DECC

SEVERN TIDAL POWER - SCOPING TOPIC PAPER

Migratory & Estuarine Fish

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ABBREVIATIONS

The following abbreviations are used in this Topic Paper:

A	Anadromous
ABPmer	ABP Marine Environmental Research Ltd
AONB	Area of Outstanding Natural Beauty
APEM	Aquatic Pollution and Environmental Management
ARL	Alden Research Laboratory Inc.
BAP	Biodiversity Action Plan
BES	British Ecological Society
BL	Body Length
BMa	Macrobenthivores
Bmi	Microbenthivores
C	Catadromous
CCW	Countryside Council for Wales
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CITES	Convention of International Trade in Endangered Species
CL	Conservation Limit
CPUE	Catch Per Unit Effort
cSAC	Candidate Special Area of Conservation
DECC	Department of Energy and Climate Change (previously BERR)
DEFRA	Department for Environment, Food and Rural Affairs
DO	Dissolved Oxygen
DOE	Department of Energy
DV	Detritivore
EA	Environment Agency
EAW	Environment Agency Wales
EC	European Commission
ES	Estuarine species
EU	European Union
EUFG	Estuarine Use Functional Group
FMFG	Feeding Mode Functional Group
FS	Freshwater stragglers
FW	Freshwater
HD	Habitats Directive
HP	Hyperbenthivorous-piscivores
HZ	Hyperbenthivorous-zooplanktivores
ICES	International Council for Exploration of the Seas
IMER	Institute for Marine Environmental Research
IUCN	International Union for the Conservation of Nature
MM	Marine migrants
MNEV	Minimum Net Economic Value

MS	Marine stragglers
MSW	Multi- Sea-Winter
NE	Natural England
NREC	Northern Research and Engineering Corporation
Ob	Oviparous fish species with benthic eggs
Og	Oviparous fish species who guard their young as they develop
Op	Oviparous fish species with pelagic eggs
Os	Oviparous fish species who shelter their young in a part of their body
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic
Ov	Oviparous fish species with adhesive eggs
OV	Omnivore
PB	Parsons Brinckerhoff
PL	Planktivores
RMFG	Reproductive Mode Functional Group
SAC	Special Area of Conservation
SAP	Salmon Action Plan
SCIs	Sites of Community Importance
SEA	Strategic Environmental Assessment
STP	Severn Tidal Power
SPA	Special Protection Areas
SSSI	Site of Special Scientific Interest
UK BAP	UK Biodiversity Action Plan
UKCIP	UK Climate Impacts Programme
V	Viviparous
WFD	EC Water Framework Directive (2000/60/EC)

EXECUTIVE SUMMARY

Introduction

A cross-departmental Government study of the feasibility of tidal power generation in the Severn Estuary is being undertaken. This study will inform a decision on whether the Government could support a tidal power project in the Severn Estuary and if so, on what terms. The decision will be made in the context of the Government's energy and climate change goals, the alternative options for achieving these, and after public consultation.

A SEA is being conducted as part of the feasibility study, in accordance with the requirements of the SEA Directive and European guidance, as well as the UK Regulations. The SEA comprises two phases: phase 1 is the scoping stage, and phase 2 is the main assessment of short-listed options.

Scoping is the systematic identification of the main environmental issues associated with the Feasibility Study; and defines the scope and level of detail of the work that will be undertaken in phase 2 to explore these issues. The scope of the SEA has been broadened to include social and economic effects; in order that sustainable development considerations are addressed.

For the purposes of scoping, the issues are considered in detail within 'topic papers', prepared by specialists in each area. These papers feed into the main Scoping Report, which consolidates and summarises the main findings, and also addresses the other aspects of the scoping process required by law and guidance.

This topic area considers migratory fish and marine/estuarine fish found within the Severn Estuary / Bristol Channel and neighbouring freshwater habitats that might be affected by the operation of the proposed tidal power barrage or tidal lagoon options. It also describes and assesses potential effects on sea and freshwater angling in these habitats.

Baseline Information

The baseline first identifies key functional groups for estuarine fish species found within the Bristol Channel and the Severn Estuary as diadromous species (i.e. anadromous or catadromous), marine migrants, marine stragglers and freshwater species (including freshwater stragglers). In addition, feeding mode and reproductive mode functional groups were identified where possible for species present in the estuary.

Seven diadromous fish species migrate through the Severn Estuary during differing phases of their life cycle; Atlantic salmon, twaite and allis shad, river lamprey, sea lamprey, sea trout and eel. Each of these species with the exception of sea trout and eel is an Annex II species protected under the European Habitat and Species Directive (92/43/EEC), and the Rivers Usk and Wye have been designated as SACs due to their presence. The Severn

Estuary has been designated as a cSAC to protect allis and twaite shad and river and sea lamprey. All seven of the diadromous fish species that pass through or use the Severn Estuary are part of the qualifying criteria for the estuary's Ramsar status and are UK BAP priority species. There are also a number of non-SAC rivers within the potential STP schemes effected area which support populations of protected diadromous species including the Rivers Avon, Parrett, Ely, Taff, Rhymney and Ebbw. In addition to the rivers situated upstream of the proposed STP schemes stocks from rivers outside of this area and indeed outside of the UK may also be effected due to the straying nature of many of the returning diadromous species and importance of Severn Estuary as a nursery area for several marine fish.

The paper describes the different species caught within the Bristol Channel and Severn Estuary. The most speciose EUFG in the inner Bristol Channel are the marine stragglers (59% of species), followed by marine migrants (28%). In terms of abundance and diversity marine migrants provide the greatest contribution to the fish assemblage and most individuals within the estuary are juveniles (0+). The estuarine fish community as a whole is a qualifying feature for the estuary's Ramsar status and ten of the non-diadromous species found in the estuary are on the UK BAP list of priority habitat and species (a list prepared under the CroW act, 2000) comprised of five marine migrants and five marine straggler species.

The rivers entering the Severn Estuary support a diverse range of fisheries, including coarse, migratory salmonids and eel. River angling is a major recreational pastime, and contributes considerably to the regional economy. The Rivers Severn, Usk, Wye and Taff alone represent 8% of the England and Wales salmon rod catch. Sea angling in the Bristol Channel is of recreational importance although there is relatively little commercial fishing activity in the area. Net and fixed engine fisheries for salmon have been historically very significant in the Severn Estuary and its rivers. The fishery is now small as a result of buyouts however the remaining fisheries are traditional and often unique and as such are of cultural and heritage importance. The heritage values of the River Severn Estuary and the Welsh coracle fisheries are discussed.

The potential effects of climate change and associated changes in water temperature and flow regime on diadromous and other fish species are considered in the paper. The Rivers Wye, Usk and Severn are subject to periodic condition assessments and the salmon populations within both the Rivers Usk and Wye are classed by CCW and NE as being in unfavourable condition. Trends in catches of salmon and sea trout are described in the paper for the Rivers Severn, Wye and Usk. If these continue river Wye and Severn salmon stocks are expected to show a continued minor reduction over the next five years whilst a slight upward trend is predicted for the River Usk.

The River Severn has historically had breeding populations of allis shad, however, there are currently no definitively known spawning populations of this species in the UK. An assessment of the genetic structure of shad in the UK however revealed allis shad haplotypes in each of the populations sampled suggesting present or past hybridisation and introgression between the two species. The greatest introgression was observed within the most seaward located populations (Tywi and Usk). The last four remaining UK rivers known to support a spawning population of twaite shad are the Rivers Tywi, Usk, Wye and Severn (including its tributary the River Teme). The limited data available for shad populations are summarised in this topic paper, however, it was not possible to use these to accurately predict future trends in shad abundance.

Over half of the 20 England and Wales SAC designations for the presence of lamprey species are situated on the Welsh coast including the Rivers Wye and Usk and the cSAC Severn Estuary. During the most recent round of condition assessments the only UK river deemed to have favourable river lamprey status was the River Usk, and for sea lamprey it was the River Wye. Information available for lamprey populations in the major Severn Estuary rivers is discussed. Overall, however, it is not possible at this stage to confidently predict future trends for river or sea lamprey populations.

Fishing effort for eel and variability in catch over recent years is described in the paper. Declared catches of glass eel in the Severn Estuary have fallen since the late 1970s although an extensive programme of recent surveys funded by DEFRA indicated no discernible trend in population density, biomass or population structure over recent years. Current scientific advice is that the European stock is outside safe biological limits. However, the 70% decline in commercial catches of glass eel in the River Severn since the end of the 1970s is less than that described Europe-wide. Eel Management Plans should aim to provide an escapement of silver eel biomass that is at least equal to 40% of the potential escapement to be expected in the absence of anthropogenic influences (EA 2006). In addition, the European Eel Regulation requires that a system is in place to ensure that by 2013, 60% of eel less than 12 cm long which are caught each year are made available for restocking in suitable habitat (EA 2006).

A number of factors are considered in the text to help predict the future status of the marine and estuarine fish populations within the Severn Estuary. The Severn Estuary represents a seasonally compartmentalised ecosystem with different seasons supporting different age cohorts of a given fish species, dominated by juveniles of marine migrant species. This is likely to increase its resistance to short-term change however, the benefits would no longer be evident in the presence of long-term effects. The current organisation appears to be in a naturally occurring stable state.

The sensitivity of fish to change was assessed based on numerous potential changes to their environment (e.g. concentrations of contaminants, temperature, dissolved oxygen levels and changes to flow). Other considerations included the conservation importance of species and their current status. Diadromous fish were examined on a species by species basis and sensitivities were classed as follows: salmon, allis shad, twaite shad, eel, river and sea lamprey were all considered to have **high** sensitivity; sea trout was of **medium** sensitivity. Although no population is known to currently exist in the Severn Estuary the sensitivity of sturgeon was also described as **high**. Marine and estuarine fish were assessed on the basis of their EUFG. Marine migrants and stragglers were classed as having **medium** sensitivity to change, whereas estuarine and freshwater species were considered to have **low** sensitivity. There are a number of limitations associated with the available data. For diadromous species there are considerable knowledge gaps for a number of aspects of ecology and behaviour including the route of passage through the estuary, depth of passage, tidal transport, swim speed, transit time, residence time within the estuary, diurnal timing, seasonality, migratory cues, homing behaviour and stock status. The behaviour of diadromous species can vary among estuaries and therefore site specific studies are suggested in order to reduce uncertainty in predicted responses within the Severn Estuary. Whilst some aspects may change post-STP (e.g. residence time, tidal transport), others will remain unchanged (e.g. depth of passage). The majority of data available for marine and estuarine fish populations within the Severn Estuary is derived from long-term sampling at power station intake sites. This form of sampling may be biased towards species with certain habitat preferences, and certain lifestages, depending on the location and operation of the intake. Other survey methods are required to gain a more representative understanding of the fish community within a wide range of areas, in particular there is a lack of information regarding pelagic species within the Bristol Channel and Severn Estuary. Significant knowledge gaps also exist for the different EUFGs. For example, little is known about marine stragglers especially in terms of spawning location, route of passage, tidal transport, transit time, residence time, seasonality, and stock status. Further information is also required for spawning location, route of passage, transit time, tidal transport and stock status of estuarine species, which live and breed within the Severn Estuary. In terms of the freshwater stragglers, although a considerable amount of information is available regarding their behaviour in rivers, little is known of their status and behaviour in estuaries.

Environmental and Social Issues

Key environmental and social changes resulting from the development of a representative range of proposed tidal power options that are most relevant to migratory fish, marine/estuarine fish and angling (estuarine and upstream freshwater) are discussed. These are:

- Alterations to migratory cues

For fish which display natal homing behaviour, such as Atlantic salmon and shad, a potential reduction in the influx of freshwater into the estuary during times of impoundment due to the STP option may further delay migration by disrupting their ability to locate their natal rivers contained within freshwater discharge during these periods. Reduced mixing upstream however and increased surface freshwater downstream wedge may aid natal river identification and decrease transit time and straying upstream of the STP option.

- Disruption to route of passage

One of the prime sources of impact for fish is the presence of the STP structure and the operation of turbines. In particular consideration has been given to the potential effects of turbine passage, shear stress, mechanical injury, pressure, cavitation, any indirect effects, sluice passage and noise and vibration.

- Habitat changes

It is predicted that minimum water depths could potentially change post-STP and tidal range could be reduced within at least part of the estuary, resulting in a smaller intertidal area. Potential effects are discussed in terms of physical effects both upstream (landward) and downstream (seaward) of the STP option.

- Water quality change

There are a number of potential effects of the STP option on water quality including potential changes to salinity, temperature, suspended sediments, dissolved oxygen and contaminants. Issues associated with each of these parameters are discussed in the paper.

- Angling

Potential effects are also examined for both freshwater and sea angling, mainly from a recreational perspective. Commercial fisheries and the economics associated with angling are considered elsewhere.

Although the specific changes will vary depending on the different STP schemes there are a number of effects expected to be common to all options. Each of these issues and associated effects are first discussed in generic terms. Specific information is then presented for a representative range of STP options to indicate any specific considerations relevant to each design. This range of options has been chosen solely to represent and illustrate the issues that may arise under the development of tidal power in the Severn Estuary. This does not presuppose that these, or any other, options will definitely form the short-list of options that will be considered in the main assessment phase of the SEA.

The magnitude of these effects for each designated species/EUFG are assessed for each option according to: the distribution of the species/group within the Severn Estuary/main rivers flowing into the estuary, the habitat/environmental preferences of the species, the magnitude of the effects, the timescale that each might operate over, and whether or not the effects are reversible.

