013
Tidal Volume (m^3)	3,105,414,100	3,105,414,100
Mean glass eel density per tide (eel m^{-3})	0.001372736	0.004205789
Number of tidal cycles Immigration period (14 day tidal cycle Spring and Neap tides)	4	4
Number of tides per tidal cycle.	Total estimate of glass abundance (kg)	
1	5,684	17,414

Parameter	2012	2013
2	11,368	34,829
3	17,052	52,243
4	22,736	69,657
5	28,419	87,071

Table 6 indicates that a total of between 5.6 – 28.4 t and 17.4 – 87.1 t of glass eel would have entered the Bristol Channel assuming the mean density of glass eel per tide were available on between 1 - 5 tides in each of the four tidal cycles in 2012 and 2013, respectively. This assumes there was no recruitment on the remaining tides.

3.5 Estimation of glass eel abundance entering the River Basins post exploitation

Removal of the catch (**Table 7**) enables the abundance of glass eel available for settlement and the exploitation rate for 1 - 5 tides per tidal cycle to be estimated (**Table 8**).

Table 7 - Catch of glass eel (kg) from the rivers Parrett and Severn in 2012 and 2013

Year	Parrett	Severn	Total
2012	1,756	1,951	3,707
2013	3,298	4,375	7,673

Table 8 - The amount of glass eel available for settlement (kg) and exploitation rate in relation to a maximum of five tides per tidal cycle for 2012 and 2013

Number of tides per tidal cycle Neap and Spring	Settlement of glass eel (kg)		Exploitation rate	
	2012	2013	2012	2013
1	1,977	9,741	65.22%	44.06%
2	7,661	27,156	32.61%	22.03%
3	13,344	44,570	21.74%	14.69%
4	19,028	61,984	16.31%	11.02%
5	24,712	79,398	13.04%	8.81%

3.6 Silver eel equivalents and compliance with EMP pristine output

The quantities of silver eels can be estimated assuming a mortality between the glass eel and silver eel stages. For this assessment it is proposed to use the mortality relationship obtained from Lough Neagh (Appendix 4. - Density Dependence) and shows that mortality increases with settlement density. Though the mortality for the Severn is not known the Lough Neagh relationship was considered reasonable as it provides a carrying capacity limit of ~17 $kgha^{-1}$, close to that for the wider Severn EMP of ~ 14 kg ha^{-1}.

Applying the same relationship to the Severn, then natural mortality will increase and the mass of silver eel per kg of glass eel will decrease with increasing settlement density. These estimates are shown in **Table 9** for between 1 - 5 tides per tidal cycle. It is evident that the overall output in terms of silver eel remains relatively constant ranging from 16.2 – 19.5 kg ha^{-1} depending on the year and number of tides in a tidal cycle and are in excess of the 14 kg ha^{-1} the recalculated pristine escapement target (Alan Walker Pers. Comm. - July 2019 meeting).

Table 9 is the estimated output of silver eel from the Severn RBD in the presence of the glass eel fishery (it needs to be noted that cells in yellow indicate a negative natural mortality from the model - this relates to the fact that there were very few data points at the lower end of the model and thus great uncertainty to the actual value, a value of 0 yr^{-1} has been assumed).

Table 9 - Estimated settlement of glass eel, natural mortality, silver eel equivalents (the quantity of silver eel generated from 1 kg of glass eel) and output of silver eel from the Severn RBD in the presence of the glass eel fishery

Number of tides per tidal cycle	Settlement of glass eel (kg)		Glass eel density #/ha		Natural Mortality		Silver eel equivalents		Silver eel output kg/ha	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
1	1,977	9,741	79.0	389.3	-0.00356	0.089422	615.2	134.9	16.20	17.50
2	7,661	27,156	306.2	1085.2	0.075423	0.149189	170.6	50.2	17.41	18.16
3	13,344	44,570	533.3	1781.1	0.107771	0.178075	99.4	31.5	17.67	18.70
4	19,028	61,984	760.4	2477.0	0.128453	0.197303	70.6	23.1	17.89	19.07
5	24,712	79,398	987.5	3172.9	0.143691	0.211738	55.0	18.4	18.10	19.46

Table 9 indicates that output should exceed the pristine escapement target of 14 $kgha^{-1}$ under all the various scenarios. Though note should be taken of the uncertainty regarding the single tide estimate where the mortality was assumed to be zero.

The benefit of not having a fishery increases silver eel output to between 17.3 – 19.6 kg ha^{-1} depending on the year and number of tides in a tidal cycle (*Table 10*). The difference is estimated at between 1.08 – 0.03 kg ha^{-1} (Table 11) and the impact of the fishery on silver eel output is between 6.3 – 0.2% i.e. if there was no fishery present the output would be between 6.3 – 0.2% higher (**Table 11**).

Table 10 ***Estimated settlement of glass eel, natural mortality, silver eel equivalents (the quantity of silver eel generated from 1 kg of glass eel) and output of silver eel from the Severn RBD in the absence of the glass eel fishery***

Number of tides per tidal cycle	Settlement of glass eel (GE kg)		Glass eel density individual GE/ha		Natural Mortality		Silver eel equivalents		Silver eel output kg/ha	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
1	5,684	17,414	227.1	695.9	0.0580	0.1233	228.3	76.9	17.29	17.84
2	11,368	34,829	454.3	1391.8	0.0984	0.1637	116.1	39.7	17.58	18.42
3	17,052	52,243	681.4	2087.7	0.1221	0.1873	78.4	27.1	17.81	18.86
4	22,736	69,657	908.6	2783.6	0.1388	0.2041	59.2	20.7	17.93	19.21
5	28,419	87,071	1135.7	3479.5	0.1518	0.2171	48.1	16.9	18.21	19.60

