European smelt (*Osmerus eperlanus* (L.)) Recovery Management Plan for the Solway Firth Marine Conservation Zone (MCZ)

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European smelt (*Osmerus eperlanus (L.)*) Recovery Management Plan for the Solway Firth Marine Conservation Zone (MCZ)

For Natural England

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1. BACKGROUND AND INTRODUCTION

The Galloway Fisheries Trust (GFT) has been commissioned by Natural England to produce a Smelt Recovery Management Plan for the Solway Firth Marine Conservation Zone (MCZ). The Solway Firth MCZ was designated in May 2019 and has the fish species European smelt (*Osmerus eperlanus*) as a feature.

The intention of designating MCZs in England is to help protect the remaining populations of smelt and prevent further loss or decline of populations. The designation and subsequent protections also aim to allow numbers of smelt to recover where they are known to have declined.

This report provides a framework and plan for restoring smelt to the Solway Firth MCZ and has the wider aim of rolling the plan on to other MCZs with smelt as a feature.

GFT has worked primarily with Solway Firth Partnership and Steve Colclough (SC^2) to produce this management plan.

SC^2 was contracted by Natural England to work alongside GFT and provide some wider perspective on smelt.

This report is composed of two parts: Part 1 - Smelt Management: a National Perspective; and Part 2 - Smelt management in the Solway Firth MCZ.

2. AIMS

2.1 To carry out a desk study to review existing literature and collate expert opinions.

2.2 To engage with stakeholders and experts to determine the current status of smelt in the Solway Firth MCZ.

2.3 Produce a management plan detailing the pressures, restoration options and opportunities for the recovery of smelt in the Solway Firth MCZ.

Part 1: Smelt Management: a National Perspective

3. SMELT

3.1 Ecology

European smelt (*Osmerus eperlanus*), also known as sparling, is a rare species of fish in the UK which has historically been found in 76 water bodies around the British Isles. Smelt are a UK Biodiversity Action Plan priority species included in the regional biodiversity lists of England, Wales and Scotland (Etheridge, 2010). The species has a broad distribution around the western coasts of Europe to north west Spain. There are several non-migratory populations in freshwater lake systems in Scandinavia. The species is primarily anadromous in the west of its distribution and lacustrine in the east.

Balyanina (1969) and Nellbring (1989) have provided reviews of the ecology of the species. Maitland and Campbell (1992) provided a summary of the ecology of the species in the British Isles.

Smelt are a short-lived anadromous species with a typical maximum lifespan of four years, reaching sexual maturity at 1+ (Ribbens and Graham, 2004), at which point smelt then enter the spawning stock (Hutchinson, 1983). Mature adults are believed to form pre-spawning shoals during October/November prior to moving into the lower river to spawn between February and April (Ribbens and Graham, 2004). Smelt can form the dominant part of the fish communities found in estuaries. Thiel (2001) estimated that smelt accounted for 96% of the total annual production of all dominant fish species of age groups 0+ and 1+ in the Elbe estuary.

The majority of the smelt lifecycle is spent in the marine and estuarine environments but they require freshwater to complete their lifecycle, spawning in suitable freshwater and littoral habitats around the upper tidal limit of natal rivers (Rochard and Elie, 1994). The thermal regime of the lower reaches of rivers is considered the primary factor to initiate reproduction, with fish spawning after water temperatures rise in the spring to over 5°C (Etheridge, 2010). Year on year the exact location of spawning is strongly influenced by the height of the tide and the river flow conditions (Maitland and Lyle, 1997). Due to their relatively weak swimming ability, higher river flows may hinder their ascent to optimal spawning areas with ideal substrates (Etheridge, 2010).

For approximately a week in spring smelt utilise the incoming flow of the spring high tides, usually during the hours of darkness, to migrate to suitable spawning grounds (Etheridge, 2011). They typically spawn in shallow, fast flowing riffle sections of river, with pebble and cobble substrates (Etheridge, 2011). Smelt spawn en mass and during the spawning period each female will release between 40,000 and 106,000 eggs (Etheridge, 2011). These eggs adhere to substrates and water weed to develop over the forthcoming weeks, depending on water temperatures. This can take between 20 and 35 days (Maitland and Campbell, 1992). Hatching duration is also dependent on temperature, varying between 2 and 10 days (McCarthy and others, 2019), then the young fry are swept downstream into the upper estuary where they start to feed on zooplankton (Ribbens and Graham, 2004). Fry may grow up to 10 cm in the first year, then to 15 cm by the end of their second year (Maitland and Campbell, 1992). Over the first year they feed on minute zooplankton such as rotifers and then as they grow their diets comprises of larger planktonic crustaceans before becoming voracious predators feeding on small fish such as herring, sprat or gobies (Maitland and Campbell, 1992).

3.2 Habitat requirements

3.2.1 Spawning habitat

The location of spawning is very important in terms of salinity and temperature which affect the development duration as well as the hatching success of smelt eggs. Lower temperatures lead to a longer incubation period and hatching duration, and as salinities rise over 10ppt, the hatching success proportionately decreases (McCarthy and others, 2019). Thus, the upper tidal reaches, or just above the tidal limit, is ideal for egg development as salt water inundations are less frequent and more diluted, reducing egg exposure to salt water. High egg mortality rates have been shown in conditions exceeding 20ppt (Doherty and McCarthy, 2004).

Spawning should ideally occur in areas of shallow, fast flowing riffles with pebble and cobble sized substrates and sufficient mosses (Etheridge, 2011) or vegetation. The pebble and cobble substrates and mosses/vegetation provide a large surface area to which the eggs can adhere securely, developing in situ for the forthcoming weeks (Etheridge, 2010). River flow velocities in the spawning location are also an important factor (Graham and Stevens, 2004); insufficient flows do not disperse eggs effectively, possibly leading to clusters of eggs unable to develop or possibly being washed away by river flows. It can be seen in the field that spawning smelt favor faster flowing water to enable better egg dispersal. Costello and others, (2002) noted that the egg of the smelt possesses a second outer membrane which folds back to form an adhesive stalk which acts as the means of attachment. When the egg shears off, the outer membrane acts as an umbrella, which may serve the purpose of further aiding dispersal. Unattached eggs close to hatching have been reported from the Thames in April in the Wandsworth area (C. Conroy, pers comm and Section 5.2.3).

3.2.2 Juvenile habitat

Salt marsh habitats are known to be utilised by nekton species as nursery grounds (Moller and Scholz, 1991, Colclough and others, 2005), as they provide food as well as protection from predators. Protecting valuable nursery grounds such as salt marshes, could support juvenile smelt development and increase recruitment to adult stages (Minello and others, 2003) as nekton survival has proven to be higher in salt marsh environments that in open water (Minello and others, 2003).

During the juvenile stages, smelt are opportunistic feeders with a diet typically consisting of small zooplankton including copepods and small crustaceans such as cladocerans (Northcote and Hammar, 2006). As the juvenile fish continue to develop their diet expands to larger crustaceans and small fish, possibly including drifting smelt larvae.

3.2.3 Adult habitat

Smelt are thought to be primarily an estuarine species and have been recorded in various locations. Little is known about how smelt utilise the marine environment in the course of their life cycle. Maitland (2003) considered the smelt be an estuarine species with limited capability to move through full strength sea water. This view has important implications for the restoration of former isolated populations. Colclough (2013) cites seasonal catches made in 2010 at Sizewell Power Station in Suffolk. This intake is situated in full strength sea water some 12 km from the nearest estuary to the north, the Blythe and 25 km from the nearest estuary to the south, the Alde/Ore. There are smelt in the Alde/Ore. The Blythe has yet to be sampled. This data demonstrates for the first time that smelt can move between estuaries some distance apart. This view is supported by later information under the authorisations section in this report, where smelt were taken as bycatch in a black bream fishery off the south coast of England between Selsey Bill and Shoreham for several years in the middle of the last decade. There are no known smelt riverine populations on this section of the south coast (Colclough, 2013). Adults are known to form pre-spawning concentrations in lower estuaries in the autumn and winter, before migrating into freshwater to spawn in the spring (Sepulveda and others, 1993). After spawning has taken place, adult smelt migrate into coastal waters close to estuaries (Freyhof, 2011).

Little is known about the requirements of adult smelt. If we consider typical smelt diets, which consist of species such as herring, sprat and gobies it would be assumed that adult smelt favour areas where this prey is abundant enough to support large populations of predatory smelt.

3.3 Location

Maitland undertook reviews of the status of smelt in England and Wales (2003) and in Scotland (2010). Colclough (2013) conducted a further review in England and Wales. In total smelt have been recorded in 76 waterbodies around England (59), Wales (3) and Scotland (15). Those recorded in English and Welsh systems have been grouped into 36 populations based on the hydrographic areas in which they were found although it is understood that these populations are likely not discrete. Maitland (2003) had previously concluded that 52 waterbodies in England and Wales had historic or present records of smelt. Colclough (2013) found evidence of an additional five populations and since that review evidence of a further two populations have been found in the River Burn and the River Glaven (part of the Norfolk R G hydrographic area) (Colclough, S. pers obs).

The following information relates to geographic groupings of smelt populations, going clockwise around the coast, starting in the north east of England (NB not all populations are mentioned):

- The Tyne now supports a recovering population of smelt, with spawning known to occur somewhere near the head of tide at Newburn

- The Yorkshire Ouse and Trent, which jointly drain to the Humber, both now support significant authorised fisheries for smelt in their upper tidal reaches. Smelt have been captured in Water Framework Directive (WFD) surveys in both systems

- The Great Ouse system supports significant populations of smelt in a number of connected watercourses, as shown in past freshwater fish surveys, WFD surveys near the Wash and in modern commercial authorised fisheries. Colclough (2013) agreed with Maitland (2003) that the populations across all the watercourses that share the Wash are probably linked, ie Nene, Welland, Witham, Ouse

- The Norfolk Broads supports large populations of smelt. As demonstrated by past freshwater fish surveys, WFD surveys in Breydon Water and the current authorised fishery on the Waveney. Tracking by Cefas on the Waveney (Moore, 2016) has shown extensive movements. It is very probably that this is a common population across the Norfolk Broads system, ie Bure, Waveney, Yare, Ant, Wensum, Thurne

- The Thames and Medway now both support very significant populations of smelt with known local spawning. The populations across the Greater Thames estuary, including the above plus the Blackwater, Crouch Roach and Swale are probably linked

- Maitland reported no smelt from rivers to the east of Southampton on the south coast. The WFD programme reported no smelt in the Adur or Arun. Both Maitland and Colclough report small numbers of smelt taken by marine fishermen off the south coast. Some have been taken from Shoreham PS at the mouth of the Adur. The only population on this section of the south coast appears to be associated with the River Frome and Poole Harbour, although smelt have not been taken in WFD surveys in Poole Harbour itself. The only other significant population anywhere on the south coast is in the Tamar

- Very small numbers of fish were taken in the WFD programme in the Nyfer (Nevern) and Conwy. WFD demonstrated a significant recruiting population in the Dee and a very modest population in the Mersey, which might well be linked

- WFD reported modest numbers of smelt in both the Ribble and Wyre, both showing evidence of local recruitment

- WFD reported evidence of a modest population associated with the Lune. In the Solway, 27 fish have been captured in WFD seine netting between 2008-2012 at sites at Silloth and Bowness.

Historically there were 15 known populations recorded in Scotland, nine of the rivers flowed into the Solway: the Rivers Bladnoch, Cree, Fleet, Kirkcudbrightshire Dee, Urr, Nith, Lochar Water, Annan and the Border Esk (Etheridge, 2010). Historically, there had been a further six known populations around Scotland: in the Rivers Almond, Clyde, Forth, Girvan, Stinchar and Tay. In the present day only three populations are known to remain; those in the Rivers Cree, Forth and Tay (Maitland, 2003).

Such significant declines in populations of smelt over the UK are attributed to overexploitation, the building of impassable barriers and the decline in water quality (Maitland and Lyle, 1997).

3.4 Conservation and legal status

3.4.1 UK level

Smelt are listed on the International Union for Conservation of Nature (IUCN) Red list of Threatened Species as a species of least concern, stating that the species has a widespread distribution with no known major widespread threats. However, is locally threatened by pollution and barriers to migration (Freyhof, 2011). Winfield and others, (1994), described the European status of the smelt as vulnerable, (rare and very sensitive to anthropogenic environmental changes), while it was considered rare in the British Isles.

Smelt conservation in the UK has much been advocated by experts in the field of fish biology and management (Maitland, 2003). Conservation of the species after such significant declines is desired by many but until recently there have been no legislative targets to ensure improvements are made and conservation of smelt progresses. Smelt are not an ‘iconic species’ such as the Atlantic salmon, therefore there has been relatively little in the way of protection for the species.

The smelt was adopted under the UK Biodiversity Action Plan (UK BAP) as a Priority Species in 2007. Actions required for the species, identified by experts in Version 2 of the UK BAP (December 2010) were as follows:

Species–specific research:

- Review the case for the introduction or reintroduction of smelt to new or previously occupied sites
- Investigate the impact of climate change on smelt populations
- Complete a sampling programme for genetic analysis to determine origin of fish around UK and report.

Species-specific management action:

- Restoration of stocks to previously occupied rivers (e.g. Rivers Tyne, Nith, Annan, etc). Galloway Fisheries Trust – Cree to Water of Fleet.

Wider "landscape" action:

- Ensure existing fisheries are monitored and sustainable. Removal of man-made barriers to migration in all UK rivers
- Removal of man-made barriers to migration in all UK rivers.

The 'UK Post-2010 Biodiversity Framework' succeeds the UK BAP and ‘Conserving Biodiversity – the UK Approach’ and is the result of a change in strategic thinking following the publication of the Convention on Biodiversity's ‘Strategic Plan for Biodiversity 2011–2020’ and its 20 ‘Aichi targets’, at Nagoya, Japan in October 2010, plus the launch of the new EU Biodiversity Strategy (EUBS) in May 2011 and to better reflect UK devolution. The Environment Departments of all four governments in the UK work together through the Four Countries Biodiversity Group. The lists of priority species and habitats agreed under UK BAP still form the basis of much biodiversity work in the countries. The smelt is listed as a priority species in all four country lists.

Other measures are in place in England, Wales and Scotland.

3.4.1.1 England and Wales

Information relating to the River Dee (on the border of England and Wales) and the Dee estuary Site of Special Scientific Interest (SSSI) notably makes reference to smelt being present and important. However it alone is not a reportable feature or a feature monitored in its own right. The Dee Estuary SSSI was designated in 1998 covering approximately 6320 ha. The River Dee SSSI was then itself designated in 2003 protecting a further 362 ha. Wales has another SSSI designation which mentions smelt, Milford Haven Waterway, which was designated in 2002 protecting approximately 2192 ha (Welsh Government, 2019).

Modifications to the salmon and freshwater fisheries legislation in England and Wales made through the Marine and Coastal Access Act, 2009 have brought the smelt into the legislative stream as a migratory species. Through a further modification via the same route, regulation of smelt fisheries is now operated by the Environment Agency in England through a process of authorisation, rather than licensing. Conditions are applied to each authorisation to promote sustainable fisheries and environmental management. There are no authorised fisheries permitted through this legislation in Wales.

Further details of the authorisation process and charging scales can be found at the following link - http://www.environment-agency.gov.uk/research/library/consultations/125480.aspx. A specimen authorisation is included in Appendix 3.

3.4.1.2 Scotland

Smelt are listed as a species of principle importance for biodiversity and conservation on the Scottish Biodiversity List. In terms of protective designations smelt are features of two SSSI designations in Scotland, both along the River Cree giving them protection under the Wildlife and Countryside Act 1981 (as amended). The Cree Estuary SSSI was designated in 1987 and covers approximately 3442 ha. Shortly after, in 1991, the Lower River Cree SSSI was designated to extend the protection of known smelt spawning grounds, covering approximately 143 ha. Currently there are no other protection zones designated for smelt around Scotland.

3.4.2 Marine Conservation Zones

Marine Conservation Zones (MCZs) were established under the Marine and Coastal Access Act (2009). The designation of these areas aims to protect important, rare or threatened marine species and habitats of national importance based on an ecosystem approach (JNCC, 2019).

A total of 91 MCZs have been designated in English inshore waters in three tranches between 2013 and 2019 (27 in 2013; 23 in 2016 and 41 in 2019), covering areas which protect not only important species but geological and geomorphological features. The smelt is a Feature Of Conservation Importance (FOCI) species for the designation of MCZs in England. There are now five estuarine MCZs where the smelt is a supporting designated feature, these are the Medway, Ribble, Tamar, Wyre/Lune, and Solway Firth. Further descriptions of these five sites are provided in the section below. Aside from these recent designations, there are no other designated marine protection areas (MPAs) featuring smelt (Natural England and JNCC, 2012).

The equivalent to MCZs in Scotland is Nature Conservation Marine Protected Areas (NCMPA), of which there are 18. The Solway Firth has not been designated as a NCMPA. In Wales smelt are not protected under any MCZ, SAC, SPA or RAMSAR designations (Welsh Government, 2019).

3.4.2.1 Medway Estuary

The Medway Estuary MCZ was originally designated in 2013 covering a total area of 60 km^2 from Rochester down to its mouth on the coast of Kent (DEFRA, 2019). The Medway was designated to protect nine features, habitats and species to be maintained in favorable condition. Smelt was added as an additional feature in 2019, along with a small extension to the boundary which only applies to smelt, upstream of the original upper boundary to include potential spawning habitat.

3.4.2.2 Ribble Estuary

The Ribble Estuary MCZ was designated in 2019, covering 15 km^2 of inshore waters to the mean tidal limit of the Ribble and the River Douglas, extending only to the estuary mouth at Lytham St Annes, in Lancashire (DEFRA[2], 2019). This designation was for the sole purpose of recovering smelt to favourable condition.

3.4.2.3 Tamar Estuary

The Tamar Estuary MCZ was designated in 2013, covering 15 km^2 in two spatially separate areas, the upper reaches of the Tamar and Lynher estuaries of South Devon and Cornwall. This designation protects five featured species and habitats, including the smelt (DEFRA, 2013).

3.4.2.4 Wyre-Lune Estuary

The Wyre-Lune MCZ was designated in 2019, covering an area of approximately 92 km^2 in the southern part of Morecambe Bay in Lancashire, extending to the upper reaches of the Wyre and Lune Estuaries (DEFRA[3], 2019). Smelt are the only feature of this designation with the aim of recovering them to favourable condition.

3.4.2.5 Solway Firth

In May 2019, as part of the third and final tranche of MCZ designations, the English part of the inner Solway Firth, covering 45 km^2, was designated as an MCZ, with smelt as the feature. The Solway Firth MCZ boundary includes the upper tidal limits of three rivers which flow into the Solway from Cumbria (the River Eden, River Wampool and River Waver) and extends up to the border with Scotland (DEFRA[4], 2019).

4. PRESSURES

Given the life history and environmental sensitivities of smelt, the species is considered to be a sensitive indicator species of good ecological status under the WFD (Coates and others, 2007). A combination of pressures, some more significant, can be attributed to the decline of smelt around the UK. Such pressures can include over-exploitation prior to spawning, pollution, barriers to migration, river channel alteration, flow augmentation, habitat loss, and these can prevent smelt spawning successfully (Doherty and McCarthy, 2004). These pressures can also affect the post-spawning development of eggs and larvae (Maitland and Lyle, 2001), particularly pollution events and siltation from upstream activities. It is likely that in some areas the direct pressures on smelt are no longer present but due to the legacy of previous impacts, and in some cases extinctions, populations of smelt in some systems still remain impacted and only a few populations appear to have re-established (Colclough, 2013).

4.1 Historic over-exploitation

In the past, smelt populations have been the basis of several large fisheries, targeting this popular delicacy (Colclough, 2013). Due to demand in the food trade, fisheries were able to exploit large numbers of smelt as they formed pre-spawning shoals in estuaries (Maitland, 2003). Particularly prominent fisheries for smelt as a food source were based on the Conwy, Humber, Medway, Thames and Tyne (Colclough, 2013).

