AZTEC MANAGEMENT CONSULTANTS

PORT OF WATERFORD MAINTENANCE DREDGING PROGRAMME: FISH REPORT

January 2024

Report Prepared By: [redacted]

Contents

1 Introduction

Dr. [redacted] T/A Aztec Management Consultants was commissioned by the Port of Waterford to prepare an assessment of the impacts of a maintenance dredging programme on fish communities within the Waterford Harbour (Barrow-Nore-Suir estuary).

This report provides a description of the development (maintenance dredging programme), an assessment of the current status of fish in Waterford Harbour (Barrow-Nore-Suir estuary) and designated fish species in the estuary based on best scientific knowledge, and an assessment of the potential impacts of the maintenance dredging programme. A conclusion on the potential impacts of the maintenance dredging programme is provided which is based on a literature search and the current status of fish in Waterford Harbour (Barrow-Nore-Suir estuary).

1.1 Statement of Authority

This report has been prepared by Dr [redacted], T/A Aztec Management Consultants, Dublin. [redacted] has been involved in fish and fisheries related survey work in Waterford Harbour since the 1990s on behalf of New Ross Port Company, Port of Waterford, Electric Ireland (former owners and operators of Great Island thermal electricity generating station) and Scottish and Southern Energy (SSE) (current owners and operators of Great Island thermal electricity generating station).

In recent years (2020-2023)[redacted] has carried out a total of four fish impingement studies at Great Island thermal electricity generating station cooling water system and this work has provided him with a first-hand impression of the variety of fish species present in Waterford Harbour and also their relative abundances.

Outside of Waterford Harbour, [redacted] has a long track record working as a fisheries consultant in Ireland and internationally and a summary CV is provided in Appendix 1.

1.2 Dredging Areas

In total there are 16 areas that are included in these applications (‘Proposed Dredging Areas’). This includes 3 locations known as ‘Primary Dredge Areas’ that experience a high degree of sedimentation and therefore, over time, trigger the requirement for a maintenance dredging campaign to be undertaken. The Primary Dredge Areas therefore require dredging at least twice a year and these include Belview Berths, Cheekpoint Lower, and Duncannon Channel. There are also 13 that require less frequent dredging (referred to as ‘Secondary Dredge Areas’). The areas to be included in the forthcoming application may be broken down as presented in Table 1 and shown in Figure 1 below.

It should be noted that 13 of the areas included in this application are the same size and location as those previously authorised under previous permits held by the Port of Waterford. However, there are 3 areas of extended ploughing that the Port of Waterford are seeking, which include:

- Cheekpoint Lower Bar;
- Cheekpoint Harbour Access; and,
- O’Brien’s Quay.

Further information on these extended areas for dredging is provided below.

Figure 1: Proposed Dredging Areas to be Maintained by Port of Waterford

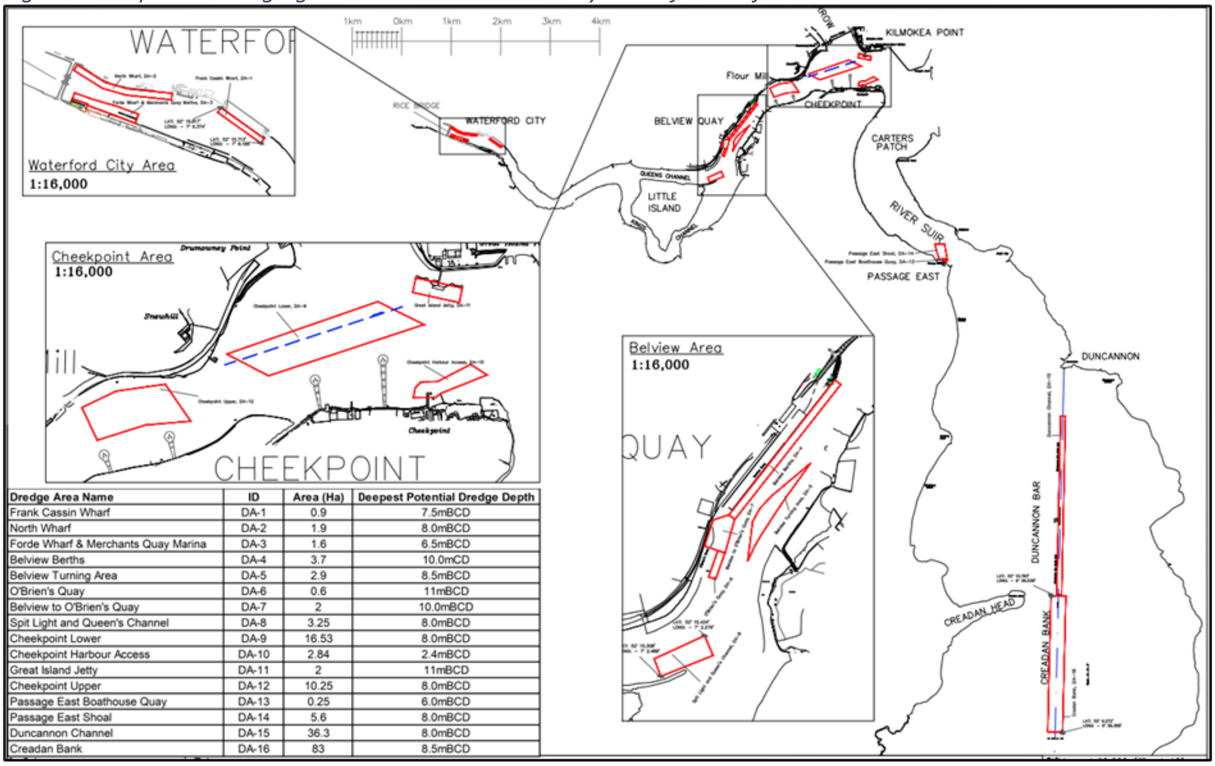


Table 1: Proposed Dredging Areas to be Maintained by Port of Waterford (Note: grey shaded rows indicate proposed extended areas)

Dredging Areas	Dredge Area Name	Current Permitted Area (ha)	2026-2033 Area (ha)
Primary Dredge Areas	Duncannon Channel	36.0	36.0
	Cheekpoint Lower	8.4	16.53
	Belview Berths	3.7	3.7
Secondary Dredge Areas	Belview Turning Area	2.9	2.9
	Belview to O'Brien's Quay	2.0	2.0
	Cheekpoint Harbour Access	0.8	2.84
	Cheekpoint Upper	10.3	10.3
	Creadan Bank	83.0	83.0
	Frank Cassin Wharf	0.9	0.9
	Forde Wharf & Merchants Quay Marina	1.6	1.6
	Great Island Jetty	2.0	2.0
	North Wharf	1.9	1.6

Dredging Areas	Dredge Area Name	Current Permitted Area (ha)	2026-2033 Area (ha)
	O'Brien's Quay	0.5	0.6
	Passage East Boathouse Quay	0.3	0.3
	Passage East Shoal	5.6	5.6
	Spit Light and Queen's Channel	3.3	3.3
Total Area		**163.2**	**173.17**

2 Description of the Proposed Dredging Activities

The Port of Waterford intends to apply for an eight year Dumping at Sea permit from the EPA and a Maritime Licence from MARA to dredge and dump at sea (2026-2033 inclusive). The maintenance dredging programme will consist of:

- Dredging of approximately 823,513 wet tonnes of spoil annually to maintain the Navigation Channel;
- Disposal of the dredged material at the existing licenced offsite disposal site; and,
- 3No. areas of extended dredging and/or ploughing at Cheekpoint Lower Bar, Cheekpoint Harbour, and O'Brien's Quay.

The proposed dredging methodologies are outlined below.

2.1 Description of the Development and Methodology

The dredging methodology utilised will vary depending on the following characteristics:

- Seabed / water depth;
- Access / manoeuvring within the area;
- Sediment type;
- Volume of sediment; and,
- Timeframe for the works.

The primary dredging method will be by Trailing Suction Hopper Dredger (TSHD), supported by a bed leveller. Allowances are also made for the utilisation of Mechanical Dredging and Plough Dredging. In some areas, multiple strategies may be required to be engaged. Descriptions of each dredging activity are provided in the sections below and Table 2 outlines the dredging activity proposed at each location.

Table 2: Dredging Activity at each Location

Dredging Areas	Dredge Area Name	Dredging Activity		
		Loading		Plough
		TSHD	Mechanical	
Primary Dredge Areas	Duncannon Channel	✓		✓

Dredging Areas	**Dredge Area Name**	**Dredging Activity**		
		Loading		**Plough**
		TSHD	**Mechanical**	
	Cheekpoint Lower	✓		✓
	Belview Berths	✓	✓	✓
Secondary Dredge Areas	Belview Turning Area	✓	✓	✓
	Belview to O'Brien's Quay	✓	✓	✓
	Cheekpoint Harbour Access	✓	✓	✓
	Cheekpoint Upper	✓		✓
	Creadan Bank	✓		✓
	Frank Cassin Wharf			✓
	Forde Wharf & Merchants Quay Marina			✓
	Great Island Jetty	✓	✓	✓
	North Wharf			✓
	O'Brien's Quay	✓	✓	✓
	Passage East Boathouse Quay	✓	✓	✓
	Passage East Shoal	✓	✓	✓
	Spit Light and Queen's Channel			✓

2.1.1 Trailing Suction Hopper Dredging

Due to the specific characteristics of the Port of Waterford the TSHD is the primary dredging method used to maintain the design depth of the navigational channels, and the other accessible areas of the Port's berths. The areas to be dredged will be identified regularly by hydrographic survey.

To start the dredging operations, the TSHD will sail to the area to be dredged. Once in the vicinity of its dredging area, the TSHD will lower the draghead(s) to the seabed and dredging can commence. The centrifugal dredge pump, installed inside the dredger, takes up a mixture of water and soil through the draghead, and suction pipe, and pumps the mixture into its integral hopper. The sediment will settle in the hopper and, if advantageous, only the water is discharged through an adjustable overflow system. When the draught of the vessel reaches the dredging loading mark or when circumstances do not allow for further loading, dredging will cease, and the suction pipe hoisted on deck. The dredger will fill its hopper in each of the identified dredging areas as efficiently as possible.

Upon filling its hopper, the dredger will sail to the licensed disposal site and slows to approximately one to two knots. The dredger will then open bottom doors, or split along its hull, to allow the release of its contents over several minutes. During the disposal operation the dredger is travelling at between one to two knots within the disposal area. Due to this the material is spread over the disposal site and ensures against accumulation of material within an isolated area (i.e., the centre of the disposal site). This process is repeated for each disposal operation with the master of the vessel referring to the previous disposal locations used, within the on-board tracking system, and selecting a new disposal location within the licensed area. By using as much of the disposal site as possible any impacts of excessive accumulation in one location from the disposal activity will be minimised.

This process will be continued until interim hydrographic surveys show that the required safe navigation depths required have been achieved and dredging can cease.

2.1.2 Plough Dredging

A plough vessel generally uses, if available, a bulldozer type plough to relocate material, although a standard open box plough can suffice on occasion. Sediment movement is achieved by towing a bottomless rectangular box shaped fabricated steel implement behind a powered vessel, usually a small workboat or tug. When used correctly, the plough is suspended at a controlled height from an A-frame mounted over the stern of the towing vessel. Height, or depth of submergence, is controlled by a deck mounted hoist winch. The cutting blade at the leading edge of the plough slices the surface sediment which is then contained within the sides and rear of the following plough until reaching an area where the bed level is lower than the suspended level of the plough, whereupon the contained sediment falls from the open bottom of the plough. The plough is then raised above the general seabed level and the towing vessel returns to the area from which sediment is to be moved and repeats the cycle.

2.1.3 Mechanical Dredging

There is also the potential for utilisation of a mechanical dredger in some areas. These dredgers use a bucket lowered to the seabed to excavate the targeted sediment material which is then raised to the surface. However, these dredgers do not have any means of transporting the dredged sediment so ‘hopper barges’ are required to be filled and transit to the licensed disposal site. The areas that may require the use of a mechanical dredger are limited to quay walls and berths where material has been compressed and has consolidated to a degree that it cannot be removed by other methods of dredging. This option is not favoured by the Port as it is significantly more expensive that the use of a TSHD/plough and it is only utilised as a last resort when conditions dictate the standard processes are technically unfeasible.

2.2 Current Maintenance Dredging

TSHD has previously been undertaken at three main locations (Belview, Cheekpoint and Duncannon) in Waterford Harbour.

The following are the indicative loading times (active dredging and manoeuvring) at each location:

- Cheekpoint 0.88hrs
- Duncannon 0.47 hrs
- Belview 1.16hrs

During dredging operations, the average dredging time (active dredging and manoeuvring) for all three locations is 0.84hrs.

The area of activity in the proposed maintenance dredging areas in Waterford Harbour totals approximately 173.17ha which represents 2.06% of the area of Waterford Harbour (83.9km^2). The active suction field of the dredger is approximately 1m in diameter and the overall width of Waterford Harbour where dredging is taking place is approximately 700m.

POW has monitored and modelled the evolution of suspended solids into the water column caused by the plough dredger, which is considered to result in higher total suspended solids levels (mg/L) in the water column than the TSHD, and how that plume dissipates over a tidal cycle (Cunningham, 2021).

Two assessment buoys at Carter's Patch and Belview (see Figure 2 below) were equipped with an Aqua TROLL 500 Multi-parameter Sonde which monitored a range of parameters which included Turbidity (Nephelometric Turbidity Units - NTU) from which Total Suspended Solids (mg/L) were calculated.

Figure 2: Belview and Carter's Patch Monitoring Bouy Locations and the Plough Zone (Extract taken from Cunningham 2021)

Variations in turbidity are mediated by tidal and density factors. (2) At the Belview Control Buoy site, dredging/ploughing at the mouth of the River Barrow has a minor effect on the turbidity at that site.

According to Cunningham (2021) it is immediately apparent that the mean turbidity values are substantially lower at Carter's Patch than at Belview. Daytime turbidity values increased from 12.42±2.57NTU to 16.41±2.14NTU when dredging was ongoing; a rise of 3.99NTU. This is only 53% of the 7.57NTU rise observed at Belview. The natural fall in turbidity at night is also apparent. On days when there was no dredging, turbidity fell from 12.42±2.57 to 9.53±2.83NTU overnight; a drop of 2.89NTU. When dredging was ongoing, turbidity dropped from 16.41±2.14 to 13.62±2.01NTU overnight; a drop of 2.79NTU.

According to Cunningham (2021) there is a straightforward linear relationship between turbidity (NTU) and Total Suspended Solids (mg/L) (1 NTU = 1.25 TSS mg/L).

Table 3: Relationship between Turbidity and Total Suspended Solids (Cunningham, 2021)

	Turbidity (NTU)	**Total Suspended Solids (mg/L)**
Max	924.78	1155.98
Min	0.01	0.01
Mean	16.74	20.93
Std. Dev	18.75	23.43
N	34528	34528

When the turbidity data for Belview and Carter's Patch are converted to Total Suspended Solids (mg/L) the statistical breakdown is as follows:

Table 4: Total Suspended Solids (Cunningham, 2021)

	No Dredging		**Dredging**	
	Day	Night	Day	Night
Mean Belview	27.38	23.24	36.79	31.25
Mean Carter's Patch	15.53	11.91	20.51	17.03

There was an average rise of 9.41mg/l TSS at Belview, with the onset of dredging, and 4.98mg/l TSS at Carter's Patch.

Cunningham (2021) states that In the Port of Waterford's Turbidity Monitoring Proposal (May 2020), there is a section entitled Alarms and Reporting which contains the following text:

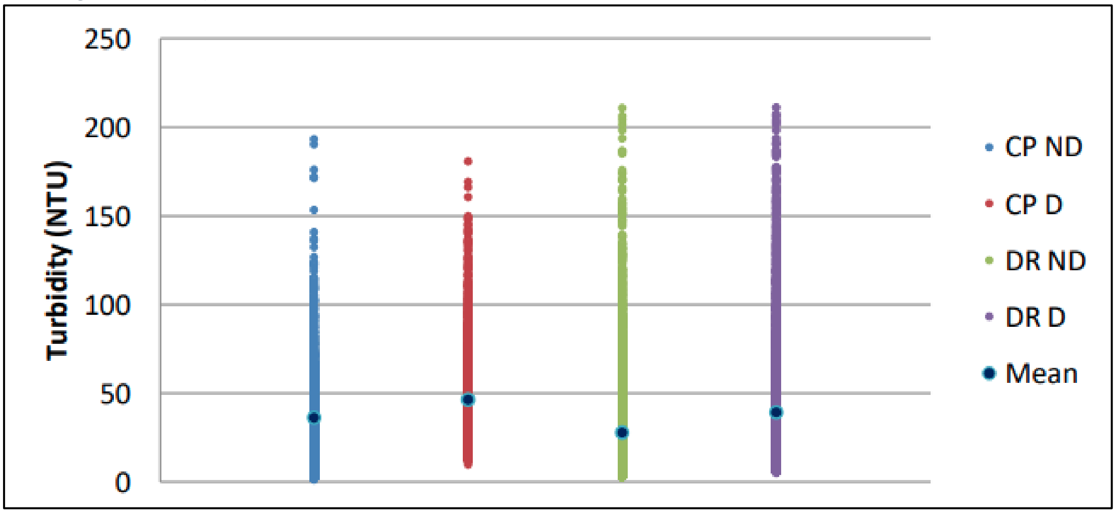
'….it is proposed to have an alarm level of 600mg/L included. This is in consideration of a background TSS level of up to 500mg/L in Carter's Patch and the model's predicted maximum levels of TSS from ploughing activities of approximately 100mg/L. Given that, during this campaign, the maximum recorded turbidity when dredging was not ongoing, was 506.10NTU for Carter's Patch (equivalent to 632mg/l TSS), the alarm level of 600mg/l (480NTU) may have been appropriate for Carter's Patch.'

The above text demonstrates that during plough dredging campaigns (which normally result in higher total suspended solids levels in the water column compared to TSHD campaigns) relatively low total suspended solids levels occur but that much higher total suspended solids levels can also occur when plough dredging was not taking place. A later section of the current report deals with the implications of suspended solids levels for fish in estuarine environments.

In addition, the 2023 review and analysis undertaken by Cunningham also used the same water quality monitoring buoys to measure turbidity before and during the plough dredging campaign of early 2023.

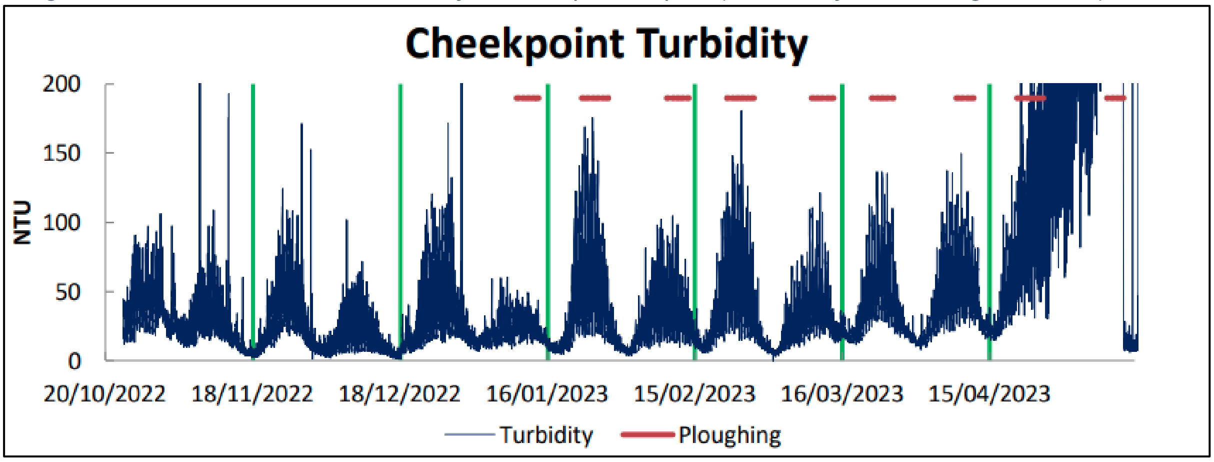
As shown in Figure 3 below, the report showed the range of water turbidities measured at the two buoys during ploughing operations and outside of ploughing operations was assessed. The range of turbidities at both locations approximated 0-200 NTU with mean values typically less than 50 NTU (Cunningham, 2023).

Figure 3: The visual spread of turbidity data with extreme high values removed. CP = Cheekpoint; DR = Drumroe; ND = No Dredging, and D= Dredging. The Mean = the arithmetic average value of the data (Extract from Cunningham, 2023)



In addition, the report showed Cheekpoint turbidity data for the period October 2022 to May 2023, and most recorded values are less than 50 NTU with a small percentage of values exceeding this value but not exceeding 200 NTU (Cunningham, 2023). The NTU range on the graph is 0-200.

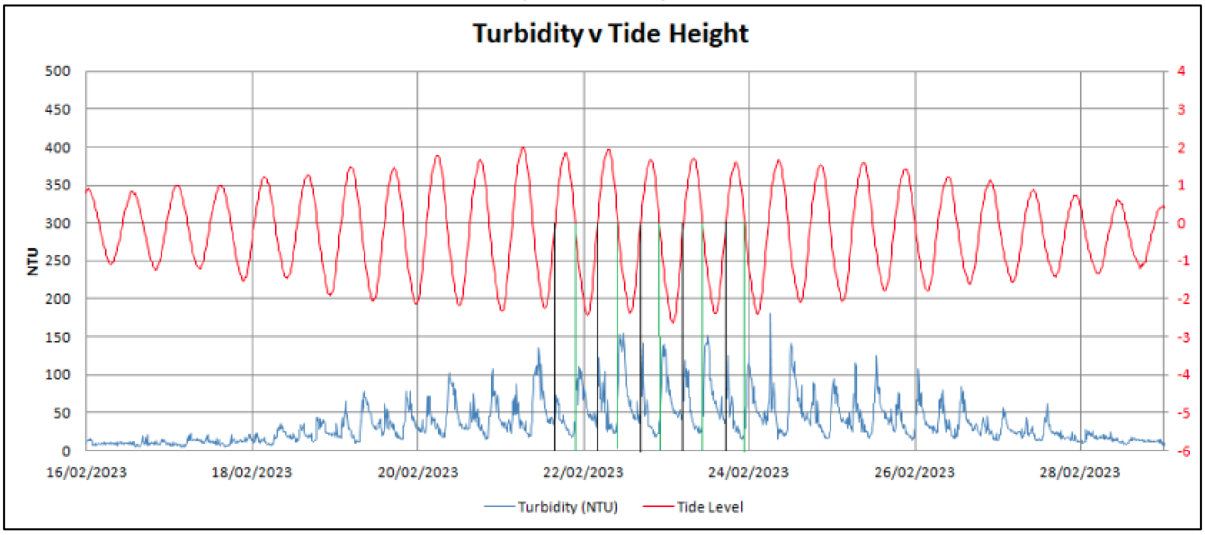
Figure 4: Cheekpoint turbidity data with most of the fouled data removed. Plough dredging times are included. The green vertical lines indicate the start of a 29.5 day lunar cycle. (Extracted from Cunningham, 2023).



The effect of tidal conditions on turbidity is also assessed. Figure 5 below shows the turbidity values and tidal range valued for the latter half of February 2023. While turbidity ranged from close to zero to 200 NTU it was clear that higher levels of turbidity pertained during mid-ebb tidal conditions which occurred on days with greater tidal ranges.

The rise in suspended solids/turbidity, due to ploughing, was of no practical significance as it was hidden within the natural variability of the turbidity within the estuarine system.

Figure 5: Tide data superimposed on turbidity data. The black vertical lines indicate mid-flood tide and the green lines indicate mid-ebb tide conditions (Extracted from Cunningham, 2023).