Three options are assessed:

a) Large barrage
b) Small barrage
c) Land connected lagoon

It was concluded that for each generic option, all of the identified effects could potentially significantly affect protected migratory species and marine fish species.

Proposed application of the SEA Framework

For this topic paper a number of objectives have been identified under the SEA. These set out the key aims of the SEA regarding migratory fish, marine/estuarine fish, and recreational fisheries which are:

- To avoid adverse effects on designated wildlife sites for fish of international and national importance.
- To avoid adverse effects on the populations of other protected fish species and habitats.
- To avoid adverse effects on national and local biodiversity target features that include fish habitats and species.
- To avoid adverse effects on recreational and heritage fishing.
- To avoid adverse effects on commercial fish resources.
- To minimise the risk of introduction of non-native invasive fish species.

In order to determine whether the above aims would be met, the five principal assessment criteria proposed are:

- Will the option result in adverse impacts upon the favourable conservation status and hence integrity of status of internationally designated sites supporting fish?
- Will the option adversely affect the achievement of favourable conservation status for internationally and nationally important fish species or their capacity to recover if currently designated as in unfavourable condition?
- Will the option result in changes in the populations of designated fish species of national importance, i.e. SSSI features?

- Will the option maintain BAP fish species in line with UKBAP targets?
- Will the option affect other statutory or non-statutory wildlife sites important for fish?

Based on the review of existing information and the potential significant environmental issues in relation to migratory and estuarine fish the following suggestions are made for the scope of the assessment under phase 2:

- Turbine passage study

Injury and mortality sustained from passage through turbines is likely to have one of the greatest effects upon migratory fish populations. It is therefore suggested that all possible measures and turbine design alterations are considered. Approaches to be taken could include liaison between engineers and fisheries specialists and further investigation of emerging technologies from the States.

- Assessment of the economic impacts to fishing

It is suggested that assessments of the values of the recreational (freshwater and estuarine), heritage net and commercial fisheries of the Severn Estuary are undertaken to enable potential economic impacts to be identified and compensation measure costing determined.

- Studies to determine the feasibility, success and confidence of mitigation and compensation measures.

It is suggested that assessments are made of a number of mitigation and compensation measures including sluice design and fish swimming speeds, behavioural screening, fish transportation, habitat enhancement/creation, stocking, translocation, pheromone release, fish herding, additional sites for inclusion in the SAC list and life history model.

- Investigation into the behaviour of migratory species within the Severn Estuary

A number of knowledge gaps regarding the behaviour of migratory fish species have been identified within the assessment of sensitivity of receptors to change section of this topic paper. It is suggested that further information is collected concerning the behaviour and ecological requirements of migratory adult behaviour of river and sea lamprey and silver eels through tagging and tracking studies.

- Sampling of the ecology of the Upper Severn Estuary

It is suggested that further information is required to fully assess effects associated with the different STP schemes and to examine the potential effects of any mitigation and compensation measures.

Other topic issues for the Environmental Report

Potential mitigation measures are outlined in the paper and are summarised here:

Mitigation

For the majority of these measures it was considered that they have the potential to **partially** avoid effects from the STP option but they have a **low** or **unknown** confidence of effectiveness, although some were allocated a **medium** confidence level (see text for details).

Physical screening: the mesh size required is dependent upon the size and life stage of the species that needs protecting, however, presence of a screen could result in impingement and cleaning would likely be impractical.

Behavioural screening: Behavioural deterrents can substitute or supplement physical screening however they do not achieve the same level of exclusion as physical screens. Behavioural fish deterrents operate on the response of fish to stimuli such as sound and vibration, light, temperature, taste and odour, pressure change, touch, hydraulic shear, electrical and possibly magnetic fields.

Fish passage solutions: Conventional fish passes are not suitable to the tidal environment therefore sluices and bypasses should be considered. Solutions must consider the migratory species to be protected, the route and depth of passage of these species through the estuary, their swimming ability and their willingness to pass through dark or narrow passages.

Low-impact turbines: The development of a number of low-impact turbines that maintain efficient energy production is ongoing in the US and Canada.

Transporting fish past the barrage: Although there are examples of this approach being utilised successfully, major issues exist however especially in relation to osmoregulation of the fish and sustainability of the operation.

Fish herding: Acoustic herding has traditionally been used in commercial fisheries to steer fish into nets. It may be possible to adapt this technique to decrease transit time of migrants passing through the estuary and thus through the barrage sluices within one flood tide.

Habitat enhancement: Habitat enhancement (e.g. removal of weirs or gravel cleaning) within the rivers of the Severn Estuary. It should be noted however, that under the WFD objectives are already under consideration to meet the conservation objectives. As such, it is only improvement measures beyond these that can be viewed as mitigation for a STP scheme. Such an approach has the potential to form a mitigation measure increasing the overall population within the rivers.

Habitat creation: For marine, estuarine, and freshwater straggler species habitat creation upstream or downstream of the barrage may be required. Artificial irrigation of exposed areas and managed realignments are potential measures which could be deployed.

Turbine/sluice operation regime: Injury and mortality of priority species and life stages could potentially be reduced by amending the operating regime of the STP option including both turbine generation and sluice operation. Management of the timing of the tidal exchange and amount of water exchanged could also at least partially manipulate water quality within the estuary, and influence the area of intertidal zone which is submerged at different stages of the tide (inundation regime). There are currently, however, considerable uncertainties associated with the expected morphological and ecological changes within the Severn Estuary post-STP.

Stocking and improved access for anglers: Stocking of rivers and streams to boost resident fish populations is a relatively common practice for a number of fish species. Stocking alone however would not be an effective mitigation measure in isolation as further measures would need to be taken to ensure that at least a proportion of the stocked fish were able to return unharmed. Further shore-based angling opportunities could be developed and new platforms/areas for anglers to fish from provided; potentially facilitating access to new fishing grounds/sites.

Predator control: If migratory fish are delayed for any reason the potential exists that predation attempts on these fish may increase. Piscivorous waterbirds are controlled, worldwide, using a number of methods but generally involve scaring the birds using a variety of non-lethal harassment techniques such as noise generating scarers or encouraging aggressive birds such as gulls and pigeons. Although birds are protected by law, there are provisions to be able to shoot and kill them under license for certain circumstances. Where the birds are SPA or SSSI interest features however this action may be considered a significant effect upon the feature. Like birds, the most common methods used to control predation by seals at dams and barriers are non-lethal harassment techniques (firecrackers, rubber bullets, high-pressure water hoses) and acoustic deterrents.

Compensation

Whilst further study in phase 2 will explore the potential mitigation measures detailed above so as to elucidate the effectiveness of those measures, it is possible that when combined they may only partially avoid the potential effects from the STP. As such compensation measures may be required. Potential compensation measures are considered within the paper and a summary of the options is provided here. The majority of these measures are predicted to have the potential to **partially** offset effects from the STP although generally confidence is considered to be **unknown** or **medium** (see text for details):

Stocking: In addition to stocking migratory fish within the tributaries of the Severn Estuary, fish originating from either the river requiring stocking or those from the Severn Estuary could be introduced to rivers outside of the Severn Estuary. It should be noted however, that due it the genetically unique fish populations affected within the Severn Estuary SACs that stocking would not represent a like-for-like compensation measure for these migratory fish.

Translocation: There is some evidence to suggest that shad, salmon and eel can be translocated between rivers to enhance stocks.

Novel techniques – pheromone release: The Great Lakes Fishery Commission has undertaken extensive research over the last decade to investigate the possibility of the future application of sea lamprey pheromones as a population control mechanism. Although information currently only exists for lamprey there may also be some potential for the development and application of synthetic pheromones for other natal homing species such as salmon and shad. A study to assess its efficacy would be required before this option could be implemented with any degree of confidence.

Additional sites for inclusion in the SAC list: It may be possible to identify rivers in the UK or indeed other parts of Europe that currently support populations of protected migratory fish species which do not have any international designation for their protection. Large populations of salmon are known to exist in non-designated rivers within the UK for example on the River Tyne. It may therefore be feasible to include additional sites to the SAC list for the protection and enhancement of a number of species. There is however currently no clear process for designating additional non like-for-like SACs and this would need to be addressed as part of the wider feasibility study.

Habitat enhancement: It may be possible to compensate for fish losses from the Severn Estuary with the enhancement of stocks within other river systems through habitat enhancement. Habitat enhancement will mirror that described above as mitigation for within-river population improvements. This would however, require a significant amount of monitoring to ensure that the objectives were met and the enhancement would need to be fully functional prior to the onset of any losses caused by the proposal.

Habitat creation, modification and ecological enhancement: By creating or modifying habitats in other areas in order to, for example, develop suitable nursery grounds for juvenile and adult fish and diadromous species utilising estuarine habitats pre-STP it may be possible to potentially compensate for fish losses from the Severn Estuary.

Improved access for anglers: Management to increase fishing opportunities for anglers via the creation of pontoons in suitable coastal areas or facilitating access to good fishing sites along other estuaries and rivers could be applied outside the Severn Estuary and its rivers.

Monetary compensation: Monetary compensation should be considered for businesses negatively affected by the STP option (i.e. charter vessels, angling shops). It is also suggested that financial compensation could be considered for fishery owners affected financially by the loss of angling revenue resulting from the operation of the STP option.

Possible cumulative effects of combined STP proposals
Effects would likely be greater than for the options in isolation.

Possible construction of a Swansea Bay lagoon
This would be outwith the area considered in this SEA and would potentially reduce the availability of habitat to fish utilising the estuary.

Other possible future tidal technologies, e.g. tidal stream proposals
Such proposals could lead to further change in the tidal flow regime of the estuary which could potentially increase overall effects of the STP option on fish.

Potential 'Round 3' development of offshore windfarms in the Irish Sea
Although unlikely to have a considerable direct effect on fish communities in the Severn Estuary the potential for cumulative effects with the STP option should be considered.

Possible construction of a new nuclear power station at Hinkley, Somerset.
Entrainment of individuals within power station intakes could reduce numbers of individuals of numerous species within the estuary and its rivers.

Further potential 'in-river' issues will need to be considered for migratory species and these will be examined in more detail in phase 2 when information becomes available.

Following this section other topic-issues are then outlined, including trans-boundary effects and a monitoring strategy.

Trans-boundary effects

Close consideration must be given to eel owing to their current status and the legislation in place to try and conserve stocks. Elver from the Severn Estuary are currently removed and translocated to other estuaries and rivers both in the UK and other European countries such as Sweden. A reduction in the population within the Severn Estuary could therefore potentially affect stocks elsewhere. The Severn Estuary supports large populations of juvenile marine migrants and is an important nursery ground for several species. For example, a large number of bass individuals spawn in the Irish Sea and Bristol Channel and adults which spent their time as juveniles within the Severn Estuary may emigrate to other parts of Wales, England, Scotland and potentially Ireland and contribute to adult stock throughout the UK. For some species such as shad where known breeding rivers in the UK are limited it may be necessary to carry out compensation measures such as stock enhancement and designation of new SACs within other countries such as Ireland, Portugal, France and Spain. Although these measures may maintain numbers of shad individuals there would still be a loss of distinct genetic populations and high level decisions would be required to assess whether or not this was acceptable.

Monitoring

To assess changes in fish populations and identify appropriate levels of mitigation and compensation from the installation of a STP scheme it will be necessary to monitor both migratory and estuarine fish population's pre and post construction. Sufficient post construction monitoring would be required to distinguish between temporary construction and longer term operational effects and assess the effectiveness of mitigation and compensation measures.

Current condition assessment monitoring within the riverine SACs and other major river systems such as the Rivers Severn and Avon should be continued, although annual sampling is suggested rather than the current 6 year cycle. Estuarine fish sampling is currently undertaken on the Severn Estuary as part of the WFD monitoring programme. It may be necessary to supplement the current WFD monitoring programme in the Severn Estuary with additional techniques, sites and potentially frequency. It is suggested that statistical tools are applied to determine the appropriate number of sites that will need sampling so as to detect the required level of population change. It is suggested that power station entrainment monitoring be continued and data acquired for use within the suite of monitoring for the STP option.

For mitigation and compensation measures for which confidence is currently unknown and indeed for those where a level of confidence has been applied in a precautionary way, it is suggested that trials and monitoring programmes be initiated before STP implementation.

SECTION 1

INTRODUCTION

1 INTRODUCTION

1.1 Background to the Severn Tidal Power Feasibility Study

On 25th September 2007 the Secretary of State for Business, Enterprise and Regulatory Reform (now the Department of Energy and Climate Change (DECC)) announced a feasibility study of tidal range power development in the Severn Estuary. Terms of Reference for the Study were published on 22 January 2008, which are as follows:

"Building on the work of the Sustainable Development Commission and earlier studies, the feasibility study will:

- assess in broad terms the costs, benefits and impact of a project to generate power from the tidal range of the Severn Estuary, including environmental, social, regional, economic, and energy market impacts;

- identify a single preferred tidal range project (which may be a single technology/location or a combination of these) from the number of options that have been proposed;

- consider what measures the Government could put in place to bring forward a project that fulfils regulatory requirements, and the steps that are necessary to achieve this;

- decide, in the context of the Government's energy and climate change goals and the alternative options for achieving these, and after public consultation, whether the Government could support a tidal power project in the Severn Estuary and on what terms."