Smelt are particularly vulnerable to over-exploitation and population collapse if a high proportion are exploited annually prior to spawning (Hutchinson, 1983) because smelt have few spawning opportunities over their short lifespan (Maitland, 2003). Maitland and Lyle (2010) considered over-exploitation to be the leading factor in local extinctions in the Solway area, including the Eden (Maitland, 2003). Maitland and Lyle (2010) cite the fishery in the Tay, where the annual catch from a single vessel in the 1990's varied between 10 and 15 tonnes. They also cite a former fishery on the Cree where catches of between 0.6 and 6.3 tonnes of smelt were made between 1980 and 1986. Maitland and Lyle (1997) cite that catches in the Forth estuary peaked at 15 tonnes in the 1910's. The former trawl fishery in the lower Thames estuary off Blythe Sands was reported as catching 6.2 tonnes in 2009 (Colclough, 2013). In none of these cases was there any information available then or now to indicate whether these levels of extraction were sustainable (S. Colclough, pers obs).

The Marine Management Organisation (MMO) reports all fish catches made at sea by vessels in English waters under the Buyers and Sellers Regulations. Through this process, they had identified a bycatch trawl fishery for smelt in the Thames which operated in the last decade (Colclough, 2013). That fishery has now ceased (Cousins, T. EA pers comm). The only known example of catches of smelt at sea by marine fishermen reported by the MMO existed between Selsey Bill and Shoreham for several years after the 2013 review was completed. These were fish taken as unintended bycatch in a black bream fishery. Small boxes of smelt were sold to France for the table market trade. Subsequent mesh size increases have removed smelt from the fishery since 2018. (P.Johnson, MMO, pers comm).

The most recent recorded active fishery in the Solway occurred in the River Cree which was active until the late 1980s (Maitland and Lyle, 1997). The Cree smelt fishery was highly variable and recorded catches of zero to six tonnes per year, these smelt were targeted for the English food market.

4.2 Current smelt fisheries

The demand for smelt in the present day is primarily for the pike dead-bait market as there is no longer a recorded food market demand in the UK (Maitland, 2003). Recently, a secondary market has developed for smaller and less well conditioned fish for a table market in Ukraine

(D. Bartlett, EA, pers comm as cited in Colclough 2013). The Fishmongers' Company report low numbers of smelt moving through Billingsgate Fish Market but these are imported fish aimed largely at eastern European food markets (C. Leftwich, Chief Inspector, pers comm as cited in Colclough 2013).

Exploited smelt fisheries for the pike-deadbait market that take place in England today originated as bycatch from eel fisheries. They are prosecuted with fyke nets and pot traps in certain rivers and estuaries, with a historical focus on the Norfolk Broads and Fens (Colclough, 2013). In 2011, these became directed smelt fisheries regulated under the then new authorisation process. Initially, authorisations were provided to two individuals in three locations in England. There was a total reported catch of 3240 kg between the three populations in the Humber estuary, the Great Ouse and Boston Haven and the Waveney in the Norfolk Broads (Colclough, 2013). In 2012 the fishery was expanded, with authorisations given to three individuals in eleven locations, including the Nene and Welland, with a total reported catch of 11,269 kg. In 2013 there were 11 authorised fisheries in operation, using fyke nets and pot traps. By 2019, the same operations were still occurring with the same fishermen, but with an increase in catch from a reduced effort in the past few years (I. Dolben, EA. pers comm).

Catch per unit effort (CPUE) collected as part of Colclough (2013) shows information on annual returns of smelt in several English rivers. This is presented in Appendix 2. There are several reasons for the increase in exploitation pressure; the total effort increased, the number of instruments used increased and the timing is more effective as interception fisheries target the spawning run. It should be noted that Appendix 2 also includes some information on the returns from the Yorkshire Ouse and Trent for 2007 and 2009, prior to the authorisation process.

Colclough (2013) concluded that the conditions attached to the authorisations ensured that the catch effort was sustainable (Appendix 3) at that time, but given the risk of over-exploitation, he provided recommendations that adequate surveillance should take place and the fishery should be subject to regular review. In 2020 the Environment Agency intends to conduct a review of the smelt fishery, which could result in further restrictions under the authorisation process described in the Colclough 2013 review, in order to prevent over-fishing (I. Dolben, EA pers comm).

Colclough (2013) suggested that there is potentially a modest further level of fyke and trap activity for smelt in England that is still to be detected. It was not believed that there are any other large smelt populations, exploited or otherwise, yet to be identified, so future investigations into unreported and regulated smelt fisheries should be targeted in the Humber basin, the Wash and tributaries, Norfolk Broads, Blackwater and Chelmer, Thames, Medway Conwy, Dee and Ribble.

The formation of pre-spawning shoals in the lower estuaries can also make smelt vulnerable to exploitation as by-catch when trawl fisheries target marine species. Today the MMO reports minimal catches of smelt at sea by marine fishermen in England.

There are no active smelt fisheries in Scotland today and Marine Scotland have no reports of smelt appearing as by-catch from marine fishing vessels.

4.3 Degraded water quality

Smelt are considered sensitive indicators of water quality (Andrews, 1988; Barker, 2016) and is considered to be an indicator species due to its sensitivity to polluted water (Thomas, 1998; Turnpenny and others, 2004 as cited in Best and others, 2007). Diffuse and point pollution can negatively impact the suitability of in-river spawning habitat, which could prevent spawning or impact the post-spawning development of eggs. During the early stages of development, smelt eggs and larvae are very sensitive and require good water quality. In the River Forth in Scotland, smelt were previously thought to have died out as a result of declining water quality (Hutchinson, 1987). Given the life history and environmental sensitivities of smelt, the species can be extremely vulnerable to pollution incidents. Thiel and others, (1995) describe repeated population crashes in smelt in the Elbe estuary associated with intermittent pollution incidents over many years.

Pollution from sources such as sewage effluents and road surface run-off can lead to eutrophication in river and estuarine environments resulting from increased concentrations in nitrogen and phosphorus (Cloern, 2001). Excess nutrients can lead to excessive algal and macrophyte growth, potentially leading to anoxic areas (Moss, 2010) which is harmful to all smelt life stages, particularly to smelt larvae which are unable to escape unsuitable environments (Moller and Scholz, 1991). Nutrification can also have detrimental impacts on the water qualities of estuaries and coastal regions. For instance, the influx of excessive nutrients, such as nitrogen and phosphorus, can lead to an increase in phytoplankton biomass. This results in reduced water transparency, which alters the balance production and metabolism in the coastal zone (Cloern, 2001). This could potentially affect the recruitment of juvenile smelt to adult life stages.

In terms of in-river water quality, heavy metal concentrations are important as high concentrations can induce damage on the developing eggs and larvae (Sepulveda and others, 1993). Oxygen availability is also a key factor. Sewage effluents can reduce oxygen availability which could cause significant mortalities of smelt larvae unable to escape (Moller and Scholz, 1991).

Water quality of the estuary is important as estuaries are a key element of the migratory route, and blockage of this route such as severe pollution could potentially impede the upstream migration of smelt to spawning grounds in freshwater (Buysse and others, 2008). Poor water quality in estuaries can also affect the post larval development of juvenile smelt, affecting recruitment rates to adult hood and the health of the future spawning stock. For example, low oxygen concentrations can cause significant egg mortalities and larval deformities in developing smelt (Sepulveda and others, 1993).

4.4 Instream modifications and barriers to migration

Previous studies have highlighted the potential issue in which anthropogenic instream modifications may cause changes to river flow regimes. For example, straightened channels may result in increased water velocity making it increasingly difficult for smelt to reach suitable or upper spawning habitats (Ribbens and Graham, 2004).

The relatively short migration of this weak swimming species can be obstructed by physical barriers, such as weirs and other structures (Maitland, 2003). Alongside physical barriers to migration, chemical barriers, even temporary ones created by pollution events, can prevent smelt from reaching suitable spawning habitat (Maitland, 2003).

Barriers to migration can also include those designed for passage of other fish species, for instance the conventional Larinier and Denil salmon fish passes were not designed for the passage of smelt. The only form of fish pass that might accommodate the smelt would be a shallow gradient by-pass channel.

4.5 Habitat disturbance, damage and loss

Smelt are a good indicator of environmental conditions and access to good quality habitat is very important for recruitment success. Smelt spawning sites are highly vulnerable to physical disturbance, particularly in industrialised rivers where the tidal limits tend to be in urban areas. The Thames Guidance Document for Planning (ZSL, 2016) recommends that there should be no disturbance of the river bed in the vicinity of known smelt spawning sites in the spring of each year.

Habitats can be damaged as a result of pollution events, causing a die off of suitable spawning substrates such as water weeds which could have lasting effects on the success of smelt recruitment (Maitland and Lyle, 2001). Habitats can also be affected by agricultural and forestry activities further upstream which can cause excessive silting of the habitat (Maitland, 2003), as well as the release of harmful substances into the aquatic environment.

In-channel modifications not only affect access to suitable habitat, but may also result in the destruction of suitable spawning habitat which may already be limited due to migration barriers in certain rivers (Maitland and Lyle, 2001). Activities in river catchments can also affect the area of habitat available suitable for spawning, with agricultural and forestry industries causing changes in local hydrology and as a result, contributing to habitat loss (Maitland and Lyle, 2001).

4.6 Disease

To date, smelt have not been of particular focus for study in relation to diseases, so there is little information on the occurrence and effect of disease in smelt populations on a large scale. In the Thames, a microsporidian parasite, *Glugea hertwigii*, which causes cysts, can be a significant fish pathogen under optimum conditions for the parasite. From 2017 there has been a noticeable increase in the prevalence of this parasite and it was noted in the body cavity of several juvenile smelt caught in the Thames estuary. In a sample of 0+ smelt caught in 2018, the parasite was found on between 70% and 100% of samples taken between sites. It is expected that in such high abundance this parasite has a physiological impact on the host smelt. It is suspected that an environmental trigger has led to such a significant increase in this parasite. In summer of 2018 the Thames experienced very low freshwater flows and prolonged high-water temperatures which could explain the increase in parasite abundance. It should be noted that lower levels of cysts were recorded in 2019 (T. Cousins EA pers comm).

4.7 Impingement

Impingement is a pressure which will only be applicable in some rivers, but could be significant in those cases. Where any new water intakes are proposed, adequate modern screening and deterrents must be applied to protect smelt from impingement to which they could be particularly vulnerable due to their shoaling habits and weak swimming ability.

Maitland and Lyle (2010) cite up to 3312 smelt per day being impinged on the cooling water intake screens at Longannet Power Station, situated on the River Forth. Smelt had largely disappeared from the Forth for most of the early life of the power station. These heavy catches of smelt were reported only five years after the recovery of the Forth population had been observed. It is possible that the spawning site of the recovered population might be close to the power station intake. (A. Pearce pers obvs as cited in Colclough 2013).

4.8 Climate change: species shift

The smelt is an Artic-Boreal (cold water) species (Wither and others, 2012) and populations may be challenged by climate change, particularly in southern Britain. Pronier and Rochard (1997) describe a smelt population at the southern end of its natural distribution range in the Gironde estuary in France. That population has now been lost and some of the new species moving into the estuary have a North African distribution (M. Lepage, pers comm) indicating a warming of the waters.

There is growing evidence that transitional water bodes are heating up due to climate change. Migratory salmonid smolts from rivers around the inner estuaries may be subjected to increased stress and mortality as they leave rivers and head out to sea. There is a lack of data to confirm this as a pressure and how this would relate to smelt.

The phenology and productivity of any species/population is strongly linked to water temperatures (Mills and others, 2013). The geographic distribution of a species is strongly linked to the temperature tolerance of that species. Climate change has impacted the geographic distributions of marine organisms (Sunday and others, 2012), which are generally presenting a poleward shift as temperatures warm (Poloczanska and others, 2013; Pinksky and others, 2013). These geographic shifts have been observed in global fish catches (Cheung and others, 2013).

4.8.1 Species shift: bass predator example

European bass (*Dicentrarchus labrax*) is a species of commercial value in England and Wales, as well as being a popular sport fish (Pawson and others, 1987). Found in the north east Atlantic, the southern limit for seabass is Morocco and the Mediterranean, and Scotland and Norway lie at the northern most limit (Picket and Pawson, 1994). The northern limit of seabass has recently been reported to have expanded northward both in the Baltic Sea and the Norwegian coastline (Illestad and others, 2012). This northward expansion has been linked to climate change, warmer water temperatures allowing bass to be supported in more northern waters as temperatures influence growth and survival rates of juvenile base (de Pontual and others, 2019; Pawson, 1992). Communications with local anglers in the Solway anglers suggests a significant increase in bass presence in the Solway in recent decades (M. Smith, pers comm). 0+ bass were first reported from the Solway in Water Framework Directive fish sampling in 2007 from the mouth of the Wampool and off Bowness (A. Waugh EA pers comm).

European bass are a ferocious predator migrating large distances between winter pre-spawning grounds and summer feeding grounds (Pawson and others, 1987), with adults predating on small fish such as smelt. Increased presence of known smelt predators could be affecting natural recovery of populations now that the most significant anthropogenic pressures (over-exploitation) have been removed. As the effects of climate change increase there is the potential for other predatory marine fish to move northwards.

4.8.2 Species shift: plankton community structure prey example

The size of phytoplankton species has been shown to decrease with warming, affecting the overall biomass (Sommer and others, 2015; Sommer and others, 2012) present. Warming has also led to shifts in the taxonomic composition of phytoplankton (Sommer and others, 2012). This could affect the juvenile stages of smelt which feed on zooplankton during their first year of development, before moving on to predate on small fish and crustaceans.

Climate change affects not only ocean temperatures, but the pH. Ocean acidification is a greenhouse effect resulting from increased concentrations of dissolved carbon dioxide which results in lower pH levels (Sommer and others, 2015). This too could affect the taxonomic composition of plankton available as prey for juvenile smelt.

4.8.3 Conclusions of climate change: species shift as a pressure

Together the perceived small changes in species composition of plankton, and the suggested increases in predation pressure from predatory fish species such as bass, climate change could be altering the balance in the community structure of estuaries. These changes could affect the recruitment rates of smelt larvae to adults, as well as decreasing survival rates of adults reaching sexual maturity to spawn in the spring. Research would be required to test this hypothesis.

4.9 Marine developments

Currently, it is thought that smelt utilise inner estuaries and coastal areas and little is known how they use the wider estuarine and coastal environment (see Section 3.2.3). Marine developments such as offshore wind farms and tidal energy schemes, depending on their location, have the potential to impact upon adult smelt migration routes. Developments could potentially interrupt migration routes and this could affect recruitment rates over the long term. Research specific to each individual proposed development would be required in order to prevent renewable energy developments impacting on known smelt populations.

Activities in the English marine environment are regulated and licensed by the Marine Management Organisation (MMO) through the marine licensing regime. Any activity, operation or development which has the potential to affect the population, recovery, status, usage or habitat for smelt associated with an MCZ will need to be subject to a specific MCZ assessment. This assessment will determine if the activity has the potential to hinder the MCZs conservation objectives, if it does then management and potentially compensation measures will need to be implemented to address the risk. Due to the high mobility and range of smelt and the ability of impacts in the marine environment to cover large distances, activities occurring outside the boundary of a smelt MCZ may also need to be subject to MCZ assessment and subsequent management measures under a regulatory regime.

5. CASE STUDIES

5.1 River Cree case study

The population of smelt in the River Cree are the last remaining known population in the Solway Firth (Maitland and Lyle, 2001). Historically 10 of the rivers flowing into the Solway Firth had a population of smelt (River Annan, River Bladnoch, Kirkcudbrightshire Dee, River Eden, Border Esk, Water of Fleet, Lochar Water, River Nith, Urr Water) (Maitland and Lyle, 1997; Maitland, 2003). Therefore, the Cree population are very important in terms of conservation (Graham and Stevenson, 2004). Monitoring of this population is vital and periodic condition assessments provide information on the status of the population (Etheridge, 2010). The Cree population is also a potential source of natural re-establishment of smelt to surrounding rivers, as well as genetically similar source for translocation projects (Etheridge, 2010).

5.1.1 Smelt population behavior in the River Cree

The importance of the Cree smelt has meant this population has been relatively well studied compared to other UK populations. Over the last few decades, the GFT was assisted with and carried out research on the Cree smelt population. Smelt are known to enter the lower regions of the river in January, increasing their exposure to freshwater conditions in the lead up to the spawning event (Maitland and Lyle, 2001). In the lower reaches of the Cree the movement of smelt is dominated by flow patterns and it is suggested they move up and downstream extensively, controlled by river currents and tidal flows, before beginning their spawning migration (Lyle and Maitland, 1997). Smelt have previously been caught year-round at an area in the lower river estuary called “The Boathouse” which is around 12 km downstream of their main freshwater spawning ground (Hutchinson, 1983).

5.1.2 Smelt surveys in the River Cree

In 2003, Maitland set out a defined procedure for surveying, monitoring and reporting for a Site Condition Monitoring (SCM) Assessment of the River Cree smelt population for Scottish Natural Heritage. This protocol was designed to assess individual smelt stock sites against a predetermined set of conservation objectives to consider the conservation status of smelt across its geographical range (Ribbens and Graham, 2004). This includes recording the habitats in one of four categories; favourable, unfavourable (declining, maintained or recovery), partially destroyed or destroyed. The assessment gives information on the smelt present status and an indication to the trend and sampling protocols allow for comparisons between different sites and over time periods (Maitland, 2003).

In 2004, SCM determined that the quality of habitat in the lower River Cree was suitable to support the spawning population of smelt (Ribbens and Graham, 2004). It was highlighted that the construction of fishing croys in the lower river, aimed to create more suitable conditions for salmonid fishing, have altered the local flow pattern, possibly creating a barrier to upstream smelt migration and therefore reducing the possible area of spawning habitat (Ribbens and Graham, 2004). Also highlighted was the erection of street lighting along the right bank to illuminate a riverside walk, the lights were positioned within close proximity of the most important spawning location and the artificial light falls onto the water surface close to the bank (Ribbens and Graham, 2004). Concerns raised suggested that smelt may avoid the artificial light, further reducing the spawning habitat available (Ribbens and Graham, 2004). An improvement in water quality has been noted due to the construction of a new wastewater treatment plant discharging further downstream of the spawning grounds and giving greater dilution and dispersion of the wastewater (Ribbens and Graham, 2004). The wastewater facilities have a greater stormflow capacity and higher level of treatment and purification which should improve water quality at the spawning location (Ribbens and Graham, 2004).

Further SCM occurred in 2010 and 2011 which concluded that the smelt population was in favourable condition, and it was determined that there had been no appreciable change in the quality of habitat for smelt in the lower reaches of the River Cree and the estuary which is still suitable for smelt spawning (Etheridge, 2011). The report highlighted the invasive non-native plant, Japanese Knotweed (*Fallopia japonica*), as a potential problem but ongoing treatment has reduced the dominance of this invasive species in the lower river (Etheridge, 2011). Other concerns highlighted included potential developments in Wigtown Bay and the Solway Firth which may adversely affect smelt migration and feeding grounds (Etheridge, 2011).

5.1.3 Spawning in the River Cree

The River Cree smelt population typically spawns between the middle of February and the middle of March (Table 1), the exact timing of which is influenced by several factors including tide heights, river temperatures and river flows (Etheridge, 2011). Although factors such as river flows and tide heights are influential in the timing of the spawning event, river temperature has been shown to be the main influence on timing of the event (Maitland and Lyle, 2001). It should be noted that in previous years despite recording 'ideal' river temperatures, adverse conditions, such as high river flows, have delayed the expected arrival of smelt and has prevented them reaching ideal spawning habitat (Lyle and Maitland, 1997; Ribbens and Graham, 2004). In some years there have been two recorded spawning runs (Maitland and others, 2008), and it has been suggested that these multiple spawning episodes are linked to adverse conditions delaying much of the spawning.