Table 11 - Estimated net effect of the glass eel fishery on output of silver eel

Number of tides per tidal cycle	Silver eel output kg/ha – No fishery		Silver eel output kg/ha - Fishery		Net benefit of no fishery (kg/ha)		Impact of fishery on output (%)	
	2012	2013	2012	2013	2012	2013	2012	2013
1	17.29	17.84	16.20	17.50	1.08	0.33	-6.27%	-1.87%
2	17.58	18.42	17.41	18.16	0.17	0.26	-0.97%	-1.41%
3	17.81	18.86	17.67	18.70	0.14	0.16	-0.78%	-0.84%
4	17.93	19.21	17.89	19.07	0.03	0.13	-0.19%	-0.70%
5	18.21	19.60	18.10	19.46	0.10	0.14	-0.57%	-0.72%

4 Risk that the fishery is the cause of the EMP's failure to meet its escapement target

There are two key criteria which can be used to assess compliance with EMP output targets. Firstly, the pristine silver eel output (~14 $kgha^{-1}$). This is a revised figure calculated by Alan Walker (July 2019 Defra meeting) to account for the River Parrett and some of the smaller rivers upstream of the Lavernock to Hinkley Point transect line. Secondly, the EU compliance target of a 40% escapement with respect to the pristine production (~5.6 $kgha^{-1}$). The EMP 2018 review indicates non-compliance with both targets.

From the 2012 and 2013 study, [**Table 9** to **Table 11**] the indication is that there is a high probability that the glass eel fishery is unlikely to be impacting on the Severn RBD meeting its escapement target since this can be met by the recruitment of a single tide, of the 27 tides within each 14 day tidal cycle, per tidal period. There are, however, several discussion points when evaluating the risk of non-compliance with the EU output targets. These are outlined below:

a) Natural Mortality: The estimate of natural mortality plays a pivotal role in the estimation of the output of silver eel. From the work carried out as part of the Lough Neagh study natural mortality was found to increase in relation to stocking (settlement) density.

In the NDF a constant natural mortality (0.1385), irrespective of settlement density has been assumed by DEFRA. This equates to 1 kg of glass eel producing 59.4 kg of silver eel and has also been used in the EMP evaluations for 2015 and 2018. From studies carried out on Lough Neagh [Ref 15 & Appendix 4] and elsewhere a constant mortality rate would seem doubtful and a density-dependent relationship is more likely (i.e. the survival of glass eel to silver eel decreases with increasing density of glass eel, see Appendix 4. - Density Dependence). The implications of a constant mortality means that the output at low densities will be underestimate and vice a versa at high densities (this is evident in Table 9 & 11 where the silver eel equivalents function is higher than the 59.4 at low densities and lower at high densities). In the absence of any other information the same density-dependent mortality relationship (Appendix 4. - Density Dependence) was applied to the Severn, both in the absence and presence of the fishery. The conclusion from **Table 11** is that the fishery has little (<5%) impact on silver eel output.

b) That recruitment takes place on more than one tide per tidal cycle. Studies have shown that glass eel do not migrate on one tide in a tidal cycle but migrate continually on each tide. This is known from the Vilaine in France (Briand, 2009) [REF. 18] where there is a very efficient fishery that removes nearly all the glass eel available on a single day / tide, but even after they have been removed there were more glass eel available to be caught on the subsequent day / tide. This continued over the migration period. Though there were fluctuations in numbers emigrating into the Vilaine on a daily basis it does seem that there is continuous emigration over the two-month period. There is the issue of mean density and the assumption it is constant, that the same level of abundance emigrates per tide. This is certainly not valid; the number of glass eel emigrating will almost certainly vary on a daily / tidal basis. On some tides it might be greater and on other less. The analysis took the view that it was constant and that 1 - 2 tides per tidal cycle were enough the meet the RBD's output even in the presence of the fishery. This assumes that there is **NO** input on the other 25 tides. Alternatively, it could be assumed that more tides contributing but at a lower density, would produce the same result.

c) Double Accounting: It is well documented that glass eel use tidal stream transport (see review by Harrison et al.,2014) i.e. Glass eels migrate upstream on the flood tide and stem displacement on the ebb either by moving to the bottom or to the sides of the channel. It is possible that some may get swept downstream to the transect line and therefore there is a risk of double accounting.

   It was shown above in **Table 9** just one tide was sufficient to provide the required output of ~14 $kgha^{-1}$. This is conservative as it would seem unlikely that this would be the case for all 27 tides in a tidal cycle, otherwise no progress upstream would be made. There is some evidence to suggest (**Figure 3**), from the South Bank Inshore sampling area, a steady recruitment of glass eel at the transect line. This indicates that tidal stream transport was occurring and that the glass eels were not being washed passively up and down by the tide. Furthermore, it is noted during sampling, few glass eels were caught once the tide had started to ebb. All of the above support a view that the tidal stream transport process is applicable. This is further explored in [Appendix 2. Estimate of Glass Eel Abundance from Migration Rate].

d) Survey Period: The survey undertaken by CEFAS, though extensive, did not cover the whole migration period. There is thus some uncertainty as to how representative the estimated glass eel abundance per tide is of the whole migration period. However, inspection of the data shows no lead in or tail off at either end of the 52-day sampling period and hence an underestimate of the migration period is conservatively assumed.

e) Glass eel densities at depth: While there is evidence that glass eel densities are greater near the surface than at deeper depths it is highly unlikely that there are no glass eels below 8 metres. An assessment of the total volume is presented in Appendix 1. Estimate of Total Tidal Volume, and it is evident that the volume based on 8m depth is 60% of that potential available on spring tides. It is a cautious approach.