Anon. (2023) comment that naturally occurring tidally generated suspended solid concentrations were modelled by Delft Hydraulics (Eysink et al., 2000) and vary between 50 and 500mg/l at both Belview Point in the River Suir and at Garraunbaun Rock near Ferry Point in the White Horse Reach of the River Barrow. In contrast, at Cheekpoint, the confluence of the River Barrow and the River Suir, the tidally generated suspended solids concentrations were typically less than 150mg/l. Downstream in the River Suir, between Passage East and Buttermilk Point, naturally occurring, tidally generated suspended solids exceeded 1,000mg/l. Tidally generated suspended solids at Duncannon Bar within the Suir Estuary were above 100mg/l at bed and mid-water on spring tides. Background suspended sediment concentrations (SSC) (of the fraction) in the Cheek Point area vary dynamically during the tidal cycle, with maximum concentrations at 0 to 2 hours after maximum ebb and flood currents and minimum concentrations at 0 to 2 hours following slack water (Rijn, 1990).

During ploughing operations, maximum SSC (suspended solids concentrations) (above background) at the point of disturbance were around 2,500 mg/l near-bed at the time of peak flows and 1,500 mg/l during slack flows. One day following completion of plough disturbance, peak SSC would reduce by over an order of magnitude at the disturbance site. Maximum concentrations away from the disturbance location, for the most part, would occur on peak flood flows as 'pulses' that rarely last for longer than 30 minutes per tide. Individual spikes can reach 1,000 mg/l at some locations. Elevated SSC that last for several hours are generally in the range 150-250 mg/l, depending on location, on spring flood tides, and lower on ebb tides. Average elevated concentrations are rarely above 50 mg/l. These values compare against the measured background SSC level, which were recorded between 350 and 600 mg/l between Carters Patch and the River Barrow, on a typical spring tide, increasing to up to 1,000 mg/l during an observed storm event.

Delft Hydraulics modelled the impacts of trailer-suction hopper dredging activities at the Duncannon Bar on the spreading of suspended sediment in the estuary of the River Suir (Eysink et al., 2000). Environmental Tracing Systems (ETS) undertook a fluorescent particle tracing study in order to determine the fate of dredged material from Cheek Point Harbour (ETS, 1998). The turbidity generated by the dredging activity must be weighed against the turbidity which results from natural processes (e.g., storm surges) and the background turbidity (e.g., navigation) that occurs in the dredging areas before, during and after the dredging activity. The majority of suspended sediment generated due to dredging activities is at depth (i.e., close to the seafloor). In its initial deliberations, Delft Hydraulics (Eysink et al., 2000) considered that the additional turbidity above background levels 50m around the dredging Trailing Suction Hopper Dredge would be of the order of c. 250-300mg/l of suspended solids. However, the modelling concluded that the increase in suspended sediment concentrations above background would be of the order of 100mg/l within 50m of the dredger. Assuming suspended solids in the channel are at the upper end of this observed range i.e., 100mg/l, the suspended solids concentrations local to the dredger are likely to increase to the order of 250mg/l at Cheekpoint and 200mg/l at Duncannon Bar.

3 Baseline Assessment of Waterford Estuary Fish

A comprehensive assessment of the current status of fish in Waterford Harbour (Barrow-Nore-Suir estuary) has been prepared and is included as Appendix 2 to this report.

This appendix provides an overview of the size and hydrography of Waterford Harbour, the characteristics of fish species which inhabit the estuary throughout their lives (estuarine species) and of fish species which utilise the estuary for part of their lives (diadromous species and other marine and freshwater opportunists). A generalised categorisation of fish in estuaries for part or all of their lives would include:

- Marine - species that spawn at sea;
- Estuarine-resident - species that complete their life cycle within the estuary;
- Diadromous - species that feed at sea and migrate into fresh water to spawn or undergo the reverse migration; and,
- Freshwater - species that spawn in fresh water.

For fish species inhabiting the estuary for all or part of their lives, there are corresponding preferential ranges of salinity, temperature and oxygen concentrations. Varying turbidity / suspended solids levels are normal for any estuarine regime and for many species, high turbidity and high suspended solids levels facilitate their avoidance of piscivorous fish and birds.

The description of fish species which occur in Waterford Harbour (Barrow-Nore-Suir estuary) is based on survey work carried out by Inland Fisheries Ireland, the competent authority, as part of the national Water Framework Directive surveillance monitoring programme during the years 2016 and 2019 (Ryan *et al.* 2017, 2020). The findings of these surveys formed the basis for estimating the ecological status of fish in Waterford Harbour.

Other survey results used to enhance the understanding of fish species present in Waterford harbour and their relative abundance included the results of trawl surveys throughout Waterford Harbour as part of the IFI's National Bass Conservation Programme (Ryan *et al*., 2017, 2020) and fish impingement studies carried out at Great Island thermal electricity generating station cooling water system during the years 2017, 2018, 2020, 2021, 2022 and 2023 (Teague *et al*. 2018, Anon. 2021a, 2021b, 2023a and 2023b).

The key finding from the Water Framework Directive surveillance surveys carried out during the years 2016 and 2019 using a combination of beach seine, fyke net and trawl surveying methods, was that the ecological status of fish in Waterford Harbour (Barrow-Nore-Suir estuary) in those years, and also during previous survey years (2010 and 2013) was good.

While the survey methodology used was identical in all survey years, the estuarine fish metrics used to assess status (by way of Estuarine Multi-metric Fish Index (EMFI) and Ecological Quality Ratio (EQR) during the 2016 and 2019 surveys were more sophisticated than those used during the earlier surveys.

It is clear that the numbers of species recorded using different survey methodologies (WFD – beach seines / fyke nets / trawl; National Bass Conservation Programme – trawl; Fish Impingement Studies at Great Island – station cooling water abstraction) differed among sampling methods with the highest number of species recorded during the fish impingement studies. However, sampling fish for the Water Framework Directive cannot involve exhaustive and unduly costly survey methodology and it is understandable why some species groups are more or less represented among the species recorded by different sampling methods.

For example, during the WFD surveillance monitoring surveys a total of 28 species were recorded in 2016 and 30 species in 2019. A total of 23 species were common to both survey years while 5 species were only recorded in 2016 and 7 species were only recorded in 2019. For both survey years a total of 35 species were recorded. Common and sand goby, flounder, European smelt, sprat, dace, European eel and thick-lipped grey mullet were the most abundant species recorded. Scientific names for all species mentioned in this section of the report are provided in Appendix 2.

During the 2016 and 2019 trawl surveys of Waterford Harbour as part of IFI's National Bass Conservation Programme a total of 26 species were recorded compared with 30 species in 2019. A total of 23 species were recorded during both survey years while 3 species were recorded only in 2016 and 7 species were recorded only in 2019. The total number of species recorded in both years was 33.

During the November 2017, 2020 and 2022 fish impingement studies at Great Island CWS a total of 54 species of fish were recorded as follows:

Table 5: Fish Impingement Studies from at Great Island CWS November 2017, 2020 and 2022 Results

Year	No. fish species	No. fish species common to all three years	No. fish species common to 2 years	No. species recorded in 1 year only
2017	30	23		
2020	42	23		
2022	43	23		
Total	54	23	13	18

The most abundant species recorded were sprat, herring, lesser and greater pipefish, pogge, whiting, European smelt, 5-bearded rockling, tub gurnard (2020 only) and Twaite shad. Sand goby were too numerous to count during the Nov 2022 study.

During the June 2018, 2021 and 2023 studies a total of 42 species of fish were recorded as follows:

Table 6: Fish Impingement Studies at Great Island CWS from June 2018, 2021 and 2023 Results

Year	No. fish species	No. fish species common to all three years	No. fish species common to 2 years	No. species recorded in 1 year only
2018	27	13		
2021	31	13		
2023	19	13		
Total	41	13	9	19

The most abundant species recorded were cod (2018 only), flounder, herring, European smelt, sprat, whiting and sand goby which were too numerous to count during the June 2023 study.

With 33 species contributing to the WFD assessment of good ecological status with regard to fish in Waterford Harbour, it is clear that the estuary supports a much higher number of fish species as evidenced by the other sampling methods reported on here.

Of the 70 fish species listed in Harrison & Kelly (2013) as representative of reference / undisturbed Irish estuaries, the following number of species were recorded during the various surveys and studies in Waterford Harbour.

Table 7: Fish Results from Various Surveys and Studies in Waterford Harbour

Survey / Study	**No. fish species**	**No. fish species common to all three surveys / studies**	**No. fish species common to two surveys / studies**	**No. fish species common to one survey**
WFD* 2016, 2019	32	23		
NBCP** 2016, 2019	30	23		
GI FIS*** 2017,2018, 2020,2021,2022, 2023	48	23		
Overall	49	23	12	14

*Water Framework Directive surveillance monitoring survey (beach seine, fyke net, trawl)
**National Bass Conservation Programme survey (trawl)
***Great Island CWS Fish Impingement Study

Thus, a total of 49 of the 70 fish species referenced in Harrison & Kelly (2013) were recorded in Waterford Harbour during the various fish surveys detailed above. The fish impingement studies at Great Island CWS provided by far the most comprehensive picture of the fish species present in Waterford Harbour.

3.1 Baseline for Designated Fish in Waterford Harbour

The occurrence of diadromous / designated fish species in Waterford Harbour does not seem to influence the current methods used to assess the ecological status of fish in the context of the Water Framework Directive (Harrison & Kelly, 2013). The perception appears to be that these diadromous fish species are migrating through the estuary on their way to spawning areas in freshwater in the case of anadromous species (Atlantic salmon, Twaite shad, Sea and River Lamprey) and on their way to marine spawning areas in the case of catadromous species (European eel). However, there is now evidence that some of these diadromous species populations or at least components or some age classes of these populations are more estuary dependent than previously thought.

3.1.1 Atlantic Salmon (*Salmo salar*)

The Atlantic salmon is an anadromous species (spawning in freshwater and migrating to sea, typically after one or more years of life in freshwater (depending on the productivity of the freshwater habitat and the temperature regime of the freshwater habitat, which can both be related to latitude) throughout its geographic range. There are some landlocked populations e.g., Lake Vanern's *Gullspång salmon*, but by and large the species is migratory and anadromous. Typically, migration through estuarine environments is rapid and smolt / post-smolt enter sea / ocean conditions rapidly. The duration of life at sea for feeding fish is related to several factors, including individual fish growth and condition, genetic background and in-river distance to spawning areas and can include one or more winters spent at sea before return to freshwater as a maturing adult to spawn. Atlantic salmon are iteroparous but typically, the majority of spawners do not survive to spawn a second time. Thus, they are in effect semelparous and realise iteroparity at the population level by cohorts splitting into different smolt age groups and different sea age groups. Typically, salmon smolt leave Irish catchments during conditions of elevated river flow and during a temperature window of 7-13°C and this normally encompasses the months March through May.

The current assessment of the status of Atlantic salmon with regard to Waterford Harbour / the Barrow-Nore-Suir estuary utilises some of the content of the reports of the Technical Expert Group on Salmon (Anon, 2019 and Gargan *et al*., 2020) to estimate the number of salmon smolt migrating from the Barrow, Nore and Suir catchments annually and via Waterford Harbour to the open sea.

Table 8: Atlantic salmon population model for the Barrow, Nore and Suir catchments.

Catchment	Catchment Area (km^2)	Fluvial Habitat (m$^{2)}$	Accessible Fluvial Habitat (m^2)	% of Accessible Habitat	Salmon CL	Proportion of CL Attained	Estimate of Salmon Returning
Barrow	3,011	7,662,489			11,737	0.15	1,761
Nore	2,598	8,479,921	7,134,913	84	10,420	0.84	8,753
Suir	3,547	11,448,269	10,320,082	30	14,055	1.02	14,336
Total	**9,156**	**27,590,688**			**36,212**		**24,849**

***Note:** Currently approximately 5% of migrating smolt return to the Irish coast as 1SW fish. The return rate as MSW fish is significantly lower. Irish Index Catchments (Burrishoole, Co. Mayo and Bush, Co. Antrim) have recorded 100-200 salmon smolt produced per km^2 of catchment area.

The model shows that the combined conservation limit (CL) for all three catchments is estimated at 36212 1SW (one-sea-winter) and MSW (multi-sea-winter) salmon and that as of 2019, the total number returning is 24,849 (with both the Barrow and Nore failing to achieve their estimated conservation limits).

Currently, the marine survival of salmon smolt in the North-East Atlantic is very low and has been estimated at 5-10% in index catchments. For the purposes of this assessment a figure of 5% has been used. The model depicted above shows that a total of 496,989 smolt migrate from these three catchments annually.

Atlantic salmon smolt pass seaward through Waterford Harbour rapidly, probably making most progress during periods of ebb tides. All the available evidence on the duration of passage of Atlantic salmon through estuaries suggests that they pass through the estuary during a period lasting perhaps one to several days.

With regard to the duration of passage through the estuary of maturing adult salmon on their return migration to their natal river, much will depend on the flows emanating from their natal river. During drought summer periods, it is well known that estuary residence of these returning adults can be prolonged whereas these same fish can rapidly pass through the estuary and enter their natal river when adequate freshwater flows are available to facilitate their entry and upstream migration in their natal river. Typically, early running multi-sea-winter fish enter natal rivers during the spring months while 1SW and MSW summer fish typically enter their natal rivers during the summer months. Their duration of residency in the estuary depends on natal river flows and during summer drought conditions it is not unusual for 1SW and MSW summer fish to delay their entry into natal rivers until the month of September or even later.

While salmon smolt are certainly feeding during their seaward migration, the same does not apply to maturing adults on their return migration. For each life stage, it can be stated that they have very little dependency on the estuarine environment.

Table 9: Relationship between numbers of returning adult salmon (combined 1SW and MSW) and number of migrating smolt and number of migrating smolt per catchment unit area

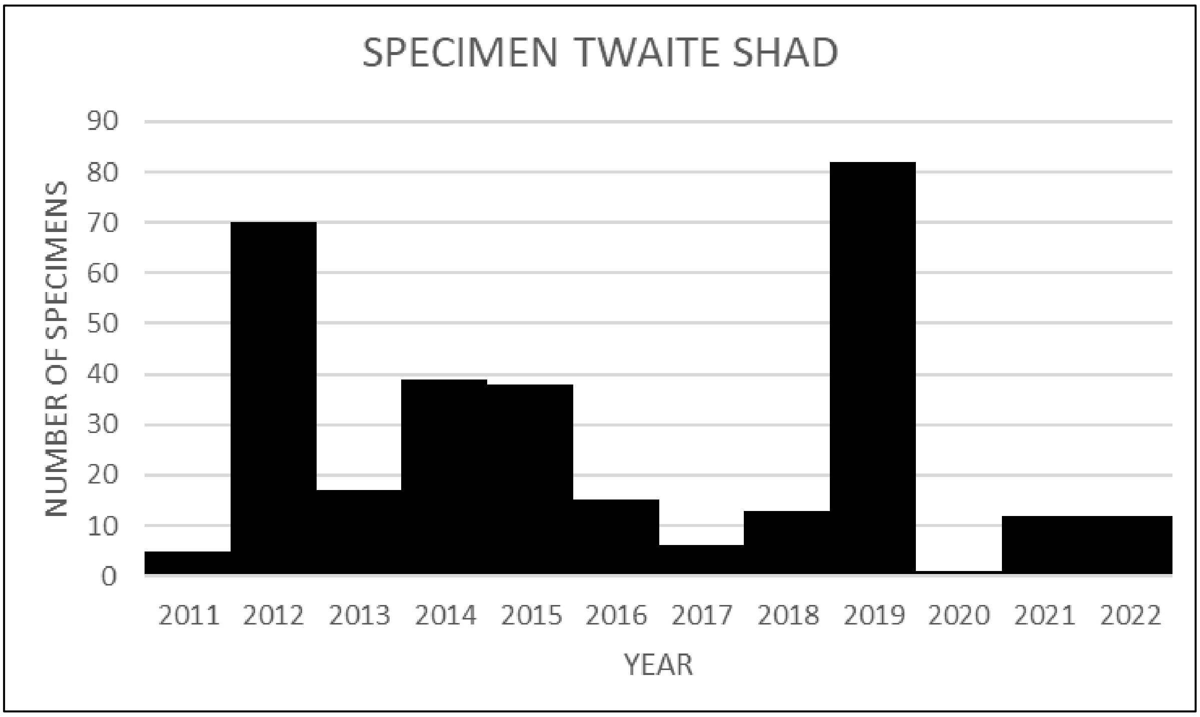
Catchment	Estimate of Salmon Returning	Estimate of Smolt Returning	Estimate of Smolt Migrating per km^2 of Catchment Area
Barrow	1,761	35,211	12
Nore	8,753	175,056	67
Suir	14,336	286,722	81
Total	**24,849**	**496,989**	

In an estuary as large as Waterford Harbour, it is very unlikely that the maintenance dredging programme will have any impact on the out-migrating smolt which are pelagic and have wide areas of the estuary to use and can easily avoid the dredge area during their migration. Returning adult salmon can do the same, even if their residence time in the estuary is prolonged due to reduced flows in their natal river.

3.1.2 Twaite Shad (*Alosa alosa*)

The Twaite shad is a diadromous species and effectively anadromous in so far as the mature adults leave the marine environment and enter the lower freshwater reaches of rivers to spawn. In the case of Waterford Harbour, adult Twaite shad typically enter the lower reaches of the River Barrow where they spawn in the vicinity of St Mullins and also provide the basis for a recreational catch and release fishery for fishermen targeting specimen fish (typically with a total length longer than 50cm (formerly 46cm) and a minimum weight of 1.64kg) which occurs in April and May each year. Figure 6 below shows the number of specimen Twaite shad (fish greater than or equal to 50cm total length in recent years) approved by the Irish Specimen Fish Committee (www.specimenfish.ie) for the years 2011-2022.

Figure 6: Numbers of specimen Twaite shad recorded at St Mullins on the River Barrow during the years 2011-2022

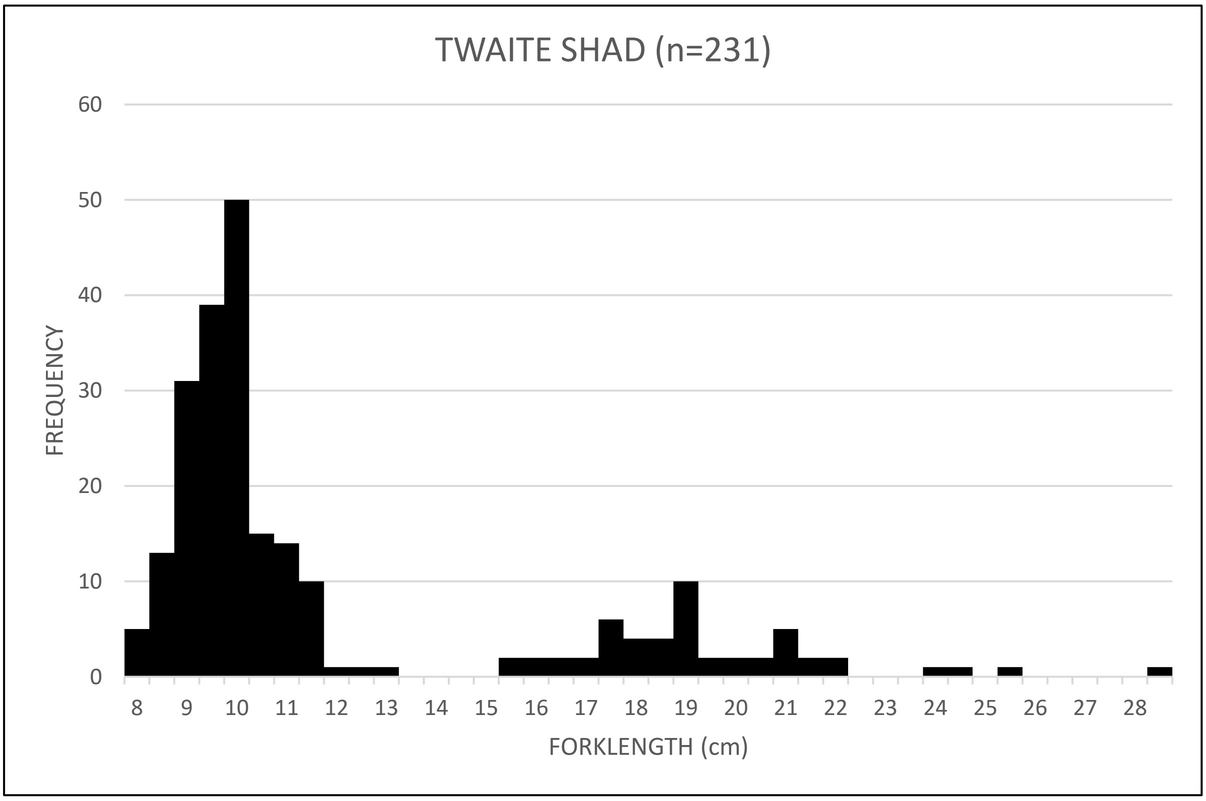


In the above figure, a total of 35 shad hybrids are included in the number recorded for 2012 but this category was not detailed in subsequent years. The Covid-19 pandemic years (particularly 2020) clearly impacted on the number of specimens recorded during those years.

There is no information available on the numbers of adult Twaite shad entering the River Barrow to spawn. The number of specimens recorded each year might indicate variations in annual numbers of spawning fish. A regular specimen hunter (Ross Macklin *pers comm*) suggested that specimen fish might represent 1% of all fish caught and released by anglers. An average of 26 specimen Twaite shad were recorded for the above 12-year period and this might represent an average annual rod catch of 2600 fish. If 25% of all adult shad were caught and returned by anglers, this might represent a run of about 10,000 fish into the River Barrow. Clearly the above numbers are 'guesstimates' and further work is required to provide more robust estimates.

With spawning activity peaking during May, eggs hatch in a short time and begin to drift into the estuary proper where conditions of relatively low salinity are experienced. While Twaite shad is considered a diadromous species, estuarine residence time for juveniles can be prolonged. There is evidence from Waterford Harbour that fish in their first and second year of life continue to reside in the estuary. This evidence comes from Water Framework Directive surveillance monitoring surveys carried out by Inland Fisheries Ireland (Ryan *et al.* 2017 and 2020) and fish impingement studies carried out at Great Island thermal electricity generating station cooling water system (Anon. 2021). The fork-length frequency distribution of Twaite shad washed off the band-screens at Great Island CWS during November 2022 (Anon. 2023) confirms the presence of 0+(<13.5cm), 1+ (15.5-22.4cm) and a small number of older fish (>24.0cm).