A model based on temperature data, developed by Maitland and Lyle (2001), can be used to predict the arrival of Cree smelt with good accuracy (Etheridge, 2010). In the Cree, spawning is initiated by river temperatures over 5°C (Etheridge, 2010), and typically occurs 150 ± 20 degree-days after 1st February (Lyle and Maitland, 1997), a degree-day in this instance meaning if the river water temperature remained at a constant 1°C then it would take 150 ± 20 days until spawning typically occurred. To more accurately determine the onset of spawning, daily surveys of river banks for eggs adhered to substrates (Maitland and Lyle, 2001), the presence of and/or accumulations of known smelt predators and for smelt carcasses along the banks should carried out from the 100th degree-day (Etheridge, 2011).

The location of smelt spawning events in the Cree is also heavily influenced by tidal heights and river flows (Etheridge, 2011). Figure 1 shows the four known locations of spawning events in the Cree located near to the upper tidal limit.

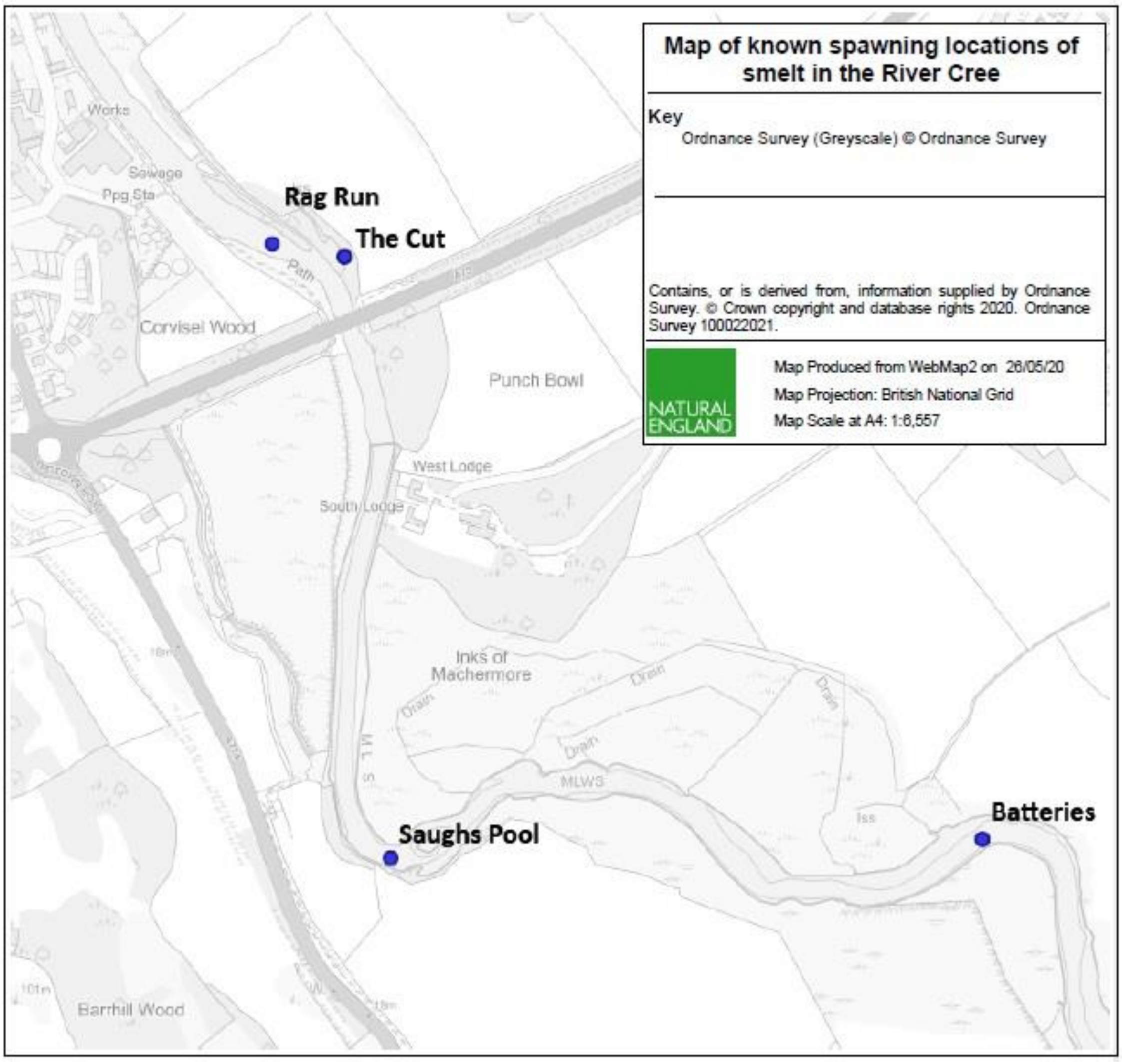
In years where the Cree has experienced high river flows, such as in spring of 2020, smelt were not observed in the area of riffle at the upper tidal limit ('Rag Run') which is considered to be their preferred and ideal spawning habitat in the Cree. In this instance, only limited evidence of spawning was found in 'Rag Run' on the 18th February, with only half a dozen dead eggs observed and presumed to be from the attempts of a sole or small group of females attempting to spawn. No further evidence of spawning was found until the 26th February, and on this occasion the thousands of eggs observed suggested a mass spawning event had occurred in a relatively shallow glide section approximately 1.5 km further downstream called the 'Batteries'. The fish were obviously not able to reach their preferred spawning location of 'Rag Run' due to elevated water levels in the river preventing them from reaching their target.

Table 1: The known dates of smelt spawning in the Cree

Date	1st spawning date	Degree-Days	Author/Reference
1980	10.03		Hutchinson and Mills, 1987
1981	10.03		
1991	14.03	163.1	Lyle and Maitland, 1997
1991	28.02	78.8	
1992	28.02	149.8	
1993	22.02	132	
1994	12.03	165.2	
1994	26.02	87.4	
1995	15.03	219.4	
1995			AERC, 1996
2004	23.02	134	GFT, 2004 (SCM)
2008	28.02		Maitland and others, 2008
2009			Lyle and others, 2009
2010	17.03		Etheridge, 2010
2011	6.03		Etheridge, 2011
2018	13.03	121	Wooton, 2018
2019	22.02	103	unpublished GFT data
2020	25.02	138.1	unpublished GFT data

The ‘Batteries’ section of the Cree is considered much less ideal for smelt to spawn in because it is a slower flowing stretch of water which is much more regularly inundated by the tide. In large spring tides, like those often seen during smelt spawning events, large amounts of tidal and estuarine muds can shift over exposed gravels in the lower river around such as those found at the ‘Batteries’ and this can cause mass smothering of any eggs deposited there, leading to lower recruitment that year. For comparison, in 2019 mass smelt spawning was observed near the upper tidal limit in the ‘Rag Run’ area when the river flow levels were notably lower and combined with the high spring tides, these conditions enabled the smelt to expend less energy reaching their ideal spawning grounds.

Figure 1: Map of known spawning locations of smelt in the Cree. The Cut NX 4155 6477; Rag Run NX 4152 6477; Saughs Pool NX 4172 6408; Batteries NX 4233 6408



5.2 Thames case study

Smelt was the basis of one of the most valuable fisheries in the inner reaches of the Thames estuary. As early as 1630, Sir Robert Ducie, Lord Mayor of London and Conservator of the River Thames, introduced conditions relating to smelt fishing to conserve the spawning stock. There was a ban on fishing for smelt between 10th March and 14th September westwards from London to Isleworth Church and to the east of London from 21st October to the following Good Friday (Wheeler, 1979). The significance of this conservation measure was highlighted in 1797, when a petition from the fishermen sought to fish for the smelt out of season, as the spring weather was so advanced "Dispensation would benefit the employment of some 500 persons and furnish liberal supply to the markets" (Wheeler, 1979).

In 1800, there were daily catches of 50,000 smelt caught in Deptford Creek on the tidal Thames, before the expansion of industry led to degrading water quality from the 1830s onwards (Wheeler, 1979). It was concluded by Wheeler (1979) that the Thames was effectively biologically dead between Kew and Gravesend at the worst levels of pollution in

1958. Considerable improvements in the mid-1960s to the major sewage treatment works led to improvements in the fish communities from that point onwards (Wheeler, 1979). As a result of such improvements in water quality, smelt had begun to re-appear in the river from 1967 on power station cooling water intake screens and were reported from the river upstream of the main city reaches at Wandsworth by April 1968.

Later reviews of the recovery of the fish communities in the Thames estuary have been provided by Thomas (in Attrill, 1998) and Colclough and others, (2000 & 2002). Specific reports on smelt in the estuary have been provided by Hutchinson (1983), Yeomans (1994) and Geoghegan (1995).

5.2.1 Smelt population behaviour in the Thames

Evidence shows that smelt form dense shoals below Gravesend in February and March prior to migrating upstream to spawn in March and April on the sub-tidal gravels below the low tide mark between Battersea and Wandsworth (Colclough and others, 2000). In April of 1994 significant congregations of smelt close to spawning were taken in fish rescue operations in the Millwall Dock Complex (S. Coates, pers comm). Most of the adult stock then descends to the lower estuary, with spent smelt found each April from the mid-1980s onwards on the screens at the former Lotts Road Power Station, Battersea (Pilcher, 1989).

Developing smelt have been found utilising selective tidal stream transport (Colclough and others, 2000 and Colclough and others, 2002) as very early post larvae have been taken regularly at Millwall and Greenwich (~18 mm) in late May and June (Geoghehan, 1995). By late June, 0+ fish have been caught as far upstream as Richmond, then, typically by autumn, most of the juvenile fish descend to the lower estuary (Colclough, 2013). Sub-adult smelt aggregations have been noted in some of the tidal creeks that discharge to the main estuary, such as Dartford Creek and Barking Creek (Colclough and others, 2002).

5.2.2 Smelt population surveys in the Thames

In November 1986 the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) conducted a trawling monitoring survey in the Thames estuary, as part of the Thames Young Fish Survey Programme which continued until 2009. This survey method then became the model for the otter trawling element of the WFD transitional waters fish sampling programme. In most years, surveys were conducted at sites in Canvey, Crossness, Gravesend, Greenhithe, Mucking, Southend and off of Shoeburyness. Over the duration of the survey over 9000 smelt were caught, ranging in sizes from 70 mm to 250 mm. In addition to the November monitoring programme, in 1997 the same survey was conducted in spring. Most of the larger smelt caught were observed to be gravid, i.e. full of eggs (S. Colclough, pers obs) and it was assumed that the fish were preparing to spawn.

Since 1994, the Environment Agency has conducted a multi-method fish population survey at six sites in the Thames estuary on a biannual basis, in spring and autumn. This has since been adopted as the standard national method for transitional waters fish sampling under the WFD (Coates and others, 2007).

In October 2012, large numbers of smelt that were close to spawning condition were caught at Mucking and Woolwich as part of the WFD otter trawling programme. In previous years smelt caught at the same stations were much less developed so this could suggest that freshwater flow could be a factor which stimulates maturation and migration in the Thames population, as freshwater flows in the Thames were extremely high throughout 2012 (D. Barlett, EA, pers comm, as cited in Colclough 2013).

5.2.3 Spawning locations in the Thames

In 2015 and 2016, the Zoological Society of London (ZSL) mounted a study to attempt to identify the spawning site for smelt in the estuary (ZSL Guidance, 2016). During the 2015 survey, a combination of ichthyoplankton netting and seine netting was completed at three locations approximately every fortnight (Putney, Wandsworth and Battersea) between March and July. Ichthyoplankton netting was identified as the most appropriate method to sample Early Life History Stage (EHLS) smelt (under 20 mm). In one transect at Wandsworth Bridge, 260 ELHS smelt were taken on 2nd April. These were the smallest ELHS smelt ever sampled in the Thames estuary, with an estimated total length of 4 mm to 7 mm. The presence of a yolk sac in the ELHS smelt specimens, suggested they had just hatched (McCard, 2015).

The results of the 2015 survey were used to inform the design of the 2016 survey methodology, with the aim to identify the specific smelt spawning location. Ichthyoplankton netting occurred more frequently at just one site (Wandsworth Bridge) in March and April. For the first time, smelt eggs were caught with the ichthyoplankton net operating in the water column. The eggs were in the “pre hatching” stage and close to hatching. The fact that eggs in “pre hatching” stage were caught using the ichthyoplankton net suggested that the Wandsworth Bridge sampling site was in close proximity to the smelt spawning site.

The average water temperature during the predicted spawning period was 8.7^{o}C in 2015 and 8.3^{o}C in 2016. Later analysis suggested that the potential spawning date in 2015 would have been 19th March, with a potential hatching date of 2nd April. Similar analysis for the 2016 data suggested spawning occurred from 1st March to 2nd April, with hatching taking place from 22nd March to 13th April. The specific timing and length of the smelt spawning period each year was thought likely to be dependent on a range of environmental factors: water temperature, tidal state, freshwater flow, salinity and lunar phase.

The hydraulics research station HR Wallingford, completed detailed numerical modelling of ZSL’s ichthyoplankton survey dataset and their analysis showed a close match between the model results and the survey data when simulated smelt hatchlings were released at Wandsworth Bridge. When the modelled hatchlings were released at other locations, the correlation between the data and model results was not as strong. The results suggest that smelt spawn in the area between Wandsworth Bridge and 600 m upstream of this point. However, it cannot be ruled out that the spawning area could extend further west to Barnes Bridge (ZSL Guidance, 2016).

A recent tagging study in Suffolk suggested that smelt spent on average 15 days and 4.7 days during the spawning period in the River Yare and River Waveney respectively (Moore and others, 2016). For 2019, ZSL are engaged with Cefas on a tracking study of adult smelt in the Thames estuary. At the time of writing, nine adult fish have been captured, tagged and released in the lower estuary (Cucknell, A. pers com).

5.3 Wider principles

Although the main pressure of smelt over-exploitation has since been removed, other pressures such as water quality and access to spawning habitat have intensified and/or remained, preventing the natural re-establishment of populations in some areas. For instance, when the main pressure of over-exploitation was removed and water quality improved in the

Firth of the Forth, the smelt population thought to be extinct has since naturally recovered and re-established.

Several examples below highlight the removal of pressures, such as water quality and exploitation, and the subsequent recovery of smelt in different areas around the British Isles. This indicates that natural recovery and re-establishment of smelt is possible once management strategies have been put in place to improve the quality of transitional habitats should there be another local population from which smelt will naturally stray.

5.3.1 Smelt recovery examples

5.3.1.1 Forth population recovery example

In the 19th century the River Forth supported an enormous population of smelt which was the basis of an important fishery, suppling local demand as well as those for luxury food items (McLusky, 1978). Commercial exploitation of smelt was occurring in the Firth of Forth as a particularly prized catch commanding a high prize until its decline in the 1970s (Maitland and Lyle, 1997). Records of annual catches indicate that until the 1910s, an average of 15 tonnes of smelt were caught each year, decreasing to 7.5 tonnes until the mid-1940s which then declined to zero by the 1950s (Howard and others, 1987). There was a slight recovery in catches in the 1960s, but again catches declined to zero in the 1970s (Howard and others, 1987; Maitland and Lyle, 1997).

By the 1980s smelt were considered extinct in the Forth (Maitland and others, 1980), until 1989 when a single smelt was recorded, then in 1990 a further three were taken (Forth River Purification Board, 1989). A study on fish assemblage in the Forth between 1979 and 1990 showed a notable increase in the number of smelt being entrained in Longannet Power Station inflow (Greenwood and Maitland, 2009). In some years in excess of 3000 smelt were recorded per day at the power station and from this it was deduced that the population was substantial enough to sustain such mortality rates (Maitland and Lyle, 1997). Smelt is now commonly caught in monitoring trawls in the Firth of Forth (Maitland and Lyle, 2010).

Improvements in water quality could have led to the recovery of smelt in the Firth of Forth, similar to the River Thames population recovery in the late 1960s (Hutchinson and Mills, 1987). It should be noted that the re-occurrence of the Thames smelt population was due to the straying of neighboring populations in the Blackwater estuary and the River Crouch (Hutchinson and Mills, 1987). In the case of the Firth of Forth population, Hutchinson and Mills (1987) had suggested that the Forth population would be unable to re-establish as there was no other local population. Current thinking suggests the Forth was re-populated from straying smelt from the River Tay, the only other known population on the east coast of Scotland, which would suggest they are capable of travelling distances further than originally suggested in literature (see Section 3.2.3).

5.3.1.2 Medway population recovery example

The first smelt to return to the Medway as the river recovered from pollution were reported from power station screens by Van den Broek in 1979. By 2001, Environment Agency surveys were reporting smelt from the inner estuary above Rochester Bridge, with 0+ post-larvae present. The historic fishery had been at Wouldham, which might have been the spawning site, indicating as elsewhere, the prosecution of an interception fishery (Lyons, J. pers comm, as cited in Colclough 2013). The spawning stock probably originated from either the Thames or the Blackwater, both which are closely adjacent.

5.3.1.3 Mersey possible population recovery example

In the 19th and early 20th century there was a significant population of smelt in the River Mersey, sizable enough to support a profitable fishery on 'Sparling Street' (Maitland, 2003). The decline of smelt recorded in the early 1950s and 1960s was attributed to degrading water quality, and increased pollution was associated with the industrial activity in the area (Maitland, 2003).

Due to lack of contemporary evidence at the time, Maitland (2003) was unable to conclude the status of smelt in the Mersey. In recent years only three specimens have been caught at Eastham, in the Mersey, during Water Framework Directive development work, running between 2003 and 2007 (Colclough, 2013). These few smelt caught could potentially indicate the very early stages of a natural recovery of smelt in the Mersey since the removal of over-exploitation pressures and improvements in water quality. There is a substantial stock of smelt in the Welsh Dee estuary. The close proximity to the Mersey suggests that this could be the source of the smelt increasingly being found in the Mersey as water quality improves (Colclough, 2013).

5.3.1.4 Thames population recovery example

The River Thames smelt population is a good example of population recovery after water quality has improved (Maitland, 2003). Maitland suggested that declines in water quality, along with over-exploitation, was a significant limiting factor for smelt population in the River Thames. Smelt recovery in the Thames was rapid and probably associated with extant populations in the Blackwater estuary, adjacent on the north bank. The first smelt were reported to be back in the Thames by 1967. By the mid-1980's sufficient numbers were migrating up the river in April for them to be noted in numbers on the screens at Lots Road Power station at Battersea on their way to the now described spawning site at Wandsworth.

5.3.1.5 Tyne population recovery example

An early recovery was evident in the Tyne at the time of the Colclough, 2013 review. That population is now much larger with spawning probably occurring in the Newburn area, close to the tidal limit (P. Rippon, EA. pers comm, as cited in Colclough 2013). This is an interesting case, since the Tyne is relatively isolated. Maitland (2003) had previously concluded that the population was extinct and therefore translocation would be required. In a focused search for smelt with gill nets and fyke nets in the spring of 2009, eight adult fish at 169-242 mm fork length were captured close to Newburn Slip (P. Rippon, EA, pers comm, as cited in Colclough, 2013). It would therefore appear that the population had never been completely eliminated.

5.3.1.6 Conclusions to be drawn from smelt recovery examples

Removing significant pressures that caused the decline of smelt populations can lead to rapid natural recoveries as has been reported in the Thames and Forth, but there are no guarantees of such success. In the Solway at present there is no evidence of smelt naturally re-establishing in other rivers in cases where the main pressure of over-exploitation has now been removed (i.e. the River Esk and Urr which previously supported sizable fisheries (Service, 1902)). Indeed, there is no evidence to suggest that the Cree population has strayed into the neighbouring Water of Fleet to establish a population there. Smelt are however caught occasionally by anglers in the lower River Bladnoch which shares the inner Wigtown Bay estuary with the Cree although there has been no evidence of them spawning in the Bladnoch itself.