f) Exploitation rates: An exploitation rate of 65 – 44%, if only 1 tide per tidal cycle was considered (Table 8), would seem too high from the literature review undertaken by CEFAS / EA. Certainly, when comparing exploitation in similar sized estuaries in France. On the Adour boats use push and scoop hand nets, exploitation range 13-30%, mean 15.7%. Another large estuary, the Loire (not too dissimilar to the Severn) using boats and push nets, the exploitation rate is 16.03%. While in the upper reaches of the Gironde Estuary and in the Dordogne – Garonne, again with boats with push nets, the exploitation rate is 12%. These are active fisheries. [Appendix 3. Exploitation Rates. Literature Review and Critique]. In these locations the fishing is heavily mechanised the majority of which is on the flood tide when the glass eels are making best use of the selective tidal transport system. Fishing takes place in daylight as well as at night and on some neap as well as the spring tides. These fisheries are largely independent of local climatic conditions. A possible but doubtful comparison of exploitation rates by handheld instruments that might be considered relevant are those of Jessop (2000) and Aranburu, et al., (2016). The first on the East River, Canada, the average total annual exploitation was 38.23 ± 6.79 (range: 30.8-51.8 %). It should be noted that in comparison with the Severn, this is a small saltwater creek just 10 metres wide. The whole river is no more than 100 metres in length with a water fall defining the fishing limit and acting as a barrier. The area to fish is just 25 metres. The second the River Oria where the annual mean exploitation rate is 31.1%; (range, 6.2–48.7%). Both of these fisheries are active fisheries using scoop nets before high-water. In contrast, the Severn and other dip net fisheries, are passive fisheries and dependent on intercepting the glass eels soon after high water when they actively migrate against the ebbing tide. The method of fishing on the East river and the Oria are completely different to that used on the Severn which is a passive fishery. All the special conditions that are applicable to the Severn are just not present in these two other fisheries. [Appendix 3. Exploitation Rates. Literature Review and Critique].

Figure 4 - A comparison between the trawl used in the French estuaries and a dip net used in the Severn (UK dip net in the foreground)

5 Discussion

This analysis and the literature review placed in the context of the Severn RBD Glass Eel fisheries and the environment in which they operate suggests that the fisheries are not preventing the Severn EMP from meeting its EU escapement target.

The impact of the glass eel fishery on silver eel output is between 6.3% – 0.2%. This conclusion is at odds with that of the EMP 2015 and 2018 evaluations.

There is a high probability that the recruitment supports an escapement to the seas of at least 40% of the silver eel biomass relative to the pristine estimate of escapement and that the fisheries are not preventing the Severn RBD [Ref 1] from meeting its EU escapement target.

The Bristol Channel/Severn estuary fishery is therefore one of the few glass eel fisheries that can be claimed to be sustainable. This conclusion is at odds with that of the EMP 2015 and 2018 evaluations, however it is consistent with the artisan nature of the fishery which is restricted to the use of handheld dip nets. The latter is in contrast to the industrial fisheries of continental Europe.

If the analysis is correct the obvious question is; "if there are enough glass eel entering the Severn RBD to theoretically meet the pristine escapement target (**Table 11**), why is it failing to do so?" There are a number of reasons as to why this might be the case:

1) The analysis presented may be incorrect and that there may be insufficient glass eel for the Severn EMP to meet the escapement target. For reasons already set out this is thought unlikely to be the case.

2) The method of assessment used to evaluate the EMPs is based on electric fishing within freshwater catchments may not fully describe the status of the resident eel population. This is certainly likely as sampling is confined to relatively small water courses that can be efficiently surveyed by electric fishing while wading. This means that large sections of the freshwater RBD and the estuary are not assessed. Similar to this study, the output is extrapolated from limited nonspecific eel survey data where the focus is on different stages of the eel's life history; resident yellow eel as opposed to glass eel. Though the results from the two assessments would appear contradictory they may be complementary, the surveys indicating that there should be enough glass eel entering the system to meet the escapement target, but the freshwater surveys indicate that the eel populations are not as abundant as would be expected. This all points to what the real issue might be, why, if there are sufficient glass eel entering the system, are eels not more abundant within the freshwater reaches of the RBD?

3) There may have been a change in productivity of the system such that the carrying capacity may be lower than that historically. The assessment of pristine production being based on the survey work carried out in the mid-1980s. The Lough Neagh study has shown a potential effect of the introduction of the Water Framework Directive, hence an improvement in water quality, to have reduced productivity and output. Improvement in water quality results in lower nitrogen and phosphorus levels and consequential impact on the overall availability of nutrients. If that has been the case, then the effect would be of a reduction in carrying capacity and thus output of silver eel.

4) Barriers are known to have a major impact on the movement of eel. Weirs, dams, water extractions sites, pumping stations and micro hydroelectric schemes are overt barriers. Their impact has been quantified by the Environment Agency and are described by Sam Chapman in a presentation of November 2015. https://ifm.org.uk/wp-content/uploads/2016/02/Opening-up-the-Severn-reds.pdf . The presentation identifies some 2800 obstructions, 72 of which were considered critical and though 65 of these will have been addressed by 2021, it is unclear as to what is the fate of those remaining. It should be noted that the green dots show the location of barriers and not an indicator of something positive. It is acknowledged that not all the remaining obstructions are critical for eel, but it is unlikely that just 72 critical obstructions need to be addressed to fully sort out the problem. Of major concern are the flap valves and similar devices on every ditch and stream that runs into the tidal parts of the rivers that adjoin the Severn estuary. Each of these has a drainage function that both diminishes the extent of wetland adjoining the estuary and prevents any access by the glass eels to what little habitat is left. These ditches and streams are the nursery areas vital to the growth of the glass eels to the sub 10g size that enables the secondary active migration in late summer by the juvenile eels into the wider river basin, beyond the tidal reaches of the estuary. The present state of the technology to address barriers is such that the new pass at Upper Lode, with an investment in excess of £100,000, currently does not facilitate the passage of glass eels and is unproven for juvenile eels. Technical solutions will need to be validated to guarantee frictionless passage at passes.