Figure 7: Forklength frequency distribution of Twaite shad washed off band-screens at Great Island CWS during the November 2022 fish impingement study (Anon. 2023)



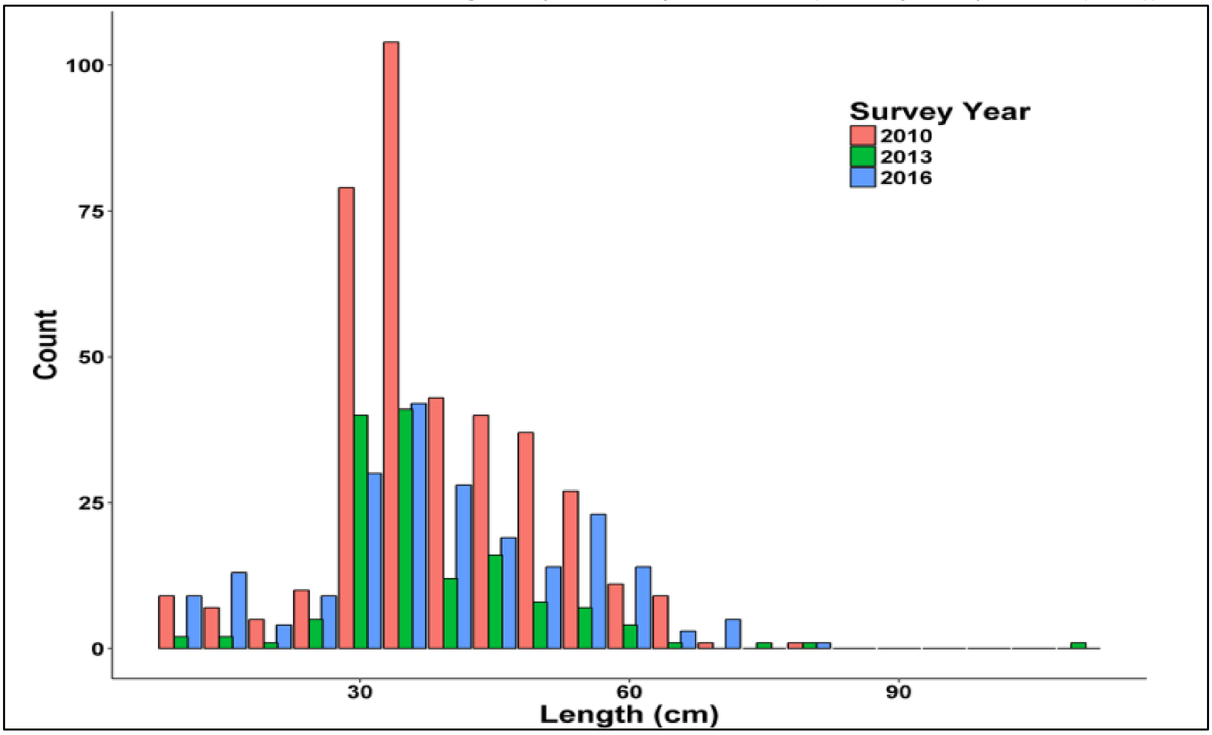
Clearly, younger Twaite shad are more estuary dependent than might be considered for a diadromous fish species. However, being a pelagic fish, it would be expected that they can easily avoid the area of the maintenance dredging operations given the vast expanse of estuary habitat available to them. Thus, it is considered that the maintenance dredging programme will not have any impact on this species.

3.1.3 European Eel (*Anguilla anguilla*)

The juveniles of this catadromous species typically arrive on Irish shores as transparent glass eels during the early winter months. Pigmentation occurs during the following spring months and a some of the survivors ascend into freshwater rivers and lakes, typically during the months of April and May. Older and larger individuals, termed bootlace eels, also migrate upstream from estuaries and the lower reaches of rivers somewhat later in the year, typically during the month of August in some monitored rivers e.g., River Shannon. Those individuals which ascend into freshwater habitat typically feed and grow for a relatively long period of time depending on the productivity of the environment and the sex of the individual before maturing sexually and commencing their downstream migration to the sea and eventually to the western Atlantic Ocean where spawning occurs. Maturing males never attain total lengths exceeding about 44cm and are typically relatively young (less than about 10 years old) while maturing females typically exceed 44cm in total length and can be much older (perhaps 10-30 years in age). These maturing eels typically migrate downstream from Irish catchments during the autumn months under conditions of elevated river flow and especially during the dark of the moon. These silver eels were formally captured in commercial fisheries as they migrated downstream. Some of the rivers discharging to Waterford Harbour supported such fisheries in the past.

It is well known that a percentage of eel do not migrate upstream into freshwater habitat but remain in productive estuarine environments throughout their feeding and growing (yellow) life stage. This is the case in Waterford Harbour where significant numbers of feeding / yellow eel live throughout their lives before maturing and migrating to sea to spawn. Prior to the termination of commercial fisheries for eel in the Republic of Ireland in 2009, a number of fishermen in Waterford Harbour exploited this resource commercially using a combination of baited baskets and fyke nets. Typically, these estuary fishers used catches from flood or ebb 'sprat weirs' at many locations throughout Waterford Harbour is collect quantities of fish. Some of which were of marketable size but most of which were small and used as bait in the baskets. The results of the WFB surveillance monitoring surveys carried out by Inland Fisheries Ireland (Ryan *et al.* 2017) also attest to the presence of large numbers of yellow eel in Waterford Harbour.

Figure 8: Illustration showing the total length frequency distributions of European eel recorded during the 2010, 2013 and 2016 WFD surveillance monitoring surveys in Waterford Harbour (Extract from Ryan et al. (2017))



The European eel is particularly abundant in Waterford harbour and being a benthic species could be vulnerable to the maintenance dredging programme. However, this species is also particularly sensitive to many environmental stimuli and would be expected to swim rapidly away from an approaching dredging operation.

3.1.4 Sea Lamprey (Petromyzon marinus)

The spawning adults of this anadromous species migrate from the sea into freshwater during the late spring months and typically spawn in suitable shallow flowing water habitat with stony substrate during the months of May and June (Note: landlocked populations also occur e.g., Great Lakes in North America where the species is invasive). The juveniles (ammocoetes) spend several years in suitable silty substrates before they transform (metamorphose), typically during the autumn months, and make their downstream migration to the sea. These transformers have been recorded in Waterford Harbour during November fish impingement studies at Great Island. It is believed that the transformers typically migrate through the estuary quickly and enter the open sea where they attach to suitable hosts and commence feeding on host blood and other body fluids. There is evidence that sea lamprey are disloyal to their natal river and accordingly this species can be considered to have at least regional populations from which adults ascend into suitable spawning rivers which are not necessarily their natal river to spawn and die.

The maintenance dredging operation in Waterford Harbour would not be expected to impact on this species as the transformer life stage migrating through the harbour is pelagic and would be expected to pass through the estuary rapidly *en route* to the open sea.

3.1.5 River lamprey (*Lampetra fluviatilis*)

The spawning adults of this anadromous species migrate from the sea into freshwater during the early spring months and typically spawn in suitable shallow flowing water habitat with stony substrate during the months of April and May after which they die. The juveniles spend several years before they transform (metamorphose) and make their downstream migration to the sea, typically during the spring months. These transformers have been recorded in Waterford Harbour during November fish impingement studies at Great Island and adults have been recorded during fish impingement studies carried out during June. Unlike sea lamprey, river lamprey spend all their adult lives in an estuarine / coastal environment where they attach to suitable hosts and commence feeding on host blood and other body fluids. Accordingly, river lamprey are highly estuary dependent during their adult lives. There is no evidence that adults return to their natal river to spawn and it is likely that regional populations exist which spawn in a number of local rivers which are not necessarily their natal river. With transformer and adult life stages essentially resident in Waterford Harbour, it is difficult to see how the maintenance dredging programme could possibly impact on this species. The transformers which recently entered the estuary will be essentially pelagic and when they find one or more suitable hosts to feed on their movement patterns throughout the estuary will be determined by their host.

3.1.6 Brook lamprey (*Lampetra planeri*)

Brook lamprey spend their entire lives in freshwater and have not been recorded in Waterford Harbour (Barrow-Nore-Suir estuary).

4 Potential Impacts from the Maintenance Dredging

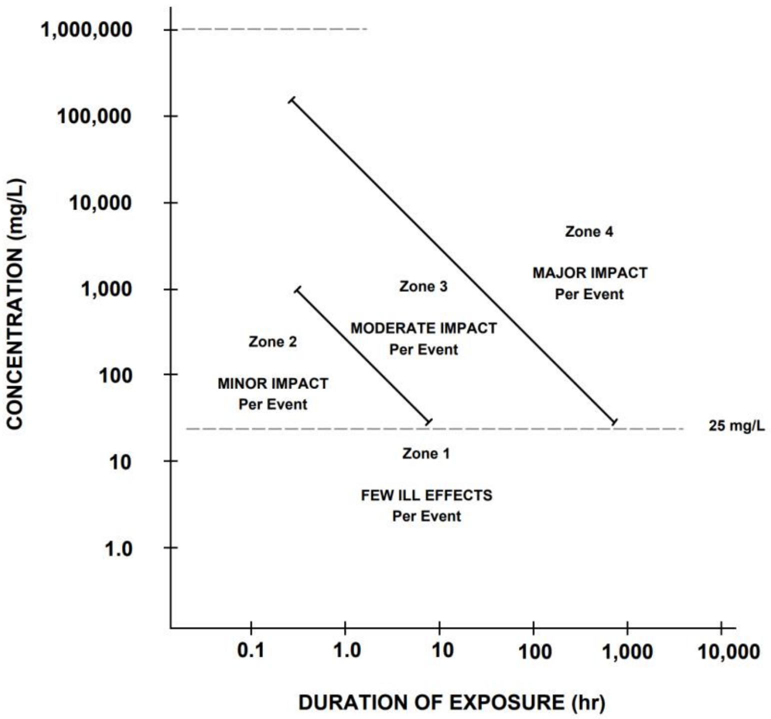
The maintenance dredging programme in Waterford Harbour occurs in estuarine waters and has now been ongoing for many decades. Estuaries are turbid environments and frequently suspended solids levels increase from a moderate background level to higher levels depending on tidal and weather conditions. The Port of Waterford deploys three methods of soil removal / relocation, namely, Trailing Suction Hopper dredging (TSHD), backhoe dredging and ploughing, with the first two involving removal of soil and deposition at a distant disposal site.

Formerly, concerns relating to suspended solids levels in aquatic environments were focused on freshwater environments and the impact on valuable salmonid species. A comprehensive review of the literature on this topic up to about 1995 is provided by Kerr (1995) entitled 'Silt, turbidity and suspended sediments in the aquatic environment: an annotated bibliography and literature review' which includes reference to a total of 1200 articles and reports. Also, Bash *et al.* (2001) published a research report entitled 'Effects of turbidity and suspended solids on salmonids' and this report cites published literature and reports up to about 2001.

Anon. (1988) summarises salmonid water quality standards and with regard to suspended solids and states that the standard (less than or equal to 25 mg/L) is expressed as an average concentration over a period of 12 months and does not apply to suspended solids with harmful chemical properties. This standard has been maintained in the Freshwater (salmonid) quality regulations (EU Directive 2006/44/EEC) where 25 mg/L is given as a "guide limit".

Ward (1992) looked at the guide limit / average annual limit for suspended solid levels in salmonid waters and in watercourses supporting fish life and assessed the consequences for fish life and particular life stages of salmonids when this average annual level of suspended solids (25 mg/L) was exceeded.

Figure 9: Severity of impact by inert sediments on aquatic ecosystems as a function of the intensity (concentration X duration) of the event based on an assumed frequency of occurrence of one episode (Extract of Figure 3 from (Ward 1992), after Newcombe and MacDonald 1991.



In Figure 9, both the suspended solids concentration (mg/L) and duration of exposure (hr) are plotted logarithmically. Up to the guide limit of 25 mg/L few ill effects on salmonids are evident. However, above that guide limit, the impact on salmonids is determined by a combination of suspended solids levels and duration of exposure of salmonids to these levels as follows:

- At suspended solids concentrations of from 1000 to 25 mg/L, an exposure duration of approximately 0.5-10 hours is expected to have a minor impact per event;
- At suspended solids concentrations of from 200,000 to 25 mg/L, an exposure duration of approximately 0.5-1000 hours is expected to have a moderate impact per event; and,
- At suspended solids concentrations of above 200,000 - 25 mg/L, an exposure duration above approximately 0.5-1000 hours is expected to have a major impact per event.

The literature review of Bash *et al.* (2001) contains extensive tables which cite the effects of various levels of suspended solids on salmonids as follows:

Table 10: Effects of Various Levels of Suspended Solids on Salmonids (Bash et al., 2001)

Physiological	Behavioural	Habitat
gill trauma	avoidance	reduction in spawning habitat
osmoregulation	territoriality	effect on hyporheic upwelling
blood chemistry	foraging and predation	reduction in B1 habitat
reproduction and growth	homing and migration	damage to redds

Newcombe and MacDonald (1991) suggested that the use of concentration of suspended solids alone was a poor indicator of physiological and behavioural effects. The authors suggested using both concentration and duration of exposure in a "stress index" to determine relative impacts on salmonids. Despite considerable research, there was little agreement on environmental effects of suspended sediment as a function of concentration and duration of exposure. More than 70 papers on the effects of inorganic suspended sediments on freshwater and marine fish and other organisms were reviewed to compile a data base on such effects. Regression analysis indicated that concentration alone was a relatively poor indicator of suspended sediment effects (r^2 = 0.14, NS). The product of sediment concentration (mg/L) and duration of exposure (h) was a better indicator of effects (r^2 = 0.64, $P < 0.01$). An index of event intensity (stress index) was calculated by taking the natural logarithm of the product of concentration and duration. The stress index provided a convenient tool for predicting effects for an episode of known intensity.

Appendix B of Bash *et al.* (2001) contains extensive tables which detail citations from Newcombe and MacDonald (1991) (species of salmonid / exposure to total suspended solids (concentration (mg/L) and duration (h)) / Stress index ($\log_e$*(concentration *duration) / effect):

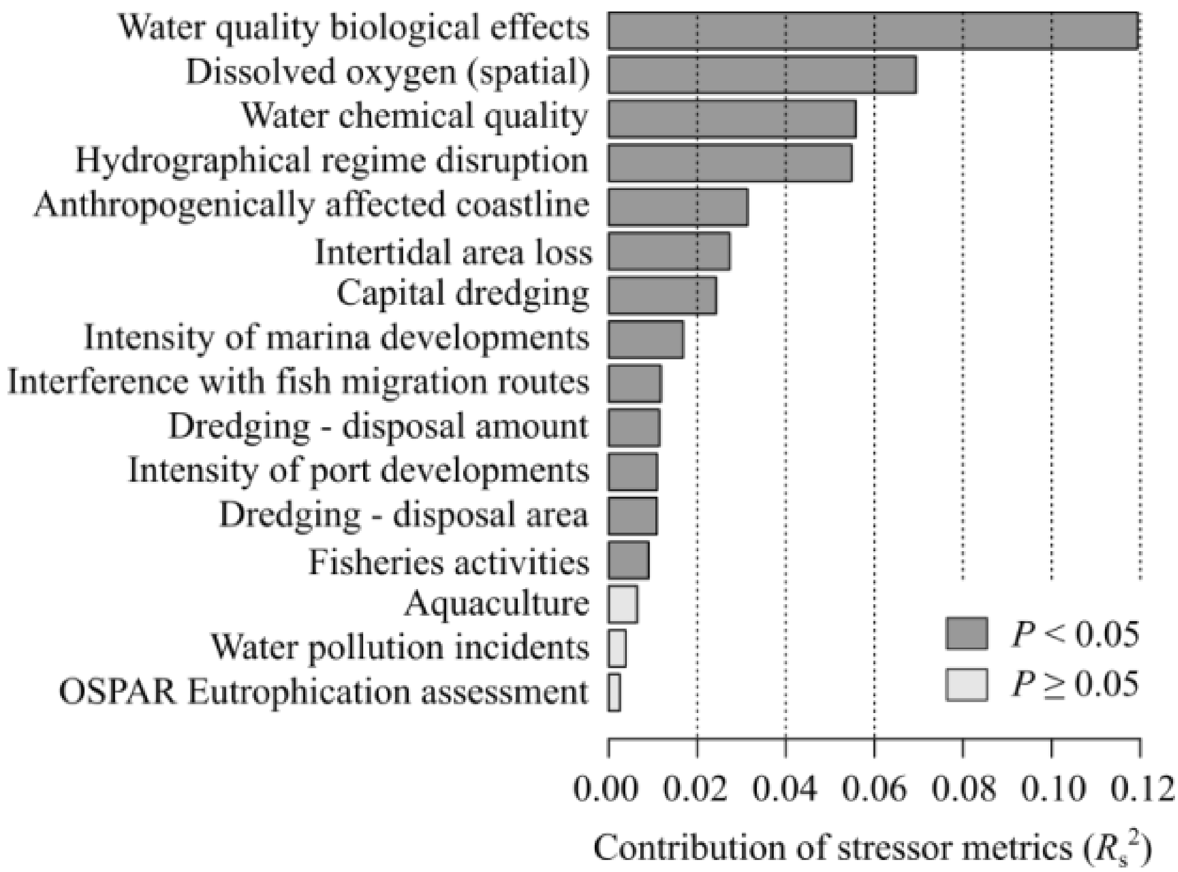
- Lethal response: Brown trout / TSS 110 mg/L / 1,440 (h) duration / 11.973 stress index / effect: 98% mortality of eggs.
- Sub-lethal response: Trout / TSS 270 mg/L / 312 (h) duration / 11.341 stress index / effect: Histological damage to gills.
- Behavioural response: Rainbow trout / TSS 100 mg/L / 0.25 (h) duration / 3.219 stress index / Effect: Coughing rate increased.

The thinking of many fisheries biologists familiar with freshwater environments and water quality regulations designed to protect salmonids is often along the lines of the suspended solids limit guidelines expressed above. However, the situation with regard to suspended solids levels and tolerances of estuarine fish species to elevated levels of suspended solids which are normal in estuarine environments is somewhat different to the freshwater scenario painted above.

Cabral *et al.* (2022) provide an overview of anthropogenic impacts in estuaries which relate to port activities. Dredging creates or maintains navigation channels and/or ports through removing bottom sediments. Consequently, benthic habitat and invertebrate food supply are changed or lost, and water turbidity increases together with the levels of pollutants in water or sediments due to the release/exposure of contaminated sediments. In addition, the levels of organic matter and dissolved oxygen might also change with dredging. The consequences of dredging for fish assemblages are often species specific and their magnitudes vary among estuaries, particularly in comparison with the ecological status of estuaries before the dredging activities commenced.

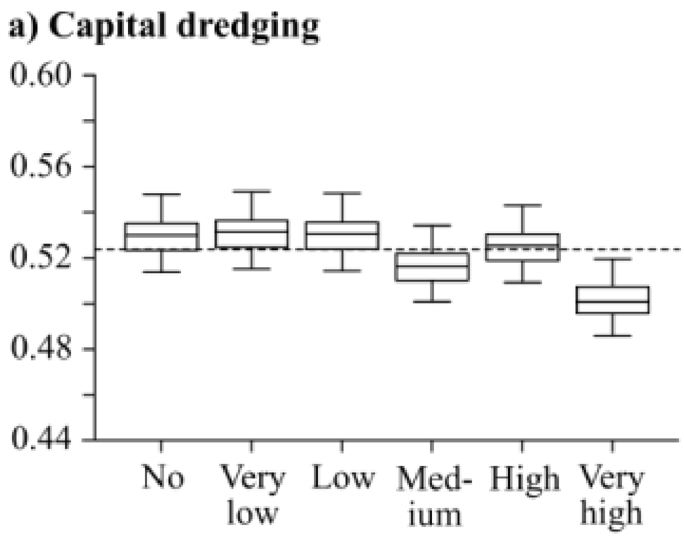
Teichert *et al.* (2016) used WFD surveillance monitoring data from a total of 90 European estuaries (including 32 estuaries on the island of Ireland) for the investigation of combined stressor impacts in estuaries on fish communities. They found that the largest restoration benefits to the ecological status of estuaries were expected when mitigating water pollution and oxygen depletion. Their study investigated the impact of nine stressor categories on the fish ecological status and modelled the dominant stressors and their non-linear effects, evaluated the ecological benefits expected from reducing pressure from stressors and investigated the interactions among stressors.

Figure 10: Extract from Teichert et al. (2016) - ranked the contributions of 16 stressors (Rs²) for predicting the fish ecological status of European estuaries.



With regard to capital dredging and maintenance dredging, their model suggested that only very high thresholds (where more than 50% of the sub-tidal area of an estuary was dredged) impacted on the assessed Ecological Quality Ratio for fish in estuaries (see their Supplementary Figure 11 below).

Figure 11: Extract of Supplementary Figure A (Teichert at al. 2016). Partial dependence plots of seven stressors with low contribution (Rs²) for predicting the fish ecological status (Ecological Quality Ratio Y axis above). The intensity of stressors was evaluated from 'No'



Threshold values for the X axis above are as follows:

- No – no dredging;
- Very Low – Less than 1% of the sub-tidal area dredged;
- Low – More than 1% and less than 10% of the sub-tidal area dredged;
- Moderate - More than 10% and less than 30% of the sub-tidal area dredged;
- High - More than 30% and less than 50% of the sub-tidal area dredged; and,
- Very High - More than 50% of the sub-tidal area dredged.

In the case of Waterford Harbour, the Primary and Secondary dredge areas extends to 1.7km^2, which represents only 2% of the estuary at high tide.

Wenger *et al.* (2017) assessed the potential impacts of estuary dredging on fish which include the following:

- Entrainment of fish with the dredged material;
- Removal of benthic habitat;
- Smothering of benthic habitat (at the dredge and dump sites for the dredged material);
- Impact of temporarily high suspended solids concentration on fish; and,
- Impact of noise on fish.

They assessed dredging-related stressors, including suspended sediment, contaminated sediment, hydraulic entrainment and underwater noise and how they directly influence the effect and the response elicited in fish across all aquatic ecosystems and all life-history stages. Their study found that contaminated sediment had significantly higher effect than clean sediment alone or noise, suggesting additive or synergistic impacts from dredging-related stressors. The early life stages such as eggs and larvae were most likely to suffer lethal impacts, while behavioural effects were more likely to occur in adult fishes. Both suspended sediment concentration and duration of exposure greatly influenced the type of fish response observed, with both higher concentrations and longer exposure durations associated with fish mortality.

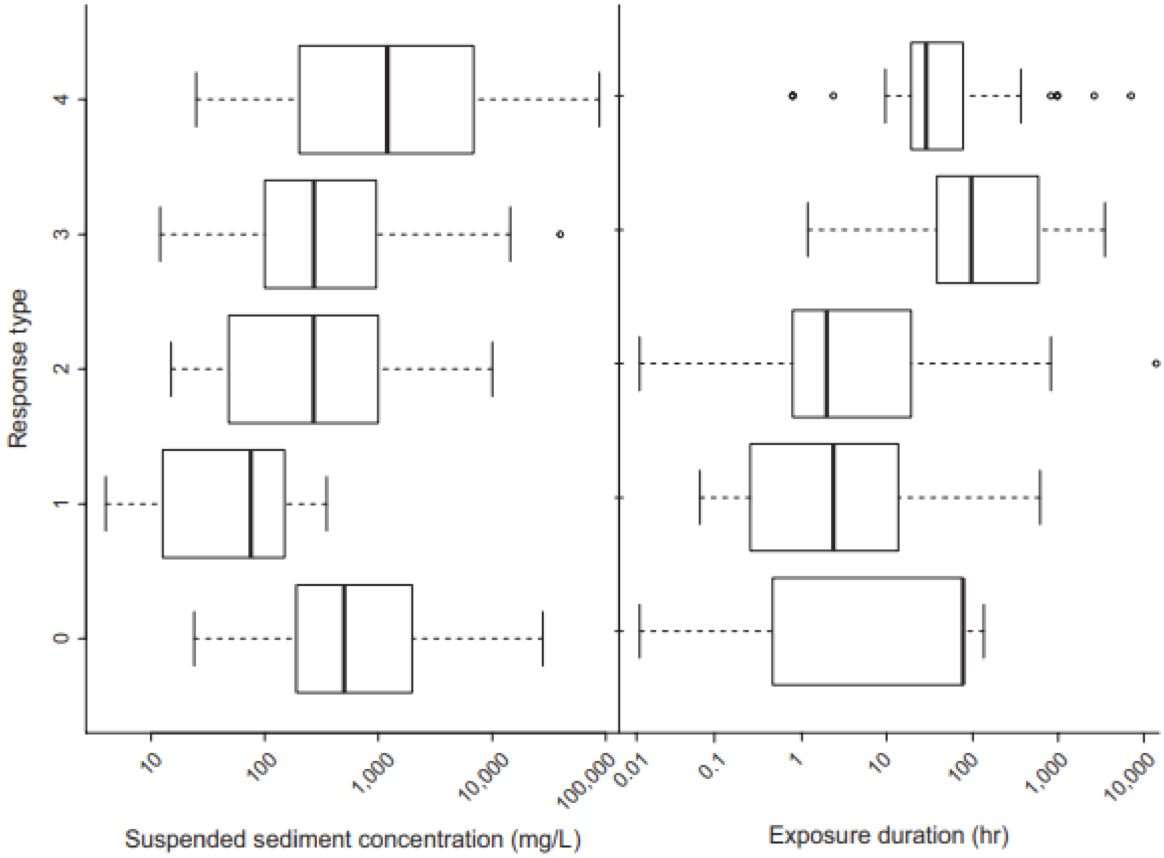
Currently, the literature on dredging-related stressors is biased towards examining the effects of suspended sediment, as is evidenced by the large number of studies that exist on the topic compared to other stressors. While suspended sediment is a ubiquitous stressor in any dredging project Wenger *et al.* (2017) highlighted the need for further research on how contaminants released during dredging, noise associated with dredging and hydraulic entrainment impact fish. There is also a paucity of direct field measurements of the effects of dredging on fish, which needs to be addressed. The characterization of multiple, long-term impacts from stressors associated with dredging needs to consider all combinations of acute toxicity, chronic stress, loss of habitat and the frequency and duration of repeated exposures. This is particularly important in the light of the results that contaminated sediment caused significantly higher effect sizes than sediment alone, which suggests there are additive or synergistic impacts occurring. An increased understanding of how each stressor acts alone or in combination will improve the ability of regulators to effectively manage potential impacts from dredging.