The life history and ecology of the smelt determined that the species was selected as a good indicator of Good Ecological Status under WFD (Colclough, 2013). Exclusively improving the quality of instream habitat and access, as well as improving water quality, will, unfortunately, not guarantee the natural return of smelt to rivers. Providing suitable access, good habitat and good water quality needs to be established before re-introductions are considered, as a population cannot be self-sustaining without these features.

5.3.2 Examples of the recovery of other migratory species

The life history and ecological requirements of a species determines their "fitness" for natural recovery or formal restoration schemes. With limited data available on how smelt utilise marine environments, drawing successful elements from recovery examples of other migratory fish species on a local scale could help to identify restoration techniques to assist in the recovery of smelt populations in the Solway Firth MCZ.

In 1978, a Salmon Rehabilitation Programme began on the River Thames, aimed at restoring a self-sustaining population of salmon. Originally this included the stocking of smolts and pre-smolts to likely nursery streams and the construction of fish passes on the freshwater Thames and Kennet, however stocking activities by the EA ceased in 2011.

In 2014, as part of the ongoing Salmon Action Plan on the Thames, the fish trap/pass at Molesey Weir was removed and a multi-species Larinier fish pass was installed to facilitate the passage of a greater range of species. Up until the removal of the Molesey Weir fish trap, sea trout numbers were also monitored, with up to 60 fish per year being recorded. These fish were later caught in a number of tributaries upstream. The sea trout is becoming increasingly common in East Anglian rivers today (D.C. Day, EA, pers comm). There is now evidence that due to rising temperatures, the lower Thames estuary is too warm in the middle summer months to permit the upstream migration of returning salmon (S. Colclough, pers obs).

There is now strong evidence that two species of sturgeon, *Acipenser sturio* and *A. oxyrinchus* commonly used British rivers and estuaries as part of their life cycle in the recent past. There is good evidence suggesting intent to spawn and even some very limited evidence of reproduction historically. There are eight sturgeon records from the Solway, from the River Annan in 1793, 1839, 1846, and 1990 (2) and from the River Eden in 1816 (2) and 1852. (NBN Atlas, Scotland & UK Sturgeon Alliance database). The life history of sturgeon makes them very vulnerable to over-exploitation, as well as habitat modification.

The two species of sturgeon cited above are currently the focus of several restoration projects underway along the Atlantic coast in France, Germany and the Netherlands as well as in the Baltic. Since 2017 there have been five late adolescent specimens of these two species of sturgeon reported in UK coastal waters. Sturgeon are homing species but show significant straying behavior (J. Gessner, pers comm). This, together with the high stocking rates of the restoration projects, may lead to many more records of sturgeon in future and it is probable that they will penetrate into UK estuaries and rivers as they have done historically. A new UK Sturgeon Alliance has formed recently to help co-ordinate and facilitate future developments. Any establishment of a UK stock of sturgeon might take place over decades, given the life history of these species.

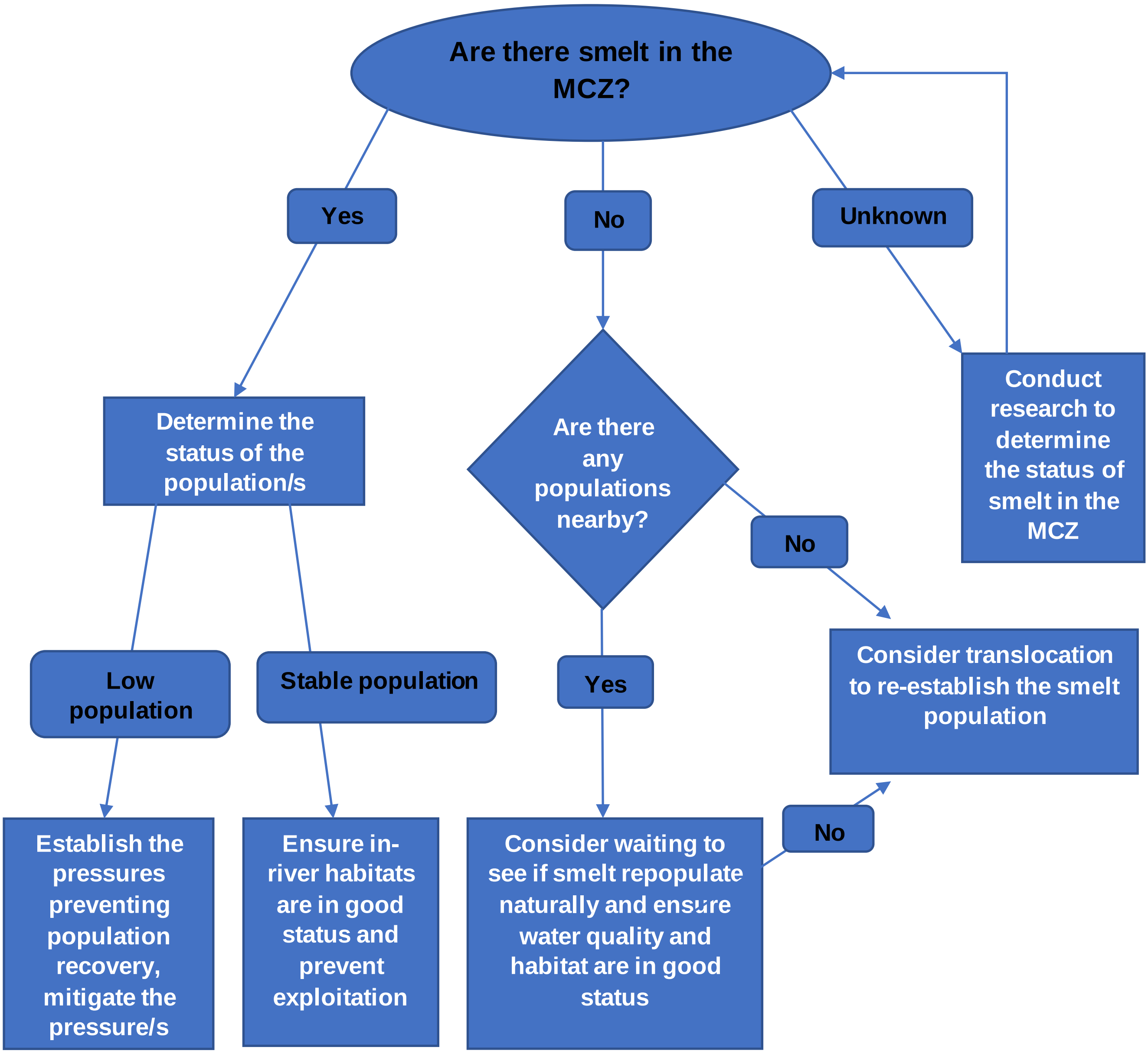
It is apparent from these examples that long term restoration and monitoring projects are required to protect and recover migratory species which use a variety of habitats throughout their lifecycle. Restoration works of vital habitats such as spawning grounds and feeding habitats will assist with the recovery efforts, as long as all the key limiting factors are addressed, as these migratory species are known to naturally stray from known locations. Improving habitats and water quality could help to restore these migratory species on a national scale.

6. RESTORATION OF MARINE CONSERVATION ZONES

6.1 Before starting work on MCZ restoration projects...

Before commencing smelt restoration work within an MCZ, the current status of the species within the MCZ must be ascertained and this requires research (Section 6.2). For example, is a spawning population known to be present within rivers in the MCZ? If not, then surveys should take place to verify if rivers hold a spawning stock. If none are identified then the rivers surrounding and out with the MCZ boundary should be investigated as these may hold a stock of smelt that could repopulate, or 'stray' back to rivers within the MCZ. Figure 2 below shows a flow chart detailing the options to consider in more detail when assessing the status of smelt in the MCZ.

Figure 2: A flow chart for decision making prior to undertaking smelt restoration work



The requirements of smelt must also be considered. Factors such as spawning habitat availability, the current water quality situation in the rivers and estuaries, river flow regimes and potential barriers to migration must all be identified and investigated. Walkover and more detailed habitat surveys, combined with water quality data and assessments are key aspects of these investigations.

Pressures on smelt within and surrounding the MCZ then need to be identified to determine whether it is desirable and feasible to carry out restoration. Cost benefit analysis should also be undertaken.

6.2 Research is required

The key action is identifying whether there is currently a population of smelt population within the MCZ. The easiest way to do this is to carry out research on the rivers in the MCZ (or if desired, over a wider area out with the designated area) over a set period of time covering the known smelt spawning period in early spring (see Section 3.1). Three methods of research are detailed below.

6.2.1 Environmental DNA

Environmental DNA (eDNA) is a technique recently developed to detect species through extracellular DNA present in environment samples (Dejean and others, 2011), the utility of which has been well established (Yates and others, 2019). Animals continuously shed fragments of DNA into surrounding environments through waste secretion which is thought to be the primary source (Klymus and others, 2015), as well as shedding of dead skin cells, organelles and tissues, as well as the release of reproductive gametes (eggs and sperm) (Buxton and others, 2018). Environmental DNA analysis allows for a cost-effective survey of aquatic environments of macro-organisms to determine the presence and absence of target species (Minamoto and others, 2017).

How detectable the fragments of eDNA are in the aquatic environment can vary according to several factors including density of target species, degradation of DNA, the period of year (Dejean and others, 2011), with persistence of DNA varying from a few hours to two months, depending on the conditions (Buxton and others, 2017). EDNA is removed from the aquatic environment by various processes including degradation, transports in water flows or transported vertically out of suspension by binding to particulate matter (Buxton and others, 2017), absorbed in organic or inorganic particles, transformed by competent soil microorganisms (Dejean and others, 2011).

The use of eDNA sampling would be limited to time periods where smelt would be active. This is particularly important as in lotic environments the eDNA can be diluted to undetectable levels when transported out of the system very quickly (Buxton and others, 2018).

The use of eDNA could be particularly useful to determine the presence and absence of spawning activity of smelt in rivers within designated MCZ boundaries. This could help prioritise habitat improvements or determine if reintroduction/intervention is necessary. This could also be a useful tool to establish baseline/present population status' of smelt around the UK.

When looking at an MCZ which has more than one associated river, sampling for eDNA would have to take place on the lower rivers at the same time to ascertain whether smelt are using the rivers to spawn.

The collection of samples for eDNA analysis is relatively low cost and in recent years the analysis has become very cost effective.

6.2.2 Scientific research

Research on the status of smelt within an MCZ can be carried out by local environmental organisations, or organisations such as the Environment Agency, Natural England or Rivers Trusts. These organisations usually employ staff who are likely to hold the skills necessary to lead research projects and carry out surveys.

A project should initially be targeted at determining the presence or absence of smelt populations in rivers within MCZ boundaries, particularly beginning in rivers which may historically have had populations of smelt. The programme could also be designed to be used by local volunteers, perhaps in partnerships with local organisations.

Some basic training may be required to ensure that accurate and relevant information is being recorded in the right area, i.e. in the upper tidal reaches of the river and areas extending beyond the tidal reaches, perhaps even as far upstream as the first barrier to migration.

1) Predicting the estimated arrival of smelt

Daily river temperatures should be collected from a fixed accessible point upstream of the tidal influence. For instance, in the River Cree, daily river temperatures are taken from a set of steps leading down to the river, next to a Scottish Environment Protection Agency river gauging station. Along with this, a record of the total number of degree-days, calculated from temperatures recorded from the 1st February, would allow for a structured survey plan to be made (a model based on temperature data, developed by Maitland and Lyle (2001), can be used to predict the spawning date of Cree smelt (Section 5.1.3)). This temperature data would allow the arrival period of smelt (if they are present) to be estimated to approximately 150 $\pm$ 20 degree-days.

Observation surveys for known smelt predators (piscivorous birds, seals, otter, mink etc.), should be carried out on a regular/arranged basis around lower rivers/potential smelt spawning locations after the 100th degree-day and during the predicted spawning period. This could be organised on a per-river basis from a fixed point along the river bank, or as a river bank walking survey (should there be a path or good access route along and extending beyond the tidal reaches).

2) Looking for physical evidence that smelt are present around spawning time

The next step would be conducting basic bankside surveys, looking for evidence that smelt have visited the river. This would include searching for and identifying smelt eggs and potentially smelt carcasses (from predator kills) along the river banks. As these indicators are not necessarily in the water but potentially exposed along the banks during low tide periods. Depending on the access and conditions in the lower rivers, this task may require some additional training and additional health and safety protocols to be developed.

Live smelt eggs are approximately 1 mm in diameter are translucent when under water. Spotting dead eggs which are pale yellow/cream in colour (see Figure 3) is much easier and is a useful indicator to show that smelt are/have been present in the area. Eggs can travel downstream in the current and can adhere to moss and substrates a distance downstream of where they were released. In the River Cree surveys, low numbers of eggs are usually spotted a few days prior to the initiation of the main spawning event. A bathyscope is useful as this allows surveys for eggs to be conducted in areas of shallower water (if health and safety allows), to determine if any dead eggs have adhered to moss, and stones underwater. This would mean the survey is not only limited to the exposed banks.

Figure 3: Live (clear) and dead (white) smelt eggs adhering to a rock from the River Cree

Smelt carcasses can often be found along the river banks during the spawning period, some having been easily predated and others exhausted from the strain of migration. Carcasses are much easier to spot than eggs but it is useful if the two surveys are undertaken at the same time.

3) Alongside steps 1) and 2), a variety of surveys can be undertaken to determine whether there are smelt present.

Seine netting can be carried out at specific points in lower river areas to establish if any smelt are using the lower rivers as a refuge during daylight hours. It may be however that they are coming in and out of the river with the tide so a nil result would not necessarily mean they are not present. In addition, they may be sheltering in parts of the lower river that are unsuitable for netting. Seine netting is unlikely to help determine where the exact spawning grounds for smelt could be but may help indicate how far upstream they are travelling.

It is not recommended to undertake gill netting as a tool for investigating whether there are smelt present in an area as some populations may hold very low numbers of fish. This method of survey should be given very careful consideration and used with caution.

Observation surveys of the river around suitable spawning locations can be carried out during the day, over the predicted spawning period. If the clarity of the water is suitable, smelt are very obvious to the trained eye. In the Cree, pilot fish often enter the rivers prior to the initiation of the main spawning period and can often be seen holding station in the current near to the main spawning grounds (river height and flow permitting). These surveys may give an indication of where the spawning grounds are, or at least, an indication of how far upstream smelt are travelling.

Lamping surveys can be carried out on night tides. Surveys during the Cree night tides around smelt spawning time have been very successful in identifying shoals of fish coming in on the high tide to spawn. High candle-power handheld lamps are used to survey the river from the river banks and whilst standing in the river over the period of the high tide. Surveying of the river over night tides is likely to be most successful if specific spawning locations have firstly been identified as it is much harder to move around and survey a large area during the hours of darkness. In addition, these types of surveys have specific Health and Safety implications and need to be thoroughly risk assessed beforehand.

4) The next steps

Information should be collected for a few years, if possible, to determine whether a population is present, absent or has been struggling to reach ideal spawning grounds for a few years with suboptimal conditions preventing them from accessing the upper tidal limit. Should evidence of smelt be found, ideally this would to be verified by trained experts, with a plan of further survey work to be developed thereafter.

If this survey model works on rivers within MCZ designations, it should be expanded to rivers outside of the MCZ boundaries as smelt is a transient species. This could lead to re-established populations being recorded in rivers where smelt were thought to be extinct.

6.2.3 Citizen science

Citizen Science is not a modern phenomenon however the name that has been coined is useful as it helps general individuals realise that they can be part of and assist in scientific research projects. The careful use of Citizen Science in assisting in determining whether smelt are using rivers within the MCZ to spawn would have wide ranging benefits.

Individuals could be recruited to assist in collecting data over the known smelt spawning time, such as predator surveys and counts, smelt egg searches, adult carcass searches (smelt killed by predators) and river temperature monitoring. Carcasses are much easier to spot than eggs and may be an easier survey to conduct for some Citizen Scientists. A basic tool kit would be distributed to those signed up to help with the project. An excellent starting point to recruit potential Citizen Scientists would be local Rivers Trusts[1] and their volunteers. In a MCZ with more than one or two associated rivers of interest, or on a river with several potential spawning locations over a wide area, recruiting more individuals would provide more people on the ground and allow survey work to take place on all rivers/areas of interest simultaneously over the smelt spawning period in early spring.

The basic tool kit would be handed out to Citizen Scientists could compose of:

- Information Pack/Guide
- Recording system

[1] See: https://www.theriverstrust.org/who-we-are/find-your-local-trust/ for local Rivers Trusts

- Thermometer
- Predator ID Guide
- Bathyscope

Citizen Scientists could be trained by someone expert in carrying out surveys for smelt, in particular smelt egg detection which is a fine art.

Information and data from these surveys over the period of one or two spawning seasons could cover much ground and could be crucial to identifying if smelt are using the rivers in the MCZ to spawn in, and where they are spawning.

The development of an app or website to log photo evidence or findings would allow for verification, before further survey work is undertaken, i.e. photo of a carcass with geotags.

6.2.4 Key groups to be involved

This should very much be a partnership project between Natural England and local groups to increase the scope and effectiveness of such a project, available to anyone interested. For instance, this could be set up through Natural England and run through the Rivers Trust network to increase scope, by-in and involvement.

An example of local groups that could be contacted include local Wildlife Trusts, angling clubs and syndicates predominantly in the lower reaches or tidal stretches of rivers, possibly local water sports/activity groups, and interested volunteers who might live within the vicinity or regularly visit and area ideal for the collection of river water temperatures.

ZSL and the IFM have both been active in recent years separately and together on the Thames and elsewhere in England training Citizen Scientist groups in the basics of intertidal fish ecology, sampling and fish identification. Clients have been Wildlife Trusts, River Trusts, those in academia, even regulators. There is growing demand for Citizen Science. There is also now a wealth of knowledge that could reach out to support other citizen science projects nationally. In today and tomorrow’s world, regulators are not capable of conducting all of the basic environmental monitoring that will be required to sustainably manage the aquatic environment. Engaged and empowered Citizen Scientists will become an important element in future monitoring and management frameworks. This process is well underway in freshwaters through WFD and the Catchment Based Approach, but only just starting in transitional and coastal waters. (S. Colclough pers obs).

6.2.5 Follow up studies

Depending on whether restoration of the smelt population in the MCZ takes place, and by which method, follow up studies could comprise of the following:

- What is the size of the population of smelt within the MCZ? Is it at favourable status? Are numbers increasing or decreasing over time?
- Are the smelt in the MCZ part of a wider population present in the region? Do they mix in the marine/estuarine environment or are they separate, using separate rivers for reproduction?
- How far do smelt move from their natal rivers and estuaries? For example in the Solway Firth MCZ, are the fish here part of a population present in the wider Solway?

- Where do adult smelt go in the marine environment? Do they only use lower estuaries or do they travel further afield?
- How do juvenile and adult smelt use salt marshes?
- How many smelt can be removed from the MCZ before it becomes an issue (absolute number/ relative number as a percentage of the spawning stock biomass (SSB))?
- Conduct research on assessing activities, applications and developments: regulators face the problem of applicants deferring to the SSB as defined by the International Council for Exploration of the Sea (ICES). This is a problem because:
    - A fishery assessment is not an Environmental Impact Assessment
    - It is not possible for all fish
    - There is evidence to suggest that there are more fine-scale sub and metapopulations present than ICES recognises.

An essential element of all studies should be a long-term detailed study of water quality in the upper tidal regions of smelt rivers over the spawning period. Point sampling does not allow for adequate conclusions to be drawn on water quality in the spawning section of rivers as the accumulated effect of long-term exposure to low concentration pollutants can also be harmful to smelt. This study should begin at least one year in advance of any restoration works, because if water quality is the limiting factor then restoration efforts will not result in the return or recovery of smelt.

A national Citizen Science smelt project could be developed to help increase data collected on the distribution and behaviour of smelt on a national scale. More information on the behaviour of smelt populations can allow for improved management strategies, as well as gaining public support for conservation efforts. It is emphasised that a Citizen Science project should focus on accumulating evidence that smelt could be present (smelt eggs, carcasses and predator presence) rather than attempting to predict their arrival and observe them during the night. Evidence collected would have to be verified in the years following by trained experts before a population is counted as restored/re-established.