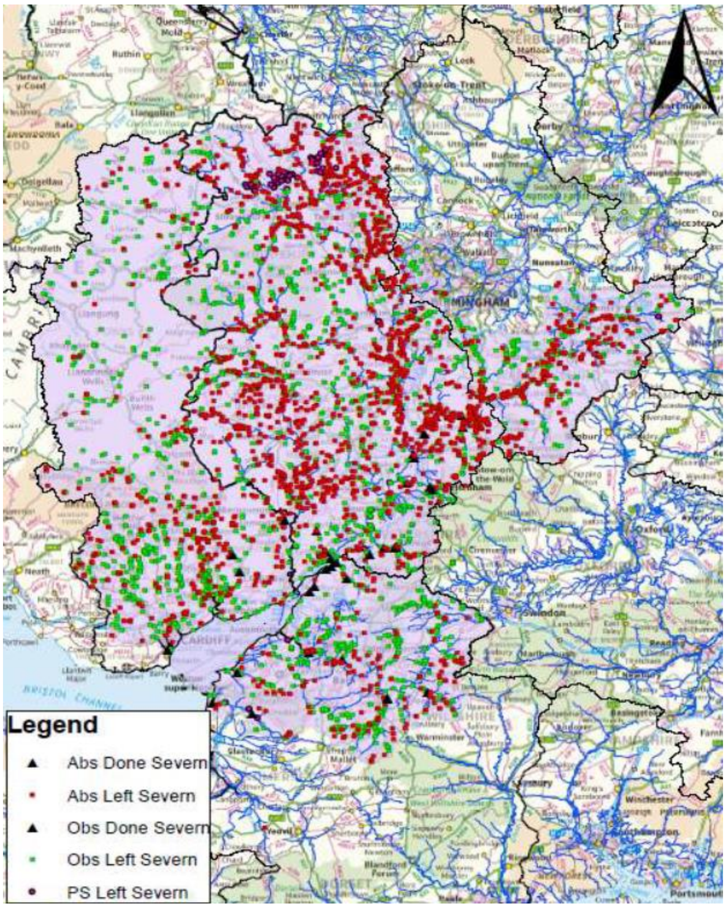

Figure 5 – Severn RBD Obstructions Nov 2015

6 Conclusions

A conservative analysis of an extensive survey by CEFAS to quantify glass eel abundance in the Bristol Channel provides evidence that that glass eel recruitment into the Severn estuary is more than enough to meet the output of silver eel for compliance with the pristine escapement level.

Catch data for the Rivers Severn and Parrett with a validated settlement model based on research data from Lough Neagh shows the impact of the fishery on silver eel output to between 6.3% – 0.2%.

This conclusion is at odds with that of the EMP 2015 and 2018 evaluations, however it is consistent with the artisan nature of this fishery which is passive and restricted to the use of handheld dip nets. The latter is in contrast to the active, mechanised fisheries of continental Europe, upon which the body of glass eel management expertise has been built.

The data shows the fishery is not the cause of the failure of the RBD to meet its escapement target. Even in the absence of the fishery the EMP would be non-compliant. Other factors: principally loss of critical habitat and migratory pathways are likely to be having a significant impact on the eel population in the Severn River Basin district.

It is also a reminder that notwithstanding the presence of the fishery, the application of accurate and proportional corrective measures, specifically the opening up of the migratory pathways, could reap significant benefits in terms of the recovery of the eel in the Severn River Basin district.

Appendix 1. Estimate of Total Tidal Volume

Low water spring tide estimate – the volume of water at low tide.

Parameter	Transect		
	Newton to Sand Point	Lavernock Point to Brean Down	Lavernock Point to Hinkley
Distance NM datum (km)	12.96	11.11	20.37
Cross sectional area (m^2) [measured]	83,300	110,700	138,500
Tidal Velocity (ms^{-1})	1.23	1.34	0.98
Time (seconds) [6 hours]	21,600	21,600	21,600
Tidal Volume (m^3)	2,221,319,117	3,197,979,583	2,923,870,175

The mean tidal volume of the three transects is 2,781,056,275 m^3.

High water spring tide estimate - the volume of water at various states of tide

Hrs before HW	Transect								
	Newton to Sand Point (13.89 km)			Lavernock Point to Brean Down (12.04 km)			Lavernock Point to Hinkley (20.37 km)		
	Speed (ms^{-1})	Depth (m)	Volume (m^3)	Speed (ms^{-1})	Depth (m)	Volume (m^3)	Speed (ms^{-1})	Depth (m)	Volume (m^3)
-5	0.995	0.3	14,918,793	1.029	0.2	8,916,980	0.658	0.2	9,657,775
-4	1.655	2.5	206,848,213	1.698	2.5	183,912,712	1.389	2.2	224,090,566
-3	1.869	5.8	542,049,494	1.903	6.0	494,892,388	1.656	5.2	631,678,861
-2	1.680	8.8	739,423,416	1.698	8.3	610,590,203	1.553	8.0	911,452,537
-1	1.123	11.5	645,837,996	1.183	10.5	538,362,666	1.132	10.5	871,463,311
HW	0.257	12.2	156,904,551	0.206	11.8	105,220,364	0.422	11.5	355,753,205
Total			2,305,982,464			1,941,895,313			3,004,096,255

The mean tidal volume of the three transects is 2,417,324,677 m^3, giving a total volume at high water of 5,198,380,952 m^3.

Low water neap tide estimate – the volume of water at low tide.