Table 11 and Figure 12 below provide a summary of their thinking on the impacts of estuarine dredging on fish (Wenger *et al.* (2017)).

Table 11: The types of effect ranked to facilitate comparison (from Wenger et al. (2017))

Rank	Type of Effect
0	No effect
1	Minor behavioural changes—avoidance of a stressor
2	Minor physical damage—gill damage, skin abrasions and changes to development times, OR Moderate behavioural changes—reduced foraging rate or changes to habitat association, but did not record any physiological changes
3	Physiological changes—changes in hormone levels, reduced growth rate, organ function or developmental abnormalities
4	Increase in mortality or reduced hatching success

Figure 12: Extract from Wenger et al. (2017). The impact of (a) suspended sediment concentration (left) and (b) exposure duration on the type of effect elicited by suspended sediment (right). Response type is outlined in Table 11 above.



It is clear from the above figure that a wide range of suspended solids concentrations and exposure durations (both $\log_{10}$ in the above figure) have no effect on fish in estuaries.

Increasing both the concentration and exposure time to suspended sediment increased the severity of fish response (Figure 12 a, b). While there is a clear trend between response type and increasing concentrations and exposure to suspended sediment, fish have markedly different tolerances to suspended sediment, with some species able to withstand concentrations up to 28,000 mg/L, while others experience mortality starting at 25 mg/L (Figure 12a).

Wilbur and Clarke (2001) provided the most comprehensive and succinct interpretation of the relationship between the duration of exposure of non-salmonid and estuarine fish and non-salmonid and estuarine eggs and larvae to varying concentrations of suspended solids (mg/L) and survival.

Figure 13: Illustrations from Wilbur and Clarke (2001). Illustration on the left shows the relationship between the duration of exposure of non-salmonid and estuarine fish (their Figure 4 - left) to varying concentrations of suspended solids (mg/L) and survival. Illustration on the right shows non-salmonid and estuarine eggs and larvae (their Figure 3 - right) to varying concentrations of suspended solids (mg/L) and survival.

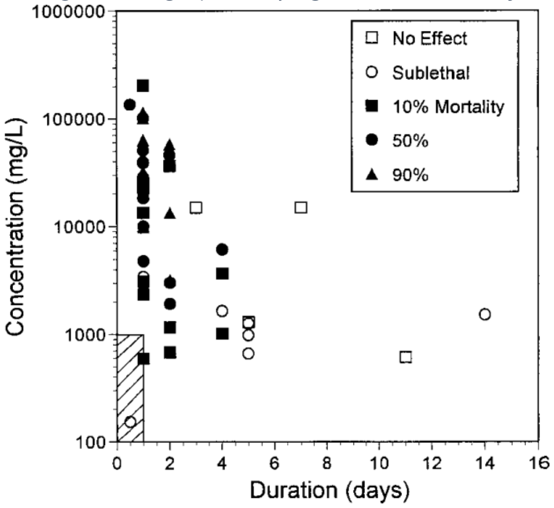


FIGURE 4.—Responses of nonsalmonid and estuarine fish to suspended sediments. Data for this graph are given in Table A.2.

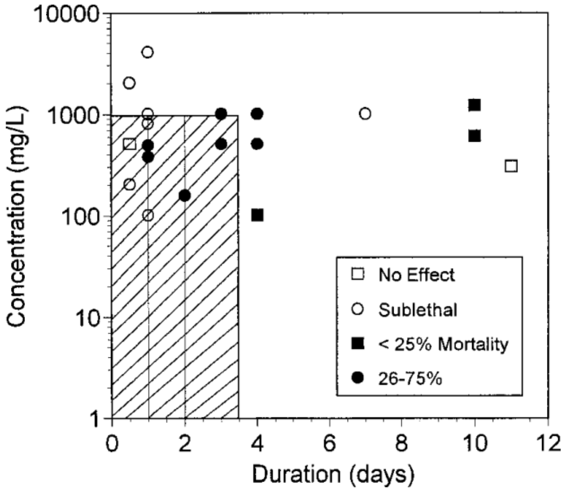


FIGURE 3.—Responses to suspended sediments of nonsalmonid and estuarine fish eggs and larvae. The longest probable exposure duration (3.5 d) corresponds to species with demersal adhesive eggs, whereas shorter durations are expected for demersal semibuoyant and pelagic egg forms. Data for this graph are given in Table A.1.

Note: The Y axis concentration ranges differ in the above on the right (their Figure 3) has a max 10,000 mg/L and on the left (their Figure 4) has a max of 1m mg/L.

From the above it is clear that suspended solids levels under 1000 mg/L and event durations of less than one day duration have largely no effect or only a sublethal effect on estuarine fish eggs and larvae. In Figure 13 (their Figure 4), only two data points relate to suspended solids levels below 1000 mg/L and an event duration of one day or less and the effects described are sublethal and 10% mortality.

In the context of the Waterford Harbour maintenance dredging programme and with particular reference to plough dredging, which probably results in higher suspended solids levels in the water column than TSH dredging, we know from Cunningham (2021) that similarly low mean levels of suspended solids (c. 30-40 mg/L) occur in the vicinity of operations during periods of active dredging and during periods when dredging is not taking place. The duration of individual dredging events in Waterford Harbour (particularly TSH dredging) average less than one hour. This short duration coupled with relatively low suspended solids levels indicate that the maintenance dredging programme in Waterford Harbour is very unlikely to cause problems for fish, either in the vicinity of operations or in the greater Waterford Harbour area.

Finally, there is indirect evidence that the maintenance dredging operations in Waterford Harbour which involve TSH dredging and plough dredging in the vicinity of Cheekpoint Lower bar do not affect the behaviour of fish in that general area. During the Great Island CWS fish impingement studies carried in November 2022 and June 2023, there were several days during the study periods when TSH dredging / plough dredging were also carried out. However, the numbers and fish species range washed off bandscreens at the Great Island CWS (approximately 400m from the dredge area) did not vary between days when dredging occurred and when no dredging was carried out. It can thus be deduced that the maintenance dredging operation did not have any measurable local effect on fish.

5 Conclusion

5.1 Ecological status of fish in Waterford Harbour

Inland Fisheries Ireland, the competent authority in the Republic of Ireland, carried out Water Framework Directive surveillance monitoring survey work before and during 2016 and 2019 (Ryan *et al.* 2017, 2020), and concluded that the ecological status of fish in Waterford Harbour in those years was good.

A wide range of fish species life stages are present in Waterford Harbour and these species represent various categories which in general relate to their level of dependency on the estuarine environment to complete their life cycles.

The estuary environment is complex in terms of hydrological and hydro-chemical status with gradients of temperature and salinity being the principal determinants of fish species distribution and relative abundance throughout the estuary.

Estuaries are typically turbid aquatic environments and levels of suspended solids which pertain vary in accordance with freshwater inflows, tidal prism and other factors like average depth and quantity of intertidal habitat exposed during periods of low tide. It is clear that most fish species life stages benefit from their presence in an estuarine environment because high turbidity and high suspended solids levels screen them from piscivorous and avian predators thus enabling them to complete otherwise vulnerable life stages.

5.2 Maintenance Dredging in Waterford Harbour

Two of the three dredging methodologies (TSHD and backhoe ploughing) involve the removal of soil and its subsequent disposal at a distant site. The TSHD involves the deployment of a suction head into the sediment and suction occurs only when the suction head is immersed in the sediment at the commencement and termination of individual dredging events which are less than one hour in duration. Fish are mobile animals which, depending on species, can rest on the bottom or occupy the water column at varying distances from the bottom or surface. Either way, it can be expected that fish species can swim at normal or burst speeds (typically up to seven body lengths per second) away from any sudden disturbance in their immediate vicinity. Entrainment of fish during the TSH dredging or the backhoe dredging is therefore unlikely to be significant.

With regard to the plough dredging, soil is moved but not removed and it is likely that fish on or close to the bottom will be disturbed and flee to adjacent areas to avoid the disturbance.

Disturbance of fish is likely to be very localised and restricted to the immediate vicinity of operations. Noise levels associated with the maintenance dredging are probably insignificant compared with the noise emanating from normal ship traffic in the estuary. The soil being moved / removed as part of the maintenance dredging programme is of recent origin and very unlikely to contain material which would be detrimental to fish during the removal / resuspension process. Some temporary habitat loss will occur for fish, particularly benthic fish, but in the context of the overall dimensions of Waterford Harbour, this temporary loss of habitat is not significant. During the TSH dredging operation, suction will only occur when the head is immersed in the estuary bed and accordingly, the danger of entrainment of fish will be minimised. Any small number of fish entrained will be transported (in about one hour) to the soil deposit area immediately outside Waterford Harbour and will have every chance of surviving the journey. During the Great Island CWS fish impingement studies carried in November 2022 and June 2023, there were several days during the study periods when TSH dredging / plough dredging were also carried out. However, the numbers and list of fish species washed off band-screens at the Great Island CWS (approximately 400m from the dredge area) did not vary between days when dredging occurred and when no dredging was carried out. It can thus be deduced that the maintenance dredging operation did not have any measurable local effect on fish.

It is clear that the duration of individual maintenance dredging events (which average 0.84hrs at the three primary maintenance dredging locations in Waterford Harbour) and which result in higher than background levels of suspended solids in the immediate vicinity of the working dredger are not high enough or of a sufficiently long duration to impact fish which can easily move away from the location of dredging activity to areas of lower suspended solids or to areas distant from the disturbance caused by the maintenance dredging operation. The worst-case scenario involves entrained fish being discharged with the soil on the deposit site for the dredged material immediately outside Waterford Harbour. For all of the maintenance dredging locations, the average time to steam to the dump site with the dredged material and deposit the dredged material is about 1 hour and it is possible that entrained fish could survive this journey and then enter fully marine conditions safely.

Based on best available scientific research and information that has been established throughout several years of sampling fish as part of the Water Framework Directive surveillance monitoring programme in Waterford Harbour, it can be concluded that the Waterford Harbour has good ecological status with regard to fish (Ryan *et al.* 2017, 2020), and that the ecological status of fish has not previously been significantly affected. In addition, based on the assessment of potential impacts on fish in Waterford Harbour, the ecological status of fish in Waterford Harbour will not be significantly affected by the maintenance dredging programme in Waterford Harbour.

6 References

Anon. (1988) European Communities (Quality of Salmonid Waters) Regulations, 1988.

Anon. (2019) Appendix IV River / stock specific information used in the salmon catch advice process for 2019 advice. Report of the Technical Expert Group on Salmon – to Inland Fisheries Ireland (IFI), Dublin, Ireland

Anon. (2023) Port of Waterford Benthic Ecology Survey. AQUAFACT International Services Ltd (APEM Group)

Anon. (2023a) Great Island CWS Fish Impingement Study (November 2022). Aztec Management Consultants, Dublin and Triturus Environmental Ltd., Cork

Bash,J., Berman,C. and Bolton,S. (2001) Effects of turbidity and suspended solids on salmonids. Final Research Report. US Department of Transportation. 92pp

Cabral, H.N, Angel Borja, Vanessa F. Fonseca, Trevor D. Harrison, Nils Teichert, Mario Lepage, and Miguel C. Leal (2022) Fishes and Estuarine Environmental Health. Fish and Fisheries in Estuaries: A Global Perspective, Volume I, First Edition. Edited by Alan K. Whitfield, Kenneth W. Able, Stephen J.M. Blaber, and Michael Elliott. John Wiley & Sons Ltd. Published 2022 by John Wiley & Sons Ltd.

Cunningham,M. (2021) A Review and Analysis of Water Quality Monitoring Data from the Port of Waterford Before During and After the Plough Dredging Campaigns of July 2020 to Feb 2021. Report prepared for the Port of Waterford by LCF Marine

Cunningham, M. (2023) Review and analysis of the turbidity data before and during the plough dredging campaign of early 2023. Report prepared for the Port of Waterford by LCF Marine

ETS. 1998. Fisheries impact assessment of plough dredge bed-levelling, Waterford Estuary, Ireland.

Eysink, W.D. et al. (2000). Dredging of Duncannon Bar. Environmental impact of dredging and spoil dumping. Report H3544. Report prepared by Delft Hydraulics for the Port of Waterford Company and New Ross Port Company.

Harrison, T.D. and Kelly,F.L. (2013) Development of an estuarine multi-metric fish index and its application to Irish transitional waters. Ecological Indicators **34** 494-506.

Gargan, P., Fitzgerald, C., Kennedy, R., Ó Maoiléidigh, N., McLean, S. and Millane, M. (2020). The Status of Irish Salmon Stocks in 2019 with Catch Advice for 2020. Report of the Technical Expert Group on Salmon (TEGOS) to the North-South Standing Scientific Committee for Inland Fisheries. 51 pp.

Kerr, S.J. (1995) Silt, turbidity and suspended sediments in the aquatic environment: an annotated bibliography and literature review. Ontario Ministry of Natural Resources, Southern Region Science & Technology Transfer Unit Technical Report TR-008. 277 pp

Newcombe,C.P. and MacDonald,D.D. (1991) Effects of Suspended Sediments on Aquatic Ecosystems. North American Journal of Fisheries Management 11: 72-82

Rijn, L.C. van. 1990. Hydraulic studies Cheekpoint Upper and Lower Bay, Waterford Ireland. Delft Hydraulics Report H1118, Annex 2: Field Survey December 1990.

Ryan, D., Coyne, J., Putharee, D. and Roche, W. (2017). Fish Stock Survey of Transitional Waters in the Southern River Basin District – Barrow, Nore, Suir Estuary 2016. Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24, Ireland.

Ryan, D., Cooney, J., Leonard, E., Nolan, K. and Roche, W. (2020). Fish Stock Survey of Transitional Waters in the Southern River Basin District – Barrow, Nore, Suir Estuary 2019. Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24, Ireland.

Teichert, N.A , Angel Borja, Guillem Chust, Ainhize Uriarte, Mario Lepage (2016) Restoring fish ecological quality in estuaries: implication of interactive and cumulative effects among anthropogenic stressors . Science of The Total Environment **542** (A) 383-393

Ward,N. (1992) The problem of sediment in water for fish Technical Notes. Northwestern Ontarion Technology Development Unit. Ministry of Natural Resources Ontario.

Wenger,A.S., Euan Harvey, Shaun Wilson, Chris Rawson, Stephen J. Newman, Douglas Clarke, Benjamin J. Saunders, Nicola Browne, Michael J. Travers, Jennifer L. Mcilwain, Paul L. A. Erftemeijer, Jean-Paul A. Hobbs, Dianne Mclean, Martial Depczynski and Richard D. Evans (2017) A critical analysis of the direct effects of dredging on fish and fisheries. **18**: 967–985.

Wilber,D.H. and Clarke,D.G. (2001) Biological Effects of Suspended Sediments: A Review of Suspended Sediment Impacts on Fish and Shellfish with Relation to Dredging Activities in Estuaries North American Journal of Fisheries Management 21:855–875

Appendix 1: [redacted] T/A Aztec Management Consultants CV

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Appendix 2: Overview of fish and fish ecology in Waterford Harbour (Barrow-Nore-Suir estuary)

Introduction

Cabral *et al.* (2022) provide a comprehensive review of estuarine environmental health with regard to fish. They provide a commentary on the Water Framework Directive (WFD; European Commission 2000), which included for the first time the concept of '*good surface water status'*, for transitional (i.e. estuaries, lagoons) habitats for the legislative basis of estuarine management). In this context, 'ecological status' is an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters. The good status is achieved when the values of the biological (fish) quality element show low levels of distortion resulting from human activity but deviate only slightly from those normally associated with the surface water body type under undisturbed, pristine reference conditions.

Cabral *et al.* (2022) also identified changes in river flow as affecting temperature and saline estuarine gradients which in turn impact on diadromous fish species that use estuaries during part of their life cycle and also estuarine fish that are dependent on estuarine habitat throughout their entire lives. Other anthropogenic impacts result from water abstraction for industry and for agriculture and which may have significant impacts. Global climate change is also impacting on estuarine fish with most impacts resulting from changes in temperature, intrusion of saline waters into the estuarine environment, sea level rise and changes in pH due to ocean acidification.

Cabral *et al.* (2022) also state that anthropogenic pressures on estuarine systems act cumulatively, and it is often difficult to identify the individual causes and effects. They distinguish between exogenic and endogenic pressures (the former has the causes outside the estuarine environment and the consequences inside the estuary, whereas the latter endogenic pressures have their causes and consequences inside the estuarine environment). Several anthropogenic pressure indices have been proposed for estuarine ecosystems, some being used for evaluating the response of fish communities, as within the scope of the Water Framework Directive in Europe, where holistic assessments have been developed using a number of different fish ecological metrics which are combined into a single integrated measure. Such multi-metric approaches have been applied in the USA, South Africa, Spain, Belgium, UK, Italy, France, Australia, Brazil, Germany, Portugal, Ireland (Harrison & Kelly 2013) and Poland, among others. The metrics used in these indices include measures of species diversity and composition, abundance, estuarine use (ecological guilds), trophic classification (feeding guilds), and tolerance and health. The fishes in this multi-metric approach have been shown to respond to environmental stress. For example, significant correlations were found between a multi-metric fish index and oxygen saturation and ammonia in Basque estuaries (Spain) while a negative relationship was reported between an estuarine multi-metric fish index and an index of contamination based on heavy metals and organic pollution in French estuaries. Harrison & Kelly (2013) reported a significant correlation between an estuarine multi-metric fish index (EMFI) and two separate indicators of environmental condition for Irish estuaries. Significant correlations were also reported for several European multi-metric fish indices and an anthropogenic pressure index.

Fish have emerged as a relevant element in assessing the quality of estuaries because of their position in the food chain and a good general knowledge of their ecology. Many studies have shown that fish are responsive to the quality of water, food and habitat and these responses are used in the development of quality indicators based on fish in an estuarine environment.

An index should make it possible to measure fish species and fish community responses to anthropogenic stressors. There are now more than 20 fish-based indices covering estuaries and Ireland now relies on the estuarine multi-metric fish index developed by Harrison & Kelly (2013) when assessing the ecological status of fish in estuaries.

Cowley *et al.* (2022) provide an overview of the conservation of estuarine fishes and argued that the coastal zone will continue to be exposed to increasing development, including urbanisation and industrialisation, coupled with numerous other human-induced impacts such as habitat alteration and degradation, overexploitation of natural resources, pollution and the growing threats of climate change. Estuaries have more human-induced pressures than other systems and these include both exogenic unmanaged pressures and endogenic managed pressures. Consequently, their management has not only to accommodate the causes and consequences of pressures within the system but, more than other ecosystems, they need to respond to the consequences of external natural and anthropogenic influences.

Cowley *et al.* (2022) ranked future human impacts on estuarine ecosystems worldwide as habitat loss and alteration, eutrophication, sewage, fisheries overexploitation, chemical contaminants, freshwater diversions, introduced species, sea level rise, land subsidence and debris/litter.

With respect to estuary-associated fishes, the primary threat is overexploitation and the associated ecosystem effects of fisheries and habitat loss and modification, followed by pollution with exploitation and habitat loss the main factors responsible for depleting 95% of valued fishery species across multiple taxonomic groups.

Estuaries are dynamic environments with ever changing environmental conditions (e.g. temperature, salinity, dissolved oxygen, turbidity and water level) linked to tidal cycles, flood and drought events and human-induced stressors like pollution. Estuarine fishes are however extremely resilient and have evolved to cope with highly dynamic natural conditions. Most of them are also highly mobile and use movement to avoid unfavourable or stressful conditions.

Most fish species in estuaries are adapted to normal salinity (10–35 ppt) fluctuations, and can even tolerate prolonged oligohaline (<5ppt) or hypersaline (>40ppt) conditions, provided these changes occur gradually over an extended period.

There is increasing evidence to suggest that the magnitude of the ingress of early juveniles of estuary associated marine fish species into estuaries is linked to river flow entering the upstream estuary. The hypothesis is that the larger the magnitude of riverine input, the greater the export of riverine and estuarine olfactory cues for recruiting juveniles from the sea to follow. This highlights the importance of river flow to the ecological connectivity of coastal systems. The maintenance of river base flows and freshets into estuaries therefore has considerable value to the nursery function and overall conservation goals for fishes in estuaries.

In the marine environment, climate change has caused ocean warming, acidification, reduction in oxygen concentration, changes in nutrient cycling and primary production and the distribution of biota and estuaries are no exception to the effects of climate change as, by their geomorphology and location, these systems are strongly influenced by tidal action, water inflow, wind, wave action, water and air temperature and rainfall.

Increasing salinities will impact those fish species that are close to their upper salinity tolerance limits the most, potentially altering their biology. From an estuarine fish community composition perspective, there has been a reduction in the spatial distribution and abundance of freshwater species in temperate estuaries and a concomitant increase in the number of marine species.

In permanently open macrotidal estuaries decreased freshwater inflows may lead to increased salinities (marinization), greater penetration of marine species into estuaries and salinity-induced shifts in community structure and increasing water temperatures may lead to range extensions of tropical species. Declining freshwater in flows may also cause increased stratification in middle-upper estuary leading to increased hypoxia and emigration of mobile fish species to refuge areas.

The content of this report aims to provide an overview of fish and the ecology of fish in Waterford Harbour / the Barrow-Nore-Suir estuary which is intended to provide information of relevance to the ongoing maintenance dredging programme implemented by the Port of Waterford in the estuary. The description of estuaries in general and the fish species which utilise them during some or all of their life cycles is provided in the context of the perceived impact of such a maintenance dredging programme, limited in geographic extent in the context of the overall size of Waterford harbour, on fish in Waterford Harbour.

The general assessment of the status of fish in Waterford Harbour utilises the results of recent fish surveys carried out in Waterford Harbour as part of ongoing Water Framework Directive surveillance monitoring work (Kelly *et al.* 2013; Ryan *et al.* 2017, 2020), European sea bass trawl surveys (Ryan *et al.* 2017,2020) and fish impingement studies carried out at a thermal electricity generating station which abstracts cooling water from Waterford Harbour (Teague *et al.* 2018; Anon. 2021a, 2021b, 2023a, 2023b).

An extensive literature review has also been carried out as part of this exercise with the focus of the review on fish in estuaries and the assessment of the status of fish in estuaries and impacts of anthropogenic activities, including dredging, on the overall status of estuaries with reference to fish and fish ecology.

Fish species of conservation concern are also discussed. All of these species are diadromous which in some cases e.g. Atlantic salmon, migrate quickly through the estuary as juveniles and migrate through the estuary on their return migration as non-feeding maturing adults which may spend varying amounts of time in the estuary depending of discharge conditions in natal rivers flowing into Waterford Harbour while other species e.g. River lamprey, may spend their entire adult / parasitic lives in the estuary prior to ascending into freshwater to spawn.