Another suggestion for further study would be to determine the location of spawning sites by carrying out ichthyoplankton netting surveys (see Section 5.2.3), as conducted by ZSL and the Institute of Fisheries Management. This could help in the protection of known smelt juvenile habitats such as saltmarshes.

NB Sampling techniques should not kill smelt if at all possible as some populations may hold very few fish.

6.3 Species recovery within a MCZ

MCZ designations can help to widen the scope of protection for transient species and direct conservation efforts based on scientific evidence. Since MCZs are a relatively new concept, there are limited examples which can be highlighted as a model where recovery of a species has been successful over the long term. One example of how conservation projects can be successful is the Blackwater, Crouch, Roach and Colne MCZ which was designated in 2013.

After the designation, located in part of the wider Thames estuary, the Essex Native Oyster Restoration Initiative (ENORI) was formed aiming to progress restoration of the region's native oyster population through conservation and management practices. ENORI comprises of conservation groups, statutory bodies, regulatory authorities and industry groups.

In 2012, four populations of oysters were known to remain within the MCZ boundaries, as part of a survey undertaken by the Essex Wildlife Trust and Blackwater Oystermen's Association. The survey identified the pressures on the population that were preventing natural recovery.

It was identified that the population had limited substrate ('cultch') on which spat could attach, and brood stock were limited. From this, restoration efforts were able to be focused on reducing these pressures. Restoration activities include brood stock enhancement, limiting dredging and trawling activities, cultch laying, cultch management and monitoring of the population.

In the Medway estuary, the Rochester Oyster and Floating Fishery hold historical private rights of commercial fishery. Subsequent to the original designation of the estuary as an MCZ in 2013, the Kent & Essex Inshore Fisheries and Conservation Authority introduced a closure byelaw prohibiting all commercial and recreational fishing in an area of 12.1 sq km of saltmarsh and mudflat habitat downstream of Rochester on the north bank of the estuary. The Institute of Fisheries of Management (IFM) provided technical support in the negotiations with the fishing interests (W. Wright K & E IFCA pers comm). A Medway Estuary Research Forum has now been established to study the benefits of this closure in this important marine nursery ground and juvenile smelt habitat. Citizen science is planned to be an important element of these studies going forward (T. Ferry Living River Foundation pers comm).

6.4 River habitat restoration and management

In-river habitat restoration can be an easy and cost-effective way to improve conditions for fish species. A large amount of practical habitat improvements has taken place in rivers over the UK to improve instream conditions for freshwater fish but it is not clear if any such works have specifically benefited smelt. In many rivers where smelt have previously been present, barriers to migration have been installed in rivers and changes to the banks for flood prevention have caused the flow regime to be altered, so that smelt, who are known to be poorer swimmers (Etheridge, 2010), cannot access their preferred spawning grounds. Barriers to migration and river bank modification has reduced the available spawning habitat for smelt, causing pressure on them during the spawning period at which they are most vulnerable (Etheridge, 2011).

6.4.1 Habitat creation

For spawning purposes it appears that smelt require access to fast flowing riffle habitat near to the upper tidal limit of rivers. These habitats are important for egg dispersion during the spawning process and keeping eggs in freshwater until they hatch. Riffle-pool sequences are important features in natural rivers but these can be lost where rivers have been modified, for example in flood prevention schemes or reclaiming land for development. These instream features can be restored by re-establishing a more natural flow and sediment regime to encourage more naturalised erosional and depositional processes to occur. This type of restoration would normally need to be considered at a sub-catchment or even catchment scale and can be extremely costly and difficult to achieve.

Creating artificial gravel bars and riffles is a mitigation measure which can be more affordable and realistic to achieve at some locations. However, creating riffles may not be always sustainable in the long term but may be considered justifiable to protect or return particular species such as smelt to a certain location or river. In some circumstances, where there has been a lack of mobile substrates, simply adding suitable substrates back to the river upstream of where a riffle should be will result in a riffle reforming. As these substrates will then effectively become mobile then in most circumstances it will be necessary to 'top up' the substrates periodically as natural sediment transport occurs. This technique is commonly used in river systems where the natural movement of substrates has been impacted by hydroelectric dams.

In modified rivers, where sediment is present but is not depositing into the riffles bars desired for smelt spawning, then it may be suitable to add in structures, such as fixed woody debris, to encourage the sediment to be retained and form riffle bars. This technique would only be possible in certain circumstances and where the river morphology is suitable.

When considering instream works to enhance riffle habitats, it is essential to take guidance from a hydrogeomorphologist to understand what techniques would be appropriate, cost effective and likely to be retained in the longer term. Heavily modified rivers, especially those which have been heavily dredged, narrowed, straightened and lack a flood plain, may not be suitable for such restoration techniques.

6.5 Coastal habitat restoration and management

The management of coastal habitats around the UK to date have mainly focused on anthropogenic benefits such as flood management and coastal defences. In recent years there has been a renewed focus of how natural coastal habitats can afford the same protections whilst contributing to other environment ecosystems services. For example, salt marsh habitats have been proven to play an important role in carbon sequestration and storage, coastal protection, wave attenuation, nutrient stripping and food provisions (Solway Coast AONB Partnership, 2019).

6.5.1 Saltmarsh habitats

Salt marsh habitats represent some of the most productive aquatic habitats on the planet, providing a wealth of important ecosystems services so managing and protecting such ecosystems is very important not only on the habitats themselves but also the surrounding marine environment.

It is estimated that 80% of UK salt marshes have been lost as a result of coastal squeeze, whereby embankments and anthropogenic changes prevent the natural landward migration of saltmarsh as a response to sea level rise (Foster and others, 2013). One theoretical study in the Forth estuary estimated that the loss of intertidal habitats in the estuary due to land claim and sea defense construction over the past 200 years had probably removed 66% of the in-situ fish production capacity (McLusky and others, 1992).

Studies of how fish utilise salt marshes only began in the early 2000s in the UK as a new generation of managed realignments began to be created to offset the loss of salt marshes (UK BAP habitats) through coastal squeeze (Lyndon and others, 2002; Colclough and others, 2005; Nunn and others, 2016). Since then, some 25 managed realignments and associated mature saltmarshes have now been studied across the UK. Studies have shown that salt marsh habitats represent some of the best nursery grounds for the early life stages of a range of fish species, such as the sea bass *Dicentrarchus labrax* (Colclough and others, 2005).

Smelt have only been recorded in low numbers in these studies on salt marsh (S. Colclough pers obs). On the Thames at two locations, large smelt (>15 cm) have been captured in the channels at the foot of the realignment of a salt marsh. Since smelt are predators, they are probably displaying the same behavior observed by large sea bass which wait around the mouth of the breach in the realignment to feed on the small fish emigrating on the ebb tide. Many studies have now demonstrated that these intertidal habitats are far more productive than their subtidal counterparts (Elliot and Taylor, 1989). The enhanced production of juvenile fish and small species in saltmarshes will provide optimal food resources for predators such as larger smelt. Due to their relatively weak swimming ability, first year smelt are probably not capable of utilising selective tidal stream transport sufficiently to be able to penetrate deep into the marsh on the flood tide and safely exit on the ebb (S. Colclough pers obs).

6.6 Marine habitat restoration and management

There are two different approaches to achieve marine habitat restoration; reducing pressure on systems to allow for natural recovery to take place, or intervening with positive action to restore marine habitats and species (ZSL, 2020). When considering marine habitat restoration in estuaries where adult smelt are known to live, the former is the most appropriate course of action: this means management of the estuary and reducing the impact of identified pressures and activities on the system to give the estuary the best chance to recover naturally.

6.6.1 Managing commercial fishing activities

6.6.1.1 Managing smelt fisheries

In areas where smelt fishing takes place, the development of population baselines, based on further research, would allow for catch limits and methods to be set out in local byelaws or national legislation. If smelt remain a target species for the dead-bait or food market they must be protected from over-exploitation. More needs to be known on self-sustaining population sizes so that appropriate sustainable catch limits can be set and over-exploitation will not lead to further local extinctions.

The period in which smelt can be targets should also be addressed. Set seasons need to be defined, i.e. no fishing should occur between January and May, for instance, when smelt are preparing for the spawning migration by forming high density pre-spawning shoals, and in the weeks following spawning when smelt will be recovering from the event. This would protect this species from commercial fishing during their most vulnerable period (spawning) will hopefully allow for sustainable fishing to continue.

Caution should be applied when the fishing is authorised in a small watercourse, where a large fyke net could be set so as to obstruct most of the flow. The English authorisation process under the Marine and Coastal Access Act 2009, provides a modern and flexible way to manage the fishery, provided surveillance is sufficient to fully inform appropriate management action in a timely manner. Efficient and effective surveillance can only be achieved through close collaboration between all of the regulators operating in the locale and with a broader awareness of the issue among other interests and even the general public.

The situation is less clear in Scotland, where the fisheries legislation does not specifically cover the smelt as now takes place in England. However no known smelt fisheries are currently operating in Scotland. In Maitland and Lyle (2010), a long running dialogue is described in Scotland to see the introduction of a close season to protect spawning stocks. This would appear to be a very sensible measure to take in all areas where historical or current smelt fisheries exist, whether they impact on an MCZ or not.

Several examples have been cited of the rapid recovery of smelt stocks in some rivers (see Section 5.3.1). Exploitation is driven by both demand and availability. Maitland and Lyle (2010) illustrate that there is a small demand for the table market. The English market for smelt is for pike dead baits and this, to some extent is self-limiting. If in the future the demand for smelt for the table were to redevelop significantly, and this coincided with a rapid local recovery of smelt in an urbanised estuary, there is the potential for a new, uncontrolled and potentially over-exploited fishery to establish. Vigilance is a necessary prerequisite of smelt management in the future (S. Colclough pers obs).

6.6.1.2 Managing other fisheries in the MCZ and surrounding area

The careful management of commercial catch techniques such as bottom trawling can help to protect the wider marine environment, protecting important habitats such as reefs helps to maintain a natural community structure and ecosystems services. Although this is not a habitat that smelt are known to utilise, this could benefit smelt by restoring ecosystem balance, ensuring good food availability and manageable predation rates from known smelt predators such as marine mammals.

Similar effects on by-catch and prey availability could also apply to other commercial netting activities occurring in or around other MCZs however there are likely to be an array of management measures and byelaws which limit the impact of fishing on other environmental features, eg salmon, which offer protection to smelt. Removing or regulating this pressure with considerations of smelt behaviours and spawning activities, could help to reduce the effect of this potential pressure on population recovery.

6.6.2 Monitoring and control of marine invasive non-native species

Marine INNS are an increasing problem around the UK, with some species having significant ecological and economic impacts on local aquaculture (DEFRA, 2015). Invasive species can displace native biota, competing for space and food resources (DEFRA, 2015).

Preventing the introduction of INNS, monitoring their distribution and abundance as well as control should all be key aspects of managing an MCZ designated for smelt. This can include strict education, guidance and regulations regarding activities within the designation. For example, strict rules on shipping to prevent the introduction of a new species via ships ballast water from international or regional destinations with known high-risk species.

6.7 Other restoration techniques

6.7.1 Natural recovery of a population

If there is a small remnant population of smelt within the MCZ then it may be that the most suitable cost-effective action to take would be to let the population recover naturally. This would also protect the genetic integrity of any smelt population present. If this was decided to be the strategy then efforts should be put into habitat maintenance and protection and continued water quality improvements.

In the case of an MCZ without a spawning population of smelt, rather than intervention, it may be that there is a population in a nearby river that can repopulate rivers within the MCZ naturally as smelt are known to stray from natal rivers. If this was the management decision then it is likely to take some time, may not be successful or may not occur at all. Continued annual monitoring of identified spawning substrates would have to take place to determine whether smelt were returning to the MCZ to spawn.

6.7.2 Translocation techniques

Translocation of smelt from a neighbouring waterbody should only be used in circumstances where you are re-establishing an extinct smelt population and the habitat and water quality are deemed suitable or suitable improvements have been made, otherwise a self-sustaining population will have great difficulty re-establishing.

Another important consideration when undertaking translocation projects is genetic diversity. The donor population must be selected carefully and also must be considered healthy enough to sustain the removal of spawning stock.

In the instance of the Solway Firth MCZ, the Cree population could be considered a suitable donor population if it is properly evaluated to be able to withstand the loss of spawning stock. Below are two examples of translocation studies using the River Cree as a donor population.

6.7.2.1 Translocation of eggs and substrates

In 2007, a three-year translocation project commenced to re-introduce smelt into the neighbouring Water of Fleet by means of translocating smelt eggs from the River Cree to the Fleet (Maitland and others, 2008). The Fleet was chosen as the receiving river as the presence of suitable substrates and river flows in the lower reaches appeared to show the potential for a population to become self-sustaining (Maitland and others, 2008). Based on the conditions monitored in the Cree, the lower reaches above the tidal limit of the Fleet were surveyed to identify areas with suitable substrates and flows for potential smelt spawning activity (Maitland and others, 2008). Several potential areas were identified with good levels of moss/vegetation cover, based on the known conditions for the Cree (Maitland and others, 2008).

In the spring of 2008, the first smelt eggs were found in the Cree on the 28th February but no smelt shoals were observed and only one adult fish was seen during the study period due to high river levels limiting access (Maitland and others, 2008). This meant that adult fish could not be stripped and their eggs input directly to the Fleet and the only feasible method of translocation was moving batches of eggs which were already attached to moss and stones (Maitland and others, 2008). On the 13th and 14th of March, suitably sized substrates, each with several live eggs attached, were translocated to the Fleet and positioned carefully so they remained stable and to prevent desiccation (Maitland and others, 2008).

Over the three-year project it is estimated that roughly 75,000 live eggs were translocated to the River Fleet on substrates taken from the River Cree. This is a relatively low number of eggs when a female smelt may lay between 43,000 and 106,000 eggs annually (Maitland and Lyle, 1997). A monitoring effort was required in the years after the project to determine if smelt had successfully established in the Fleet, scheduled for when the smelt arrived to spawn in the Cree. No eggs or signs of spawning activity were seen (Etheridge, 2010) and it was determined that there was no evidence of spawning in the Fleet, with concerns relating to the exposed a nature of attachment sites possibly resulting in a high wash of eggs off substrates post transfer (Etheridge, 2010). However it was noted that the population may not be discovered for several years as a low population may not be capable of producing sufficient eggs to enable detection (Maitland and others, 2008). Surveys have been carried out in some years since but no evidence of an established smelt population in the Water of Fleet has been found aside eggs found the same seasons as translocation efforts.

6.7.2.2 Direct stripping of smelt into the river

Another attempt was made in 2010 to translocate smelt from the Cree to the Fleet using a different method: stripping smelt directly into the Fleet in an area of suitable flows and substrates.

Male and female smelt were captured from the 'Rag Run' spawning location of the Cree on the 17th and 18th of March, before being stored in separate holding tanks. A total of 257 specimens were caught and most were then transported by aerated tank to the pre-determined translocation site on the lower Fleet around the upper tidal limit. The site was considered to have suitable substrates to sustain smelt eggs: pebbles, cobbles, good macrophyte coverage and faster riffle flows.

A total of 71 gravid females were stripped out the 111 caught from the Cree. The females were stripped in running water, whilst three to five males were stripped adjacent to and directly behind each female so that an almost continuous stream of milt was released, simultaneously surrounding the female's egg release. Etheridge (2010) considered the methodology to mimic natural spawning resulting in a higher percentage of eggs fertilised and adhering to suitable substrates.

After the stripping had occurred surveys were undertaken to predict the success of the experiment. Due to very high river flow conditions in the following days no live eggs could be observed as substrates could not be reached to be removed. In the following weeks live eggs were observed but it was expected that a large number of eggs were dislodged due to fast flows (Etheridge, 2010). Similar studies using the closely related rainbow smelt, *Osmerus mordax*, indicate that there is the potential that this experiment was successful however little evidence has been found to suggest this is the case, as no smelt eggs have been found during inspections of habitat in the years following.

6.7.3 Hatcheries

It has been proven that it is possible to raise smelt from fertilised eggs using enclosed hatchery techniques. This has been described by McCarthy and others, (2019) and they conclude that conservation programmes could utilise established culture techniques for the rainbow smelt, *Osmerus mordax*, for short-term stock enhancement. If conditions are monitored and controlled correctly hatching success in the region of 96% could be achieved, this was reported in conditions of salinity and temperature of 0ppt between 5°C and 10°C. McCarthy and others, (2019) concluded that since smelt required live feed production, the logistical and technical implications of producing live food was too great and that it was therefore recommended to instead release the larval stages into known spawning areas in rivers. This would allow the smelt larvae to drift out into the estuary and complete their life cycle naturally (McCarthy and others, 2019).

If it is found that there are no smelt within and near to a MCZ then this method may be appropriate to kick-start a population. The donor population would have to be carefully chosen, with the knowledge that it could support the loss of brood stock to a hatchery programme.

6.7.4 Translocation techniques

Translocation of smelt from a neighboring waterbody should only be used in circumstances where you are re-establishing an extinct smelt population and the habitat and water quality are deemed suitable or suitable improvements have been made, otherwise a self-sustaining population will have great difficulty re-establishing.

Another important consideration when undertaking translocation projects is genetic diversity. The donor population must be selected carefully and also must be considered healthy enough to sustain the removal of spawning stock.

PART 1 APPENDICES

Appendix 1

Waterbodies in the UK where smelt have recently or historically been present are recorded by Maitland (2003) including estuarine and marine waterbodies and, in red, the additional five population cited by (Colclough, 2013) and the further two populations recorded since 2013 (S. Colclough pers comm).

<table>
<tr><th>Country</th><th>Hydrometric Area</th><th>Rivers</th><th>Estuarine/marine waterbodies</th></tr>
<tr><td rowspan="32">England</td><td>Avon & S</td><td></td><td>Christchurch Harbour</td></tr>
<tr><td>Coquet Gp</td><td>Blythe, Wansbeck</td><td></td></tr>
<tr><td>Dart Gp</td><td></td><td>Knightsbridge Estuary</td></tr>
<tr><td>Esk (Cumbria)</td><td>Duddon</td><td></td></tr>
<tr><td>Essex R Gp</td><td>Blackwater, Crouch</td><td></td></tr>
<tr><td>E Suffolk Rs</td><td>Alde, Deben</td><td></td></tr>
<tr><td>Frome</td><td>Frome</td><td></td></tr>
<tr><td>Frome Gp</td><td>Piddle</td><td>Poole Harbour, Christchurch Harbour, Portland Harbour</td></tr>
<tr><td>Great Ouse</td><td>Great Ouse</td><td></td></tr>
<tr><td>Hants R G</td><td></td><td>Southampton Water</td></tr>
<tr><td>Kent Gp</td><td>Kent, Leven</td><td></td></tr>
<tr><td>Kent R Gp</td><td>Medway, Rother, Swale, Stour</td><td></td></tr>
<tr><td>Mersey & I</td><td>Mersey</td><td></td></tr>
<tr><td>Nene</td><td>Nene</td><td></td></tr>
<tr><td>Norfolk R G (34)</td><td>Bure, Thurne, Waverney, Wensum, Yare, Burn, Glaven</td><td></td></tr>
<tr><td>Ouse</td><td>Ure, Ouse (W Yorks) Esk (Yorkshire)</td><td></td></tr>
<tr><td>Ribble</td><td>Ribble</td><td></td></tr>
<tr><td>Stour (E&S)</td><td>Orwell, Stour</td><td></td></tr>
<tr><td>Sussex R Gp</td><td>Adur, Ouse, Arun</td><td></td></tr>
<tr><td>Tamar</td><td>Tamar</td><td></td></tr>
<tr><td>Tees Gp</td><td>Tees</td><td></td></tr>
<tr><td>Thames</td><td>Lee, Thames</td><td></td></tr>
<tr><td>Trent</td><td>Trent</td><td></td></tr>
<tr><td>Tweed</td><td>Tweed</td><td></td></tr>
<tr><td>Tyne (N'ld)</td><td>Tyne</td><td></td></tr>
<tr><td>Welland (31)</td><td>Welland</td><td></td></tr>
<tr><td>Witham (30)</td><td>Witham</td><td></td></tr>
<tr><td>Witham & S</td><td>The Haven (Boston)</td><td></td></tr>
<tr><td>Wyre & L</td><td>Lune</td><td></td></tr>
<tr><td>Wyre/Lune +</td><td></td><td>Morecambe Bay</td></tr>
<tr><td>Wear</td><td>Wear</td><td></td></tr>
<tr><td>4 Ha's</td><td>Humber, Wash</td><td></td></tr>
<tr><td></td><td>5 Ha's</td><td>Solway</td><td></td></tr>
<tr><td rowspan="2">Wales</td><td>Conwy &</td><td>Conwy</td><td></td></tr>
<tr><td>Dee (Ch-re)</td><td>Dee</td><td></td></tr>
</table>

	Nevern	Nevern	
Scotland	Clyde	Clyde	
	Firth of Forth	Almond, Forth	
	Firth of Tay	Tay	
	Girvan	Girvan	
	Solway Firth (Scotland)	Annan, Bladnoch, Cree, Esk, Fleet, Lochar, Kirkcudbrightshire-Dee, Nith, Urr	
	Stinchar	Stinchar	

Appendix 2

Available Catch Per Unit Effort Data (CPUE) taken from annual authorisation returns (Colclough, 2013).