The feasibility study is being managed by a cross-government group led by the DECC, which includes the Cabinet Office, Department for Environment, Food and Rural Affairs, Department for Transport, Department for Communities and Local Government, Her Majesty's Treasury, Wales Office, the Welsh Assembly Government, and the South West Regional Development Agency.

The location of the Severn Estuary and the wider study area is shown in Figure 1.1.

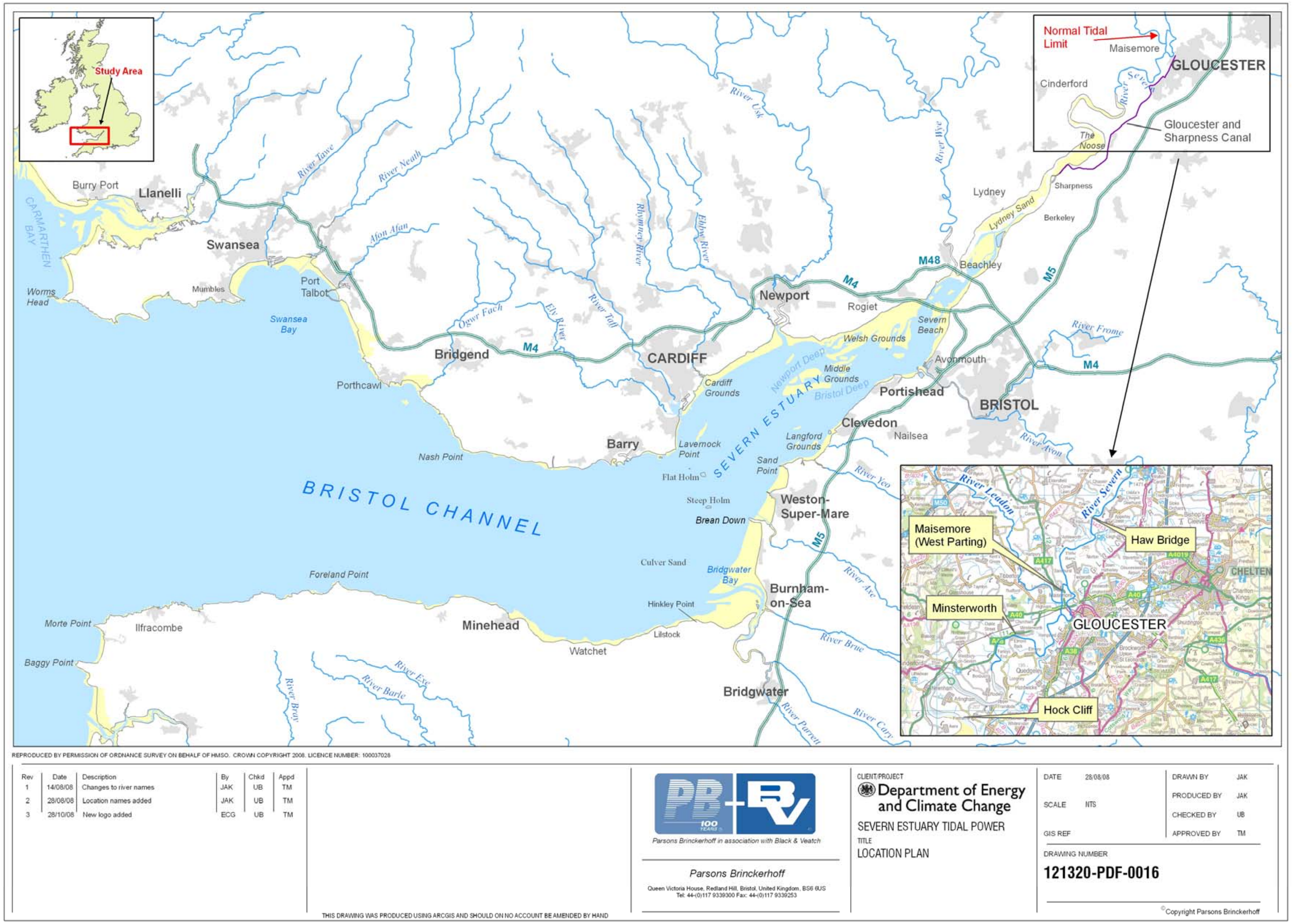


Figure 1.1 The Severn Estuary and Bristol Channel

1.2 Overview of the SEA process and its purpose

A SEA of short-listed options for tidal range energy development in the Estuary, will inform the feasibility study. The SEA is being conducted in two phases: phase 1 is the scoping stage, and phase 2 is the main assessment of short-listed options, including strategic-level Appropriate Assessment. Any scheme that is subsequently promoted will also be subject to formal Environmental Impact Assessment and related assessments, for example under the Habitats Regulations 1994.

Scoping is the systematic identification of the main environmental issues associated with the feasibility study; and defines the scope and level of detail of the work that will be undertaken in phase 2 to explore these issues. It also describes the proposed approach to the main assessment of options.

The SEA Scoping Report adheres to the requirements of the SEA Directive and EU guidance as well as the UK Regulations. Government guidelines as published by the ODPM in 2005 have also been applied.

For the purposes of scoping, the issues are considered in detail within 'topic papers', prepared by specialists in each area. These papers feed into the main Scoping Report, which consolidates and summarises the main findings, and also addresses the other aspects of the scoping process required by law and the guidance. The SEA scoping topics and how they relate to the requirements of the SEA Directive are shown in Table 1.1 below:

Table 1.1 SEA scoping topics

STP SEA Scoping Topic	SEA Directive Topic
Hydraulics & Geomorphology	Water
Society and Economy	Population, Human Health, Air
Ornithology	Biodiversity, Fauna
Migratory and Estuarine Fish	Biodiversity, Fauna
Marine Ecology	Biodiversity, Fauna, Flora
Terrestrial and Freshwater Ecology	Biodiversity, Fauna, Flora
Marine Water Quality	Water
Freshwater Environment & Associated Interfaces	Water, Soil
Flood Risk and Land Drainage	Water, Material Assets
Noise & Vibration	Population
Carbon Footprinting	Climatic factors, Air
Other Sea Uses	Material assets, Population
Navigation	Material assets, Population
Historic Environment	Cultural Heritage

STP SEA Scoping Topic	SEA Directive Topic
Landscape & Seascape	Landscape
Resources and Waste	Material Assets

The intention of this SEA is to consider social and economic effects of the options, as well as environmental effects, and thereby address key aspects of sustainable development. The Scoping stage principally covers effects relevant to social and economic aspects of sustainable development within the 'Society and Economy', 'Resources and Waste' and other topic areas.

The Scoping Report will form part of a wider consultation in Winter 2008/9 on the feasibility study and associated work being done outside the SEA process (including engineering options comparison, financing, ownership structures, and energy market impact).

1.3 Structure of the Scoping Topic Paper

The purpose and content of each of the chapters of this topic paper are described below.

Table 1.2 Content of the SEA Scoping topic paper

Chapter	Content
Baseline information (chapter 2)	Describes the key receptors within the topic, their status, and their sensitivity to changes in the environment. At this scoping stage, this is based on judgment of the importance of the receptor and its vulnerability to environmental change. The sources of data used to date to define the baseline are summarised, and the limitations attached to them explained.
Environmental issues (chapter 3)	Discusses the implications of the changes to the environment posed by an illustrative range of options. This will allow the potential significant issues to be identified. It is not the intention to undertake an assessment of significance of effects at this stage. It is however essential to have a clear process for the identification of significant issues that need to be considered within phase 2 of the assessment. The identification of potentially significant issues is therefore based on a systematic process. This topic paper describes how each of these aspects has

Chapter	Content
	been considered. Having identified the potentially significant issues, the scope and level of detail of data collection and assessment work needed to address these in phase 2 is described. A statement is made of the potentially significant issues to be 'scoped-in' to the assessment in phase 2. The detail and scope of the studies needed in phase 2 to assess these issues is described.
Proposed application of the SEA framework (chapter 4)	Provides the topic-specific objectives and assessment criteria that will be used in phase 2 to compare options. The SEA objectives draw upon an understanding of the wider policy framework (provided within the main Scoping Report), supplemented with topic-specific policy issues, and an appreciation of the potential issues associated with options and the significance of effects consequently arising. Baseline issues and consultation therefore inform the development of the objectives, to ensure they reflect the local issues and problems identified as part of the topic study. Having developed objectives, the assessment criteria (in the form of questions) and associated indicators (and their source: a combination of published data and where necessary, new data) are provided. These are the tests against which compliance with objectives can be assessed. Where possible, specific and quantitative targets are identified that provide threshold levels to determine if the objective has been met.
Other topic-issues for the Environmental Report (chapter 5)	Other issues in relation to the phase 2 Environmental Report will be described, including the consideration of cumulative and synergistic effects, trans-boundary effects, potential requirements for mitigation and compensation and development of an effective monitoring strategy.

1.4 Scope of issues covered in the Scoping Topic Paper

This topic paper considers the migratory fish and marine/estuarine fish within the Severn Estuary/Bristol Channel and in the main rivers flowing into the estuary (where appropriate) which could potentially be effected by the proposed development. It also considers potential effects on recreational freshwater and sea angling within these habitats. Effects on commercial fisheries are considered elsewhere.

SECTION 2

BASELINE INFORMATION

2 BASELINE INFORMATION

2.1 Existing baseline

2.1.1 Baseline receptors

Within this topic paper, the range of species found within the Bristol Channel and the Severn Estuary will be indicated, and the key species described. Assessment will be based upon the categorisation of different species into appropriate ecological, feeding and reproductive guilds and the relative proportions and behaviour of these guilds within the area. Details of angling and fisheries are also given together with an indication of their potential sensitivity.

The main functional groups for estuarine fish species has recently been refined (e.g. Elliott & Dewailly 1995, Potter & Hyndes 1999, and Elliott *et al*. 2007), and are summarised below based on the categories in Franco *et al*. (2008):

Estuarine Species: Can be resident (i.e. entire life cycle estuarine) or migrant (i.e. adults spawn in estuaries, marine larval phase, with juveniles returning to an estuary). Species with discrete populations in both estuarine and fully marine environments are included.

Marine Migrants: Adults live and spawn in marine environments, with juveniles frequently found in estuaries in large numbers. Juveniles can be opportunistic (i.e. can find suitable conditions within or outside estuaries), or dependant (i.e. require estuarine types of habitat).

Marine Stragglers: Live and breed in the marine environment. No estuarine habitat requirements but can enter lower reaches accidentally. Up-estuary movement is restricted by salinity as these stenohaline species generally avoid areas with salinities less than 35.

Anadromous: Most growth occurs at sea, adults migrate from coastal marine areas to freshwaters to spawn. Includes semi-anadromous species (migrate from sea to spawn within the upper extents of estuaries), and species which migrate from the sea to freshwater despite having no reproductive requirement for the migration.

Catadromous: Adults migrate from freshwaters to marine areas to spawn, but most growth occurs within freshwaters. Includes semi-catadromous species (migrate into lower estuarine waters to spawn but not out to sea), and species which migrate from freshwater to the sea despite having no reproductive requirement for the migration.

Anadromous and catadromous species are grouped together in this account as diadromous, i.e. migrating between marine and freshwater environments.

Freshwater Species: Those freshwater species found frequently and in moderate numbers in estuaries and whose distribution occasionally extends beyond the low salinity reach. Freshwater stragglers, species found in low numbers in estuaries that are restricted to areas of low salinity, are also included.

Marine and estuarine species have been further classified into feeding mode and reproductive mode functional groups as defined below (from Franco *et al*. 2008):

Microbenthivores: Feed mainly on small benthic, epibenthic and hyperbenthic animals (<1 cm size).

Macrobenthivores: Feed mainly on larger benthic, epibenthic and hyperbenthic animals (>1 cm size).

Planktivores: Mainly consume zooplankton and occasionally phytoplankton.

Hyperbenthivorous-zooplanktivores: Feed principally on small mobile invertebrates found on or just above the sediment, and zooplankton.

Hyperbenthivorous-piscivores: Feed principally on larger mobile invertebrates on or just over the sediment, and other fish.

Detritivore: Predominantly consume detritus and/or microphytobenthos.

Herbivore: Consume living macroalgae and macrophyte material or phytoplankton.

Omnivore: Ingest a combination of plant and animal material.

Fish within estuaries utilise a wide variety of reproductive strategies which can influence interactions between fish species and the estuarine environment. Reproductive strategies can be separated into the following categories (from Franco *et al*. 2008):

Viviparous: Young are fertilised internally and these species give birth to live young.

Oviparous: Young are fertilised and develop externally. This category can be subdivided into oviparous fish species with pelagic eggs (Op), benthic eggs (Ob) and adhesive eggs (Ov), and those that guard their young as they develop (Og) or shelter their young in a part of their body (Os).

Diadromous species

Seven diadromous fish species migrate through the Severn Estuary during differing phases of their life cycle. Six of these; Atlantic salmon (*Salmo salar*), twaite shad (*Alosa fallax*), allis shad (*Alosa alosa*), river lamprey (*Lampetra fluviatilis*), sea lamprey (*Petromyzon marinus*) and sea trout (*Salmo trutta*) are anadromous. The remaining species; eel (*Anguilla anguilla*) is catadromous.