With regard to the historical and ongoing maintenance dredging programme carried out on behalf of the Port of Waterford in Waterford Harbour / the Barrow-Nore-Suir estuary, the current favourable status of fish in the estuary, assessed in the context of the Water Framework Directive, suggests that the maintenance dredging programme has not had and continues not to have any measurable or significant impact on the range and relative abundance of fish species recorded throughout the estuary.

Waterford Harbour

Waterford Harbour / the Barrow-Nore-Suir estuary and estuaries in general are productive and complex environments in terms of fish community which can vary spatially and temporally in line with changes in hydromorphology, salinity, turbidity, oxygen levels and temperature and it is useful to provide some definitions with regard to estuaries and also transitional waterbodies.

Tweedley *et al.* (2016) defined an estuary as 'a semi-enclosed coastal body of water which has a free connection with the open sea, and within which seawater is measurably diluted with fresh water derived from land drainage'. Tweedley *et al.* (2016) also stated that 'the estuaries in Europe have been considered, for legislative purposes, to be just one of the types of water body listed under the term "transitional waters" as part of the Water Framework Directive (European Parliament and Council of the European Union 2000). Transitional waters are defined by the directive as "bodies of surface water in the vicinity of river mouths which are partially saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows" (European Commission 2003).

According to the estuary definitions used in Tweedley *et al.* (2016), Waterford Harbour / the Barrow-Nore-Suir estuary is categorised as a macrotidal (tidal range greater than 2m) coastal plain (or funnelshaped) estuary, V-shaped in profile, found on low relief coasts, and generally shallow (<20 m) and bordered by broad, shallow flats.

In macrotidal estuaries, the pronounced changes in tidal height within a tidal cycle result in extensive intertidal areas becoming exposed at low tide and it has been estimated that the percentage contribution of the intertidal area to the total area of an estuary can be up to 55% in coastal plain estuaries. In the case of Waterford Harbour, this percentage is closer to 20% (Dr Brendan O'Connor, personal communication).

The turbulent mixing that occurs in macrotidal estuaries is a two-way process, whereby fresh water is mixed downward and saline water upward. During each tide, the volume of fresh water leaving the estuary, mixed with marine water from below, must be equivalent to river inflow. There is thus a mean outflow of water at the surface and a mean inflow of more saline water directly above the estuary bed, i.e. a two layered gravitational circulation

The rate at which water in the estuary is exchanged with the ocean is greater in macrotidal systems, which typically have a wider mouth than microtidal systems and a tidal prism (i.e. the volume of water between mean high tide and mean low tide) that can be several orders of magnitude greater than the volume of freshwater inflow.

The objective of this section of the report is to provide perspective within Waterford Harbour with regard to the volumes of water circulating. This perspective involves relating the river inflows and drainage from surrounding lands to Waterford Harbour high water volumes, low water volumes, tidal prism volume, flushing rate and residence time.

The Barrow-Nore-Suir estuary receives an average inflow of 157 m^3 sec^{-1} from the three main inflowing rivers (Suir – 76.9 m^3 sec^{-1}; Nore -42.9 m^3 sec^{-1}; Barrow – 34.7 m^3 sec^{-1}) (source: Wikipedia.org).

Two sources of information (Neill, 2000 and EPA data) have been accessed in the calculation of water volumes in the Barrow-Nore-Suir estuary. According to Neill (2000) the water surface area of the estuary is approximately 80 km^2 (50.4km^2 is the statistic used by Inland Fisheries Ireland when totalling the areas of all the transitional waterbodies in the Barrow-Nore-Suir estuary (Waterford Harbour) and the mean spring tidal range varies from 3.6m at Dunmore East to 3.9m at New Ross while the mean neap tidal range varies from 2.2m at Dunmore East to 2.4m at New Ross. The tidal prism at the mouth of the estuary varies from approximately 168 x 10^6 m^3 at neap tides to about 280 x 10^6 m^3 at spring tides.

According to the EPA (Dr Sorcha Ni Longphuirt) the total surface area of all 9 waterbodies (8 transitional waterbodies and 1 coastal waterbody) is 83.9 km^2. The high-water volume is 1.08 km^3 and the low-water volume is 0.84 km^3. Accordingly, the volume of the tidal prism is 0.24 km^3. The mean residence time for all waterbodies was calculated at 26.46 days.

These estimations and calculations lead us to assess the volumes of water circulating in Waterford Harbour as follows:

- Volume of freshwater circulating in the Barrow-Nore-Suir estuary (Waterford Harbour) over a 12-hour period: 0.0067 km^3 (6.78m m^3).
- Volume of water circulating in the Barrow-Nore-Suir estuary (Waterford Harbour) over a 12-hour period (low water to high water to low water): 0.84-1.08 km^3.

Neill (2000) also provides information on salinity throughout the Barrow-Nore-Suir estuary (Waterford Harbour). At Cheekpoint the average salinity is about 22 ppt (range 8-30ppt). At Buttermilk Point, the average salinity is about 23ppt (range 12-31ppt). These readings have been taken from a figure in Neill (2000) which refers to salinity results from samples collected in 1999.

Fish Ecology in Estuaries

Fish inhabiting estuaries for part or all of their lives are faced with varying salinity, turbidity, temperature, oxygen levels, current speed and direction, water volumes and accessible habitat.

This literature review has relied upon several key publications on fish in estuaries (Dando, 1984; Whitfield, 2016; Tweedley et al. 2016; Connor *et al.* 2019).

Connor *et al.* 2019 is a very comprehensive account on fish in Irish estuaries, based on several years of surveillance monitoring of transitional waterbodies as part of national Water Framework Directive requirements.

Tweedley *et al.* (2016) also references the Estuarine Usage Functional Group (EUFG) of Elliott *et al.* (2007) and Potter *et al.* (2015), a classification scheme which recognizes that fish species can be assigned to one of four main categories:

- marine - species that spawn at sea,
- estuarine-resident - species that complete their life cycle within the estuary,
- diadromous - species that feed at sea and migrate into fresh water to spawn or undergo the reverse migration, and
- freshwater - species that spawn in fresh water.

Tweedley *et al.* 2019 also state that each of the above four categories are subdivided into a number of guilds.

Connor *et al.* 2019 categorised fish sampled in Irish transitional waterbodies as:

functional guilds:

- freshwater migrants
- marine stragglers
- freshwater stragglers
- estuarine species
- diadromous species
- marine migrants

and feeding guilds:

- zoobenthivores
- piscivores,
- zooplanktivores,
- detritivores
- omnivores

Hadderingh & Jager (2002) described fish in the Ems estuary, The Netherlands, in ecological guilds as follows:

- catadromous / anadromous (CA)
- estuarine resident (ER)
- marine juvenile, (MJ)
- marine seasonal (MS)
- marine adventitious (MA)
- fresh water (FW)

There are minor differences in categorisation of fish recorded in the Barrow-Nore-Suir (Waterford Harbour) and the Ems estuary, The Netherlands, as detailed in Table 1 below.

Table 1: Fish species recorded in Waterford Harbour waterbodies during Inland Fisheries Ireland WFD surveillance monitoring (2010 and 2013) (Kelly et al. 2013) and by Hadderingh & Jager (2002) in the Ems estuary, The Netherlands

Common name	Sceintific name	Ecological guild*	Functional guild**	Feeding guild**
Atlantic horse mackerel / scad	*Trachurus trachurus*	MA	MS	PV
Black goby	*Gobius niger*		ES	ZB
Brill	*Scophthalmus rhombus*	MJ	MM	PV
Cod	*Gadus morhua*	MJ	MM	PV
Common sole	*Solea solea*	MJ	MM	ZB
Dab	*Limanda limanda*	MJ	MM	ZB
Dace	*Leuciscus leuciscus*		FM	ZB
Deep-snouted pipefish	*Syngnathus typhle*		ES	ZP
European eel	*Anguilla anguilla*	CA	DI	ZB
European sea bass	*Dicentrarchus labrax*	MJ	MM	PV
Five-bearded rockling	*Ciliata mustela*	MS	MM	ZB
Flounder	*Platichthys flesus*	ER	MM	ZB
Haddock	*Melanogrammus aeglefinus*		MS	PV
Herring	*Clupea harengus*	MJ	MM	ZP
Lesser sandeel	*Ammodytes tobianus*	ER	ES	ZP
Lesser weever	*Echiichthys vipera*		MS	ZB
Long rough dab	*Hippoglossoides platessoides*	MA	MS	ZB
Minnow	*Phoxinus phoxinus*		FS	ZP
Nilsson's pipefish	*Syngnathus rostellatus*	ER	ES	ZP
Nine-spined stickleback	*Pungitius pungitius*	FW	FS	ZB
Perch	*Perca fluviatilis*		FS	PV
Plaice	*Pleuronectes platessa*	MJ	MM	ZB
Pogge	*Agonus cataphractus*	ER	MM	ZB
Pollack	*Pollachius pollachius*	MA	MM	PV
Poor cod	*Trisopterus minutus*		MM	ZB
Roach	*Rutilus rutilus*		FS	OV
Rudd	*Scardinius erythrophthalmus*		FS	OV
Salmon	*Salmo salar*		DI	ZB
Sand goby	*Pomatoschistus minutus*	ER	ES	ZB
Sand smelt	*Atherina presbyter*	MJ	MM	ZP
Trout (brown and sea)	*Salmo trutta*		DI	ZB
Smelt	*Ormerus eperlanus*	CA	DI	PV
Sprat	*Sprattus sprattus*	MJ	MM	ZP
Spotted dragonet	*Callionymus maculatus*		MS	ZB
Sea lamprey	*Petromyzon marinus*		DI	PV
Stone loach	*Barbatula barbatula*		FS	ZB
Thick-lipped grey mullet	*Chelon labrosus*	MS	MM	DV
Three-bearded rockling	*Gaidropsarus vulgaris*		MS	ZB
Three-spined stickleback	*Gasterosteus aculeatus*	CA	FM	ZP
Turbot	*Psetta maxima*	MJ	MM	PV
Twaite shad	*Alosa fallax*	CA	DI	ZP
Whiting	*Merlangius merlangus*	MJ	MM	PV
*Hadderingh & Jager 2002				
** Connor et al. 2019				

Dando (1984) provides an overview of reproduction in estuarine fish. This overview includes a classification of estuarine fish, a description of the problems of estuarine life for fish, a commentary on fish which breed outside the estuary and those which do so in the estuary and finally, an account of the adaptations of young fish to estuarine life. Dando (1984) provides a concise summary of how fish use estuaries when he states that estuaries typically exhibit rapidly fluctuating conditions, which are not ideal for egg and larval development. Many species inhabiting estuaries migrate into either freshwater or the sea to spawn. Only a few estuarine fish are true estuarine residents in that they both live and breed in estuaries. Some marine fish spawn in estuaries or the lower reaches of rivers. The majority of fish that breed in estuaries show some reproductive specialization. Numerous marine species use the sheltered and nutrient-rich estuaries as nursery grounds. Post-larvae of marine spawners often enter the estuaries when only a few weeks old and concentrate, together with post-larvae from estuarine spawners, in narrow zones within the estuaries.

Dando (1984) categorised fish which spend some or all of their lives in estuaries as follows:

- Diadromous (catadromous / anadromous)
- Freshwater
- Marine species which penetrate the lower reaches of an estuary as opportunist feeders
- Estuarine fish are those that spend most or all of their lives in euryhaline conditions
- Marine species which use estuaries as nursery grounds
- Marine species which enter freshwater as adults to breed

Anadromous species include the Atlantic salmon (*Salmo salar)*, Trout (*Salmo trutta)*, River lamprey (*Lampetra fluviatilis)* and catadromous species include species such as the European eel (*Anguilla anguilla).*

Many freshwater species may be displaced into the estuary by river spates e.g. dace (*Leuciscus leuciscus)* which are known to form permanent populations in the tidal freshwater regions of long estuaries.

Some marine species enter estuaries and leave with the tide. Examples include conger eel (*Conger conger)* and mackerel (*Scomber scombrus)*

Estuarine fish are considered to be those that spend their entire life cycle in the estuary. Examples of these are the common goby (*Pomatoschistus microps).* Other estuarine fish leave the estuaries for the open sea for short periods, usually for breeding, e.g. the flounder (*Platichthys flesus).*

Marine species which use estuaries as nursery grounds are often the dominant members of Atlantic estuaries. They include members of many major groups such as the herring (*Clupea harengus), sprat (Sprattus sprattus)* and *sea bass (Dicentrarchus labrax).*

Marine species which ascend into freshwater to spawn, but their post-larvae or young juveniles have estuarine nursery grounds include e.g. Twaite shad (*Alosa fallax*) and European smelt (*Osmerus eperlanus).*

Mass mortalities of estuarine fish, especially juveniles, are not uncommon after sudden changes in conditions and abrupt decreases in temperature have been reported to cause larval and juvenile mortalities in many species. Sudden salinity changes can have catastrophic consequences on estuarine young while low oxygen levels are another major cause of heavy mortalities in eggs, larvae and juveniles. This problem is frequently associated with high levels of suspended matter in the water and siltation. Since estuarine conditions are hostile to egg and larval development it is not surprising to find that many estuarine fish spawn elsewhere. For example, in the Tamar estuary, England, only six of the seventy-six recorded species spend their entire lives in the estuary.

Many marine species that use estuaries as nursery grounds also ascend into freshwater to spawn, e.g. European smelt and Twaite shad (both categorized as Diadromous (anadromous) by Connor *et al.* 2019). This enables the eggs to develop in clean well-oxygenated water. Typically, these fish produce demersal, and frequently adhesive eggs, and the larvae possess large yolk-sacs. During the larval period, and egg stage in shad, they are carried downstream and feeding commences in the productive oligohaline or mesohaline zones of the estuary. One of the requirements of a spawning site is that it should be far enough upstream so that there is a sufficient transport distance to allow the eggs and larvae to develop before they are carried too far down the estuary. The ova and larvae of European smelt will not survive salinities above 16ppt.

However, the majority of estuarine fish undertaking spawning migrations breed at sea, e.g. flounder, *Platichthys flesus* (Hartley, 1940). In the Tamar estuary, England, Hartley (1947) showed that flounder have narrow home-ranges within the estuary and return to these areas after being displaced by spates or when transplanted elsewhere. Flounder usually spawn within about 20km of the estuary mouth and females may spend less than two weeks at sea during the spawning season. The majority of fish return to their own home range in the estuary during the post-spawning period each year.

The young of many other marine fish migrate up-estuary to near the freshwater-saltwater interface. Most of these young fish probably utilize the net up-stream flow of the saline current along the estuary bottom.

In a study of fish larvae and post-larvae in an estuary it was observed that 97% had hatched from demersal eggs. Estuary spawning by species producing pelagic eggs is uncommon. This is not surprising since pelagic larvae can be rapidly flushed out of the estuary and dispersed by the net seaward transport of the surface layers. The post-larvae rapidly ascend the estuary, possibly transported by the salt-wedge, to the nursery grounds at the saltwater-freshwater interface from where there is a rapid up-estuary migration to the low salinity nursery grounds.

The true estuarine residents show various adaptations to spawning under estuarine conditions and most deposit demersal eggs which can suffer from the disadvantage that they may be buried in silt and deprived of oxygen. A tactic that prevents silting of demersal eggs is parental care and gobies which breed in estuaries frequently deposit their eggs in shells or on the underside of stones where they are guarded and aerated by the male, using his pectoral fins, until they hatch. Gobies appear to be particularly successful estuarine breeders, since their larvae and post-larvae dominate the ichthyoplankton in many estuaries and adult gobies frequently predominate among fish species impinged and subsequently washed off the band-screens of thermal electricity generating station cooling water systems.

Pipefish species (Syngnathidae) are well adapted for estuarine breeding. The eggs and larvae are brooded by the male in special brood flaps. On release the young may be demersal or pelagic, for a period.

In an estuary, the highest concentrations of post-larvae are normally found in the highly productive 1-15ppt salinity region of the estuary. It has been reported that 95% of the post-larvae collected in a survey of an east coast US estuary were caught in the 0-11ppt salinity region. This estuary zone has been termed the "critical zone".

Post-larval flounder, *Platichthys flesus,* acquire a greater tolerance to fresh water as they develop. After metamorphosis they actively swim towards river water, as opposed to seawater. Fish post-larvae can reach high concentrations on the nursery grounds and fishery workers have observed juvenile *Platichthys flesus* at densities of 3-4 m^{-2} in the upper reaches of the Tamar estuary, England. The post-larvae of the goby *Pomatoschistus microps* have been observed at mean densities up to 75 m^{-3} in the region of the freshwater-saltwater interface in the Tamar estuary, England.

As the young fish grow they usually descend to the middle and lower reaches of the estuary. Several studies have shown that competition between the different species in the juvenile stage is minimized by differences in temporal and spatial distribution as well as diet. Populations of fish living permanently in low salinity areas are able to genetically adapt to them. Frequently the juveniles and adults show similar salinity tolerances, for example some adult *Platichthys flesus* co-exist with the O-group on the freshwater nursery grounds.

In marine species, the adults are mostly less tolerant of lower salinities than the young, which are found to move progressively into more saline conditions as they grow. This difference in tolerance effectively prevents the adult fish from invading the nursery areas and preying upon the dense concentrations of larval and young fish.

Connor *et al.* 2019 described fish sampled using fyke nets and beach seines in Irish estuaries in terms of functional guilds (freshwater migrants, marine stragglers, freshwater stragglers, estuarine species, diadromous species and marine migrants) and feeding guilds (zoobenthivores, piscivores, zooplanktivores, detritivores and omnivores). They examined the biogeography and fish community structure of Irish estuaries using a large dataset comprised of 208,313 individual fish, 80 different species sampled from 37 estuaries from 2008–2017 during the WFD surveillance monitoring programme. Species richness was strongly correlated with the area of shallow littoral and subtidal habitats. Estuaries at higher latitudes tended to have lower species richness in shallow littoral areas. Estuary mouth width and proportion of subtidal area were both positively related to species richness in subtidal habitats. In the larger, more open estuaries marine migrants consistently dominated the fish population and this highlights the important nursery role of Irish estuaries.

Fish Density, Biomass and Production in Estuaries

Whitfield (2016) reviewed available information on coastal fish biomasses (g m^{-2} wet mass) and productivity (g m^{-2} wet mass $year^{-1}$) in order to place South African data on these topics into a global perspective. He concluded that knowledge concerning fish production in fresh water was more advanced than that in estuaries and compared fish production estimates for rivers and lakes with those for estuaries. An assessment of fish community production at 55 river sites (273 kg ha^{-1} $year^{-1}$ or 27g m^{-2} yr^{-1}) and 22 lake sites (82 kg ha^{-1} $year^{-1}$ or 8g m-2 yr-1), determined that river fish assemblages can be at least three times more productive than those at lake sites. No such comprehensive habitat specific fish production comparisons have ever been conducted in estuaries.

Whitfield (2016) referenced a review by Day *et al.* (1989) which indicated that detailed studies of individual fish species in estuaries showed that these taxa were more productive than marine or freshwater counterparts. This was, in part, explained by the fact that estuaries tend to be dominated by the juveniles of mostly marine species at an age when somatic productivity on a per unit area basis is usually maximal. It might also be explained by the fact that estuaries are also one of the most productive aquatic environments, mainly due to the high primary and secondary productivity linked to high nutrient and organic matter availability. These views are supported by a comparison of fish community productivity in the North Sea (2.5 g wet mass m^{-2} $year^{-1}$), which was much lower than that in one of the adjacent North Sea estuaries, namely the Forth system in Scotland (4.3 g wet mass m^{-2} $year^{-1}$ (Elliott & Taylor 1989)

Whitfield (2016) referenced published accounts of fish productivity in Cool temperate estuaries (North Sea) as follows:

Location	**Fish productivity (g m^{-2} $year^{-1}$)**	**Reference**
Forth Estuary (Scotland, U.K.)	4.3	Elliott & Taylor (1989)
Southern North Sea estuaries	5.2	Korringa (1967)
Wadden Sea (Netherlands)	10.0	Postma & Rauck (1979)

Within estuaries, the environmental variables (temperature, salinity, turbidity) can add more complexity to the interpretation of fish biomass and production estimates. For example, Matveev &

Steven (2014) examined fish production is estuaries and found that there was a negative correlation between estimated fish biomass and salinity and a positive correlation between estimated fish biomass and turbidity.

Fish inhabit a three-dimensional environment yet typically their quantitative ecology (density (no. ha^{-1}), biomass (kg ha^{-1}), production (kg ha^{-1} yr^{-1}) is described in two dimensions, the area of habitat occupied.

Rivers are regarded as the most productive habitat occupied by fish. This habitat also has descriptive challenges which relate to bank width (usually the bank-to-bank width of a river) and wetted habitat (usually the wetted channel during periods of the year when fish populations are studied). Then there are further constraints which relate to the wetted habitats occupied by fish (habitats with a minimum depth / macrophyte and substrate composition / available cover etc) and typically fish occupy a varying percentage of wetted habitat.

A similar scenario pertains to lake habitat where lake areas with suitable depths / macrophyte and substrate composition / available cover etc are more attractive than other areas to fish which can result in the absence of fish from large areas. Also, lakes and reservoirs which are used as water supplies / hydro purposes etc and where water level changes expose large littoral areas, may become very unproductive in fisheries terms with time.

With regard to estuaries, the exposure of large intertidal areas every tidal cycle provides access to benthic fauna for wading birds etc but prevents access to these food resources for fish during several hours of each tidal cycle. As with the 'wetted channel' scenario for rivers, the surface area of estuaries has two perspectives, that at high tide and that at low tide. In the case of the Barrow-Nore-Suir estuary (Waterford Harbour) the estimated high tide area is 83.9 km^2 and the estimated low tide area (covered by water) is 66.0 km^2 (a decrease of 21.3%).

In the case of rivers, two dimensional estimates of fish density, biomass and production will not change when converted to three dimensions using a mean depth of 1m. In this case, a river section with 1ha (10,000 m^2) of area holds 10,000 m^3 of water with an average depth of 1m. A typical fish biomass of 10g m^{-2} (100kg ha^{-1}), is also 100kg 10^{-4} m^3. However, if the average water depth is 0.5m, this statistic becomes 200kg 10^{-4} m^3.

The following table details how applying three dimensions to fish habitat alters density, biomass and production estimates (over an area of 1ha (10,000 m^2)) which was originally calculated in two dimensions at 100 kg ha^{-1} (10,000m^2) and is now calculated in three dimensions:

Waterbody / average depth (m)	**0.5**	**1**	**10**	**20**
River	200	100		
Lake		100	10	5
Estuary		100	10	5

Hadderingh & Jager (2002) sampled fish in the Ems estuary using anchor nets and beam trawls in an attempt to relate species composition and densities in the anchor nets (number /10000m^3) and in the beam trawls (number /15000 m^2) to numbers impinged on the Eems power station band-screens.

The anchor net had a circular opening of 2m diameter and 6 mm mesh size and was used to sample pelagic fish species. It was deployed from an anchored vessel with the net opening facing the ebb tide. Fish moving downstream were collected by the net. The whole water column with depths between 10m and 14m was sampled by leaving the net for 10 minutes in five successive water layers of 2m. The current velocity in the net ranged from 0·75–0·97 m s^{-1}. Fish density, as number /10000 m^3, was calculated from the total number of fish in combined samples taken within 24 h and the volume of filtered water, measured with a flow meter mounted in the net opening.

A beam trawl was used to sample benthic fish species. It had a width of 3m, a height of 0·54m and a mesh size of 20mm. The hauls were taken parallel to the shoreline. Average haul distance was 1250m, covering a bottom surface area of 3750m^2. The four consecutive hauls taken in 24h were combined to one sample and catch density was then expressed as number of fish /15000 m^2.