Parameter	Transect		
	Newton to Sand Point	Lavernock Point to Brean Down	Lavernock Point to Hinkley
Distance NM datum (km)	12.96	11.11	20.37
Cross sectional area (m^2) [measured]	132,563	147,370	211,839
Tidal Velocity (ms^{-1})	0.67	0.72	0.51
Time (seconds) [6 hours]	21,600	21,600	21,600
Tidal Volume (m^3)	1,914,789,523	2,292,401,329	2,353,753,825

The mean tidal volume of the three transects is 2,186,981,559 m^3.

High water neap tide estimate - the volume of water at various states of tide

Hrs before HW	Transect								
	Newton to Sand Point (13.89 km)			Lavernock Point to Brean Down (12.04 km)			Lavernock Point to Hinkley (20.37 km)		
	Speed (ms^{-1})	Depth (m)	Volume (m^3)	Speed (ms^{-1})	Depth (m)	Volume (m^3)	Speed (ms^{-1})	Depth (m)	Volume (m^3)
-5	0.523	0.9	23,535,683	0.525	0.9	20,464,469	0.350	0.9	23,088,119
-4	0.866	1.8	77,937,835	0.895	1.8	69,819,953	0.741	1.8	97,784,974
-3	0.977	3.0	146,615,728	1.008	3.0	131,079,606	0.874	3.0	192,400,991
-2	0.883	4.5	198,702,895	0.895	3.8	147,397,679	0.813	3.8	226,505,010
-1	0.592	5.5	162,692,014	0.617	5.0	133,754,700	0.597	4.6	201,304,252
HW	0.134	5.9	39,457,636	0.116	5.5	27,586,907	0.226	5.2	86,316,366
Total			648,941,791			530,103,313			827,399,712

The mean tidal volume of the three transects is 668,815,000 m^3, giving a total volume at high water of 2,855,795,000 m^3.

Appendix 2. Estimate of Glass Eel Abundance from Migration Rate

The issue of double accounting can be addressed if it is possible to estimate the net migration rate. Double accounting arises because an unknown proportion of the glass eel stock that migrated upstream past the transect line on a flood tide are subsequently swept downstream on the following ebb tide, these glass eels will then contribute to any fresh recruits migrating upstream on the subsequent flood tide. The net migration rate is the proportion of the glass eel population on any given tide that make a net movement upstream.

Figure 2 shows that there is a delay of about a month (60 tides) between the glass eel arrival at the River Parrett and their occurrence at Gloucester on the River Severn, circa 100 km. This suggests a net migration rate of 3.3 km day^{-1} (1.66 km tide^{-1}). The authors recognise that the literature would suggest faster migrations and that the migration may not be linear.

One tide travels on average 26.7 km upstream on each tide (assume a 6 hour tide with a mean speed of 1.23 ms^{-1}; mean tidal velocity Table 1). Assuming the glass eel are distributed evenly through the tide then the mean abundance per km in 2013 is:

(0.004205789 * 3,105,414,100 / 26.7) = 489,165.4 glass eel = 163 kg km^{-1}

Assuming a net upstream migration of 1.66 km tide $^{-1}$ then the net movement of glass eel upstream on each tide is:

163 * 1.66 = 270.6 kg tide^{-1}

The total estimate of abundance over the 52-day (98 tides) period between Feb 19th and April 11th, 2013 is:

270.6 * 53 * 2 = 28,681 kg.

The catch in the Severn in 2013 was 4,375 kg (Table 5) representing an exploitation rate of 15.3% and if the total catch (Parrett and Severn; 7,673 kg) is included the exploitation rate is 26.8%.

A very cautious approach has been taken. It should be remembered that the CEFAS / EDF sampling only took place over a period of 52 days. It is highly probable that the actual recruitment is much greater than 52 days, the tidal volume of 3,105,414,100 has been calculated on the basis of trawls to the depth of 8 metres. The true mean tidal volume across the three transects is 5,731,608,126 m^3 (Appendix 1. Estimate of Total Tidal Volume) nearly twice the cross section transect restricted to the 8 metre depth sampled in the CEFAS Survey.

Appendix 3. Exploitation Rates. Literature Review and Critique

At the July 2019 meeting it was agreed that CEFAS / EA would carry out a literature review of exploitation rates in glass eel fisheries. It was agreed at the meeting and had been highlighted in the review by ICES that the assumption of 100% exploitation used in the NDF is likely to be over cautious. Some of the references in relation to the review have been withdrawn for the current NDF. An additional reference Red Barn Dyke fishery at Leighton Moss has been introduced to support the concept of 70-80% exploitation rate.

This complete DEFRA literature review is presented in Table A3.1 together with a critique and a conclusion from the authors that puts the findings of the review into the context of the UK glass eel fishery.

It is important when reviewing the literature that cognisance is given to the nature of the fishery and the environment in which the fishery operates.

Glass eel fisheries

Due to the exceptionally fast river flows caused by the tidal range being in excess of 15 metre in the South West, the evolution of the UK glass eel fishery has been different from the rest of Europe. The fast current makes it impossible to use a scoop net. With the exception of the river Parrett, all the glass eel fishing in the UK use the artisan dip net (not a scoop net) that date back to time immemorial. This fishery is the most environmentally sensitive glass eel fishery in Europe. It is a passive fishery not the active fishery described in the UK NDF. These active fisheries are fished on the flood tide and sometimes on the ebb tide as well. The fishing period is up to 7 hours per tide. In contrast, the UK passive fishery operates exclusively in the first 2 to 3 hours after high water from the start of the ebb tide.
For some spate rivers it could be as short as an hour. At this point in time, the glass eels will, on occasions, actively swim against the receding tide and close to the bank in order to have minimum resistance against the current. To capture the glass eels, the net is placed in the water, mouth downstream and the glass eels swim into the net on their upstream migration and literally give themselves up.