Of the anadromous species all but sea trout are listed under the European Habitat and Species Directive (92/43/EEC) in Annex II (species whose conservation requires the designation of SACs). Atlantic salmon and river lamprey are additionally listed under Annex V (species whose exploitation and management in the wild may be subject to management measures). A number of UK Rivers have been designated under the Natura 2000 series of sites as SACs for, amongst other features, the presence of either all or some of these migratory fish species. The Rivers Usk and Wye have been designated as SACs with regards to the five protected anadromous fish species utilising the Severn Estuary. There are a number of other rivers entering the Severn Estuary which may also support these diadromous and estuarine migratory species including the Rivers Avon, Parrett, Ely, Taff, Rhymney and Ebbw. For the purpose of this assessment however, focus will be given to the Natura 2000 rivers and the River Severn. The Severn Estuary itself is a cSAC due to the presence of allis and twaite shad and river and sea lamprey. In addition to fish stocks within the rivers entering the Severn Estuary upstream of the proposed options, those from other rivers outside of this area may also be affected. A number of the diadromous fish species within the Severn Estuary stray during their migratory movement and can enter numerous estuaries and rivers before returning to their natal river. As such, fish populations from these rivers, potentially including stocks from outside of the UK, may also be impacted by a STP.

The Severn Estuary is a Ramsar Site (a wetland site of international importance under the 1972 Ramsar Conventions). All seven diadromous species are qualifying features under Ramsar Criterions 4 and 8 in that the Severn Estuary is 'important for the run of these migratory fish between sea and river via the estuary' and the estuary is 'a key migration route to their spawning grounds in the many tributaries that flow into the estuary' (http://www.jncc.gov.uk/pdf /RIS/UK11081.pdf).

All seven of the diadromous fish species passing through the Severn Estuary are on the UK list of priority species and habitats requiring conservation action under the UK BAP. This list has been prepared by the Secretary of State for Environment, Food and Rural Affairs under Section 74(2) of the Countryside and Rights of Way Act 2000. The list identifies the habitats and living organisms (species) which the Secretary of State, following consultation with its statutory nature conservation advisers, Natural England, considers are of principal importance for the conservation of biological diversity in England, in accordance with the 1992 UN Convention on Biological Diversity.

Historical records indicate that of the anadromous common or Atlantic sturgeon (*Acipenser sturio*) utilising the Severn Estuary and its tributaries. The common sturgeon spends the majority of its life at sea before migrating to large rivers to spawn between May and June, with juveniles remaining in freshwater for up to three years before migrating seaward (Vevers 1978). The IUCN Red List (1994) lists the common sturgeon as 'endangered' in the UK. The species are afforded protection under Annexes IIa and IVa of the EC Habitats and Species Directive, under Appendix III of the Bern Convention, Appendix I of CITES and Schedule 5 of the 1981 Wildlife and Countryside Act. They have also been added to the UK BAP list of priority species and habitats. There is no confirmation that sturgeon have bred recently within British waters. A European reintroduction programme started in 2007 on the Gironde Estuary, France.

Estuarine and marine species

Estuarine Use, Feeding Mode and Reproductive Mode Functional Groups (Franco *et al*., 2008) are shown in Table 2.1 for 83 species recorded in Bridgwater Bay (inner Bristol Channel) from entrainment screens at Hinkley Point B Power Station between 1981 and 2008 (Henderson *pers. comm.*). In combination with recent transitional water surveys a total of 88 fish species have been recorded in the region. Species can be allocated to more than one EUFG and FMFG. Franco *et al.* (2008), Elliott & Dewailly (1995), Froese & Pauly (2008) and Potter *et al.* (1986) have been used as data sources for the allocation.

The most common EUFG in the inner Bristol Channel (based on records for Bridgwater Bay) was marine stragglers (59%), followed by marine migrants (28%). The other ecological guilds comprised ≤5% of the fish assemblage each. Of the ten most abundant species recorded in Bridgwater Bay (see 'Current status and future trends' section), nine were considered to be purely marine migrants with one marine straggler. In terms of abundance and diversity marine migrants provided the greatest contribution to the fish assemblage, and while marine straggler diversity was relatively high they were frequently represented by a small number of individuals.

FMFG allocations (Table 2.1) include the prey preferences for species across all life-stages. Most of the fish species are Bmi and BMa (~52 and 46% respectively). Many of the species classed as BMa were also allocated to the Bmi category possibly reflecting ontogenetic shifts in diet. Numerous species also belong to the HP category either exclusively, or in combination with other categories (48% of the species). The other feeding guilds represent ≤15% of the fish species recorded in the area.

Numerically (as opposed to biomass) most fish within the estuary are juveniles (0+). This is especially so within the inner estuary (Claridge *et al*. 1986), reflecting its use as a nursery area. RMFG allocations indicate that just under half of the species recorded are Op, while oviparous species with benthic, guarded and adhesive eggs account for 18, 17 and 12% of the fish species, respectively. Only five species are Os, and none of the species are viviparous.

Table 2.1 Species list of fish sampled in Bridgwater Bay, inner Bristol Channel from 1980 to 2008. See abbreviations list for explanation of abbreviations (species list taken from Henderson 2007 and updated from Henderson *pers.comm*).

Common name	Scientific name	EUFG	FMFG	RMFG
Anchovy	*Engraulis encrasicolus*	MS	PL	Op
Angler fish	*Lophius piscatorius*	MS	HP	Ob
Ballan wrasse	*Labrus bergylta*	MS	Bmi, BMa	Og
Bass	*Dicentrarchus labrax*	MM	HZ, HP	Op
Black goby	*Gobius niger*	ES	Bmi, HP	Og
Black sea bream	*Spondyliosoma cantharus*	MM	OV	Ob
Blonde ray	*Raja brachyura*	MS	Bmi, BMa	Ob
Blue whiting	*Micromesistius poutassou*	MS	Bmi, BMa	Op
Brill	*Scophthalmus rhombus*	MS	HP	Ob
Cod	*Gadus morhua*	MM	HZ, HP	Op
Common goby	*Pomatoschistus microps*	ES	Bmi	Og
Common sand eel	*Ammodytes tobianus*	MS	PL	Ob
Common sea snail	*Liparis liparis*	MM	Bmi, BMa	Ov
Conger eel	*Conger conger*	MS	HP	Op
Corkwing wrasse	*Crenilabrus melops*	MS	Bmi, BMa	Og
Crystal goby	*Crystallogobius linearis*	MS	PL	Og
Cuckoo wrasse	*Labrus mixtus*	MS	Bmi, BMa, HP	Og
Dab	*Limanda limanda*	MS	Bmi, BMa	Op
Dover sole	*Solea solea*	MM	Bmi, BMa	Op
Dragonet	*Callionymus lyra*	MS	Bmi, BMa	Op
Eel	*Anguilla anguilla*	C	Bmi, BMa, HP, PL	Op
Fifteen-spined stickleback	*Spinachia spinachia*	MS	HZ	Og
Five-bearded rockling	*Ciliata mustela*	MM	Bmi, BMa	Op
Flounder	*Platichthys flesus*	MM	Bmi, BMa	Op
Garfish	*Belone belone*	MM	HP	Ov
Golden mullet	*Liza aurata*	MM	DV	Op
Goldsinny wrasse	*Ctenolabrus rupestris*	MS	Bmi, BMa	Op
Greater pipefish	*Syngnathus acus*	MS	Bmi	Os
Greater sand eel	*Hyperoplus lanceolatus*	MM	PL, HP	Ob
Grey gurnard	*Eutrigla gurnardus*	MS	Bmi, BMa, HP	Op
Hake	*Merluccius merluccius*	MS	HP	Op
Herring	*Clupea harengus*	MM	PL	Ov
Hooknose (Pogge)	*Agonus cataphractus*	MS	Bmi, BMa	Ov
Horse mackerel	*Trachurus trachurus*	MS	HP	Op
John dory	*Zeus faber*	MS	HP	Op
Lemon sole	*Microstomus kitt*	MS	Bmi, BMa	Op
Lesser spotted dogfish	*Scyliorhinus caniculus*	MS	Bmi, BMa, HP	Ob
Lesser weaver	*Trachinus vipera*	MS	Bmi, BMa, HP	Ob
Ling	*Molva molva*	MS	HP	Op
Lumpsucker	*Cyclopterus lumpus*	MS	HZ	Og
Nillson's pipefish	*Syngnathus rostellatus*	MM	HZ	Os
Northern rockling	*Ciliata septentrionalis*	MM	Bmi, BMa	Op
Norway pout	*Trisopterus esmarkii*	MS	HP	Op

Table 2.1 (*continued*) Species list of fish sampled in Bridgwater Bay, inner Bristol Channel from 1980 to 2008. See abbreviations list for explanation of abbreviations (species list taken from Henderson 2007 and updated from Henderson *pers.comm*).

Common name	Scientific name	EUFG	FMFG	RMFG
Painted goby	*Pomatoschistus pictus*	MS	Bmi, BMa	Og
Pearlsides	*Maurolicus muelleri*	MS	PL	Op
Perch	*Perca fluviatilis*	F	Bmi, BMa, HZ, HP	Ov
Pilchard	*Sardina pilchardus*	MS	PL	Op
Piper	*Trigla lyra*	MS	Bmi, BMa, HP	Op
Plaice	*Pleuronectes platessa*	MM	Bmi, BMa	Op
Pollack	*Pollachius pollachius*	MM	HP	Op
Poor cod	*Trisopterus minutus*	MM	Bmi, BMa, HP	Op
Pout	*Trisopterus luscus*	MM	Bmi, BMa, HP	Op
Raitt's sandeel	*Ammodytes marinus*	MS	PL	Ob
Red mullet	*Mullus surmuletus*	MS	Bmi, BMa	Op
River lamprey	*Lampetra fluviatalis*	A	HP	Ov
Rock cook	*Centrolabrus exoletus*	MS	Bmi, BMa	Og
Rock goby	*Gobius paganellus*	MS	Bmi, HP	Og
Saithe	*Pollachius virens*	MS	HZ, HP	Op
Salmon	*Salmo salar*	A	Bmi, BMa, HP	Ov
Sand goby	*Pomatoschistus minutus*	ES	Bmi	Og
Sand smelt	*Atherina boyeri*	ES	HZ	Ov
Scaldfish	*Arnoglossus laterna*	MS	HP	Op
Sea lamprey	*Petromyzon marinus*	A	HP	Ov
Small eyed ray	*Raja microocellata*	MS	HP	Ob
Snake pipefish	*Entelurus aequoreus*	MS	Bmi, BMa, HZ, HP	Os
Solenette	*Buglossidium luteum*	MS	Bmi, BMa	Op
Sprat	*Sprattus sprattus*	MM	PL	Op
Tadpolefish	*Raniceps raninus*	MS	BMa, HP	Op
Thicklipped grey-mullet	*Chelon labrosus*	MM	DV	Op
Thinlipped grey-mullet	*Liza ramada*	MM	DV	Op
Thornback (roker) ray	*Raja clavata*	MS	Bmi, BMa, HP	Ob
Three-bearded rockling	*Gaidropsarus vulgaris*	MS	Bmi, BMa, HP	Op
Three-spined stickleback	*Gasterosteus aculeatus*	ES, F	HZ	Og
Tompot blenny	*Parablennius gattorugine*	MS	Bmi, BMa, HV	Og
Topknot	*Zeugopterus punctatus*	MS	Bmi, BMa, HP	Ob
Transparent goby	*Aphia minuta*	MS	PL	Ov
Trigger Fish	*Balistes capriscus*	MS	Bmi, BMa	Og
Tub gurnard	*Chelidonichthys lucernus*	MM	Bmi, BMa, HP	Ob
Turbot	*Psetta maxima*	MS	HP	Op
Twaite shad	*Alosa fallax*	A	PL, HP	Ob
Whiting	*Merlangius merlangus*	MM	HP	Ob
Witch	*Glyptocephalus cynoglossus*	MS	Bmi, BMa, HP	Op
Worm pipefish	*Nerophis lumbriciformis*	ES	Bmi, HZ	Os

Severn Estuary

The fish assemblage within the Severn Estuary is similar to that of the inner Bristol Channel (Potter *et al*. 1896, Henderson 2007). Consequently, proportions of the different EUFG described for the inner Bristol Channel are not expected to differ considerably within the estuary, with marine migrants, of which, sprat (*Sprattus sprattus*) is reported to be the most abundant (Steve Coates, *pers.comm*.), comprising the dominant functional group in both water bodies. However, due to the greater proximity of the River Severn, and the freshwater discharges from the Rivers Usk and Wye the proportion of freshwater straggler species in the estuary is far higher than in the Bristol Channel. Roach (*Rutilus rutilus*), trout (*Salmo trutta*), common bream (*Abramis brama*), carp (*Cyprinus carpio*), silver bream (*Abramis bjoernka*), rudd (*Rutilus erythrophthalamus*), crucian carp (*Carassius carrasius*), dace (*Leuciscus leuciscus*), ten-spined stickleback (*Pungitius pungitius*), and single specimens of gudgeon (*Gobio gobio*), goldfish (*Carassius auratus*), and chub (*Leuciscus cephalus*) have all been recorded in the Severn Estuary (Potter *et al*. 1986). If use of the estuary by freshwater species has not changed considerably over the last decade or so, as an estuarine functional group freshwater stragglers could comprise up to 10% of the fish species present within the inner estuary (Potter *et al*. 1986), compared to ~2% in the inner channel (Table 2.1).