Hadderingh & Jager (2002) do not provide information on fish biomass estimates for the Ems estuary, but they do provide three-dimensional and two-dimensional (area) density estimates (raised to number per million m^3 / number per million m^2) as follows:

Species or species category /Sampling method	**Anchor net (no./million m^3)**	**Beam Trawl (no./million m^2)**
Clupeids	2700-59700	733-7532
Smelt	340-2040	386-1066
Gobies	6300-110000	579-9790
Nilsson's Pipefish	7-174500	
Flatfish		466-9923

By way of comparison with the above anchor net catch statistics, at Great Island CWS a total of 825 fish (excluding sand goby) were washed off band-screens per million m^3 of water abstracted during a fish impingement study carried out during June 2021 (Anon. 2021b).

The above table demonstrates the differences in catches made by the anchor net (mainly pelagic species) and the beam trawl (mainly benthic species). The above data also demonstrate the huge variation in catches made using each method.

With regard to the Barrow-Nore-Suir estuary (Waterford Harbour) the high tide surface area is 83.9km^2. Applying Elliott & Taylor's (1989) fish production estimate of 4.3 g m^{-2} yr^{-1} for the Forth estuary in Scotland and assuming a production: mean biomass ratio of 2:1 – the average fish biomass per hectare would be 22kg. Expanding this statistic to the high tide area of the Barrow-Nore-Suir estuary (Waterford harbour) results in an estimated average fish biomass of 184.5tonnes.

Fish in the Barrow-Nore-Suir estuary (Waterford Harbour)

Formerly, the Barrow-Nore-Suir estuary supported a variety of commercial fisheries (salmon drift-net and snap-net; eel (baited pot and fyke-net); flood and ebb 'sprat' weirs (large variety of whitefish). However, due to conservation legislation the salmon (termination of salmon drift-netting in 2007) and eel commercial fisheries (termination of all commercial fishing for European eel in the Republic of Ireland in 2009) no longer operate and very few of the 'sprat' weirs described by Went (1959) now operate. Commercial fishing operations in Waterford harbour can now be described as artisanal and restricted to a limited amount of trammel netting for whitefish during the winter months and occasional incursions into the estuary by purse seiners in pursuit of large aggregations of sprat (*Sprattus sprattus*) during years when these aggregations occur e.g. November – December 2020.

Water Framework Directive fish surveys in Waterford Harbour

In the Water Framework Directive, there are five status classifications for surface waters, namely, high, good, moderate, poor and bad. High ecological status means that quality elements show little or no effects of human activity compared to undisturbed reference conditions. Good ecological status means that quality elements show only slight changes caused by human activity compared to undisturbed reference conditions. Water bodies with moderate, poor or bad status fail the requirements of the WFD and must be restored to at least good status. If one of the quality elements, such as fish, fails then the water body fails to meet the required status.

The following are the biological quality elements for the classification of the ecological status

of transitional waters:

- Composition, abundance and biomass of phytoplankton
- Composition and abundance of other aquatic flora
- Composition and abundance of benthic invertebrate fauna
- Composition and abundance of fish fauna

The Water Framework Directive requires Irish statutory authorities to sample fish populations in surface waters (rivers, lakes and transitional waters) to determine the ecological status of fish in these surface waters. In Ireland, the competent authority carrying out this work is Inland Fisheries Ireland, formerly the Central Fisheries Board. In transitional waterbodies, there is a requirement to assess the composition and abundance of the fish fauna.

Accordingly, Inland Fisheries Ireland personnel carry out fish surveys around the Irish coast in Autumn (September to November) using standard European methodology (CEN, 2005) on a rolling three-year basis as part of the national programme of fish monitoring for the WFD. A standard multi-method sampling approach is used to sample fish in Irish transitional waters for national reporting on the Water Framework Directive (WFD) and this consists of seine netting, fyke netting and beam trawling.

For the purposes of this review, the findings of the Water Framework Directive surveillance monitoring programme carried out by Inland Fisheries Ireland has been divided into two periods because of changes in the interpretation of findings. While the basic fish survey methodology included the use of beach seines, fyke nets and beam trawls throughout the years of survey (2010, 2013, 2016 and 2019) the reporting for the years 2010 and 2013 was related to individual water bodies within Waterford Harbour / the Barrow - Nore-Suir estuary while for the years 2016 and 2019 the reporting was related to the combined water bodies within Waterford Harbour / the Barrow-Nore-Suir estuary (Ryan *et al.* 2017, 2020). Inland Fisheries Ireland's surveys of fish in Waterford Harbour (Barrow, Nore and Suir transitional waterbodies) have been reported in www.wfdfish.ie for the survey years 2010,2013, 2016 and 2019.

Throughout the EU, Water Framework Directive transitional water body survey methodologies were adopted after a considerable amount of international discussion and inter-calibration. With transitional water bodies of varying sizes and complexity throughout the EU, the scientists from individual government competent authorities had to make decisions related to the survey methodology and the sampling effort required to provide adequate information on the fish species composition and relative abundance of fish species in any particular estuary. For Portuguese estuaries, Gamito *et al.* (2012) looked at sampling effort with regard to its influence on multi-metric fish-based indices which are composed of several metrics, mostly related to structural and functional characteristics of fish communities, such as species richness, the role of nursery areas, or trophic web structure. They looked at the influence of sampling effort on several metrics of their Estuarine Fish Assessment Index (EFAI) and found that the number of hauls (beam trawls) necessary for the means to level off differed with the metrics considered. Generally, for metrics on percentages (percentage of marine migrants, percentage of estuarine residents and percentage of piscivores) the curve levelled off with less than 20 hauls, both for the estuary as a whole and for different estuarine salinity zones. On the other hand, metrics on species richness required much larger samples. In order to minimise the estimated bias of metrics, they found that the WFD sampling costs would have to be more than 3 times higher than they currently were. The findings of the Portuguese study are of importance for an effective assessment of estuarine ecological quality and particularly in the context of the WFD, as the metrics studied in Portuguese estuaries are similar to other EU member State indices.

Water Framework Directive Fish Sampling in Waterford Harbour in 2010 and 2013

The following text summarises the main findings of fish surveys carried out in the Barrow-Nore-Suir (Waterford Harbour) transitional waterbodies by Inland Fisheries Ireland during 2010 and 2013 (Kelly *et al.* 2013).

During the 2010 and 2013 surveys, beach seining was conducted using a 30m x 3m net (10mm mesh size) to capture fish in littoral areas. The bottom of the net had a weighted lead line to increase sediment disturbance and catch efficiency. Fyke nets (15m in length with a 0.8m diameter front hoop, joined by an 8m leader with a 10mm square mesh) were used to sample benthic fish in the littoral areas. Beam trawls were used for sampling benthic fish in the littoral and open waters, where bed type was suitable. The beam trawl measured 1.5m x 0.5m, with a 10mm mesh bag, decreasing to 5mm mesh in the cod end. The trawl was attached to a 20m tow rope and towed by a boat. Trawls were conducted along transects of 100m in length.

A WFD fish classification tool, Transitional Fish Classification Index or TFCI, has been developed for the island of Ireland (Ecoregion 1) using IFI and Northern Ireland Environment Agency (NIEA) data. This is a multi-metric tool based on similar tools developed in South Africa and the UK (Harrison and Whitfield, 2004; Coates et al., 2007). The TFCI has recently completed the intercalibration process.

Using this approach, the eight individual Barrow-Nore-Suir transitional waterbodies have been assigned draft ecological status classifications based on the fish species / populations present (Table 2)

Also shown in Table 2 is the Ecological Quality Ratio (EQR) for each waterbody. The EQR is the relationship between the values of the biological parameters observed for a given surface waterbody and the values for those parameters in the reference conditions applicable to that waterbody. The relationship is expressed as a numerical value between zero and one, with high ecological status represented by values close to one and bad ecological status by values close to zero.

Table 2 details some of the characteristics of Barrow-Nore-Suir waterbodies (Figures 1-3) and their status with regard to fish (Table X code refers to the number assigned to each waterbody in Tables 3 and 4.

Table 2: Water bodies surveyed by IFI for the WFD fish surveillance monitoring programme, October 2013 (FT=freshwater tidal, TW=transitional) (Kelly et al. 2013)

Transitional Waterbody	MS Code	Easting	Northing	Type	Area (km^2)	Table X code	Fish Ecological Status (TFCI)	EQR
Barrow Estuary Upper	SE_100_0300	273066	137640	TW	1.15	1	Good	0.35
Barrow Nore Estuary Upper	SE 100_0250	272129	128644	TW	0.64	2	Moderate	0.3
Barrow Suir Nore Estuary	SE_100_0100	271527	107512	TW	28.21	3	Good	0.73
New Ross Port	SE_100_0200	267862	117105	TW	6.71	4	Good	0.6
Nore Estuary	SE_100_0400	265312	135294	TW	1.26	5	Good	0.45
Suir Estuary Lower	SE_100_0500	266073	112602	TW	4.32	6	Good	0.75
Suir Estuary Middle	SE_100_0550	249824	114070	TW	7.03	7	Moderate	0.73
Suir Estuary Upper	SE_100_0600	243887	121066	FT	1.09	8	Good	0.33
Total					**50.41**			

Table 3 below presents information on fish sampled in 2010 and 2013 in each of the 8 transitional waterbodies in the Barrow-Nore-Suir estuary (Waterford Harbour).

Table 3: Barrow-Suir-Nore estuary (Waterford Harbour) transitional waterbodies: WFD surveillance monitoring programme 2010 and 2013 (summary data extracted from Kelly et al. 2013)

Waterbody	Name	No. of fish species	No. of individuals	No. beach seine samples	No. fyke net samples	No. beam trawls	Dominant species
1	Upper Barrow Estuary	12	2155	13	10	12	dace, flounder, sand goby
2	Upper Barrow-Nore Estuary	11	1700	4	4	6	sand goby, flounder
3	Barrow-Suir-Nore Estuary	29	1535	12	8	18	sprat, sand goby, flounder, plaice
4	New Ross Port	21	5720	12	8	7	sprat, sand goby, flounder, European eel
5	Nore Estuary	14	1912	11	8	12	sand goby, dace, flounder, minnow
6	Lower Suir Estuary	19	2881	12	8	8	sand goby, sprat, flounder, European eel
7	Middle Suir Estuary	20	3811	12	12	14	sand goby, flounder, European eel, smelt
8	Upper Suir Estuary	11	3183	6	3	6	flounder, dace, sand goby, three-spined stickleback
Totals		**42**	**22897**	**82**	**61**	**83**	

Figure 1: Location map of the eight transitional water bodies on the Barrow-Nore-Suir estuary system surveyed for WFD fish monitoring, September-October 2013 by Inland Fisheries Ireland (Kelly et al. 2013)

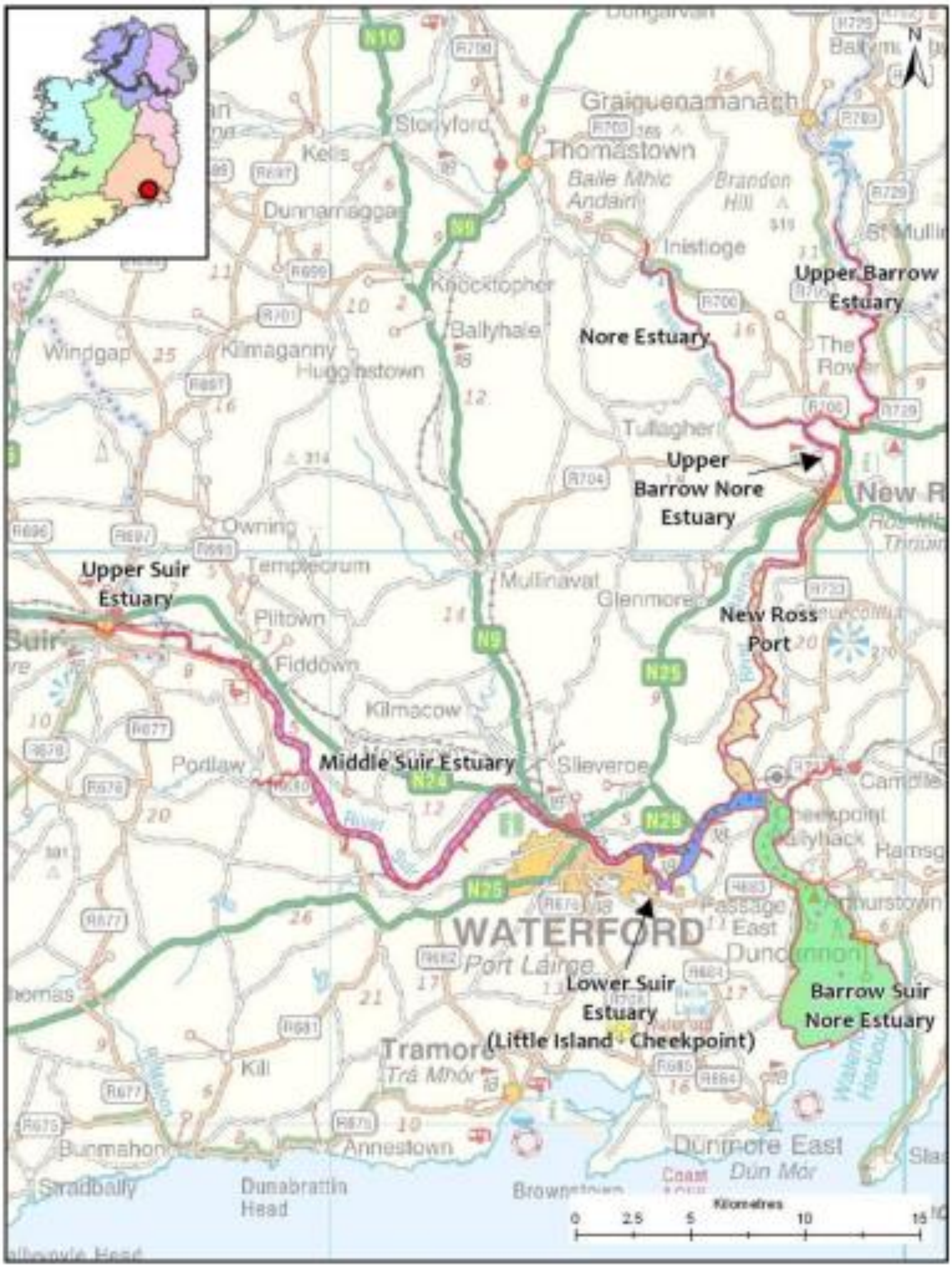


Figure 2:14 Aerial photo of the northern part of the Barrow-Nore-Suir Estuary looking north towards the Great Island power station and Barrow Bridge (from Kelly et al. 2013)

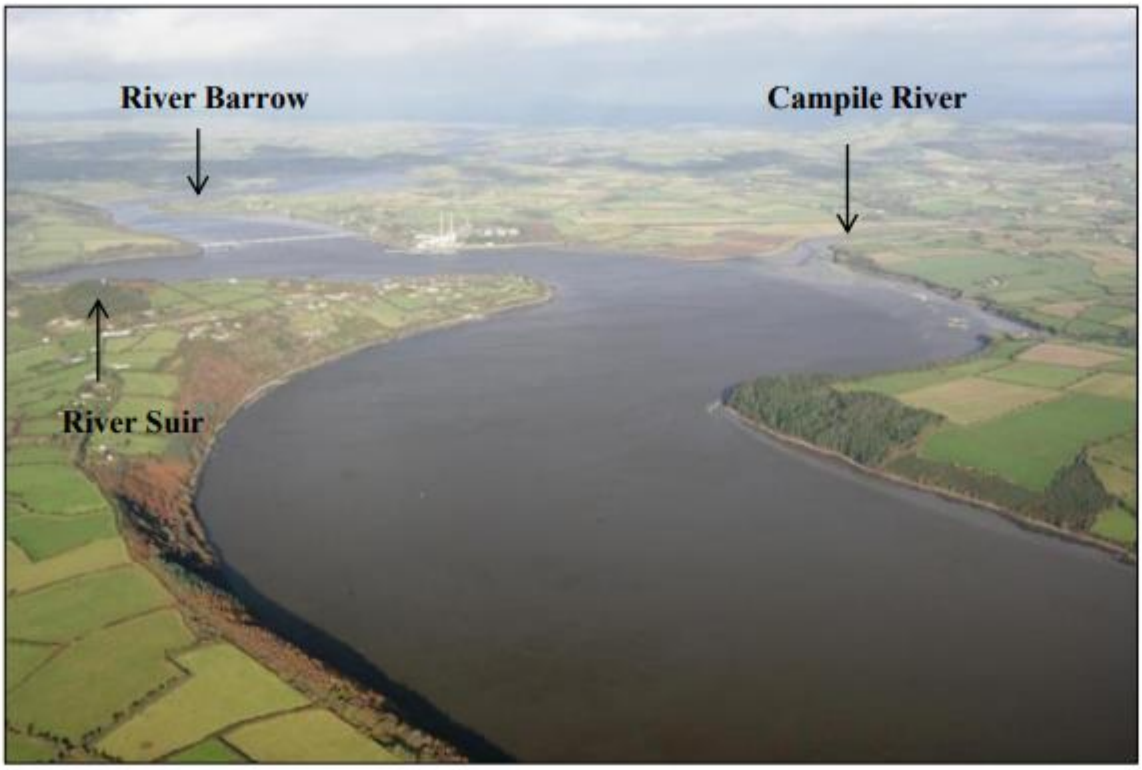


Figure 3: Location map of the Barrow-Suir-Nore estuary waterbody indicating sample sites, October 2010 and 2013 (Kelly et al. 2013)

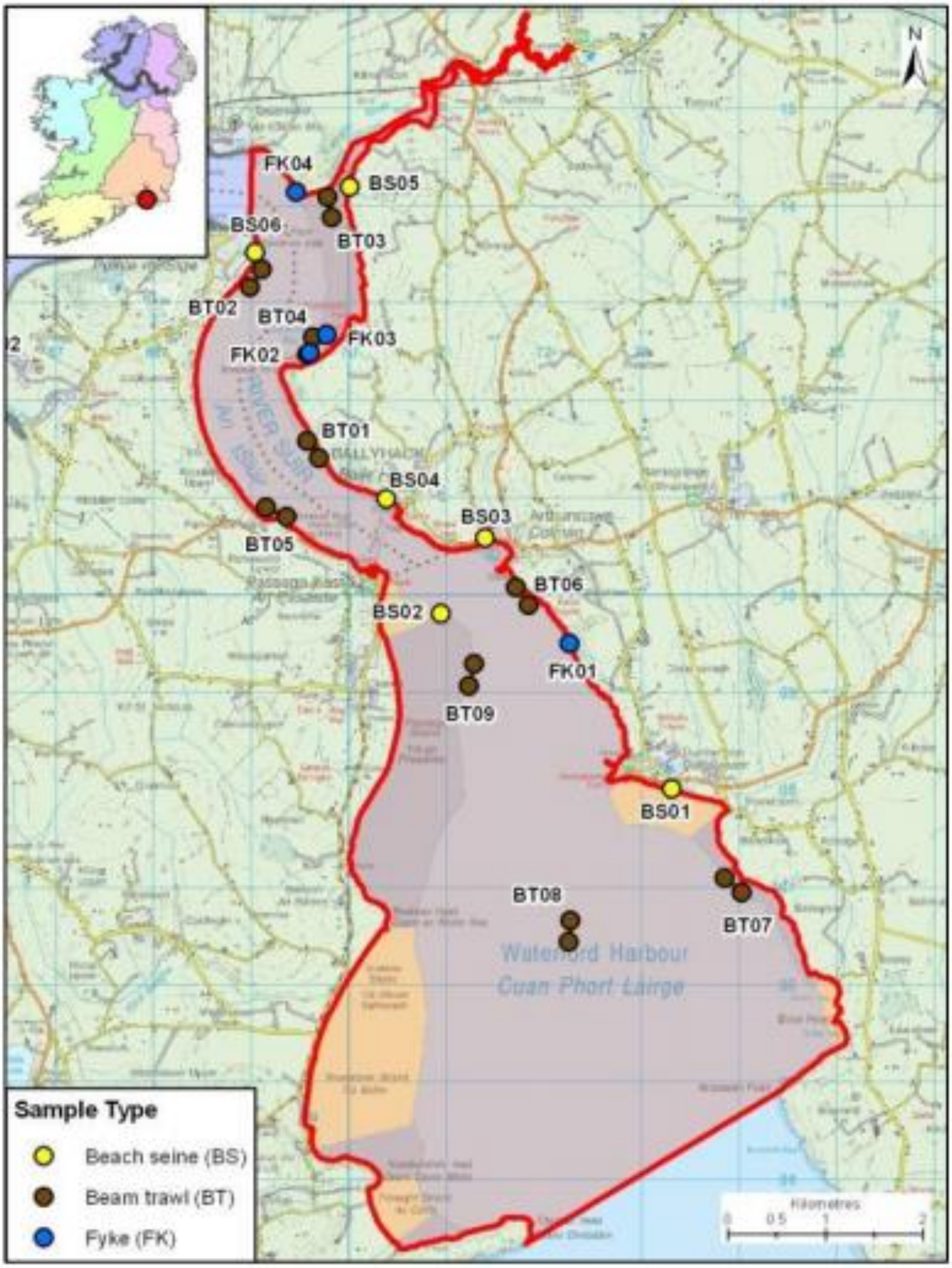


Table 4: Fish species recorded in Waterford Harbour waterbodies during Inland Fisheries Ireland WFD surveillance monitoring (2010 and 2013) (Kelly et al. 2013)

				Waterbody							
				1	2	3	4	5	6	7	8
Common name	Sceintific name	Functional guild	Feeding guild								
Atlantic horse mackerel / scad	*Trachurus trachurus*	MS	PV			+	+		+		
Black goby	*Gobius niger*	ES	ZB			+					
Brill	*Scophthalmus rhombus*	MM	PV			+					
Cod	*Gadus morhua*	MM	PV			+	+		+	+	
Common sole	*Solea solea*	MM	ZB				+				
Dab	*Limanda limanda*	MM	ZB			+					
Dace	*Leuciscus leuciscus*	FM	ZB	+	+		+	+		+	+
Deep-snouted pipefish	*Syngnathus typhle*	ES	ZP			+		+			
European eel	*Anguilla anguilla*	DI	ZB	+	+	+	+	+	+	+	+
European sea bass	*Dicentrarchus labrax*	MM	PV				+		+	+	
Five-bearded rockling	*Ciliata mustela*	MM	ZB			+	+		+		
Flounder	*Platichthys flesus*	MM	ZB	+	+	+	+	+	+	+	+
Haddock	*Melanogrammus aeglefinus*	MS	PV			+					
Herring	*Clupea harengus*	MM	ZP			+			+	+	
Lesser sandeel	*Ammodytes tobianus*	ES	ZP			+					
Lesser weever	*Echiichthys vipera*	MS	ZB			+					
Long rough dab	*Hippoglossoides platessoides*	MS	ZB			+			+		
Minnow	*Phoxinus phoxinus*	FS	ZP	+				+			
Nilsson's pipefish	*Syngnathus rostellatus*	ES	ZP			+					
Nine-spined stickleback	*Pungitius pungitius*	FS	ZB	+							
Perch	*Perca fluviatilis*	FS	PV		+					+	+
Plaice	*Pleuronectes platessa*	MM	ZB			+	+		+	+	
Pogge	*Agonus cataphractus*	MM	ZB			+			+		
Pollack	*Pollachius pollachius*	MM	PV			+	+		+		
Poor cod	*Trisopterus minutus*	MM	ZB			+	+		+	+	
Roach	*Rutilus rutilus*	FS	OV	+	+			+		+	+
Rudd	*Scardinius erythrophthalmus*	FS	OV							+	
Salmon	*Salmo salar*	DI	ZB	+	+		+	+			+
Sand goby	*Pomatoschistus minutus*	ES	ZB	+	+	+	+	+	+	+	+
Sand smelt	*Atherina presbyter*	MM	ZP			+				+	
Trout (brown and sea)	*Salmo trutta*	DI	ZB	+	+		+	+	+	+	+
Smelt	*Ormerus eperlanus*	DI	PV	+	+	+		+	+	+	+
Sprat	*Sprattus sprattus*	MM	ZP			+	+	+	+	+	
Spotted dragonet	*Callionymus maculatus*	MS	ZB			+					
Sea lamprey	*Petromyzon marinus*	DI	PV				+				
Stone loach	*Barbatula barbatula*	FS	ZB	+				+			
Thick-lipped grey mullet	*Chelon labrosus*	MM	DV			+	+		+	+	
Three-bearded rockling	*Gaidropsarus vulgaris*	MS	ZB				+				
Three-spined stickleback	*Gasterosteus aculeatus*	FM	ZP	+	+	+		+		+	+
Turbot	*Psetta maxima*	MM	PV			+					
Twaite shad	*Alosa fallax*	DI	ZP		+	+	+	+	+	+	+
Whiting	*Merlangius merlangus*	MM	PV			+	+		+	+	

Table 5 below details the numbers of each fish species recorded using beach seine, fyke net and beam trawl sampling methods in 2010 and 2013. Clearly, the majority of fish were sampled using a beach seine.