The glass eels hold themselves instinctively in the net against the water of the ebbing tide that is flowing through the net. The glass eels are not trapped, there are no inscales in the net to stop them escaping. It is the flow of water and the urge to migrate that holds the glass eels in the net. If there is not sufficient flow or there is disturbance, they, like any other fish, will just swim out of the net. Indeed, is important that the net is held very still lest the glass eels avoid it. As their metamorphosis progresses, they develop a more fish like behaviour, become increasingly susceptible to noise, vibration, and light (intensity and day length). The motivating forces for retention decrease and the glass eels avoid being caught.

The capture is reliant on this unique migratory phenomenon. The multifactorial drivers that control the migration are not fully understood. However, tide, river flows, temperature, population density, light intensity/day length and the stage of the physiological development of the glass eel are all important. The synchronous migratory behaviour, upon which this passive method of fishing depends, can be observed just a few times a season. The reality is that the window of opportunity for effective exploitation together with the correct environmental conditions to enable this migratory phenomenon is not only very limited but also a lottery.

Exploitation comparisons with an active fishery are not valid. If judgements on the efficiency and exploitation rate are going to be made, then there should be at least an understanding of the forces that impact on the exploitation rate. Otherwise policies that determine exploitation rates and precautionary margins for buffering will not be correct.

Table 1	Area	Time period	Fisheries	Data used	Mean Exploitation rate	Authors	Relevance by DEFRA	Critique by Authors
American eel	East River, Canada	1996-1998	Dip net fishery (April-June).	Fishery catches and trapping.	Average total annual exploitation: **38.23 ± 6.79 (range: 30.8-51.8 %).** Daily exploitation: 43.63 ± 3.39 % on average (41.07-62.9 %).	Jessop 2000[1]	Very High Critique low	Small saltwater creek 100m Fishing on flood and ebb tide. Critical conditions as per UK for migration not present
Japanese eel	Shuang-chi River, Taiwan	1982-1983	Mixed: Hand nets and boat beam trawling nets (November to February).	Fishery data.	Average exploitation: **62.89 ± 4.52 % (range: 44.1-74.5%)**. Average exploitation from a mark-recapture study: 60.10 ± 9.01 % (43.8-74.9 %).	Tzeng 1984[2]	Medium (if possible to separate between land and boat based fishery it could be used)	Asian fisheries are not comparable with the UK fishery. It is not a Dip net fishery requiring exacting migratory conditions to fish. The economic forces with prices as high as 22000 Euros have created a significantly different fishery
Japanese eel	Shuang River, Taiwan	1981-1994	Hand nets and small hand-towed trawl nets (October to March). Vessel-based fisheries on glass eels were nearly non-existent or of no importance.	Fishery data.	Overall exploitation rate in a season varied from **3.7% to 49.9%** with considerable variability among seasons. The daily exploitation rate was driven by the daily catch and never exceeded 4%.	Lin et al. 2017[3]	High Critique low	
Japanese eel	East Asia	1954-2010	Hand and bag nets reported.	Reports and annual fishery statistics.	Average exploitation range over years: **~ 20 -55 %** (taken from the figure, no raw data available).	Tanaka 2014[4]	High Critique low	

Table 1	Area	Time period	Fisheries	Data used	Mean Exploitation rate	Authors	Relevance by DEFRA	Critique by Authors
European eel	Vilaine and Garonne estuary	1950-2004	Boats with pushed and hand scoop nets.	A proxy for exploitation used: 1-%S/R; proportion of settled glass eels relative to a non-impacted situation.	Vilaine: 1- %S/R = **94.5 % (90 – 98 %)** Garonne: 1- %S/R = **22 %**	Beaulaton & Briand, 2007[5]	Low	Fishing on Vilaine not relevant. Push net fishery in river with limited migratory passage . Garonne. Principally push net fishery. No equivalent dip net to UK
European eel	Adour estuary, France	1998-2001	Boats with pushed and hand scoop nets (November-March)	Fishery and scientific monitoring data used.	Mean exploitation range: **13-30 %**	Prouzet, 2002[6]	Low	Principally push net fishery. No equivalent dip net to UK
European eel	Adour estuary, France	1998-2005	Boats with pushed and hand scoop nets (November-March).	Fishery and scientific monitoring data used.	Overall exploitation rate estimated as **15.7 % (range: 8.3-25.0 %).**	Bru et al. 2009[7]	Low	Principally push net fishery. No equivalent dip net to UK
European eel	Vilaine estuary, France	1996-2000	Boat fisheries (November-April).	Fishery and trapping data.	Mean overall exploitation rate estimated as **98.32 % (range 95.6%-99.4%).**	Briand et al. 2003[8]	V. Low	Push net fishery operating in river with no migratory passage
European eel	Loire estuary, France	2003-2006	Boats with push-nets.	Fishery and scientific monitoring data.	Mean global exploitation rate when corrected **16.03 % (range: 13.5 and 18.9 %).** Before correction this varied between 13.4 and 26.3 %.	Prouzet et al. 2008[9]	Part relevant	Large estuary, push net fishery, no dip nets.
European eel	Isle River, tributary of Dordogne	1996-2007	Boats with push-nets.	Fishery and scientific monitoring data used.	Mean global seasonal exploitation rate estimated as **11.98 (range: 0.7-33.2 %).**	Prouzet et al. 2008[9]	Low	Small river push net fishery, no dip nets.
European eel	Oria, Bay of Biscay	2003-2014	Mixed: boat trawlers and land fishery (October-March, and from 2019 November-January).	Fishery and scientific data.	Mean exploitation rate: **31.1% (range, 6.2–48.7%).**	Aranburu et al. 2016[10]	Medium (if possible to separate between land and boat based fishery it could be used)	Minor fishery. Mixed fishery. Boat and scoop nets. It is an active fishery. Severn Dip net is passive fishery May be good reference fishery for Bay of Biscay,