Protected species

The migratory species in Table 2.1 are protected under either national or international conservation designations (see 'Diadromous Fish' section of this topic paper). Ten other species (marine migrants: cod, herring, plaice, sole, whiting; and marine stragglers: blue whiting, hake, horse mackerel, ling, saithe) recorded in the Bristol Channel and the Severn Estuary are protected under a Species Action Plan as part of the UK BAP. In addition the whole estuarine fish community is designated under Ramsar Criterion 8 as it is 'one of the most diverse in Britain' (http://www.jncc.gov.uk/pdf /RIS/UK11081.pdf).

Recreational Angling

The Severn catchment supports a diverse range of fisheries, including coarse, migratory salmonid and eel. Participation in and value of these fisheries varies considerably according to quality, demand and availability of fishing. The major rivers are the Severn, Parrett, Usk and Wye. However, exposure to potential effects will apply also to river fisheries further along the Bristol Channel due to straying and exchange of migratory migratory salmonid and eel between them and rivers lying within the putative tidal power schemes.

Riverine Angling

River angling is a major recreational pastime licensed and regulated by the EA. Two main licence categories exist: 1) trout, coarse fish and eel and 2) migratory migratory salmonids, Atlantic salmon and sea trout. Biologically, trout and sea trout are the same species (*Salmo trutta*), sea trout being an anadromous form. However the two fisheries vary, with migratory fish also being taken in commercial catches from coastal waters and estuaries as well as from fisheries sited along the length of river through which they migrate.

Migratory salmonid angling

Migratory recreational fisheries (salmon, sea trout and eel) are potentially vulnerable to tidal power effects, because they target fish that move through the development area. The Severn Estuary (Table 2.2) contains three nationally important salmon fisheries (Rivers Severn, Wye and Usk) which together with the River Taff, represent 8% of the England and Wales salmon catch. Sea trout fisheries in the area have a lesser importance (1% of the E&W total); although adjacent fisheries (Rivers Ogmore to Tywi) are nationally significant, comprising 14% of the England and Wales total.

Table 2.2 Rod catches as indices of fishery size in Bristol Channel rivers. Net catches are shown for comparison.

River	Rod catch		Net catch	
	Salmon	Sea trout	Salmon	Sea trout
Severn	327	33	1060	0
Wye	561	43	7	0
Usk	711	255	No licensed nets	
Taff	10	58	No licensed nets	
Rhymney	0	24	No licensed nets	
Ogmore	51	602	No licensed nets	
Afan	7	130	No licensed nets	
Neath	64	481	No licensed nets	
Tawe	142	279	No licensed nets	
Loughhor	20	444	No licensed nets	
Gwendraeth	0	86	No licensed nets	

Tywi	553	3621	76	912
England and Wales	19,013	39,117	20,494	28,212

The economic value of migratory salmonid fisheries has focussed on salmon through the estimates produced in the EA Salmon Action Plans for individual catchments which, for the Rivers Severn, Wye and Usk, use data variously between 1992 and 2000. Economic values are hard to estimate, imprecise and have several separate components reflecting the perspectives of various stakeholders. Based on reported SAPs the MNEV (i.e. the sum of (1) market fishery value + (2) value to anglers + (3) value to netsmen (profit after sale of catch), for the Rivers Severn, Wye and Usk are £1.1m, £22.4m and £11m respectively. These reflect the lower value of fisheries and more local participation in the River Severn fishery compared with the River Wye (which has been historically of particularly high value) and River Usk. The salmon net fisheries have a very low economic value compared to rod fisheries. For example the River Wye net fishery (which has virtually ceased since these figures were produced) represented 0.2% of the River Wye MNEV.

Loss or reduction of the salmon fisheries would lead to net economic loss to fishery owners and anglers, but these are thought to be exceeded by the loss of cumulative indirect value to the public from the existence of salmon stocks and perhaps fisheries (EA 2001). Given that economic cost-benefit is a crucial feature of any scheme evaluation this aspect requires a more detailed review and development of a consistent approach.

License sales for migratory fishing (23,116 annual and 8,842 short term licenses in 2007) are reasonably stable at present, but fishing days show a decreasing trend (EA/CEFAS 2008). In 2007 in Wales and the Midlands (Severn) there were 68,224 and 4,800 recorded rod days respectively, a 16% and 28% reduction on the previous 5yr mean (2002-06). A summary of the recorded rod days for the Rivers Severn, Wye and Usk, and the coalfield rivers, Taff and Rhymney are given in

Table 2.3. This decline in fishing activity is likely to be due to a combination of factors, including stricter fishing controls (cf the Spring Byelaw introduced in 1999) and probably some reduced participation as catches have declined. Note that this cannot be taken as a pattern for future effort trends, because considerable actions have been taken on these fisheries (see Future Stock Trends section) that are expected to reverse or contain stock declines and it is likely that fishing activity will increase as these take effect.

Table 2.3 Recorded rod days in 2007

River	Recorded rod days
Severn	3,798
Wye	5,158
Usk	5,041
Taff	309
Rhymney	40

Estuarine Angling

Bristol Channel sea angling is of great recreational value. The fishery is targeted at a small number of species with sport or eating value, notably: bass, grey mullet, cod, whiting, pouting, eel, sole, flounder, conger, rays (several species), lesser spotted dogfish and smooth hound. Both boat and shore angling are popular and angling club records estimate the annual recreational catch at 1000 tonnes (DOE 1989). The Severn Estuary and Bristol Channel shoreline is nationally important for shore fishing competitions.

Sea angling makes a significant contribution to the local economies of Somerset, Devon and South Wales, with an estimated 30 charter vessels operating from ports upstream of Ilfracombe and Swansea, and ca. 40 angling clubs having a direct interest in the Bristol Channel. Seasonal migrations of species influence angler catches, with late summer to early autumn the best period for species richness (Table 2.4). This is due to the presence of warm water migrants such as black bream and trigger fish still being present and the arrival of early winter migrants such as cod and whiting from the Irish Sea.

Turbidity varies within the estuary, and it plays an important role in governing angling performance. The upper estuary is permanently turbid due to high water velocities, while the western area has increased water clarity due to reduced tidal energy. This plays a key role in the distribution (spatial and temporal) of species that feed by scent, and those that rely on vision to catch prey: typical night-fishing species (e.g. conger, cod and rays) are caught in the upper estuary during daylight hours. Mackerel, pollack, wrasse and tope are caught in the western waters. The consequence of the seasonal migrations is that the estuary provides angling opportunities throughout the year.

Table 2.4 Seasonality of key species targeted by anglers in the Bristol Channel (data reproduced from www.bristolchannelangling.co.uk).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cod												
Flounder												
Bass												
Bull Huss												
Pollack												
Smoothound												
Mackerel												
Thornback Ray												
Conger												
Rockling												
Whiting												
Wrasse												
Ling												
Tope												
Spurdog												
Trigger												
Black Bream												
Garfish												

Estuarine net fisheries

Net and fixed engine fisheries for salmon have been historically very significant in the Severn Estuary and its rivers. Through regulatory changes and buyouts it is now a small fishery, apart from the Severn salmon component (Table 2.2). The existing fisheries are traditional and often locally unique and as such are of cultural and heritage importance (as detailed in the Severn Estuary SAP Plan, EA 2003a).

The net fisheries within the Severn Estuary consist of five main fishing methods; draft (seine or long) nets, lave nets, drift nets, baskets (putts and putchers) and stop boats (EA, 2001a). Draft nets are operated within the upper estuary and tidal river reaches, lave nets within the middle to upper estuary and fixed engines (baskets and stop boats) in the middle to lower estuary (EA, 2001a). In the Midlands area in 2007 the following net licences were issued for the Severn fishery; 2 seine nets, 20 lave nets and 4 fixed engines. In addition to this the following licences were issued under the Environment region; River Wye – 7 lave nets, River Tywi – 8 seine nets and 7 coracle nets, River Taf – 1 wade net and 1 coracle net (EA/CEFAS, 2008).

The total value of the Severn Estuary salmon net fishery to fishermen was estimated during 2000 to be £96,200 (EA, 2001a). In addition to this value however, is the heritage value of the fishery to the general public. Following recommendations within the Severn Estuary Salmon Action Plan to quantify this value, a study was undertaken to develop a method for evaluating the heritage value of net fisheries in 2004 (Simpson & Willis, 2004). As part of the study interviews were conducted with 392 members of the general public to determine their willingness to pay (WTP) to:

- maintain the minimum level of traditional fishing methods; and
- maintain the current level of traditional fishing methods on the River Severn Estuary and the Welsh coracle fisheries on the Rivers Tywi, Taf and Teifi.

The results of this study indicated that 24% of the interviewees were willing to contribute an amount of money to maintain the minimum levels of traditional fishing on the River Severn Estuary and the three Welsh rivers. Only 3% of respondants however, were willing to donate money to maintain the fisheries current levels. The average amount of money people were willing to donate to maintain the minimum level was £12 in comparison to £8 to maintain the current levels. The heritage values for the two fisheries based upon a one off donation to maintain the minimum levels was £1.5 million for the Welsh coracle fisheries and £5.3 million for the River Severn Estuary fishery.

2.1.2 Current status and future trends

Climate change

The Central England Temperature index indicates an increase in air temperature over the last century of 0.86°C. The most noticeable rise is from the 1990s onwards, and over the past decade most years have had a mean annual temperature above the 1907 to 2007 trend line (Solomon & Lightfoot 2007). Various emission scenarios result in temperature increase predictions between 2 – 3.5°C by 2080. The extent of warming will be greater in the south and east than in the north and west (UKCIP 2002). Air and river temperature are closely linked and recent measurements also indicate increased river water temperatures but to a lesser extent (Davidson *et al*. 2006). Sea temperatures are also thought to have risen and are predicted to continue to rise. For example in the River Wye annual mean river temperatures appear to have increased by 0.3-1.9°C over the last 20 years with similar trends observed in sea surface temperatures at nearby sites (Davidson & Hazelwood 2005).

Fish body temperature is dependent on the surrounding water temperature and it regulates a number of activities and physiological processes. Changes in marine and freshwater temperatures and associated climatic variation could affect the life history and survival of migratory fish by acting on their physiology, phenology and biological systems. Such changes would directly influence population and community structure as a result of their associated affects on performance, resource use, thermal habitat availability and survival.

In freshwater habitats increasing water temperatures during egg incubation may result in the early emergence of migratory fish fry, it may also depress oxygen concentrations within redds, leading to an increased risk of mortality. For sea lamprey, Holmes (1990) found that temperature exerts a significant influence on egg hatching and larval growth rate. Increased water temperature may decrease the age of smoltification in salmon with Davidson & Hazelwood (2005) reporting a significant reduction in mean smolt age in salmon stocks in the River Wye in relation to rising temperatures. Predictions for salmon in the River Wye are that, under the low emissions scenario for 'greenhouse gases', growth rates in older smolts will improve progressively through the 2020s and 2050s but decline or level out in the 2080s (Davidson & Hazelwood 2005). Similar growth patterns up to the 2050s are predicted under the high emissions scenario, however after this rates will decline to well below the 1961-1990 average (Davidson & Hazelwood 2005). This decline is of concern as it could lead to reduced survival through increased predation due to predominance of smaller individuals.

Potential effects include changes to fish swimming ability (Davidson & Hazelwood 2005), the timing of annual migrations and maturation processes in adult fish. Growth rates are likely to reflect both increasing appetite and biochemical reaction rates (metabolism). Greater risk of summer low flows would decrease the percentage of time for which minimum physical habitat requirements for migratory species are met (Walsh & Kilsby 2007), and the flow required to initiate migration could be achieved less frequently. High flows are predicted to increase by up to 1.5% which may lead to the wash out of eggs and displacement of newly emerged fish as well as increasing the potential for increased sediment loads causing siltation of redds. Wetter springs may also induce earlier migrations which may subsequently reduce marine survival (Davidson & Hazelwood 2005). A greater freshwater influx in the estuary may also affect the distribution of fish in the estuary with freshwater species able to penetrate further downstream. Decreased salinity in estuarine habitats and shifts in water temperature would be expected to have positive and negative effects on different fish species depending on their thermal tolerance limits.

Sea level rise is a further possibility of climate change, leading to potential changes in coastal habitat availability. Oceanic circulation could also be affected. For diadromous species such changes could have severe consequences, and for example they have been hypothetically linked to declining anguillid eel recruitment (Friedland *et al.* 2007). Since the European eel is a marine spawner, recruitment to inland waters depends mainly on reproductive success and marine mortality of leptocephali and glass eel and it has been widely suggested that marine events are the main factors responsible for the decline in anguillid stocks (Feunteun 2002). Changes to the Gulf Stream currents could make transoceanic larval migration towards European coasts longer or even impossible.

When considering non-migratory species increases in water temperature could be deleterious for certain species such as sea snail which actively avoid warmer inshore waters during mild winters (Henderson & Holmes 1990). In contrast, an augmentation of water temperature would be potentially beneficial for bass and sole for which recruitment appears to be enhanced during warmer years (e.g. Henderson & Seaby 2005). Increases in availability of sunlight and elevated water temperatures can increase primary production (especially when nutrient levels are high), which could reduce dissolved oxygen levels in the water column as bacteria degrade the organic material. The levels of suspended solids within the Severn Estuary are particularly high and opportunities for photosynthesis are reduced, therefore increases in primary production would not be expected to be problematic. In less turbid conditions, however, greater phytoplankton biomass would increase zooplankton production which could provide a richer food source for benthic organisms, especially suspension feeders. Invertebrates could potentially attain a larger average size which may be advantageous for adult macrobenthivorous fish but could potentially reduce the food source available for juvenile fish which are dependent upon meiofauna and smaller macrofauna invertebrates during the early stages of growth.