Table 5: Number of each fish species captured by each gear type in the Barrow-Suir-Nore Estuary waterbody, October 2010 and 2013 (Kelly et al. 2013)

				Beach seine		Fyke net		Beam trawl		Total	
Common name	Scientific name	Functional guild	Feeding guild	2010(6)	2013(6)	2010(4)	2013(4)	2010(9)	2013(9)	2010	2013
Plaice	*Pleuronectes platessa*	MM	ZB	5	107	-	1	12	1	17	109
Sand goby	*Pomatoschistus minutus*	ES	ZB	131	103	-	-	51	1	182	104
Flounder	*Platichthys flesus*	MM	ZB	23	39	54	31	13	-	90	70
Five-bearded rockling	*Ciliata mustela*	MM	ZB	-	-	18	15	-	-	18	15
Pogge	*Agonus cataphractus*	MM	ZB	-	-	2	13	-	-	2	13
Poor cod	*Trisopterus minutus*	MM	ZB	-	-	1	9	-	1	1	10
Sprat	*Sprattus sprattus*	MM	ZP	665	8	-	-	-	-	665	8
Thick-lipped grey mullet	*Chelon labrosus*	MM	DV	94	8	-	-	-	-	94	8
Atlantic horse mackerel/scad	*Trachurus trachurus*	MS	PV	-	1	-	4	-	-	-	5
Herring	*Clupea harengus*	MM	ZP	-	5	-	-	-	-	-	5
Pollack	*Pollachius pollachius*	MM	PV	-	2	-	3	-	-	-	5
Cod	*Gadus morhua*	MM	PV	-	-	20	4	1	-	21	4
Long rough dab	*Hippoglossoides platessoides*	MS	ZB	-	-	-	2	-	1	-	3
Nilsson's pipefish	*Syngnathus rostellatus*	ES	ZP	-	3	-	-	2	-	2	3
Smelt	*Osmerus eperlanus*	DI	PV	2	3	-	-	-	-	2	3
Twaite shad	*Alosa fallax*	DI	ZP	11	3	-	-	-	-	11	3
Dab	*Limanda limanda*	MM	ZB	-	-	-	-	1	2	1	2
Deep-snouted pipefish	*Syngnathus typhle*	ES	ZP	1	2	-	-	-	-	1	2
Whiting	*Merlangius merlangus*	MM	PV	-	-	-	1	-	1	-	2
Black goby	*Gobius niger*	ES	ZB	-	1	-	-	-	-	-	1
Lesser weever	*Echiichthys vipera*	MS	ZB	-	1	-	-	2	-	2	1
Turbot	*Psetta maxima*	MM	PV	-	1	-	-	-	-	-	1
European eel	*Anguilla anguilla*	DI	ZB	-	-	21	-	-	-	21	-
Sand smelt	*Atherina presbyter*	MM	ZP	11	-	-	-	2	-	13	-
Lesser sandeel	*Ammodytes tobianus*	ES	ZP	8	-	-	-	-	-	8	-
Brill	*Scophthalmus rhombus*	MM	PV	4	-	-	-	-	-	4	-
Spotted dragonet	*Callionymus maculatus*	MM	ZB	-	-	-	-	1	-	1	-
Three-spined stickleback	*Gasterosteus aculeatus*	FM	ZP	1	-	-	-	-	-	1	-
Haddock	*Melanogrammus aeglefinus*	MS	PV	-	-	1	-	-	-	1	
Totals				**956**	**287**	**117**	**83**	**85**	**7**	**1158**	**377**

In the Barrow-Suir-Nore Estuary waterbody (waterbody number 3 in tables 2,3 and 4) a total of 22 species were recorded during the 2010 survey (beach seine = 12; fyke net = 7; beam trawl = 9) and 22 species were also recorded during the 2013 survey (beach seine = 15; fyke net = 10; beam trawl = 6). For both years a total of 29 species were recorded (beach seine = 19; fyke net = 12; beam trawl = 12) in this waterbody.

During both sampling years (2010 and 2013) a total of 42 fish species were sampled from all 8 transitional waterbodies in Waterford Harbour.

Water Framework Directive fish sampling in Waterford Harbour in 2016 and 2019

Fish in Waterford Harbour (Barrow-Nore-Suir) waterbodies were sampled during 2016 and 2019 using the same sampling methods which were used in previous years.

With regard to the interpretation of the results of sampling in 2019 and 2019, Harrison & Kelly (2013) developed an estuarine multi-metric fish index (EMFI) and applied it to Irish transitional waters. The index comprised a balanced and complimentary set of 14 metrics that represented four fish community attributes: species diversity and composition, species abundance, estuarine utilisation, and trophic composition as follows:

Harrison & Kelly (2013) first established, based on a total of 73 fish samples collected during the years 2005,2006,2007 and 2008 across a total of 29 estuaries throughout the island of Ireland that there was a relationship between fish species richness and $\log_{10}$ estuarine surface area (ha) (r^2=0.59, $p<0.01$). This equation implied, based on the data collected during the period 2005-2008, a fish species richness of about 21 for Waterford Harbour where the 8 transitional waterbodies have a total area of 5040ha (50.4km^2).

The following is a description of the metrics and their measurement and relevance to the assessment of estuary health that make up the estuarine multi-metric fish index (EMFI) (Harrison & Kelly 2013)

- Metric 1: Species richness is usually strongly linked with habitat diversity and integrity and should be sensitive to habitat loss or degradation.
- Metric 2: The occurrence of introduced non-native fish species represents a potential threat to native fish populations through competitive exclusion and predation and also represent a direct measure of human interference.
- Metric 3: Species composition measures the amount of overlap (or similarity) in the fish species present in a system and some ‘reference’ assemblage and is a useful measure of ecosystem condition and is also a key biological element required by the WFD.
- Metric 4: Species abundance measures the numerical abundance of species in an estuary in relation to a reference fish community abundance and provides a quantitative assessment of ecosystem condition and is also among the biological elements required by the WFD for assessing transitional waters. Environmental stress generally results in a change in relative abundance from ‘diverse’ communities consisting of many fish species in relatively low proportions to ‘simple’ assemblages dominated by a few species.
- Metric 5: Dominance - the number of taxa required to make up 90% of the total numerical abundance represents a simple measure of dominance.
- Metric 6: The number of diadromous species demonstrates that an estuary provides some functional connectivity between adjacent freshwater and marine environments as well as providing habitat for some diadromous species which, depending on the duration of their estuary residence can be considered opportunists or dependents.

- Metric 7: The number of estuarine species represents a group of fish that are probably most susceptible to estuarine degradation by virtue of their strong dependence on these environments.
- Metric 8: The number of marine migrant species includes fishes that utilise estuaries as nursery areas and this provides an indication of how well a system is fulfilling its role as a nursery habitat.
- Metric 9: The numerical abundance of estuarine resident fish species.
- Metric 10: The numerical abundance of marine migrant fish species are complimentary metrics used to quantitatively assess estuarine habitat quality and nursery function. An undisturbed estuary is expected to contain a relatively balanced fish community while an excessively low numerical abundance or unexpected high dominance by one particular group is considered indicative of affected conditions.
- Metric 11: The number of zoobenthivore fish species was selected on the basis that it provides an indirect measure of the condition of the benthic invertebrate fauna.
- Metric 12: The number of piscivorous species provides a measure of the presence of top carnivores, which is typically representative of a complex and stable trophic network within an estuary. Piscivores are also the trophic level most sensitive to environmental disturbance.
- Metric 13: The numerical abundance of zoobenthivore fishes provides a quantitative, complimentary analysis of trophic integrity.
- Metric 14: The numerical abundance of piscivorous fishes also serves as a quantitative, complimentary analysis of trophic stability and complexity.

According to Harrison & Kelly (2013) Metric 1 (species richness), metric 8 (marine migrant species richness), metric 9 (estuarine species abundance), metric 10 (marine migrant species abundance), and metric 4 (species abundance) were consistently among the most influential metrics on the EMFI. Metric 6 (number of diadromous species) and metric 2 (number of introduced species) were the least influential metrics. The number of diadromous species (metric 6) was measured by counting both anadromous (AN) and catadromous (CA) species.

Values of EMFI ranged from 14 to 70 and these values were then transformed to Ecological Quality Ratios (EQR) using a simple formula which brought the scores into the 0-1 range. Boundary values were then established for these values which separated high, good, moderate, poor and bad classifications.

The actual methodology used in calculation of EQR values for fish in Irish estuaries, which are based on beach seine, fyke net and beam trawl samples, has not been revealed by the competent authority and hence private sector workers are totally reliant on the information presented in official published accounts. Also, worked examples of assessing fish ecological status for individual estuaries have not been made available to fishery workers in the private sector and this scenario somewhat blurs independent examination and interpretation of assessments. Occasionally, comments are published on data which can influence the calculated EQR. For example, Ryan *et al.* (2017) recorded that 'The Barrow Nore transitional waterbody improved from "moderate" to "good" status between 2010 and 2013 up to the current survey (2016) and that this improvement was due largely to a reduction in the relative abundance of sprat captured during sampling. In 2007 and 2010, sprat dominated the catch, resulting in a reduction in the EQS score for the waterbody. This is interpreted by the EQR as an environmental stress which has resulted in a change in relative abundance from 'diverse' communities consisting of many fish species in relatively low proportions to 'simple' assemblages dominated by a few species (Harrision & Kelly 2013). However, sprat is a highly mobile marine species which tends to shoal in autumn around the Irish coast. If shoals have entered an estuary during sampling it is likely that large numbers will be caught. However, this is not necessarily an indication that the habitat is under environmental stress but rather due to sprat biology.'

The 2016 and 2019 Water Framework Directive surveillance monitoring surveys in 2016 and 2019 were reported in Ryan *et al.* (2017) and Ryan *et al.* (2020).

The sampling methodology was as reported in Kelly et al. (2013) and the waterbodies and sampling locations throughout Waterford Harbour are shown in Figures 4 and 5 below.

Figure 4: Waterbodies in Waterford Harbour (Barrow-Nore-Suir estuary) (from Ryan et al. 2017)

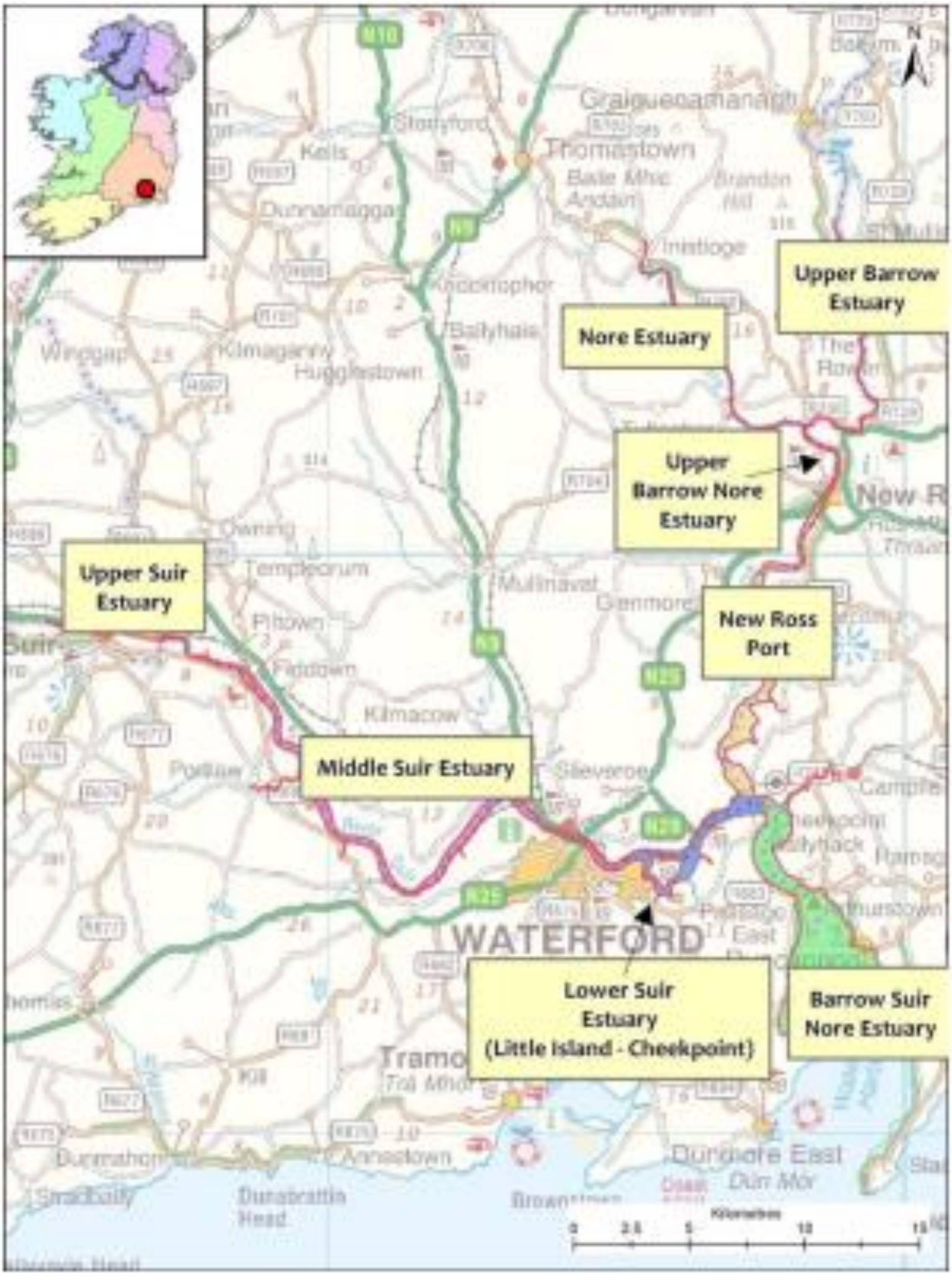
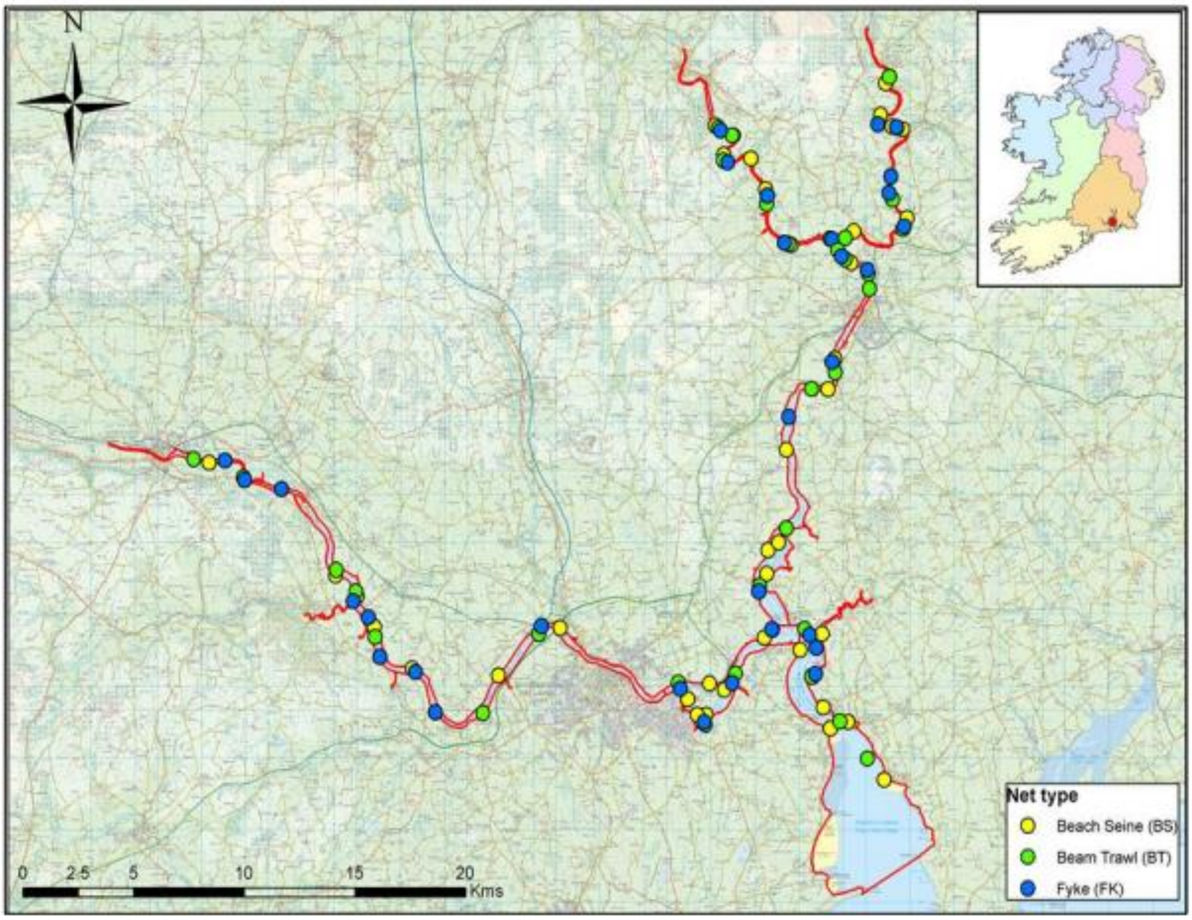


Figure 5: Waterford Harbour (Barrow-Nore-Suir estuary) showing WFD surveillance monitoring survey locations during Oct 2016 (from Ryan et al. 2017)



The fish species recorded during the 2016 and 2019 WFD surveillance monitoring surveys (Ryan *et al.* 2017, 2020) are detailed in Table 6 below.

Table 6: List of fish species recorded in Waterford Harbour transitional waterbodies during the 2016 and 2019 WFD surveillance monitoring surveys

List of species captured during the 2016 WFD survey of the Barrow Suir Nore estuary (red)			
Fish species captured in Waterford Harbour during the WFD surveys of September - October 2019 (in black)			
Species Common name	Species Scientific name	Number	Number
Brill	*Scophthalmus rhombus*	3	
Brown trout	*Salmo trutta*	74	14
Cod	*Gadus morhua*	5	2
Common goby	*Pomatoschistus microps*	1273	1173
Common sole	*Solea solea*	1	
Dace	*Leuciscus leuciscus*	974	188
European eel	*Anguilla anguilla*	219	166
European sea bass	*Dicentrarchus labrax*	51	32
15-spined stickleback	*Spinachia spinachia*	1	1
5-bearded rockling	*Ciliata mustela*	31	12
Flounder	*Platichthys flesus*	2204	698
Lesser sandeel	*Ammodytes tobianus*	7	
Minnow	*Phoxinus phoxinus*	4	12
Nilsson's pipefish	*Syngnathus rostellatus*	10	2
Perch	*Perca fluviatilis*	1	
Plaice	*Pleuronectes platessa*	21	3
Pogge	*Agonus cataphractus*	11	5
Pollack	*Pollachius pollachius*	9	3
Roach	*Rutilus rutilus*	53	22
Salmon	*Salmo salar*	2	7
Sand goby	*Pomatoschistus minutus*	2218	22
Smelt	*Osmerus eperlanus*	541	23
Sprat	*Sprattus sprattus*	1462	1035
Thick lipped grey mulley	*Chelon labrosus*	168	8
Thin lipped grey mullet	*Chelon ramada*	1	
3-spined stickleback	*Gasterosteus aculeatus*	38	1
Twaite shad	*Alosa fallax*	42	9
Whiting	*Merlangius merlangus*	25	2
Butterfish	*Pholis gunnellus*		1
Lesser spotted dogfish	*Scyliorhinus canicula*		2
Long-spined sea scorpion	*Taurulus bubalis*		2
River lamprey	*Lampetra fluviatilis*		1
Rock goby	*Gobius paganellus*		2
Sand smelt	*Atherina presbyter*		25
Scad	*Trachurus trachurus*		9

The above table shows that a total of 28 species were recorded in 2016 and 30 species in 2019. A total of 23 species were common to both survey years while 5 species were only recorded in 2016 and 7 species were only recorded in 2019. For both survey years a total of 35 species were recorded.

According to Ryan *et al.* (2019) the ecological status of all Waterford harbour waterbodies (eight in total extending to 45km^2) and referenced as the Barrow-Nore-Suir T were adjudged to be of good status for the years 2007, 2010, 2013, 2016 and 2019.

Other relevant fish survey work carried out in Waterford Harbour during recent years

National Bass Conservation Programme

Ryan *et al.* (2017) and Ryan *et al.* (2020) also reported on trawl surveys carried out in Waterford Harbour during September 2016 and September 2019 in relation to the National Bass Conservation Programme. The locations of individual trawls are shown in the Figure 6 below.

Figure 6: Map of the lower Barrow Suir Nore estuary, showing trawl tracks during the 2019 IFI trawl survey as part of the National Bass Conservation Programme

A wide range of fish species were recorded during the 2016 and 2019 trawl surveys in Waterford Harbour as detailed in Table 7 below.

Table 7: List of fish species recorded during the 2016 and 2019 trawl surveys carried out in Waterford Harbour by Inland Fisheries Ireland (Ryan et al. 2017, 2020)

List of species captured during the 2016 IFI Trawling survey of the Barrow Nore Suir estuary (red)					
List of species captured during the 2019 IFI Trawling survey of the Barrow Nore Suir estuary (black)					
Species common name	Species scientific name	Number	Number		
5-Bearded rockling	*Ciliata mustela*	1			
Ballan Wrasse	*Labrus bergylta*	1	1		
Brown trout	*Salmo trutta*	1	1		
European Seabass	*Dicentrarchus labrax*	39	291		
Brill	*Scophthalmus rhombus*	3	2		
Cod	*Gadus morhua*	16	6		
Common Sole	*Solea solea*	9	23		
Dab	*Limanda limanda*	9	94		
European eel	*Anguilla anguilla*	1			
Flounder	*Platichthys flesus*	271	1193		
Goby	*Pomatoschistus Sp.*	10	9		
Herring	*Clupea harengus*	21	3		
Nilsson's pipefish	*Syngnathus rostellatus*	2			
Lesser Spotted dogfish	*Scyliorhinus canicula*	9	13		
Lesser Weever	*Echiichthys vipera*	1	1		
Plaice	*Pleuronectes platessa*	100	167		
Pogge	*Agonus cataphractus*	12	22		
Pollack	*Pollachius pollachius*	20	9		
Pouting	*Trisopterus luscus*	2	4		
Scad	*Trachurus trachurus*	49	95		
Smelt	*Osmerus eperlanus*	51	15		
Smoothhound	*Mustelus asterias*	3	2		
Sprat	*Sprattus sprattus*	25	22		
Thick Lipped grey mullet	*Chelon labrosus*	36	32		
Tub Gurnard	*Chelidonichthys lucerna*	19	50		
Whiting	*Merlangius merlangus*	307	873		
Hake	*Merluccius merluccius*		1		
Mackerel	*Scomber scombrus*		1		
Painted ray	*Raja microocellata*		1		
Red mullet	*Mullus surmuletus*		6		
Sand smelt	*Atherina presbyter*		4		
Twaite shad	*Alosa fallax*		113		
Thin lipped grey mullet	*Chelon ramada*		17		

During the 2016 trawls a total of 26 species were recorded compared with 30 species in 2019. A total of 23 species were recorded during both survey years while 3 species were recorded only in 2016 and 7 species were recorded only in 2019. The total number of species recorded in both years was 33.