Table 1	Area	Time period	Fisheries	Data used	Mean Exploitation rate	Authors	Relevance by DEFRA	Critique by Authors
European eel	Red Barn Dyke	2002-2007	Dip net	Unpublished analysis	70-80%	Unknown	High	Artificial culvert draining an area of 7 hectares and is not representative of any river fishery

Table 2	Land based scoop net fishery	Mixed fishery	Boat fishery	All combined
Mean exploitation range (%) ± SE	18.17±7.88 - 52.23 ± 1.49	25.15 ± 18.95 – 61.60 ± 12.90	36.85 ± 17.81 – 50.75 ± 15.29	19.63 ± 10.16 – 53.13 ± 8.28

1) **UK Fishery**: The UK glass eel fishery is an artisan dip net fishery. It is a passive fishery. A dip net fishery is dependent on intercepting the glass eels soon after high water when they actively migrate against the ebbing tide. The glass eels swim into the net that obstructs their passage (swim against the ebbing tide). The glass eels hold themselves instinctively in the net against the water that is flowing through the back of the net. The glass eels are not trapped, but rather just held by the strong urge to migrate. The net is rotated and lifted. For this migration to `occur a special combination of local conditions have to be met. The multifactorial impacts that control the migration are not understood. However, tide, river flows, temperature, light intensity and physiological development are important. For a few days in the season and in most years this migration activity will be synchronous.
   The dip net fishing should not be confused with scoop net fishing where glass eels are concentrated and literally scooped out using a sweeping action. The UK dip net is too large to use repeatedly in a sweeping action.

   Red Barn Dyke: This is a small artificial culvert draining an area of 7 hectares and is not representative of any river fishery and certainly not the Severn.

2) **Asian Fishery**: The Asian fishery is very different from the UK fishery. The glass eels are only found at low densities, the fishing with bag nets and hand nets is a random and intensive activity collecting just individual glass eels at a time. With glass eel prices as high as 22,000 Euros a kilo the pressures on exploitation are just not comparable with a European fishery.

3) **Canadian Fishery**: The Canadian fishery in this literature review is set on a small sea water creek just 10 metres wide. The river is no more than 100 metres long with the ascending falls on the other side of the bridge frustrating further migration. The area available to fish is just 25 metres. This is an active fishery using scoop nets two hours either side of high-water. The elvers arrive from the sea. All these special conditions that we require on the Severn for the passive fishery are just not applicable here. What is more surprising is that with this natural trap that it is only possible to catch half the migrating elvers.

4) **French Fisheries**: There may be some merit in making comparisons with the French fisheries. The French rivers and estuaries are more comparable to the Severn and Bristol Channel. However French glass eel densities are much greater than those found in the Bristol channel/Severn estuary.
   a) **Vilaine**: The fishery on the Vilaine is blocked by the dam at Arzal. There are between e 35-50 boats with two push nets operating in front of the dam on the flood tide. There is no route of escapement for the glass eels. The exploitation rate is 90% but the fishery is atypical. It is totally different situation compared to anything in France or the UK.
   b) **Adour**: The Adour has boats using push and scooped hand nets. An exploitation range between 13-30% and mean exploitation rate 15.7%
   c) **Loire**: The other large estuary is the Loire (it is not dissimilar to the Severn) with boats with push nets. Exploitation rate 16.03%
   d) **Gironde**: The upper reaches of the Gironde Estuary the Dordogne, Garonne also have these push net boats. Exploitation rate 12%

With the mechanised fishing in France the majority of the fishing is almost exclusive to the flood tide when the glass eels are making best use of the selective tidal transport system. Fishing takes place in daylight as well as at night and on some neap as well as the spring tides. These fisheries are largely not dependent of local climatic conditions. Fog and severe winds are a problem. The mechanised fishing is conducive to a lot of fishing effort.

5) **Spanish Fishery**

   Orio: The River at Orio is small river with a 11 km lower section where there is a glass eel fishery. It could be a useful index river for the Bay of Biscay. It has a small glass eel production. The topography and hydrography are not similar to that of the Severn river basin district. It has an active fishery using trawl nets from boats and scoop nets for the land fishers. Fishing is 2-4 hours before high tide. The UK glass eel fishery is a passive fishery operating just after high tide. The Oria method of fishing is not comparable to the Severn.

A comparison with the UK dip net fishery is difficult as outlined above. The data for the comparable French rivers indicates that the exploitation rates are less than 30% and the overall mean considerably less (Appendix 3. Exploitation Rates. Literature Review and Critique; Table 2). For the reasons mentioned above it is highly improbable that the exploitation rate of an artisan passive hand net fishery (that is dependent on special local conditions to be effective) is MORE efficient than an active mechanised or scoop net fishery that can operate over a wide range of environmental conditions. The evidence presented by the literature review and from the extrapolation of the CEFAS study presented would suggest that the exploitation rate for a passive dip net fishery is likely to be less than 25%.

Appendix 4. - Density Dependence

The Lough Neagh study has shown that the survival of glass eel to silver eel is density dependent (Fig. 4.1). At low densities approximately 60% of the glass eel stocked are estimated to survive to silver as opposed 10-20% at high densities.