A further consideration is that water temperature can be an important contributory factor to the distribution of many fish species. The Severn Estuary is close to the northern limit for the marine migrant thin-lipped grey mullet, and the marine straggler small-eyed ray, and is close to the southern limit for Norway pout. Consequently, changes in temperature would be expected to influence the range of these species. In addition, species usually found at locations further south may be able to penetrate northwards and enter the Bristol Channel and/or Severn Estuary (Franco *et al*. 2008).

Increased rainfall caused by climate change can lead to decreased salinity. A gradual decrease in salinity would potentially have a negative effect on common shrimp (*Crangon crangon*) as the females try to avoid salinities <12 over winter. In order to find suitably saline waters, individuals which are ready to spawn would have to travel further and alterations in migration patterns of shrimp would potentially have knock-on effects on the movement of fish species such as 0+ whiting which are reliant on the shrimp food source. In addition, decreased salinity of estuarine waters could lead to greater penetration of freshwater species to more seaward locations.

<u>Diadromous species</u>

<u>*Salmon*</u>

As SAC rivers, the Wye and Usk are subject to periodic condition assessment using Habitat Directive protocols. Conventional salmon assessment, for EA and HD purposes, includes estimation of annual egg deposition and comparison against a reference standard, the Conservation Limit (e.g. EA 2003b; EA/CEFAS 2008, Potter *et al*., 2003). During the recent condition assessment round, the salmon populations within both the Rivers Usk and Wye were classed as being in unfavourable condition.

Assessment of adult salmon and sea trout is based variously on declared rod (and to a lesser degree net) catches, electronic counters and redd counts. Juveniles are assessed mainly by electro-fishing of nursery areas. These data are held by the EA and in the case of rod catches are reported through annual statistics (e.g. EA 2007, EA/CEFAS 2008), or intermittently in summary form for SAPs and similar (e.g. Our Nation's Fisheries, EA 2003c). Thirty SAC's in

England and Wales have Atlantic salmon as one of their designated features. Many other major salmon rivers throughout England and Wales have not been designated under the HD, for example the Rivers Tyne and Stour (Figure 2.1). Although widespread throughout the UK ICES estimates suggest the spawning population for the UK salmon stock is currently approximately 50% down on the ten-year average. A number of genetically distinct salmon populations have the potential to pass through the Severn Estuary including those inhabiting the rivers of the Severn Estuary and those individuals straying from other rivers outside of the impact area of the STP. Recordings of salmon throughout the UK are given in Figure 2.2 whilst records pertaining to the Severn Estuary rivers are given in Figure 2.3.

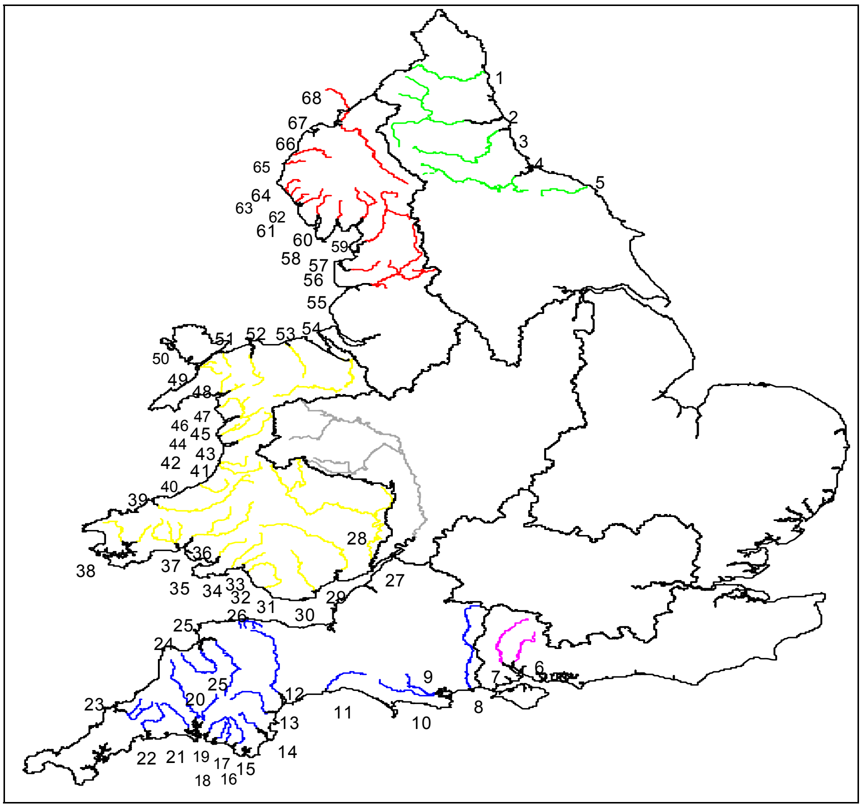


Figure 2.1 Major salmon rivers in England and Wales (EA/CEFAS 2008).

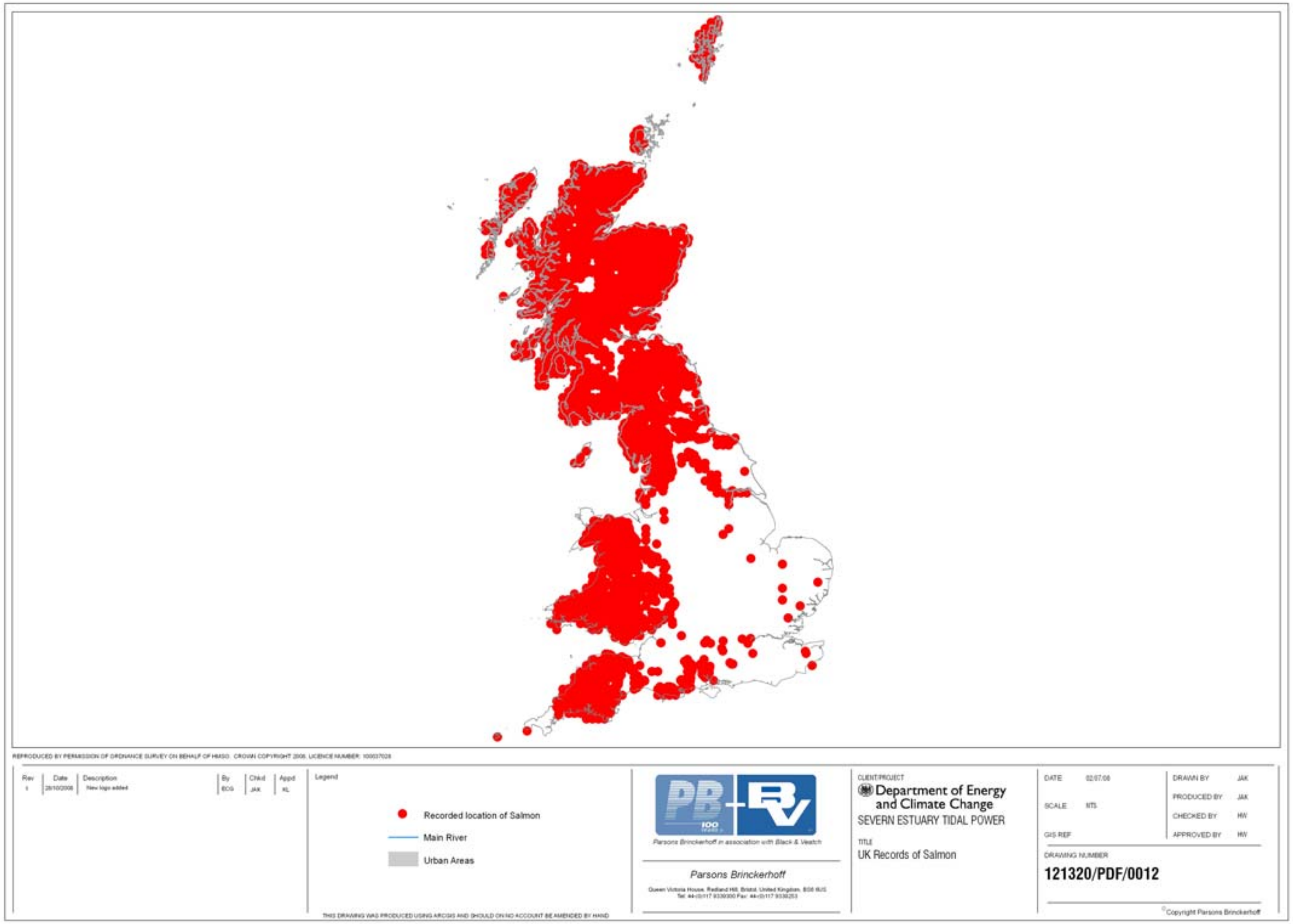


Figure 2.2 Recordings of salmon throughout the UK. Data from the NBN Gateway.

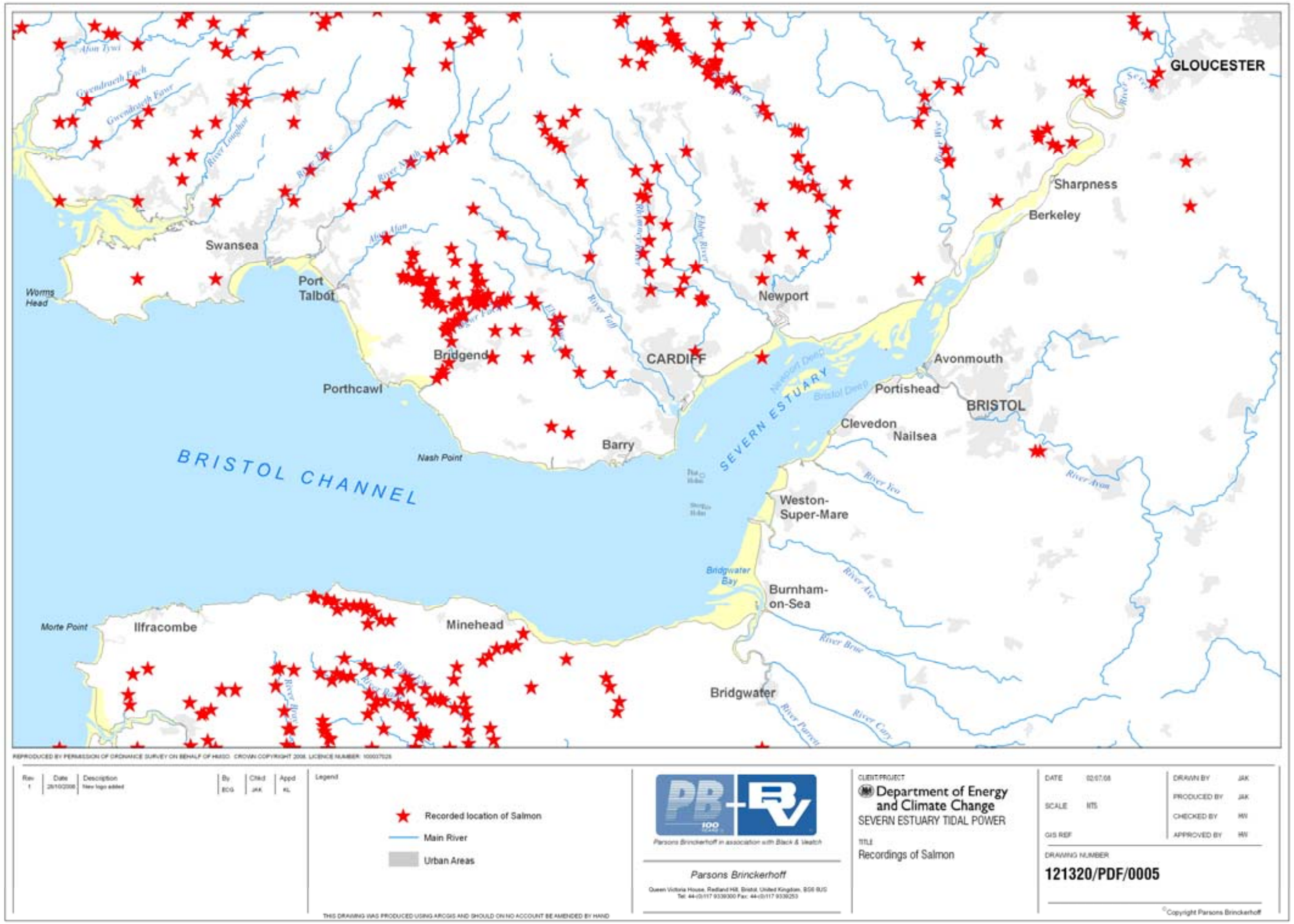


Figure 2.3 Recordings of salmon in Severn Estuary Rivers

Most of the following account refers to rod catch data for adults, taken as an index of run. There are well established caveats in the use of such data (Milner *et al*. 2001, Shields *et al*. 2006) and the data are interpreted here with these in mind.

Salmon catches have reduced considerably in recent decades; in the three major Severn Estuary rivers (Severn, Wye and Usk) in common with many other parts of the eastern North Atlantic (e.g. Mills 2003). This reduction has been most pronounced in the MSW fish which dominate the pre June catch (spring fish), although there has been some upturn since 2001 (Figure 2.4). The low 2001 rod catch is likely however to be an artefact resulting from the reduced fishing effort during the foot and mouth outbreak of this year.