Yorkshire Ouse

Year	Method	Hours	Number of Instruments	Catch (kg)	Catch/hour	CPUE (catch/instrument/hour)
2011	Pots	47	18	441	9.383	0.521
2012	Pots	14.5	40	1380	95.172	2379

River Trent

Year	Method	Hours	Number of Instruments	Catch (kg)	Catch/hour	CPUE (catch/instrument/hour
2007	Pots	480	10	9396	19.575	1.957
2008	Pots	480	20	7535	15.697	0.784
2011	Fykes	47	30	816	17.361	0.579
2012	Fykes	20.5	80	2096	102.244	1.278

River Waveney

Year	Method	Hours	Number of Instruments	Catch (kg)	Catch/hour	CPUE (catch/instrument/hour
2007	Pots	480	10	8404	17.508	1.750
2008	Pots	480	2	6464	13.467	6.733
2011	Pots	31.25	40	944	30.208	0.755
2012	Pots	32	100	5107	159.594	1.596
2013	Fykes	38.8	2	248	6.392	3.196

River Great Ouse

Year	Method	Hours	Number of Instruments	Catch (kg)	Catch/hour	CPUE (catch/instrument/hour
2012	Pots	120	10	329	2.742	0.274
2012	Fykes	48	10	140	2.917	0.292

River Nene

Year	Method	Hours	Number of Instruments	Catch (kg)	Catch/hour	CPUE (catch/instrument/hour
2012	Pots	188	20	89	0.473	0.024

River Welland

Year	Method	Hours	Number of Instruments	Catch (kg)	Catch/hour	CPUE (catch/instrument/hour
2012	Pots	20	10	80	4	0.4

Appendix 3

Smelt authorisation example, as shown in Colclough (2013).

Mr A Smelt
Cucumber Cottages
Gravel Lane
Osmershire
OE1 2AB

Date of Birth: 1 January 1972

Date of Issue: 28 February 2013

Authorisation Reference: **O/FS/04012013/A1**

The person named above is authorised under section 27A Salmon and Freshwater Fisheries Act 1975 to fish for **Smelt** in waters that are under the jurisdiction of the Environment Agency by means of the following instruments and subject to the conditions below.

This Authorisation is valid at the location(s) detailed in 'Schedule 2: Regional Conditions'.

Notes:
Net tags must be securely attached to your nets before they are used for fishing. The tags will identify your net as being authorised.

National Fisheries Byelaws 2001, Byelaw 4 requires that all fixed traps are fitted with otter guards. Failure to fit an otter guard to all fyke nets and small traps where the entrance to the net or trap is greater than 95 millimetres internal diameter is an offence.

This authorisation does not confer a right to fish - you must always obtain permission to fish in any private water from the owner or tenant.

The authorised person shall record details of their catches on the form provided (including nil catches) completed forms to be returned by 10 May 2013. The information supplied from catch returns is used to monitor the status of the fishery.

Any traps that are discovered lost, stolen or not retrievable on the last day of the authorised period should be reported to the Environment Agency as soon as practicable.

Signed:	____________________
Authorising Officers Name:	Andy Sadler
Authorising Officers Job Title:	Team Leader, Fish Movements

Brampton Office, Bromholme Lane, Brampton, Huntingdon, Cambridgeshire, PE28 4NE
Customer services line: 08708 506 506
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

Part 2: Smelt management in the Solway Firth MCZ

7. THE SOLWAY FIRTH MARINE CONSERVATION ZONE

In May 2019, the inner Solway estuary was designated as an MCZ, with smelt as the feature. The Solway Firth MCZ boundary includes the upper tidal limits of three rivers which flow into the Solway from Cumbria (the River Eden, River Wampool and River Waver) and extends up to the border with Scotland (DEFRA4, 2019). The MCZ, which covers approximately 45 km^2, contains six key habitats including important nursery grounds for estuarine fish such as smelt, Pollock and bass. Fish sampling for the WFD began in the estuary in 2016 and a summary of this work was provided to support the candidate designation by the Environment Agency in 2011. This work showed that the Solway also contained nurseries for dab, whiting, flounder, sprat, herring and sole. This area was already designated as a Special Area of Conservation (SAC), Special Protection Area (SPA) and an Area of Outstanding Natural Beauty (AONB).

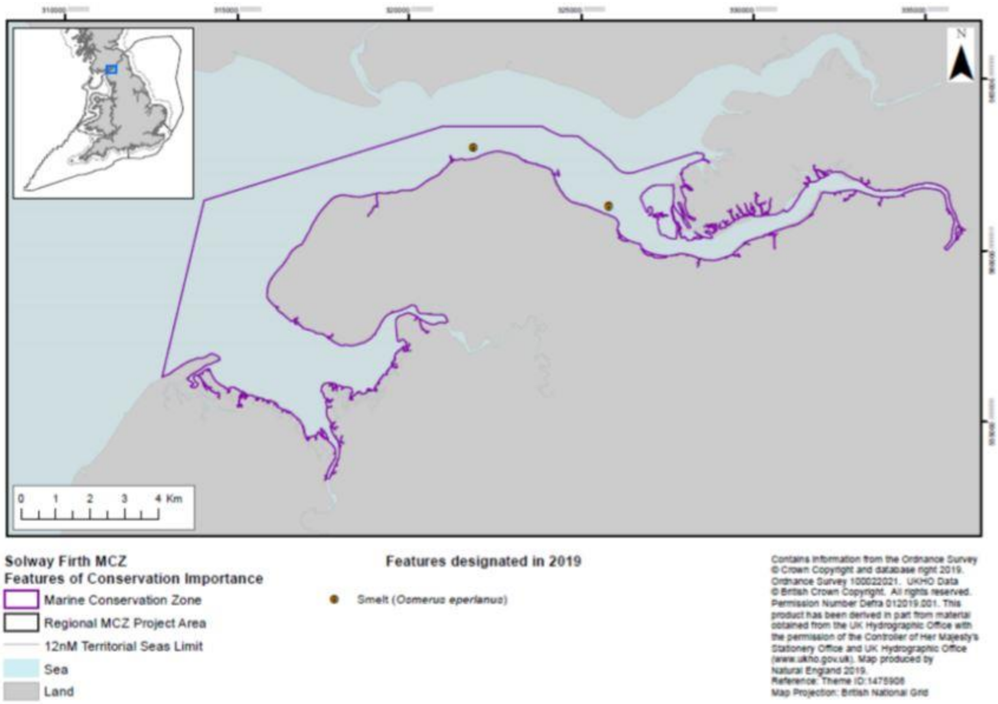
The inner Solway Firth, on both the English and Scottish side of the border, is dominated by intertidal mudflat channels (Bridges and Leeder, 1976). Within this region, large saltmarshes (Rockcliffe, Burgh, Herdhill Scar and Skinburness) surround the inner Solway and such habitats are generally considered to be good nursery habitats for estuarine fish species (Minello and others, 2003).

It should be noted that the management of this MCZ needs to take into consideration the lack of equivalent protection on the Scottish side of the Solway, as smelt is not afforded the same protection across this mid water boundary.

7.1 Description

The Solway Firth MCZ extends from Skinburness in the west, along the coast, taking in the channels and estuaries of the River Waver, the River Wampool, north past Cardurnock, Bowness-on-Solway and Port Carlisle to a stretch of the channel of the River Eden between Rockcliffe and Beaumont (Figure 4).

Figure 4: The boundaries of the Solway Firth MCZ



7.2. Anecdotal information

In order to gather historical information on smelt in the inner Solway, and to help gauge whether there were any known remnant populations, it was necessary to identify and engage with stakeholders in the surrounding area. The collection of anecdotal data from key local groups such as fisherman, netsmen and locals living in the nearby area can indicate the presence or absence of smelt as an initial starting point. Working with Solway Firth Partnership (SFP), key stakeholders were identified and encouraged to attend a stakeholder event or interviewed over the phone or in person. Two stakeholders drop in events were held in the area, the Christmas Bazar in Bowness-on-Solway on the 16th November 2019 and a hosted smelt engagement event in Bowness-on-Solway on the 10th December 2019.

During interviews and events, fishermen and haaf netters provided historical information on the location of smelt as well as some behavioral patterns. To summarise, smelt were not a commonly caught or targeted fish species within the MCZ in recent years. Since the 1970s only a few irregular sightings have been reported from haaf netsmen and some had neither heard of them nor recall ever catching any. Sightings were mainly reported by netsmen between May and September during night tides. In most instances sizes or numbers could not be estimated as most encounters were based on noticing the distinctive cucumber smell, the few caught were estimated to be between 10 cm and 20 cm long. Some netsmen had caught smelt accidently when haaf netting for salmon (using 44 mm nets), on a few occasions when they became entangled by their teeth or gills. On a few occasions smelt were sighted shoaling in the shallows.

7.3 Solway literature and data review

7.3.1 Literature review

A desk study was undertaken to review historic records and recent literature from the Solway as well as collate expert opinions on the status of smelt in the Solway. Literature relating to the presence of smelt in the inner Solway and rivers within the MCZ was very limited. Information on smelt in the wider Solway was predominantly limited to journal articles and reports produced on the River Cree population of smelt which is further north west and out with the MCZ.

A set of byelaws drawn up in 1889 placed regulations on the mesh size and season in which smelt could be fished in the inner Solway, suggesting smelt were at that time plentiful but there was no evidence of known spawning locations in the inner Solway (Solway Firth Partnership, 2020). According to a collection of memories by McPherson (1892), fishing for smelt was a profitable occupation at one time as smelt were considered delicious, but even in 1890s there was a strong suggestion that smelt were less plentiful in the inner Solway possibly due to exploitation efforts. This text references that smelt did not disappear in the winter months as they were still fished at this time of year, the best fishing season being in September but they were unpredictable then also (McPhearson, 1892).

Maitland (2003) stated with regard to smelt in the Solway that, "it seems quite likely, but not certain, that the stock of smelt which used to run into the Eden, is, like other stocks in the upper Solway, now extinct. Whether these were one population or more is uncertain, but the former is more likely."

7.3.2 Data review

7.3.2.1 Water quality data

Water quality data has been provided by the Environment Agency (Appendix 4). This point sampling, collected once a month, gives insight into the kind of pollutants which may be causing poor water quality conditions reported in the Wampool and Waver according to the parameters set by the WFD (see Section 7.3.2.1). In the Waver and the Wampool sampling sites are not located close enough to the upper tidal regions, as the three sampling sites are between 4 km and 10 km of the upper tidal limits of the respective rivers (Waver; 10 km DS NY16896 52302, Wampool; 4 km US NY67994 49975 and 6 km DS NY 42685 55716). There is a lack of data to suggest the daily fluctuations of harmful parameters, particularly during the spawning and development period, to evaluate the effect water quality might have on spawning smelt but it is presumed that water quality is a potentially significant pressure in the Waver and Wampool.

In the case of the River Eden sampling sites, the first site is located within 50 m of the upper tidal limit (NY 38371 56482) and the second site is located at Beaumont approximate 6 km downstream of the upper tidal limit. Data has been collected at these sites once a month since 2012 (upper tidal limit site) and 2010 (Beaumont site), and samples the upper tidal region which would be indicative of the conditions spawning smelt will endure during spring. However more detailed data is required to determine the suitability of the region, in terms of water quality, for spawning smelt particularly over the spawning and egg development period to assess the true extent of this pressure as a limiting factor (see Section 6.2.5).

7.3.2.2 Catch data

Data on smelt from the inner Solway is very limited. The Environment Agency recorded four smelt during monitoring surveys within the boundaries of the MCZ as well as 36 specimens a short distance south of the MCZ boundary (near Silloth) between 2008 and 2016 (Figure 5 and Table 2). The size of specimens caught ranged between 65 mm and 263 mm using seine nets and fyke nets.

Figure 5: The location of smelt caught during Environment Agency monitoring surveys, only four of which were within the MCZ boundary (map from the Environment Agency)

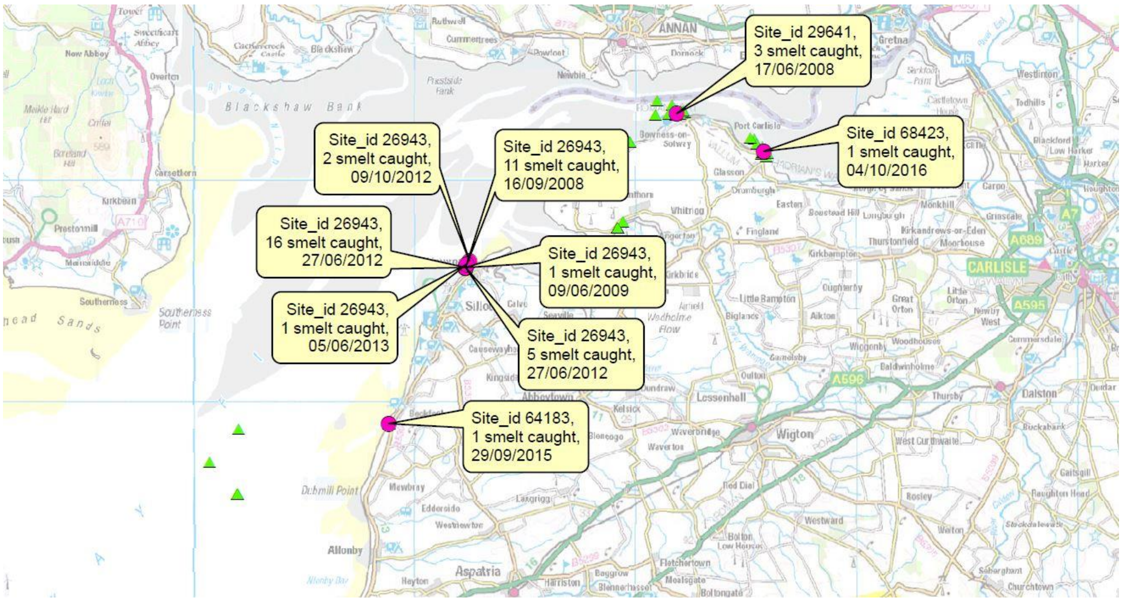


Table 2: The number of smelt caught on particular dates during monitoring surveys conducted by the Environment Agency between 2008 and 2016

Location	Date Caught	Number Caught	Caught within MCZ Boundary
Beckfoot	29/09/2012	1	N
Bowness-on-Solway	17/06/2008	3	Y
Glasson Point	04/10/2016	1	Y
Silloth	16/09/2008	11	N
Silloth	09/06/2009	1	N
Silloth	27/06/2012	21	N
Silloth	09/10/2012	2	N
Silloth	05/06/2013	1	N

7.3.3 Conclusions

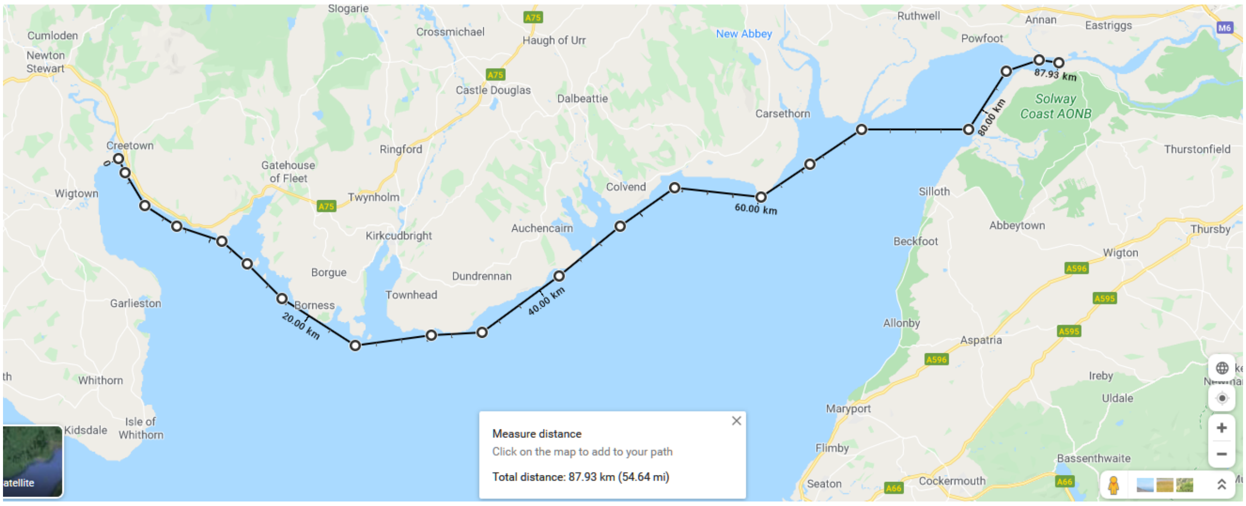
From the information gathered and data obtained the status and composition of the smelt population within the Solway Firth MCZ cannot be determined.

7.4 Present status of the smelt population in the inner Solway

There is limited literature referring to the presence of smelt in the Solway Firth. The literature available states that 10 of the rivers flowing into the Solway Firth have historically had a population of smelt (Bladnoch, Cree, Fleet, Kirkcudbrightshire Dee, Urr, Nith, Lochar, Annan, Border Esk and Eden (Maitland and Lyle, 1997; Maitland, 2003). There is no mention in the literature of the River Waver or the River Wampool historically (or presently) having a smelt population, or around Moricambe Bay, which is within the boundaries of the Solway Firth MCZ.

The last remaining confirmed population of smelt in the Solway Firth are known to spawn in the River Cree (Maitland and Lyle, 2001) which is approximately 76 km from Moricambe Bay (access to the Waver and Wampool) and 88km from the lower River Eden (see Figure 6).

Figure 6: The distance at sea, following the coast, from the lower River Cree to Moricambe Bay and the lower River Eden (source: Google Maps)



Anecdotal data collected as part of this project suggests that there may still be remnants of a historic population present in the River Eden. Several accounts state that smelt have been observed shoaling off of Glasson Point, Burgh Marsh and Port Carlisle on several of occasions in the last two decades by haaf netters targeting Atlantic salmon. Observations from the habitat survey (Section 7.5.3) indicate that the River Eden has areas of suitable spawning substrate and adequate flows to sustain spawning smelt. This was not deemed to be the case for the rivers Waver or Wampool as significant anthropogenic modifications (ie channel straightening, dredging, agricultural drains) has altered the hydrology so significantly from natural river morphology that there was observed to be no suitable spawning habitat remaining. It is impossible to estimate if the natural habitat would have been suitable prior to substantial modifications.