Fish impingement studies at Great Island thermal electricity generating station, Campile, Co. Wexford

The Great Island CCGT abstracts cooling water from Waterford Harbour. During the years 2017 and 2018 (Teague *at al*. 2018) and 2020,2021,2022 and 2023 (Anon. 2021a, 2021b, 2023a, 2023b) fish impingement studies were carried out at the station during June (2017,2021 and 2023) and November (2017,2020 and 2022) – typically over a period of 12 days.

Tables 8 and 9 detail the fish species washed off band-screens at the station during these studies (separate tables for June and November studies). Records for the November studies exclude sand goby – as they were recorded in such high numbers that they were too numerous to count. Small numbers of common goby are also excluded.

During all studies, large numbers of small / young individuals were recorded, as is typical for fish impingement studies of this kind in estuarine environments. Identification was difficult for a number of species e.g. Lesser / Nilsson's pipefish and Greater pipefish.

During the November 2017, 2020 and 2022 studies a total of 54 species of fish were recorded as follows:

Year	No. fish species	No. fish species common to all three years	No. fish species common to 2 years	No. species recorded in 1 year only
2017	30	23		
2020	42	23		
2022	43	23		
Total	54	23	13	18

Three further fish impingement studies were also carried out during June 2018 (Teague *et al.* 2018) and in June 2021 (Anon. 2021a) and June 2023 (Anon. 2023b).

During the June 2018, 2021 and 2023 studies a total of 42 species of fish were recorded as follows:

Year	No. fish species	No. fish species common to all three years	No. fish species common to 2 years	No. species recorded in 1 year only
2018	27	13		
2021	31	13		
2023	19	13		
Total	41	13	9	19

Table 8: List of fish species recorded during the November 2017, 2020 and 2022 fish impingement studies at Great Island CWS

Common name	Scientific name	Nov-17	Nov-20	Nov-22
15-spined stickleback	*Spinachia spinachis*	10	118	68
3-Spined stickleback	*Gasterosteus aculeatus*	3	1	3
5-Bearded rockling	*Ciliata mustela*	292	203	356
Butterfish / Gunnel	*Pholis gunnellus*	1	0	2
Clingfish	*Lepadogaster sp.*	**1**	**0**	0
Cod	*Gadus morhua*	119	0	0
Common goby	*Pomatoschistus microps*	0	0	0
Common snailfish / sea snail	*Liparis liparis*	2	0	0
Dab	*Limanda limanda*	9	2	3
Eel (yellow and silver)	*Anguilla anguilla*	17	8	4
Flounder	*Platichthys flesus*	54	6	66
Grey gurnard	*Eutrigla gurnardus*	12	47	1
Herring	*Clupea harengus*	230	285	2545
Hooknose / Pogge	*Agonus cataphractus*	370	968	651
Lesser sandeel	*Ammodytes tobianus*	13	9	6
Long spined sea scorpion	*Taurulus bubalis*	5	3	0
Pipefish Spp		**1957**	0	0
Plaice	*Pleuronectes platessa*	67	26	14
Pollock	*Pollachius pollachius*	39	62	12
Poor cod	*Trisopterus minutus*	4	2	9
River lamprey	*Lampetra fluviatilis*	67	10	3
Sand goby *	*Pomatoschistus minutus*	0	0	0
Sea bass	*Dicentrarchus labrax*	35	14	293
European smelt	*Osmerus eperlanus*	1539	1633	1776
Snake pipefish	*Entelurus aequoreus*	2	27	46
Sprat	*Sprattus sprattus*	1170	696	6976
Thin lipped grey mullet	*Chelon ramada*	5	3	7
Twaite shad	*Alosa fallax*	4	69	242
Whiting	*Merlangius merlangus*	1430	1628	389
Black Goby	*Gobius niger*	0	0	0
Common pipefish		**0**	**0**	0
Dover Sole / Common sole	*Solea solea*	0	3	2
Greater Pipefish	*Syngnathus acus*	0	306	1929
Horse mackerel / scad	*Trachurus trachurus*	0	0	5
Lesser / Nilsson's Pipefish	*Syngnathus rostellatus*	**0**	1095	3038
Lesser Weaver	*Echiichthys vipera*	0	0	0
Saithe / coley	*Pollachius virens*	0	0	0
Shorthorn Sculpin /Short spined sea scorpion	*Myoxocephalus scorpius*	0	1	0
Smooth sandeel	*Gymnammodytes semisquamatus*	**0**	**0**	0
Tub gurnard	*Chelidonichthys lucernus*	0	355	2
Atlantic salmon smolt	*Salmo salar*	0	0	1
Trout / sea trout / slob trout	*Salmo trutta*	0	0	0
3 bearded rockling	*Gaidropsarus vulgaris*	0	1	0
Monkfish	*Squatina squatina*	**0**	0	0
Rock goby	*Gobius paganellus*	0	1	5
Conger eel	*Conger conger*	0	1	1
sand smelt	*Atherina presbyter*	0	0	2
Sea lamprey	*Petromyzon marinus*	0	3	2
Red gurnard	*Chelidonichthys cuculus*	0	1	0
Shore rockling	*Gaidrospsarus mediterraneus*	0	1	0
Worm Pipefish	*Nerophis lumbriciformis*	0	2	3
Dragonet	*Callionymus lyra*	0	5	2
Northern Rockling	Ciliata septentrionalis	0	28	0
Eurasian Perch	*Perca fluviatilis*	0	1	4
Corkwing Wrasse	*Symphodus melops*	0	1	2
Turbot	*Psetta maxima*	0	2	0
Transparent Goby	*Aphia minuta*	0	4	0
Anchovy	Engraulis encrasicolus	0	0	0
Pouting	Trisopterus luscus	0	0	55
Goldsinny Wrasse	Ctenolabrus rupestris	0	0	2
Golden grey mullet	Liza ramada	0	0	10
Tadpole fish	Raniceps raninus	0	0	1
Roach	Rutilus rutilus	0	0	1
Total number of fish recorded		7457	7631	18539

Table 9: List of fish species recorded during the June 2018, 2021 and 2023 fish impingement studies at Great Island CWS

Fish Species (common name)	Fish Species (Scientific name)	Jun-18	Jun-21	Jun-23
15-spined stickleback	*Spinachia spinachia*		1	
3-Spined stickleback	*Gasterosteus aculeatus*			
5-Bearded rockling	*Ciliata mustela*	22	27	18
Butterfish / Gunnel	*Pholis gunnellus*	2	1	
Clingfish	*Lepadogaster sp.*			
Cod	*Gadus morhua*	700		
Common goby	*Pomatoschistus microps*	178	23	
Common snailfish / sea snail	*Liparis liparis*			
Dab	*Limanda limanda*		1	
Eel (yellow and silver)	*Anguilla anguilla*	13	24	19
Flounder	*Platichthys flesus*	524	94	59
Grey gurnard	*Eutrigla gurnardus*		1	
Herring	*Clupea harengus*	1	649	38
Hooknose / Pogge	*Agonus cataphractus*	41	219	8
Lesser sandeel	*Ammodytes tobianus*		1	
Long spined sea scorpion	*Taurulus bubalis*	1		
Pipefish Spp				
Plaice	*Pleuronectes platessa*	88	28	
Pollock	*Pollachius pollachius*	223	8	1
Poor cod	*Trisopterus minutus*			
River lamprey	*Lampetra fluviatilis*	2	3	
Sand goby	*Pomatoschistus minutus*	324	2360	
Sea bass	*Dicentrarchus labrax*		2	69
European smelt	*Osmerus eperlanus*	178	3486	28
Snake pipefish	*Entelurus aequoreus*			
Sprat	*Sprattus sprattus*	4948	1044	130
Thin lipped grey mullet	*Liza ramada*			
Twaite shad	*Alosa fallax*		2	3
Whiting	*Merlangius merlangus*	270	70	11
Black Goby	*Gobius niger*	19		
Common pipefish		1		
Dover Sole / Common sole	*Solea solea*	1	6	
Greater Pipefish	*Syngnathus acus*	7	64	28
Horse mackerel / scad	*Trachurus trachurus*	1		
Lesser / Nilsson's Pipefish	*Syngnathus rostellatus*	104	39	50
Lesser Weaver	*Echiichthys vipera*	2		
Saithe / coley	*Pollachius virens*	1		
Shorthorn Sculpin /Short spine	*Myoxocephalus scorpius*	4		
Smooth sandeel	*Gymnammodytes semisquamatus*	10		
Tub gurnard	*Chelidonichthys lucernus*	1	1	
Atlantic salmon smolt	*Salmo salar*		1	
Trout / sea trout / slob trout	*Salmo trutta*		3	
3 bearded rockling	*Gaidropsarus vulgaris*		1	
Monkfish	*Squatina squatina*			
Rock goby	*Gobius paganellus*		9	1
Conger eel	*Conger conger*		1	2
sand smelt	*Atherina presbyter*			
Sea lamprey	*Petromyzon marinus*			
Red gurnard	*Chelidonichthys cuculus*			
Shore rockling	*Gaidrospsarus mediterraneus*		1	
Worm Pipefish	*Nerophis lumbriciformis*			
Dragonet	*Callionymus lyra*			
Northern Rockling	Ciliata septentrionalis			
Eurasian Perch	*Perca fluviatilis*			
Corkwing Wrasse	*Symphodus melops*			
Turbot	*Psetta maxima*			1
Transparent Goby	*Aphia minuta*			
Anchovy	*Engraulis encrasicolus*		1	
Pouting	*Trisopterus luscus*			
Goldsinny Wrasse	*Ctenolabrus rupestris*			
Golden grey mullet	*Liza aurata*			
Tadpole fish	*Raniceps raninus*			
Roach	*Rutilus rutilus*			
Red mullet	*Mullus surmuletus*			1
		7666	8171	467

Harrison & Kelly (2013) provide a reference check list of fish species recorded in Irish estuaries against which to gauge the current status of Irish estuaries.

Table 10 below details this check list and also details those fish species, which are on the reference list, and which have been recorded in Waterford Harbour recently during Water Framework Directive surveillance monitoring surveys in 2016 and 2019 (Ryan *et al.* 2017, 2020), National Bass Conservation Programme trawls in 2016 and 2019 (Ryan *et al.* 2017, 2020) and Great Island thermal electricity generating station fish impingement studies carried out during 2017 and 2018 (Teague *et al*. 2018) and 2020, 2021, 2022 and 2023 (Anon. 2021a, 2021b, 2023a, 2023b).

Table 10: Reference estuarine fish list of Harrison & Kelly (2013) compared with WFD sampling fish list, National Bass Conservation Programme sampling fish list and Great Island CWS impinged fish list

Reference check list of estuary-associated fishes recorded in Irish waters and their associated abundance and functional guilds (Harrison & Kelly 2013)									
		Abundance			Guild		WFD sampling	NBCP Trawl	Great Island FIS
Species common name	Species Scientific name	Description	Score		Estuary use	Feeding			
Sturgeon	*Acipenser sturio*	Scarce	1		AN	ZB			
Hooknose / Pogge	*Agonus cataphractus*	Numerous	4		MM	ZB	+	+	+
Allis shad	*Alosa alosa*	Scarce	1		AN	ZP			
Twaite shad	*Alosa fallax*	Few	2		AN	ZP	+	+	+
Lesser sandeel	*Ammodytes tobianus*	Few	2		ES	ZP	+	+	+
European eel	*Anguilla anguilla*	Numerous	4		CA	ZB	+	+	+
Transparent goby	*Aphia minuta*	Many	3		ES	ZP			+
Sand smelt	*Atherina presbyter*	Abundant	5		MM	ZP	+	+	+
Garfish	*Belone belone*	Few	2		MM	PV			
Tub gurnard	*Chelidonichthys lucernus*	Many	3		MM	ZB		+	+
Thick-lipped grey mullet	*Chelon labrosus*	Abundant	5		MM	DV	+	+	
5 bearded rockling	*Ciliata mustela*	Numerous	4		MM	ZB	+	+	+
Northern rockling	*Ciliata septentrionalis*	Scarce	1		MM	ZB			+
Herring	*Clupea harengus*	Abundant	5		MM	ZP	+	+	+
Conger eel	*Conger conger*	Many	3		MM	PV			+
Corkwing wrasse	*Symphodus (Crenilabrus) melops*	Many	3		MM	ZB	+		+
Lumpsucker / sea hen	*Cyclopterus lumpus*	Few	2		MM	ZP			
Sting ray	*Dasyatis pastinaca*	Scarce	1		MM	ZB			
Sea bass	*Dicentrarchus labrax*	Abundant	5		MM	PV	+	+	+
Two-spotted clingfish	*Diplecogaster bimaculata*	Scarce	1		ES	ZB			
Anchovy	*Engraulis encrasicolus*	Scarce	1		MM	ZP			+
Snake pipefish	*Entelurus aequoreus*	Numerous	4		MM	ZP			+
Grey gurnard	*Eutrigla gurnardus*	Many	3		MM	ZB			+
Cod	*Gadus morhua*	Numerous	4		MM	PV	+	+	+
3-spined stickleback	*Gasterosteus aculeatus*	Many	3		FM	ZP	+		+
Black goby	*Gobius niger*	Many	3		ES	ZB			+
Rock goby	*Gobius paganellus*	Many	3		ES	ZB	+		+
Spiny seahorse	*Hippocampus guttulatus*	Scarce	1		ES	ZP			
Corbin's sandeel	*Hyperoplus immaculatus*	Few	2		MM	ZP			
River lamprey	*Lampetra fluviatilis*	Few	2		AN	PV	+		+
Dab	*Limanda limanda*	Numerous	4		MM	ZB	+	+	+
Common snail fish / sea sna	*Liparis liparis*	Few	2		ES	ZB			+
Golden grey mullet	*Liza aurata*	Few	2		MM	DV		+	+
Thin-lipped grey mullet	*Liza ramada*	Abundant	5		MM	DV	+	+	+
Whiting	*Merlangius merlangus*	Abundant	5		MM	PV	+	+	+
Red mullet	*Mullus surmuletus*	Few	2		MM	ZB		+	+
Short-spined sea scorpion	*Myoxocephalus scorpius*	Many	3		MM	PV			+
Worm pipefish	*Nerophis lumbriciformis*	Many	3		ES	ZP			+
Straight-nosed pipefish	*Nerophis ophidion*	Few	2		ES	ZP			
European smelt	*Osmerus eperlanus*	Numerous	4		AN	PV	+	+	+
Red / Blackspot sea-bream	*Pagellus bogaraveo*	Few	2		MM	ZB			
Sand sole	*Pegusa lascaris*	Scarce	1		MM	ZB			
Sea lamprey	*Petromyzon marinus*	Few	2		AN	PV			+
Butterfish / Gunnel	*Pholis gunnellus*	Many	3		MM	ZB	+	+	+
Flounder	*Platichthys flesus*	Abundant	5		MM	ZB	+	+	+
Plaice	*Pleuronectes platessa*	Numerous	4		MM	ZB	+	+	+
Pollack	*Pollachius pollachius*	Many	3		MM	PV	+	+	+
Common goby	*Pomatoschistus microps*	Numerous	4		ES	ZB	+	+	+
Sand goby	*Pomatoschistus minutus*	Abundant	5		ES	ZB	+	+	+
Turbot	*Psetta maxima*	Many	3		MM	PV	+		+
Thornback ray	*Raja clavata*	Many	3		MM	ZB			
Tadpole fish	*Raniceps raninus*	Scarce	1		ES	ZB			+
Atlantic salmon	*Salmo salar*	Many	3		AN	ZB	+	+	+
Trout	*Salmo trutta*	Many	3		AN	ZB	+	+	+
Pilchard / sardine	*Sardina pilchardus*	Numerous	4		MM	ZP			
Brill	*Scophthalmus rhombus*	Many	3		MM	PV	+	+	
Dover sole	*Solea solea*	Abundant	5		MM	ZB	+	+	+
Gilthead	*Sparus aurata*	Scarce	1		MM	ZB			
9- / 10-spined stickleback	*Spinachia spinachia*	Many	3		ES	ZP			
Black sea-bream	*Spondyliosoma cantharus*	Few	2		MM	OV			
Sprat	*Sprattus sprattus*	Abundant	5		MM	ZP	+	+	+
Greater pipefish	*Syngnathus acus*	Numerous	4		ES	ZP			+
Nilsson's / Lesser pipefish	*Syngnathus rostellatus*	Abundant	5		ES	ZP	+	+	+
Deep-snouted pipefish	*Syngnathus typhle*	Few	2		ES	ZP			
Long-spined sea scorpion	*Taurulus bubalis*	Many	3		MM	ZB	+		+
Piper	*Trigla lyra*	Many	3		MM	ZB			
Norway pout	*Trisopterus esmarkii*	Numerous	4		MM	ZB			
Pout / Bib	*Trisopterus luscus*	Abundant	5		MM	ZB		+	+
Poor cod	*Trisopterus minutus*	Abundant	5		MM	ZB			+
Viviparous blenny / Eelpout	*Zoarces viviparus*	Few	2		ES	ZB			

Of the 70 fish species referenced in Harrison & Kelly (2013) the following number of species were recorded during the various surveys and studies in Waterford Harbour

Survey / Study	**No. fish species**	**No. fish species common to all three surveys / studies**	**No. fish species common to two surveys / studies**	**No. fish species common to one survey**
WFD* 2016, 2019	32	23		
NBCP** 2016, 2019	30	23		
GI FIS*** 2017,2018, 2020,2021,2022, 2023	48	23		
Overall	49	23	12	14

*Water Framework Directive surveillance monitoring survey (beach seine, fyke net, trawl)
**National Bass Conservation Programme survey (trawl)
***Great Island CWS Fish Impingement Study

Thus, a total of 49 of the 70 fish species referenced in Harrison & Kelly (2013) were recorded in Waterford Harbour during the various fish surveys detailed above. The fish impingement studies at Great Island CWS provided by far the most comprehensive picture of the fish species present in Waterford Harbour.

References

Anon. (2021a) Great Island CWS Fish Impingement Study (November 2020) Aztec Management Consultants, Dublin and Aquafact International Services Ltd., Galway.

Anon. (2021b) Great Island CWS Fish Impingement Study (June 2021) Aztec Management Consultants, Dublin and Aquafact International Services Ltd., Galway.

Anon. (2023a) Great Island CWS Fish Impingement Study (November 2022) Aztec Management Consultants, Dublin and Triturus Environmental Ltd., Cork

Anon. (2023b) Great Island CWS Fish Impingement Study (June 2023) Aztec Management Consultants, Dublin and Triturus Environmental Ltd., Cork

Cabral, H.N, Angel Borja, Vanessa F. Fonseca, Trevor D. Harrison, Nils Teichert, Mario Lepage, and Miguel C. Leal (2022) Fishes and Estuarine Environmental Health Fish and Fisheries in Estuaries: A Global Perspective, Volume I, First Edition. Edited by Alan K. Whitfield, Kenneth W. Able, Stephen J.M. Blaber, and Michael Elliott. John Wiley & Sons Ltd. Published 2022 by John Wiley & Sons Ltd.

Connor,L., Ryan,D., Feeney,R., Roche,W.K., Shephard,S and Kelly,F. (2019) Biogeography and fish community structure in Irish estuaries Regional Studies in Marine Science 32: 1008 36 1-15

Cowley, P.D., James R. Tweedley and Alan K. Whitfield (2022) Conservation of Estuarine Fishes Fish and Fisheries in Estuaries: A Global Perspective, Volume II, First Edition. Edited by Alan K. Whitfield, Kenneth W. Able, Stephen J.M. Blaber, and Michael Elliott. John Wiley & Sons Ltd.

Dando, P.R. (1984) Reproduction in Estuarine Fish In: Fish Reproduction: Strategies and Tactics, G.W. Potts and R.J. Wootton (eds.). Academic Press, London (1984).

Day, J. W., Hall, C. A. S., Kemp, W. M. & Yáñez-Arancibia, A. (Eds) (1989). Estuarine Ecology. New York, NY: John Wiley & Sons

Elliott, M. & Taylor, C. J. L. (1989). The structure and functioning of an estuarine/marine fish community in the Forth estuary, Scotland. In Proceedings of the 21st European Marine Biology Symposium, Gdánsk,pp.227–240.Warsaw:PolishAcademyofSciences,Institute of Oceanology.

Gamito, R., Stéphanie Pasquauda, Anne Courrat, Hilaire Drouineaub, Vanessa F. Fonsecaa, Catarina I. Goncalves, Noémie Wouters, José L. Costa, Mario Lepage, Maria J. Costa and Henrique N. Cabral (2012) Influence of sampling effort on metrics of fish-based indices for the assessment of estuarine ecological quality Ecological Indicators 23: 9–18

Hadderingh, R.H., Jager, Z., 2002. Comparison of fish impingement by a thermal power station with fish populations in the Ems estuary. Journal of Fish Biology 61, 105–124.

Harrison, T.D. and Kelly,F.L. (2013) Development of an estuarine multi-metric fish index and its application to Irish transitional waters Ecological Indicators 34 494-506

Kelly, F.L., Matson, R., Coyne, J., Feeney, R., Morrissey, E. and Rocks, K. (2013) Water Framework Directive Fish Stock Survey of Transitional Waters in the South Eastern River Basin District – Barrow, Nore and Suir Estuary. Inland Fisheries Ireland, Swords Business Campus, Swords, Co. Dublin, Ireland.

Korringa, P. (1967). Estuarine fisheries in Europe as affected by man's multiple activities. In Estuaries (Lauff, G., ed), pp. 608–666. American Association for Advances in Science, Special Publication 83. Washington, DC: American Association for Advances in Science.

Matveev, V.F. and Steven, A.D.L. (2014) The effects of salinity, turbidity and flow on fish biomass estimated acoustically in two tidal rivers Marine and Freshwater Research, 2014, 65, 267–274

Neill M 2000 A Report on Water Quality in the Suir/Barrow/Nore Estuary 1999 Environmental Protection Agency, Regional Water Laboratory, Butts Green, Kilkenny, Ireland

Postma, H. & Rauck, G. (1979). The fishery in the Wadden Sea. In Fishes and Fisheries of the Wadden Sea (Dankers, N., Wolf, W. & Zijlstra, J., eds), pp. 139–157. Rotterdam: A. A. Balkema.

Ryan, D., Coyne, J., Putharee, D. and Roche, W. (2017). Fish Stock Survey of Transitional Waters in the Southern River Basin District – Barrow, Nore, Suir Estuary 2016. Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24, Ireland.

Ryan, D., Cooney, J., Leonard, E., Nolan, K. and Roche, W. (2020). Fish Stock Survey of Transitional Waters in the Southern River Basin District – Barrow, Nore, Suir Estuary 2019. Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24, Ireland.

Teague, N., Sutcliffe, A., Fullbrook, L., Phillips, R. and Scorey, A. (2018) Great Island Power Station - Fish Impingement Study for SSE APEM, UK

Tweedley, J.R., Warwick, R.M. and Potter, I.C. (2016) The Contrasting Ecology of Temperate Macrotidal and Microtidal Estuaries. In: Hughes, R.N., Hughes, D.J., Smith, I.P. and Dale, A.C., (eds.) Oceanography and Marine Biology: An Annual Review. CRC Press, pp. 73-171

Went, A.E.J. (1959) Sprat or white-fish weirs in Waterford Harbour. The Journal of the Royal Society of Antiquaries of Ireland, 89, No. 1, pp 91-93

Whitfield, A.K. (2016) Biomass and productivity of fishes in estuaries: a South African case study. Journal of Fish Biology