Extensive work has been undertaken by the registered charity; the Wye and Usk Foundation since the mid 1990's to improve the in-river survival and habitat availability/suitability for salmon in particular on the Rivers Wye and Usk (Wye & Usk Foundation, 2008). This work has included the removal of barriers and construction of fish passes opening up an additional 45% of the River Wye catchment and 21% of the River Usk to salmon. Other improvements by the Foundation and its partners have included habitat restoration, improvements to water quality through the 'pHish' project neutralising acidification and schemes with sheep farmers to reduce the use of sheep dips.

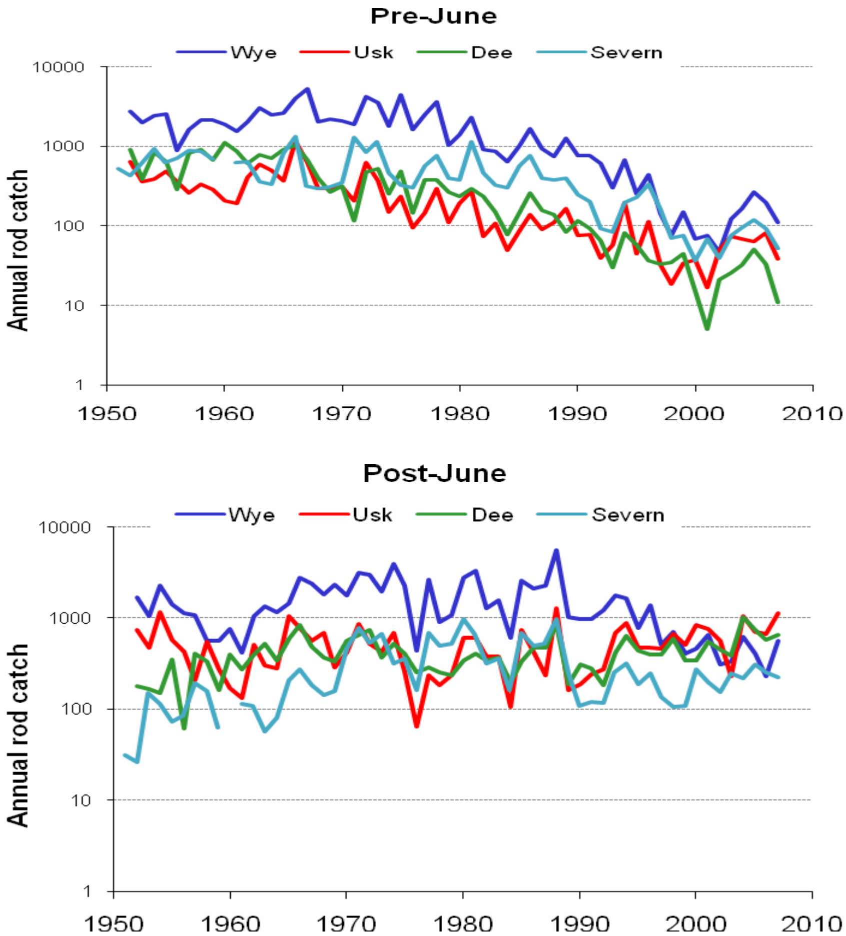


Figure 2.4 Long term changes in rod catch of pre-June 1st and post-June 1st salmon in the Rivers Severn, Wye, Usk and Welsh Dee. Note log scale.

The common long-term pattern in catch between the three rivers and, for reference, the River Dee in North Wales indicates a response to common factors, probably mainly at sea. However, even the imprecise signal from rod catches indicates river-specific variation. Note that reducing fishing effort, intentionally brought about by tighter regulation to protect stock such as the 1999 Spring salmon Byelaws, will, in the short term, restrict catches. Catch per unit effort (in this case, annual catch- per-license-day), possibly a better stock index in this context, shows stable or increasing catches in recent years in these rivers (Figure 2.5).

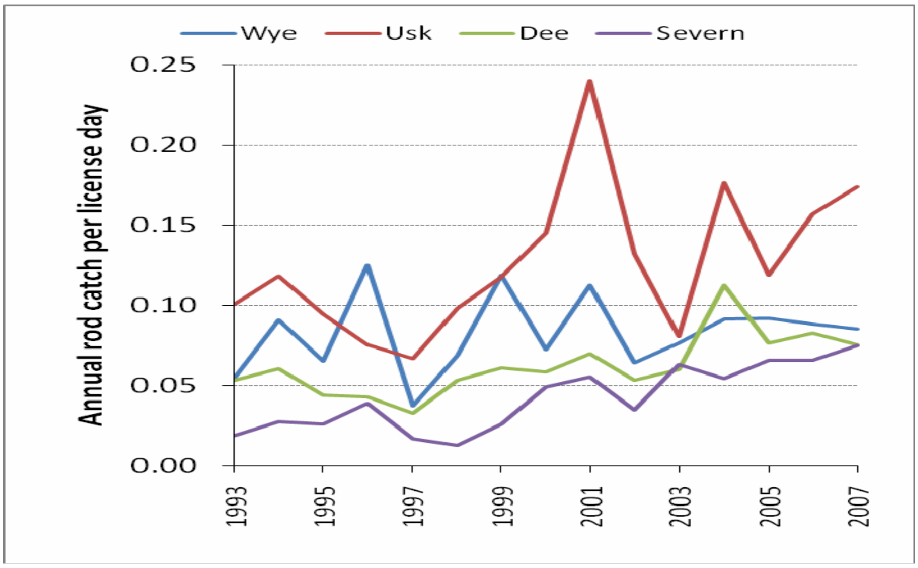


Figure 2.5 Rod catch per license day between 1993 and 2007

Since the 1950s major changes in salmon exploitation driven by the North Atlantic Salmon Conservation Organisation agreement (to which the UK is bound as part of the EU signatory), have included a virtual halt to the high seas fishery by 1994 and a reduction in the Irish Drift net fishery, which closed in 2007. Local byelaws, Net Limitation Orders and buy-outs have led to a major reduction in net/fixed engine exploitation in the Severn Estuary and associated feeder rivers. Rod fisheries, too, have declined in size (see section 2.1.1). Catch and release is now routinely practised on all rivers, enhanced by the National Spring Salmon Measures of the EA which bans killing of net caught fish before 1st June and rod caught fish before 16th June. Other changes to fishing seasons, methods and bag limits, introduced voluntarily or through byelaws, have all contributed to lowering exploitation and protecting spawning stock. Details of the changes are documented in EA/CEFAS (2008).

River Severn

Despite a decline in estimated egg deposition in the River Severn, redd counts remain high and the ratio of MSW salmon to grilse catches (2.7:1) in 2001 was considered one of the highest in England and Wales (EA 2003d). The percentage of rod-caught MSW fish in the River Severn exceeded most other salmon rivers in EA regions between 1994 and 2001.

Tagging surveys have shown that the remaining net and fixed engine fishing on the River Severn exploits stocks from a number of local rivers (Swain 1982). Total net catches of salmon between 1996 and 2007 peaked at around 1600 in 1996 (Figure 2.6). Total salmon catches are dominated by the putcher fixed engine operations with the seine nets contributing the least since 1997. In the 11 years between 1996 and 2007, after an initial decline in rod catches, a slight increase in salmon has been recorded in latter years (Figure 2.7).

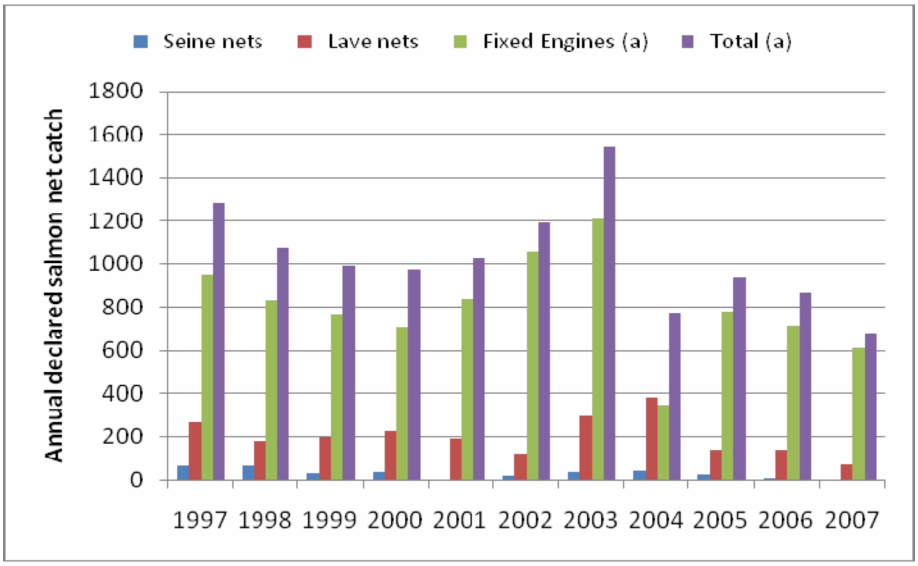


Figure 2.6 River Severn declared salmon net catch between 1996 and 2006.

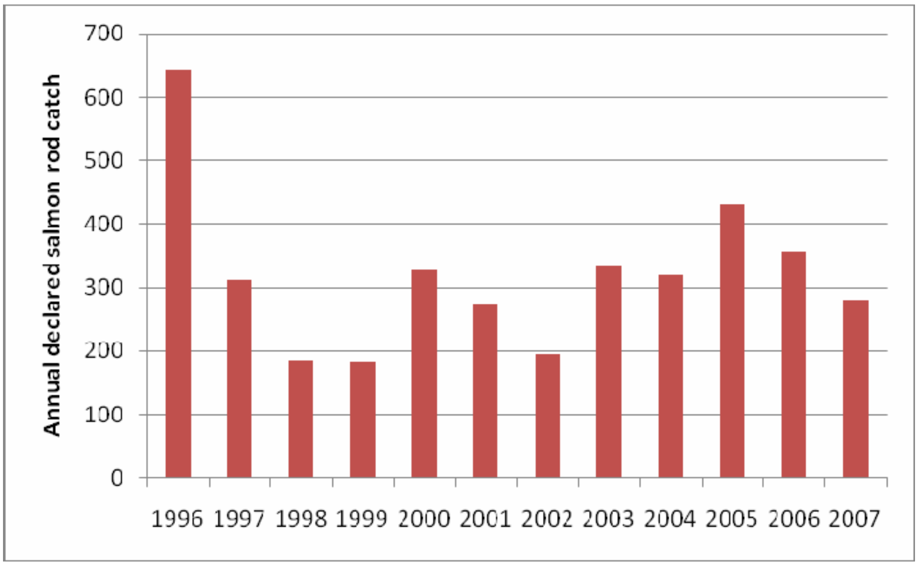


Figure 2.7 River Severn declared salmon rod catch between 1996 and 2007

River Wye

The biggest overall reduction in salmon rod catches has occurred on the River Wye in comparison to the other two major Severn Estuary Rivers (Severn and Usk). The continuing decline in the River Wye post-June catch (Figure 2.4 and Figure 2.8) is a cause of concern and the subject of a number of current initiatives to combat issues in the freshwater environment, such as acidification and siltation from intensive agriculture.

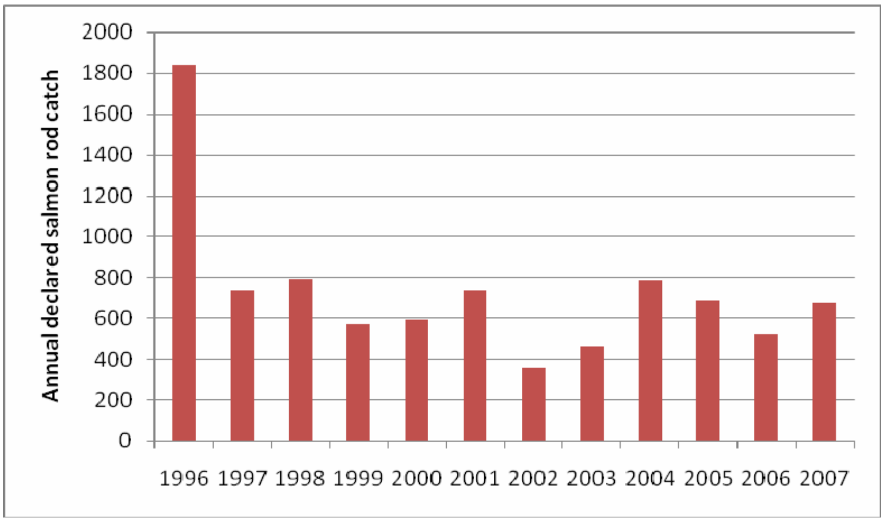


Figure 2.8 River Wye declared salmon rod catch between 1996 and 2007

The pre-June dominance of the River Wye is thought partly to be due to its greater rearing capacity (as wetted area), which is 53% of the total of the rivers draining to the Severn Estuary, upstream of Penarth, (Table 2.5), but also because it has always had a particularly high incidence of Pre June (Spring) run fish (e.g. Gee and Milner, 1980; Gough *et al.* 1992). The reasons for this are not clear, but may be related to the optimal life history strategies adopted in rivers of different size; larger catchments tend to have higher proportions of larger, more fecund, earlier running fish. The Severn Estuary group is nationally important, providing 24% of the total England and Wales Conservation Limit and 16% of current egg deposition.

Table 2.5 Comparison of wetted river area (accessible area), Conservation Limit and actual egg deposition in Severn Estuary salmon rivers (Cefas/EA 2008).