7.5 Habitat surveys

In order to gauge whether a population of smelt could be supported in the inner Solway it was necessary to carry out walkover habitat surveys. The rivers Waver, Wampool and Eden were visited in December 2019 to look at instream conditions, particularly with reference to identifying the upper tidal limit and the identification of suitable spawning habitat or potential spawning areas.

7.5.1 River Waver summary

The River Waver is not officially designated an artificially or heavily modified water body (Environment Agency[1], 2016). In the 2016 WFD assessments the River Waver had moderate ecological status (poor until 2015) and good chemical status (Environment Agency[1], 2016). The main reason the Waver has yet to achieve good ecological status is poor nutrient and soil management from the surrounding agricultural and rural land impacting the river (Environment

Agency[1], 2016). It is not known whether the water quality is good enough over the spawning period to sustain a population of smelt and more data over the spawning period is required (see Section 7.3.2.1).

In general, the channel of the River Waver has been artificially straightened and deepened, with many right-angled corners, leading to a canal-like watercourse with poor instream habitat in much of the lower catchment. Substantial dredging activities over the years have deepened and narrowed the channel, removing natural substrates from the river bed which could have potentially been suitable for smelt in the past. The straightening and deepening was carried out to drain the low lying, boggy, surrounding land to make it more productive and this has led to a presumed increase in flow rates exceeding natural conditions. The tidal limit on the Waver is located near Lesson Hall, at approximately NY 21247 51069 between Ellercarr Bridge and Lessonhall (Figure 7) and it is likely that a smelt population would be capable of spawning around or upstream of this location. Unfortunately, instream conditions upstream of this point are very similar to those encountered further downstream, with the channel highly modified, straightened and deepened. Some limited spawning opportunities may be present around the tidal limit and further upstream at Lessonhall Bridge where there is a change in gradient and corresponding areas of faster riffle flows, typical of that required to dissipate smelt eggs and milt during spawning activities. In these locations some suitable vegetation and substrates are present which would facilitate egg adhesion.

Overall, in the opinion of GFT, the River Waver is unsuitable for smelt without significant morphological improvements and changes to land management practices. Currently there is a lack of suitable spawning habitat and water quality needs to be determined more accurately during the spawning period, the potential available habitat is of poor quality and access to potential spawning habitat areas could be prevented by fast river flows caused by anthropogenic modifications.

Figure 7: The approximate upper tidal limit on the River Waver (looking downstream)

7.5.2. River Wampool summary

The lower River Wampool is designated as a heavily modified water body (Environment Agency[2], 2016). In 2016 the WFD assessments classified the lower Wampool as having moderate ecological status and good chemical status (Environment Agency[2], 2016). There are two main reasons the lower Wampool has yet to achieve good ecological status: poor soil and nutrient management as well as the negative impact land drainage management has had on aquatic invertebrates and the local ecology of the river (Environment Agency[2], 2016). It is not known whether the water quality is good enough over the spawning period to sustain a population of smelt and more data over the spawning period is required (see Section 7.3.2.1). As with the Waver, the channel of the River Wampool has been artificially straightened and deepened, and the watercourse has become canal-like but more meandering than the neighboring Waver. The river contains very poor instream habitat and substantial and comprehensive dredging activities appear to have removed much of the natural substrates and flow regimes both above and below the tidal limit. It could be that there were suitable spawning sites in the river in the past but during the habitat survey it was impossible to locate any sites suitable for spawning (Figure 8). It is likely that, like the neighboring Waver, the Wampool was straightened and deepened to improve adjacent agricultural land and has led to a likely increase in flow rates exceeding natural conditions. The tidal limit on the Wampool is located near to Gamelsby, at approximately NY 24000 54367.

Figure 8: The approximate upper tidal limit on the River Wampool (looking downstream)

In the opinion of GFT it is unlikely that smelt would be supported in the River Wampool in its present condition and it would take significant habitat improvements to support a spawning population of smelt. The natural morphology of the river has been destroyed by river engineering activities over many decades.

7.5.3 River Eden summary

The lower region of the River Eden, including the tidal reaches has not been designated as artificially or heavily modified water body (Environment Agency[3], 2016). The water body achieved good classification in 2016, but in 2014 the ecological status dropped to moderate before returning to good ecological status in 2015 (Environment Agency[3], 2016). In 2013 and 2014 the lower reaches of the Eden failed chemical status, but achieved good chemical status in 2015 and 2016 (Environment Agency[3], 2016). More data collected over the spawning period is required to ascertain whether water quality in the Eden is suitable to sustain a spawning population of smelt.

The lower tidal reaches of the Eden were much less modified than those observed in the Waver and the Wampool, with more natural conditions present, considered to be similar to those observed in the River Cree, only on a slightly larger scale. Below the tidal limit there are two long (approximately 50 m) and wide (>20 m) riffle sections with suitable substrates (NY 38405 56521 and NY 37719 58061, Figure 9) and in river lower flow conditions. It was noted that a high spring tide could assist smelt in reaching these riffle sections in which smelt could spawn effectively. Some suitable vegetation and mosses were observed in these areas upon which eggs could adhere.

Figure 9: Suitable riffle habitat with suitable spawning substrate near the tidal limit of the River Eden (NY 37719 58061)

The normal high tide limit on the Eden was located upstream of a disused railway bridge (Waverly Viaduct) near the outflow of Parham Beck, approximately at NY 38436 56542. At this point there is a change in gradient in the river and a large riffle was evident. This area also appeared suitable for smelt to spawn, with slower flowing areas observed on the right bank. On the left bank of the river, immediately adjacent and upstream of this, lies a large industrial site and sewage works. A discharge point (Figure 10) emanating from this site was noted adjacent to the large riffle and this has the potential to affect water quality in this location and further downstream. It may be however that flow conditions in the river results in the discharge flow staying relatively close to the left bank. If very high water was combined with a high spring tide then the tidal limit could potentially ascend a weir that is located upstream of the riffle and travel further into Carlisle.

Figure 10: The outflow into the large riffle section near the approximate tidal limit on the River Eden at NY 38465 56532

The weir is located upstream of the riffle near the tidal limit and it has the potential to cause a barrier to smelt travelling upstream to spawn. Upstream of this the river is generally characterised by slower flows and deeper water which suggests that smelt would spawn in the riffle around the tidal limit upstream of Waverly Viaduct. The West Coast Main Line twin bridges cross the river at NY 38861 57058 and here flows are constricted between the bridge supports (Figure 11), potentially causing a flow barrier to upstream migration, if smelt were able to ascend the weir further downstream.

Figure 11: The bridge supports of the railway line at NX 38861 57058

Initial observations from the survey undertaken on the Eden suggests it has the potential to be suitable for sustaining a population of spawning smelt however more data, especially in terms of gathering more data on water quality is required.

7.5.4 Conclusions

In the opinion of GFT it is very unlikely that smelt are present in the River Waver or Wampool, due to a combination of severely altered river morphology, degraded habitat, and to a lesser extent, poorer water quality. The River Eden appears much more suitable in terms of morphology, habitats and flow regimes. The Eden therefore has the potential to support a remnant population of smelt however research would need to be carried out to confirm if they are present or not. If smelt are not present in the Eden (a remnant or otherwise), the main cause and pressures need to be identified.

Pressures could include:

- Flood alleviation schemes could have caused excessive flows which have altered flow regimes and smelt may have difficulty accessing suitable spawning areas at different river discharge rates
- Water quality over the spawning period could be an unidentified issue. For example, the discharge point upstream of Waverly Viaduct and other discharge points may have an impact on water quality across spawning locations.
  An impact is also potentially caused by the removal of shrimp as a prey species for smelt (Solway Firth Partnership, pers comm). This could be a potential pressure on the natural recovery of smelt populations in the wider Solway region, but lack of information regarding population size and behaviour of smelt in the Solway prevents an evidenced evaluation of this pressure. In addition the shrimp population is extremely variable from year to year in overall abundance and distribution, meaning understanding the role of shrimp fishing on the population is very challenging
- Other potential unidentified pressures may have caused Eden smelt to die out and prevent re-establishment from neighbouring areas (since data suggests smelt are in the area) or the Cree smelt population.

It may be that smelt are spawning in the River Eden, or have been in the very recent past, potentially in very low numbers. It is understood that no surveys have been carried out or information collected on the population so it remains an unknown. Since it is many years since smelt are thought to have died out in the Eden (Maitland, 2003), locals may not know about the species and would not pick up on the presence of a remnant population – they can often be mistaken for salmon or sea trout smolts if anglers are fishing during the early spring.

In the opinion of GFT, the River Eden currently provides suitable habitat for spawning smelt, however the Rivers Waver and Wampool are unsuitable due to their heavily modified habitats in the lower reaches and around the tidal limits. It would take much investment, changes in land use and local buy-in from landowners to enable these degraded rivers (Waver and Wampool) to sustain a population of smelt. The Eden is in a much more favourable condition, with less investment required to sustain a population of smelt.

7.6 Inner Solway summary

The Solway Firth is an area of highly mobile intertidal sand flats, containing the third-largest area of littoral mudflats in the UK. It is a very important area providing essential varied habitats for local and transient species of importance (Eden Rivers Trust, 2020). The Solway Firth is designated as a Special Area of Conservation (SAC) primarily, in terms of habitats, for its estuaries, sub-tidal sandbanks, intertidal mudflats and sandflats, Atlantic salt meadows and Glasswort and other annual plants that colonise mud and sand.

At the beginning of the 20th century, smelt were common in the inner Solway, present in the Rivers Annan, Eden, Border Esk and the Nith (Service, 1902), and were abundant enough to support sizable fisheries (Hutchinson and Mills, 1987). Since then, declines and extinctions in these inner Solway rivers have been attributed to overexploitation and poor water quality (Maitland, 2003), and recent literature states that there are no breeding smelt populations remaining in the inner Solway.

Presently there is a lack of evidence to determine how smelt use the inner Solway and whether the populations thought to be extinct have shown any form of recovery (natural recoveries have been shown in the Thames and Forth once pressures have been removed (see Section 5.3.1)). Anecdotal data suggests that spawning has occurred in the Eden in the past 20 years, and this indicates that the population here could have recovered to some extent, without anyone being aware due to lack of knowledge and data.

Rivers such as the Kirtle Water, the Sark, the Waver and the Wampool have never been identified in literature as rivers which contain spawning populations of smelt. This may be because they held smaller, more insignificant populations unable to sustain a fishery unlike their neighbouring rivers which held substantial populations, or the location of the tidal limits could be relatively remote and hence the presence of smelt has not been observed previously. More data and research is required to determine the status of smelt in the inner Solway. Potential spawning locations need to be surveyed in detail and assessed over the spawning period to ascertain whether any remnant populations exist and have come into the rivers to spawn. More information on how to do this can be found in Section 6.2. In addition to this and once spawning sites have been surveyed over the spawning period, more information on the known pressures affecting smelt recovering in the wider Solway Firth should be gathered.
Little information is available on smelt habitat requirements in the marine and estuarine environment and it is unknown whether young life stages of smelt use salt marshes in a significant way. Therefore, more research is required in the inner Solway and wider Solway Firth to establish the roles of key species in the community structure and how these aspects affect smelt. Determining the extent to which smelt utilise different habitats within the Solway Firth can help to highlight key pressures which need to be addressed, i.e. lack of spawning habitat, water quality or poor food availability.

Haines (2017) reported that there were currently eight active vessels targeting shrimp near to Silloth and Maryport, within the vicinity of the Solway Firth MCZ. Shrimp netting also takes place in the Solway but is thought to be at a relatively low intensity. Research is required to determine the level of smelt by-catch from these fisheries.

8. RESTORATION OF THE SOLWAY FIRTH MCZ

8.1 General strategy

Due to the lack of data and detailed knowledge of smelt in the inner Solway it is difficult to set out a specific restoration programme for the Solway Firth MCZ. However, there are opportunities that can be highlighted. The Rivers Waver and Wampool within the MCZ (see Section 7.5 for descriptions) are extremely degraded in terms of morphology and habitat so only the River Eden would be viable to hold a population of smelt at the moment. It firstly needs to be established if there is a remnant population of smelt in the Eden.

It would also be prudent to look at the wider area, the bigger picture in the Solway, and look at restoring smelt to the general area of the inner Solway, and not only within the MCZ. Rivers such as the Border Esk, Annan and the smaller Lochar Water are within the same geographical area of the inner Solway as the MCZ and these all historically once held populations of smelt. These rivers are in Scotland, and as described in Section 3.3, Scotland does not have MCZs in its suite of designations so it is impossible to extend the MCZ to include these rivers. Scotland does however have Nature Conservation Marine Protected Areas (NCMPAs) so it may be possible to designate the Scottish side of the Solway and join it with the MCZ to enable a larger geographic area to be protected. Indeed, if Scottish rivers within the inner Solway area have populations of smelt, then adults from these populations would be within and surrounding the MCZ and would surely be utilising the area. Equally, if the rivers within the MCZ have smelt populations then then these would be expected to utilise the Solway Firth beyond the boundaries of MCZ. To facilitate the designation of the Scottish side of the Solway, discussion would have to be held and agreements made between Natural England and Scottish Natural Heritage. Due to the cross-border management that is likely required, management of smelt within the MCZ may require a partnership management approach.

In order to increase the possibility of smelt returning to the River Eden to spawn, or rivers in the wider MCZ, it is recommended that smelt themselves are protected. The current status within the marine/estuarine environment needs to be assessed and their movements in the inner and wider Solway need to be determined.

8.2 Managing saltmarsh habitats along the Solway coast

The Cumbrian Solway coast was designated as an area of outstanding natural beauty (AONB) in 1964 and since 1996 the site has been managed to recover natural ecosystems through supporting sustainable land management holistic ecosystem approaches (Solway Coast AONB Partnership, 2019). In recent years the extent of salt marshes, such as Bowness on Solway and Rockcliffe Marshes in particular, has increased, with these salt marsh areas rising and expanding due to deposition (Solway Coast AONB Partnership, 2019).

It is possible that the salt marsh habitats along the Solway could provide habitats and food for a potential smelt population to utilise, so it is important that salt marsh habitats are conserved and protected. At the time of writing, the Solway Coast AONB Partnership have released their 2020 to 2025 management plan for consultation which involves priority actions including conserving and extending salt marshes further, reducing impacts posed by Invasive Non-Native Species (INNS) management in salt marshes and promoting the local development of new land management agri-environment schemes for the benefit of the surrounding environment (Solway Coast AONB Partnership, 2019).

8.3 Marine habitat restoration and management in the Solway

In terms of marine habitat restoration for the Solway MCZ, the estuary is physically in good condition. The area is designated as an SAC (see Section 7.6) and a Special Protection Area (SPA, under the Birds Directive) and this helps protect it from certain activities and allows natural self-restoration to occur. Wider anthropogenic pressures such as climate change may be altering the way that adult smelt utilise the marine and estuarine environments.

8.3.1 Monitoring and control of marine invasive non-native species in the Solway

In the 2018 to 2021 biosecurity plan designed for the Solway Firth, nine marine invasive species (Japanese wireweed *Sargassum muticum*, Pacific oyster *Crassostrea gigas*, Common cord grass *Spartina anglica*, Orange tipped sea squirt *Corella eumyota*, Acorn barnacle *Elminius modestus*, Leathery sea squirt *Styela clava*, Green sea fingers *Codium fragile*, Japanese skeleton shrimp *Caprella mutica* and American Lobster *Homarus americanus*) were highlighted as species of concern found in the Solway and a further three were highlighted as species which are considered at risk of introduction (Solway Firth Partnership, 2017).

An example of a potential marine INNS that is not present in the Solway but is listed as a threat, with a high likelihood and high impact if introduced into the Solway, is the Killer Shrimp (*Dikerogammarus viliosus*). The introduction of this species would have a high impact on the Solway (Solway Firth Partnership, 2013). This voracious predator is capable of dominating habitats quickly, in doing so significantly alters community structures as it predates on small fish and invertebrates. This could not only threaten the food availability for adult smelt but could potentially reduce larval survival rates.

The SFP is working in partnership with local and national organisations to establish a framework which will prevent, detect and control marine INNS within the Solway Firth. This includes promoting the Check-Clean-Dry Campaign[2] (Solway Firth Partnership, 2017) to prevent further spread of invasive species on equipment used in and around waterbodies, this includes commercial and recreational activities.

Preventing the introduction of INNS, monitoring their distribution and abundance as well as control should all be key aspects of managing an MCZ designated for smelt. This can include strict education, guidance and regulations regarding activities within the designation. For example, strict rules on shipping to prevent the introduction of a new species via ships ballast water from international or regional destinations with known high-risk species.

8.4 Suggested restoration actions for the Solway Firth MCZ

[2] http://www.nonnativespecies.org/checkcleandry/

The restoration of the smelt population in the Solway Firth MCZ may not be straightforward. In the opinion of GFT the Eden appears much more suitable for a smelt population to exist. Restoration of the Waver and Wampool would require considerable buy-in from the agricultural sector/landowners and require a significant amount of investment.

The following is the suggested initial strategy for restoration of the Solway Firth MCZ.

1) Research: Is a spawning population of smelt present within the Rivers Waver, Wampool or Eden?

Firstly, it must be established if there is a remnant population of smelt spawning in the Waver, Wampool or Eden. Various aspects of this should be researched by following the steps provided in Section 6 which shows a flow chart (Figure 2) that can be used to help lead the plan of research in this first stage, when identifying the status of smelt in the MCZ is key.

If research is carried out and a spawning stock is not present within the MCZ then it is suggested that rivers out with, but close to the MCZ are checked for a spawning population of smelt. Then translocation of smelt to the Eden from these stocks could be an option or, if desired, waiting until potential straying of fish would establish a population naturally. In time, if a population of smelt is restored to the Eden, then it may be desirable to also try and restore populations of smelt to the Waver and Wampool. By concentrating firstly on the Eden, which it is suggested does not require significant habitat improvements, the initial financial investment required is likely to be significantly lower.

2) Water quality: Improve water quality within rivers in the MCZ

Whether smelt are deemed to be present or not, it is suggested to concentrate on improving water quality across the catchments within the MCZ. Water quality over the spawning period for smelt (see Section 4.3) is crucial to the survival of the eggs and larvae so a focus must be made to assess, monitor and improve water quality over the spawning period.

Landowners and tenant farmers need to be approached prior to commencing a water quality monitoring and improvement programme and their buy-in is crucial to success.

3) Habitat improvements: Consider re-meandering the Waver and Wampool

As mentioned in 1), it is suggested to firstly concentrate on restoring smelt to the Eden. It may then be desirable to restore smelt to the Waver and Wampool. It is likely that this may have to wait until some significant habitat restoration takes place.

In Cumbria, the Eden Rivers Trust and the West Cumbria Rivers Trust have, in partnership with the Environment Agency and Natural England, carried out significant river restoration work as part of the Cumbria River Restoration Strategy. The focus of this project has been on natural flood management (reconnecting floodplains), improving habitat quality and connectivity, and barrier removal. Through this work, some re-meandering of straightened channels has been completed – this is a habitat enhancement technique that is being increasingly used across the UK to deliver multiple benefits to river systems. Significant habitat improvements have been achieved in the Cumbria River Restoration Strategy however much of this work has been focused in the mid to upper river catchments rather than in the lower reaches near the tidal limits.

There are many benefits to this approach of river restoration however a significant drawback is cost. On the River South Esk in Scotland, 1200 m of the Rottal Burn, which was realigned and straightened in the 1830s, was re-meandered in 2012 at a cost of £200,000. The South Esk is a prime sea trout river so consideration was given to improving the habitat for this valuable game fish. Re-meandering lower rivers near the tidal limits to improve spawning conditions for smelt may not be possible in all circumstances. As smelt spawn in the lower reaches of river systems, the surrounding land is often high value productive farmland or the river is at close quarters to urban development so it may not be feasible.