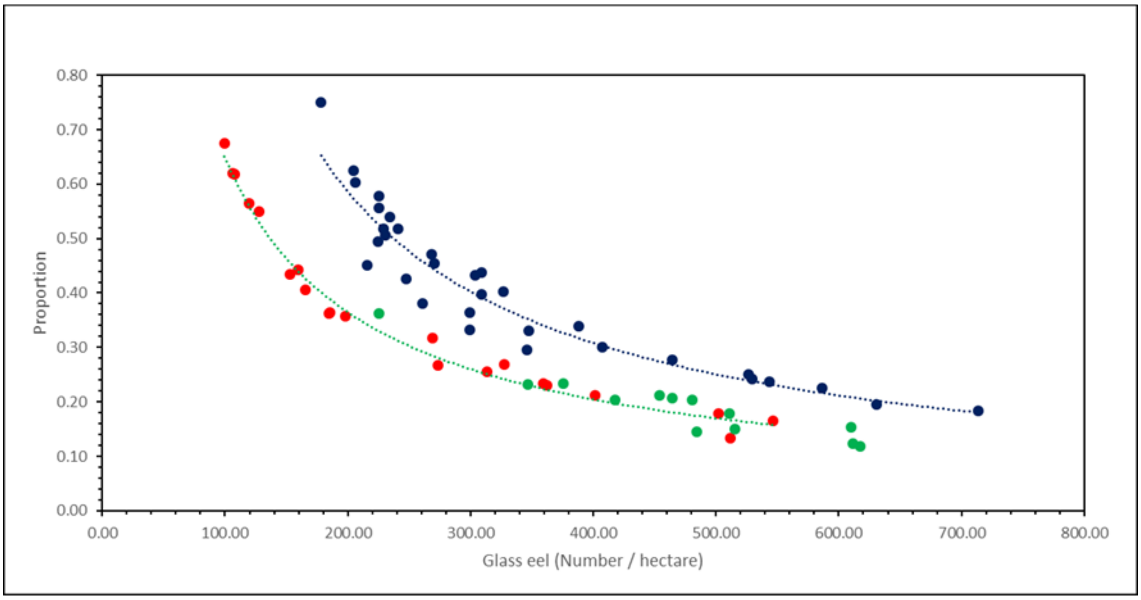

Fig. 4.1 Proportion of glass eel stocked surviving to silver in relation to stocking density for the 1923-44 cohorts (red), 1944-75 (blue) and 1976-88 (green).

The relationship with natural mortality is shown in Fig. 4.2. The instantaneous rate of natural mortality increased with the density of glass eel stocked into Lough Neagh. Mortality ranged from a low of approximately 2 % per year at low densities of 100-200 glass eel per hectare to a high of 12-14% at densities of 700 glass eel per hectare.

The relationship can be described by the equations:

Natural Mortality = 0.0583 * Log_e Stocking density – 0.2583

Where stocking density is number of glass eel per hectare

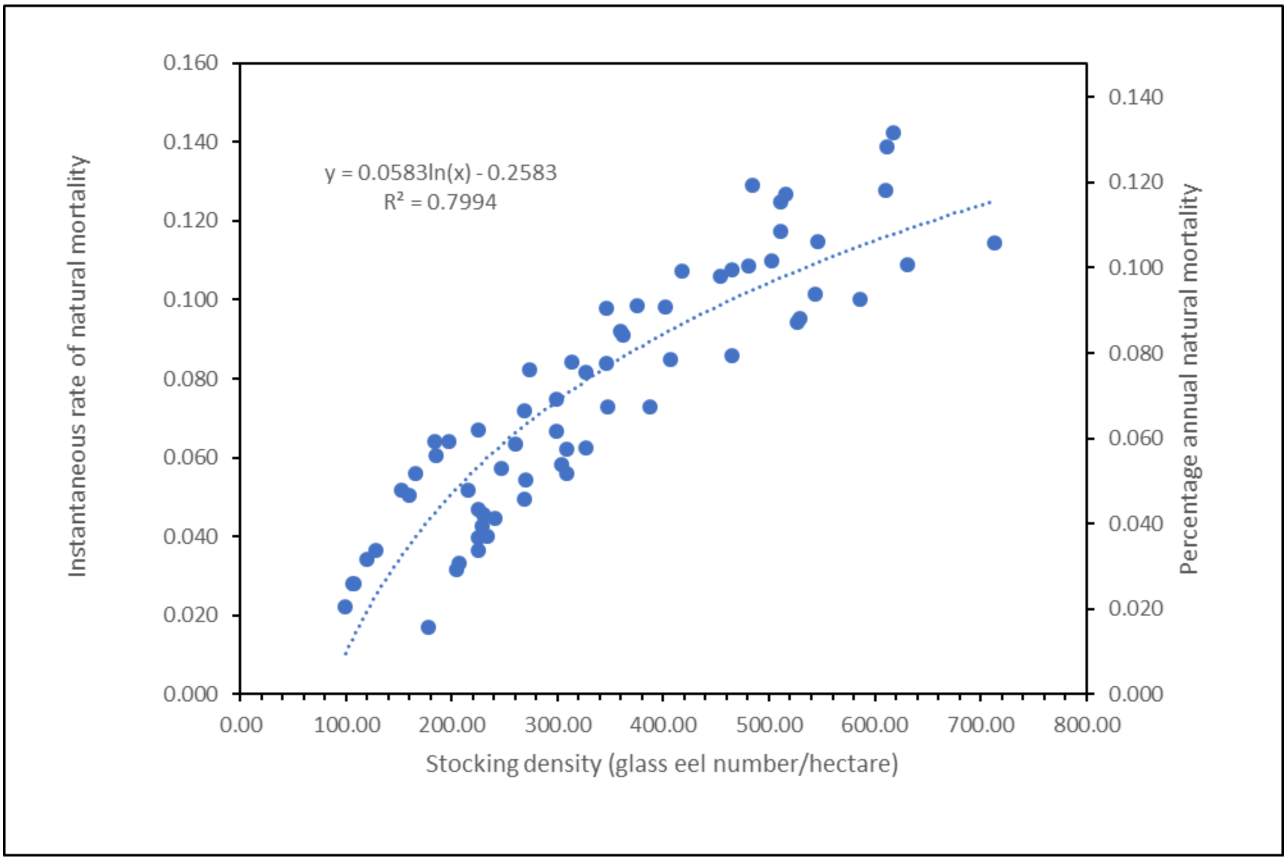

Fig 4.2. Natural mortality in relation to the stocking density of glass eel

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