In the case of the River Eden, this already appears to hold sufficient habitat in its lower reaches for smelt to spawn. In the case of the Waver and Wampool, these rivers are likely to benefit from re-meandering however the quantity of land and cost required to do this may prove cost-prohibitive. The river channels have been dredged and artificially deepened over many years making re-naturalising these rivers a significant challenge. The River Restoration Centre[3] and the West Cumbria Rivers Trust should be approached to provide expert opinion on this if it was decided to go down the line of large-scale construction works to re-meander either of these watercourses.

4) Marine environment: Shrimp fisheries

The status of shrimp netting in the Solway should be thoroughly researched to ascertain whether by-catch of smelt is a risk, and if so, is the by-catch significant. There needs to be liaison between Natural England, the fishermen, the MMO and the IFCA to record any by-catch of smelt that may occur. The relatively low intensity of shrimp fishing activity may indicate by-catch risk levels are low but further work would aide understanding of the risk.

8.4.1 Restoration options not considered suitable for the Solway Firth MCZ

8.4.1.1 Habitat creation – adding spawning gravel to rivers

We do not suggest that spawning material is added to the Waver and Wampool simply because their morphologies are currently unsuitable – since becoming heavily modified (see Section 7.5), the structures of these rivers are no longer suitable to maintain the gravel in the system. Additionally, there does not appear to be any current sources of gravel within the lower river systems and long-term gravel retention is likely to be an issue.

In the right location it may be possible to add spawning material to a watercourse. This has been carried out effectively in several locations previously for many different reasons. An example of where this has been successful is the High Cree (upper River Cree). In 2011 and 2012, 1000 tonnes of limestone gravel were added with the main river and a spawning tributary. The use of limestone gravel in this situation was to help buffer the low pH water to facilitate better survival of salmon eggs. Despite numerous flood events the gravels have stayed relatively in situ and salmon redds have been observed within the gravels. Whilst this is a relatively cheap way of restoring instream conditions, it could still prove expensive, depending on the planning costs, the quantity of aggregate required and where it was sourced, and transportation costs. It also must be meticulously planned, with heavy input from hydrogeomorphologists from the outset.

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[3] https://www.therrc.co.uk/

8.4.1.2 Other restoration options not considered

Coastal habitat restoration and management, marine habitat restoration and management and managing coastal commercial fishing activities are not suggested as options to consider for restoration of the Solway Firth MCZ as they are not relevant to this area.

Whilst monitoring coastal and marine INNS is not required at the moment, a watching brief should be held and if any marine or coastal INNS are identified that may impact on smelt then they should be tackled appropriately.

9. MONITORING

The monitoring and evaluation of any restoration project is key. Once the status of smelt in the MCZ has been established and the route of restoration has been set out, baseline surveys must be carried out, prior to any restoration work commencing. Any changes to the restored area must be monitored as well as an initial and continued (as far as practicable) assessment of the smelt population, to ascertain whether there has been an improvement in numbers. Depending on the restoration method selected (Section 6), it is easiest and likely most cost effective to assess the numbers of smelt utilising the Solway MCZ by carrying out surveys during the spawning period in the riverine environment. Carrying out studies offshore to determine numbers of smelt within the estuarine and wider marine environment of the Solway MCZ would be a useful exercise, but may prove too costly.

If the smelt population has become established after restoration then a useful monitoring technique was developed by Maitland (2003) for assessing the Cree smelt population (see Section 5.1) and a monitoring programme could be based upon this work.

Citizen Scientists could be recruited to help assess the situation with spawning smelt annually. This is also an excellent way of publicising the work and raising the profile of smelt.

10. CONCLUSIONS

Restoring and managing populations of smelt within MCZs requires a landscape approach, and in some cases this may be across borders. Smelt spend the majority of their lives in the marine environment and often within a complex of estuaries. They are able to move freely within these areas so concentrating on restoration within a single MCZ may not result in the greatest benefit to smelt populations. Certainly, in-river restoration or protection is essential where smelt are known, or thought to, spawn, as these areas are vital in terms of recruitment and long term survival of the species. However when considering management options the boundaries of the MCZ within the estuarine and marine environment should not be considered rigid borders and work should be carried out within and outside the boundaries of the designation. A wider designated area may be beneficial in some areas, for example in the case of the Solway Firth MCZ an area of similar protection on the Scottish side of the inner Solway would be valuable as this would help protect the wider habitat for adult smelt.

Once an understanding of population structure has been developed it is recommended that smelt are managed at a landscape scale, across boundaries, designations, regions and countries. This is likely to be a different way of managing a species in a protected site where usually, a boundary means just that: a boundary, and the protected species is managed within confines of that boundary. This then requires a different way of thinking and working; multiple organisations, groups and individuals will need to come together to work on a wider scale in a partnership approach if the population of smelt within the MCZ is to flourish.

In the case of the Solway Firth MCZ, this area already falls within a management plan that is cross-border, namely the Solway Tweed River Basin Management Plan. The current consultation for the updated Solway Tweed plan identifies the following as significant issues and pressures within the Solway: man-made barriers to fish movement, restoring resilience in physically modified rivers, pollution from rural land use and invasive non-native species. Management and improvements of these issues would not only benefit the rivers within the Solway Firth MCZ, but also have the potential to benefit smelt, as they are a key species which rely heavily on some rivers within the Solway-Tweed river basin for part of their lifecycle.

11. USEFUL CONTACTS AND POTENTIAL FUNDING SOURCES

11.1 Contacts

Natural England:
https://www.gov.uk/government/organisations/natural-england

Environment Agency:
https://www.gov.uk/government/organisations/environment-agency

River Restoration Centre:
https://www.therrc.co.uk/

Department for Environment, Food and Rural Affairs:
https://www.gov.uk/government/organisations/department-for-environment-food-rural-affairs

The Rivers Trust:
https://www.theriverstrust.org/

11.2 Potential funding sources

In light of the UKs recent exit from the European Union, new large value funding sources for river restoration are currently under review making it very difficult to recommended potential funding sources. Groups that focus on partnership work in the region should be contacted to undergo any large-scale habitat improvements or monitoring programmes that may involve utilising Citizen Science.

An example of a funding source that was previously available, funded by the European Agricultural Fund for Rural Development, is the Water Environment Grant Scheme. This £27 million scheme was recently launched by DEFRA, Natural England and the Environment Agency in May of 2018 with successful applicants awarded funding in August of 2018 and expected to have started their projects by March of 2019, with completion by March 2021 (UK Government, 2018). The scheme is a funding source for projects aiming to restore local ecosystems (ie improving water quality or improve fish species access to vital habitat), which would deliver substantial benefits to the local community and surrounding environment. A smelt restoration project could be a suitable application should similar funding source arise.

After determining the status of smelt in the MCZ designation and whether restoration of habitats is essential to support the recovery or establishment of a nearby smelt population, it is suggested that the groups noted in Section 11.1 are contacted to enquire about potential funding available for such a project.

PART 2 APPENDICES

Appendix 4

EA water quality data provided at five sites within the Solway Firth MCZ, data presented is limited during the months of February and March and in some years no sampling has occurred during these months.

EA water quality data on the Waver at site 'Waver Estuary at winding banks' located at NY 16896 52303.

DATE	0061 pH PHUNITS	0076 Temp Water CEL	0103 Hg Filtered ug/l	0106 Cd Filtered ug/l	0135 SId Sus@105C mg/l	0158 Hardness mg/l	0237 Magnesium-Mg mg/l	0239 Ca Filtered mg/l	0241 Calcium - Ca mg/l	0301 C - Org Filt mg/l	4925 N Dis Inorg mg/l	6450 Cu Filtered ug/l	6460 Fe- Filt ug/l	6485 Nitrite Filt mg/l	7608 SALinsitu ppt	7887 CHLOROPHYLL ug/l	9853 Nitrate Filt mg/l	9856 OrthophsFilt mg/l	9857 SiO2 Filt mg/l	9901 O Diss %sat %	9924 Oxygen Diss mg/l	9943 N Oxid Filt mg/l	9993 NH3 filt N mg/l
02/02/10		4.3									1.43			0.0172	17.5	12.9	1.06	0.037	3.85	75	8.75	1.08	0.348
02/03/10		4									1.36			0.017	18.93	17.5	1.09	0.034	2.99	86	10	1.11	0.254
03/02/11											4.31			0.0215	0.15	3.2	4.12	0.059	5.8	100		4.14	0.167
04/03/11		6.8									3.64			0.0275	0.83		3.31	0.043	7.42	100	12.1	3.34	0.298
21/02/12		7.2									2.09			0.0238	0.28	5.4	1.85	0.05	5.71	90.9	10.9	1.87	0.221
20/03/12											2.67			0.0345	0.29	18.4	2.4	0.035	7.68	86		2.43	0.244
12/02/13	7.42	3.7	0.0111		141					6.93	1.34			0.0157	11.8	7.2	1.05	0.03	4.59	88.7	10.9	1.07	0.271
25/02/13	7.21	4.1	0.0402							9.32	1.8			0.0137	0.22	2.9	1.48	0.042	11.3	90.4	11.8	1.49	0.308
13/03/13	7.64	4.9	< .01							4.92	1.07			0.0177	21.82	5.2	0.792	0.031	2.79	110.1	12.3	0.81	0.261
21/02/14	7.23	5.7	< .01		21.5	126	7.5		37.9	8.61	2.21			0.0171	0.16	8.1	1.99	0.052	5.35	98	12.3	2.01	0.199
13/03/14	7.63	6.6	< .01		6.3	181	11.5		53.4	7.62	2.66			0.0284	0.22	1.8	2.33	0.04	7.74	86.6	10.6	2.36	0.295
18/02/15	7.46	6.3	< .01			2650	516		209	6.17	1.59			0.0174	14.65	9.8	1.27	0.018	4.06	89	10.1	1.29	0.302
05/03/15	7.63	6.1	< .01					48.5		7.38	3.06			0.0211	0.22	2.6	2.85	0.038	6.83	87	10.8	2.87	0.19

09/02/16	7.65	5.7	0.018					30.3		7.41	1.56			0.017	0.12	6	1.35	0.097	3.58	83.1	10.4	1.37	0.191
09/02/17	7.73	3.9	< .01					53.2		8.41	4.44			0.0297	0.22	3	4.22	0.042	7.71	84.4	11.1	4.25	0.187
14/03/17	7.6	10.4	< .01					54.5		7.82	4.23			0.04	0.19	6.3	3.96	0.044	7.86	97.3	10.8	4	0.232
19/02/18	7.43		< .01					50.8		9.7													
14/03/18	7.62		< .01					52.6		8.36													
18/02/19	7.68		< .01					110		9.5													
06/03/19	7.14		< .01					32.5		9.81													

EA water quality data on the Wampool at site 'Wiza Beck at Dockray' located at NY 24268 55716.

DATE	0061 pH PHUNITS	0076 Temp Water CEL	0077 Cond @ 25C uS/cm	0085 BOD ATU mg/l	0111 Ammonia(N) mg/l	0116 N Oxidised mg/l	0117 Nitrate-N mg/l	0118 Nitrite-N mg/l	0119 NH3 un-ion mg/l	0135 Sld Sus@105C mg/l	0158 Hardness mg/l	0162 Alky pH 4_5 mg/l	0180 Orthophospht mg/l	0237 Magnesium-Mg mg/l	0241 Calcium - Ca mg/l	6450 Cu Filtered ug/l	6455 Zinc - as Zn ug/l	9901 O Diss %sat %	9924 Oxygen Diss mg/l
02/02/10	7.8	4.6	577	2.4	0.236	5.61	5.57	0.0411	0.00183	10.1	155	108	0.054	8.48	47.9	2.3	15.3	94	12.1
01/03/10	7.7	3.5	361	< 1	0.117	3.38	3.36	0.0186	0.00067	8.4	127	97	0.042	7.11	39.2	2.28	< 5	98	13
02/02/11	7.6	7.1		4	0.297			0.0336	0.00176	68.8	125			6.61	39.1	3.23	37.6	105	12.7
04/03/11	7.6	5.6		1.8	0.07			0.0231	0.00037	4.12	151			8.22	47.1	1.92	< 5	95	11.9
22/02/12	7.62	9.8		1.3	0.082			0.0241	0.00062	4.65	153			8.13	47.7	2.05	< 5	97.7	11.1
06/03/12	7.9	4.3		1.2	0.09			0.0168	0.00086	4.28	153			8.34	47.4	2.17	< 5	95.5	12.4
04/02/13	7.97	5.4		1.18	0.137			0.0249	0.00166	9.63	229			19.2	60.1	3.29	10.7	105	13.3
21/02/13	7.85	3.2		1.52	0.104			0.0173	0.00082	4.7	155			8.89	47.6	1.86	7.07	96.9	13
10/02/14	7.64	5.7	331		0.096	3.5	3.49	0.0138	0.00056			90	0.055					100	12.5
13/03/15	7.56	6.1	230		0.209	4.16	4.11	0.0456	0.00105			95	0.15					100.3	12.4
14/02/17	7.14	3.4	411		< .03	4.48	4.47	0.0113	< .00005			133	0.05					90.6	12

EA water quality data on the Wampool at site ‘Wampool at Lathes located at NY 8800 5880.

DATE	0052 Pb Filtered ug/l	0061 pH PHUNITS	0073 Cypermethrin ug/l	0076 Temp Water CEL	0077 Cond @ 25C uS/cm	0103 Hg Filtered ug/l	0106 Cd Filtered ug/l	0111 Ammonia(N) mg/l	0116 N Oxidised mg/l	0117 Nitrate-N mg/l	0118 Nitrite-N mg/l	0119 NH3 un-ion mg/l	0162 Alky pH 4_5 mg/l	0175 Cyanide - CN mg/l	0180 Orthophospht mg/l	9901 O Diss %sat %	9924 Oxygen Diss mg/l
02/02/10		7.6		4.2	470			0.293	5.23	5.19	0.0411	0.0014	128		0.128	93	12.1
01/03/10		7.4		3.4	421			0.133	3.86	3.84	0.0186	0.00038	124		0.063	93	12.4
03/02/11		7.3		4.4	352			0.166	6	5.97	0.0263	0.0004	83		0.117	90	11.7
03/03/11		7.2		3.3	472			0.191	5.98	5.95	0.0333	0.00034	128		0.101	97	12.9
28/02/12		7.64		9.4	434.5			0.165	3.88	3.84	0.0353	0.00127	136		0.107	87.5	10
06/03/12		7.48		4.9	435.2			0.172	4.08	4.05	0.0303	0.00066	133		0.105	87	11.1
28/02/13														< .005			
21/02/14		7.18		5.1	323			0.189	3.07	3.05	0.0188	0.00037	92	< .005	0.112	90	11.4
02/02/17	< .1	7.58		7.7	462		< .01	0.134	6.09	6.06	0.0318	0.00079	139	< .005	0.096	93.2	11.1
14/03/18	0.183	7.53		4.8	450		< .01	0.285	4.65	4.61	0.0388	0.00121	140	< .005	0.12	92.2	11.8
28/02/19		7.82				< .01											
14/03/19		7.58				< .01											

EA water quality data on the Eden at site ‘Eden at Beaumont’ located at NY 35800 58800.

DATE	0050 Lead - as Pb ug/l	0052 Pb Filtered ug/l	0061 pH PHUNITS	0076 Temp Water CEL	0077 Cond @ 25C uS/cm	0085 BOD ATU mg/l	0092 COD as O2 mg/l	0103 Hg Filtered ug/l	0105 Mercury - Hg ug/l	0106 Cd Filtered ug/l	0108 Cadmium - Cd ug/l	0111 Ammonia(N) mg/l	0116 N Oxidised mg/l	0117 Nitrate-N mg/l	0118 Nitrite-N mg/l	9901 O Diss %sat %	9924 Oxygen Diss mg/l
01/02/10	0.88	< 2	7.9	1.5	305	< 1	< 12	< .01	< .01	< .1	0.01	0.089	2.72	2.71	0.0142	99	13.9
15/02/10	0.46	< 2	8	4.3	356	< 1	< 12	< .01	< .01	< .1	0.01	0.05	3.01	3	0.0134	101	13.1
01/03/10	0.65	< 2	7.4	4.3	322	1.5	16	< .01	< .01	< .1	0.01	0.033	2.16	2.15	0.0077	108	14
03/02/11	1.96	< 2	8	5.1	257	2.1	19	< .01	< .01	< .1	0.0288	0.056	1.95	1.94	0.0099	105	13.4
14/03/11	1.1	< 2	7.9	5.7	249	1.1	22	< .01	< .01	< .1	0.0204	0.031	2.1	2.09	0.0064	96	12
16/02/12	0.962	< 2	7.81	5.7	307.6	2	14	< .01	< .01	< .1	0.0137	0.054	2.2	2.19	0.014	93.2	11.7
19/03/12	0.968	< 2	8.07	7.5	314	< 1	< 10	< .01	< .01	< .1	0.0314	0.038	2.23	2.22	0.0126	84.8	10.2
07/02/13	0.82	< 2	8.11	3.3	292	1.23	11	< .01	< .01	< .1	0.0127	0.046	1.82	1.81	0.0075	107.3	14.3
05/03/13	0.422	< 2	8.23	4.2	351	1.22	< 10	0.0112	< .01	< .1	< .01	0.054	3.16	3.14	0.0165	116	15.1
07/02/14	1.2	< 2	7.84	6	243	1.48	18	< .01	< .01	< .1	0.0158	0.05	1.76	1.75	0.0116	120	14.9
03/03/14	1.52	< 2	8.02	6.7	267	1.14	< 10	< .01	< .01	< .1	0.0213	0.068	1.49	1.48	0.0115	100	12.2
03/02/15	0.713	< 2	8.02	2.4	328			< .01	< .01	< .1	0.0121	0.064	2.77	2.76	0.0114	94	12.8
04/03/15	0.836	< 2	8.07	4.5	297			< .01	< .01	< .1	0.015	0.032	1.95	1.94	0.0064	99	12.8
16/03/16		0.318	8.11	7.5	311			< .01		< .01		< .03	2.25	2.24	0.0126	98.1	11.7

09/02/17		0.285	8.1	4.8	297			< .01		< .01		0.037	2	1.99	0.0088	95.3	12.2
08/03/17	3.72	0.302	7.84	7.5	251			< .01	< .01	0.0111	0.0379	0.078	1.8	1.79	0.0097	109.5	13.1
27/02/18		0.138	7.84	2.6	342			< .01		< .01		0.079	2.74	2.73	0.011	96.5	13.1
15/03/18		0.218	8.09	5.9	308			< .01		0.0109		0.045	2.23	2.22	0.0104	96.1	12
15/02/19	1.14	0.232	7.99	6.4	270			< .01	< .01	< .01	0.0152	0.067	2.49	2.48	0.0087	100.8	12.4
05/03/19		0.507	7.85	6.3	232			< .01		0.0166		0.085	2.25	2.24	0.011	94.8	11.7

EA water quality data on the Eden at site 'Eden 100 m downstream Carlisle STW' located at NY 38371 56482.

DATE	TIME	0061 pH PHUNITS	0073 Cypermethrin ug/l	0135 Sld Sus@105C mg/l	0158 Hardness mg/l	0235 Mg Filtered mg/l	0237 Magnesium-Mg mg/l	0239 Ca Filtered mg/l	0241 Calcium - Ca mg/l	0301 C - Org Filt mg/l	4820 Mn BLM Bio ug/l	6458 Mn- Filtered ug/l	6460 Fe- Filt ug/l	7562 DELTAMETHRIN ug/l	8896 Bifenthrin ug/l	9341 Permethrn-cs ug/l	9342 Permethrn-Tr ug/l	9472 L Cyhalothrn ug/l	9862 Flumethrin ug/l
13/02/12	12:10	7.87											87.8						
06/03/12	11:55	8.09											105						
13/02/18	13:39		0.00004												< .001	< .002	< .001	< .002	< .003
06/03/18	10:34		0.00018											< .002	< .001	< .002	< .001	< .002	< .003

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