River	Wetted area		Conservation Limit (eggs)		Recent egg deposition	
	(Ha)	% of Estuary	Total eggs (m)	% of Severn Estuary	Mean (m) (2003-2007)	% of Severn Estuary
Severn	898	29	12.85	21	16.46	29
Wye	1610	53	35.66	57	22.75	40
Usk	407	13	10.11	16	16.97	30
Taff/Ely	146	5	3.44	6	0.98	2
Sum	3061		62.06		57.17	
% "Severn Estuary" group of E & W total			24		16	

Despite former substantial netting in its estuary, only one lave now operates on the River Wye. Between 1996 and 2007 the annual catch ranged from 2 to 11 salmon. It is understood, however, that River Wye salmon are also caught in other commercial netting operations in the upper Bristol Channel and Severn Estuary (Swain 1982).

River Usk

Historical recorded rod catches were substantially higher in the late 19th century than at any time in the 20th century (EA 2001), and after 1965 the number of larger salmon caught has decreased. Since 1996 the highest recorded catch was 1,158 fish recorded in 2007 (Figure 2.9). Catch and release is particularly well supported on the River Usk, reaching a high of 79% for salmon in 2007.

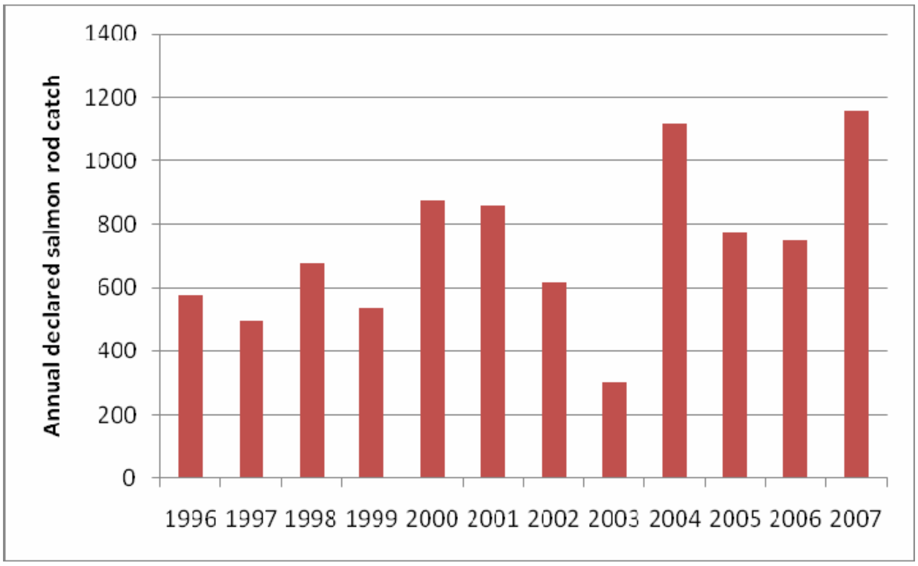


Figure 2.9 River Usk declared salmon rod catch between 1996 and 2007

Before 1992 in the Uskmouth area illegal netting was considered to be intense with several thousand salmon being exploited by unlicensed boats (Bowker *et al*. 1998). These fisheries exploited salmon stocks from several rivers, including the River Wye, although most were considered to be fish destined to return to the River Usk (EA 2001). Following the buyout and net limitation order, no catches were made after 2000. The numbers caught by both drift net and putcher methods over the 10 years from 1996 to 2007 are shown in Figure 2.10.

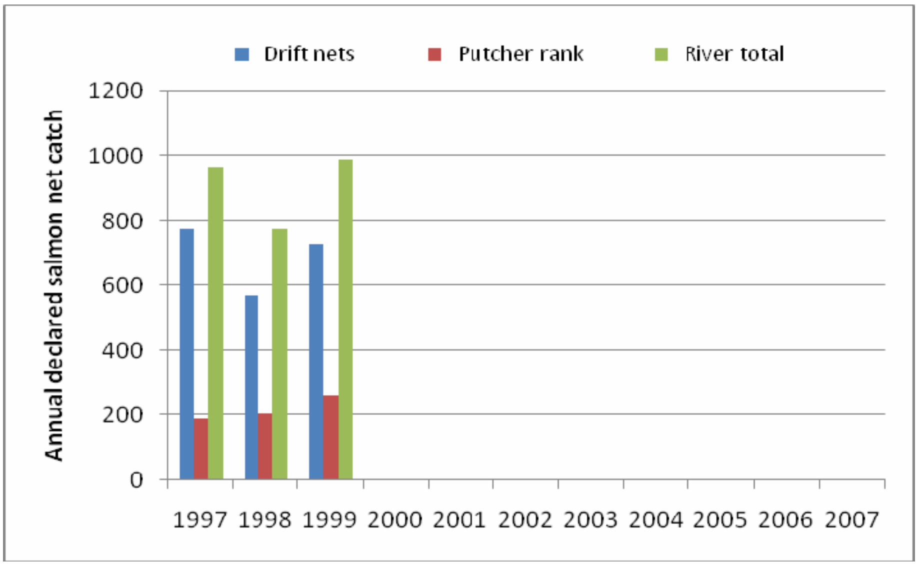


Figure 2.10 River Usk declared salmon net catch between 1996 and 2007.

Coalfield rivers

Stocks of migratory fish in the South Wales coalfield rivers (Rivers Ely, Ebbw, Taff and Rhymney) are currently small in comparison to the other Severn Estuary Rivers. There has however been substantial Government and EU investment, notably on improving water quality and fish pass construction and so stocks in these rivers have begun to recover over the last 30 years and are likely to improve further into the future (Wye & Usk Foundation, 2008). Salmon populations on these rivers however, are still constrained by barriers to migration including the Cardiff Bay Barrage, as well as the Treforest, Methyr, Bassaleg and Aberbeeg weirs (Wye & usk Foundation, 2008). The River Taff is also currently stocked as part of the Cardiff Bay Barrage proposal which will continue until 1000 salmon/sea trout equivalents are achieved (D. Crompton, *pers.comm.*). These rivers are largely urban and part of the local environment for a substantial population and support a considerable level of angling.

The Rivers Taff and Ely, while not being renowned salmon rivers, have a salmon run and both are recovering rivers (EA 2003e). The fishery currently relies largely upon stocked and stray fish from other catchments to make up this run (EA 2003e). Declared rod catch of salmon on the River Taff has increased over the past couple of years after no fish were declared in 2003 (Figure 2.11). This is likely a result of the water quality improvements seen in these once heavily polluted rivers (EA, 2003e).

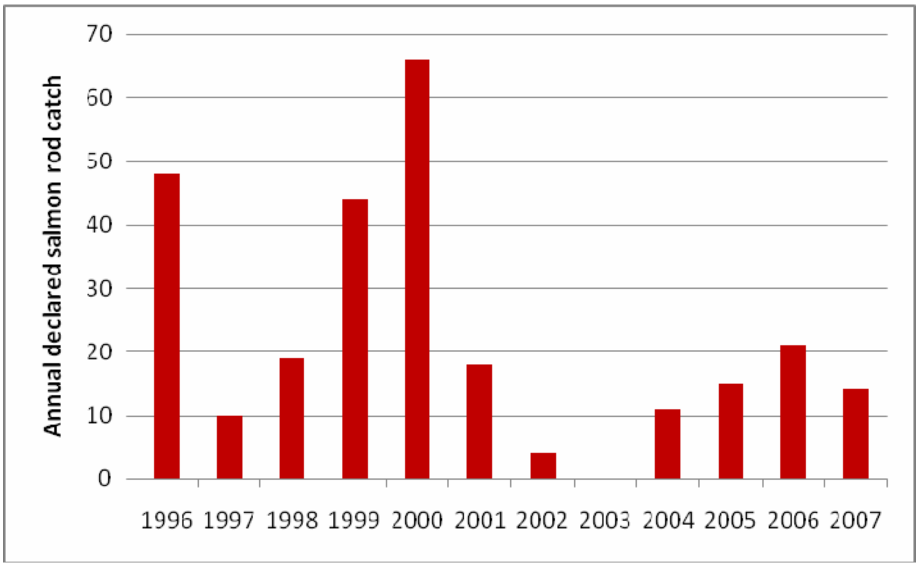


Figure 2.11 River Taff declared salmon rod catch between 1996 and 2007

<u>*Sea trout*</u>

Sea trout are less abundant than salmon in the Severn Estuary rivers (See section 2.1.1, Table 2.2). Net catches of sea trout in the drift nets and putchers of all Severn Estuary tributary rivers have generally been low since 1965, exceeding 100 individuals per year on only 10 occasions (EA 2001). No sea trout have been caught in any of these fisheries since 2000 (EA 2007) principally due to fishery reduction or closure. Furthermore low rod catches result in the data being highly variable and prone to reporting error. Therefore relationship with run size is likely weak, and interpretation should be cautious. Zero catch for the Severn from 1988 to 1990, for example, is not taken to imply absence of sea trout. The Rivers Usk and Severn have had the highest catches, although these have declined since ca. 2000 (Figure 2.15).

River Severn

Sea trout rod catches were usually below 20 per year between 1996 and 2006. Exceptions were 1998 with 66 fish, 2005 with 103 fish and 2007 with 32 landed.

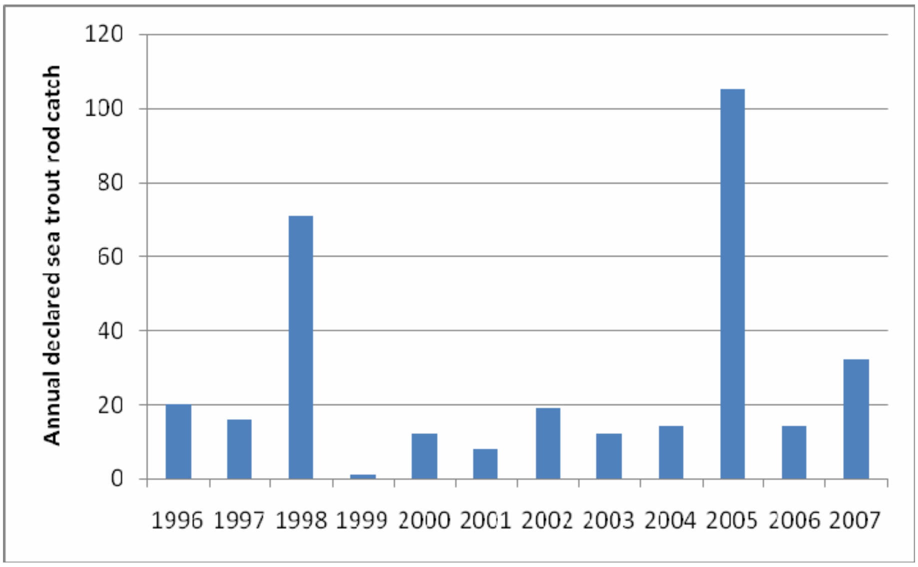


Figure 2.12 River Severn declared sea trout rod catch between 1996 and 2007

River Wye

Between 1996 and 2007 a general rise in catch was observed (Figure 2.13). Landed fish numbers peaked in 2005 at 84, before returning to standard levels of ca. 40 fish.

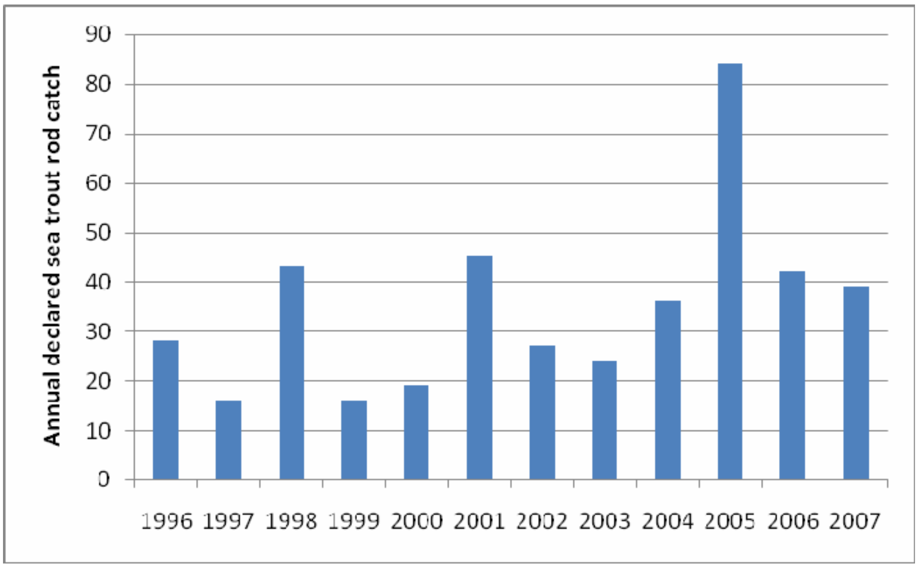


Figure 2.13 River Wye declared sea trout rod catch between 1996 and 2007

River Usk

Between 1965 and 1993 declared catches rarely exceeded 100 per year. Numbers have since increased to a peak in 1999 of 600 fish, and until

2006 over 200 individuals have usually been caught each year (Figure 2.14). Causal factors put forward to explain this include improved water quality in the River Usk estuary, closure of the driftnet fisheries (G. Mawle, *pers. comm.*), and increased sea trout fishing effort. Again, catch and release for sea trout is well supported on the River Usk.

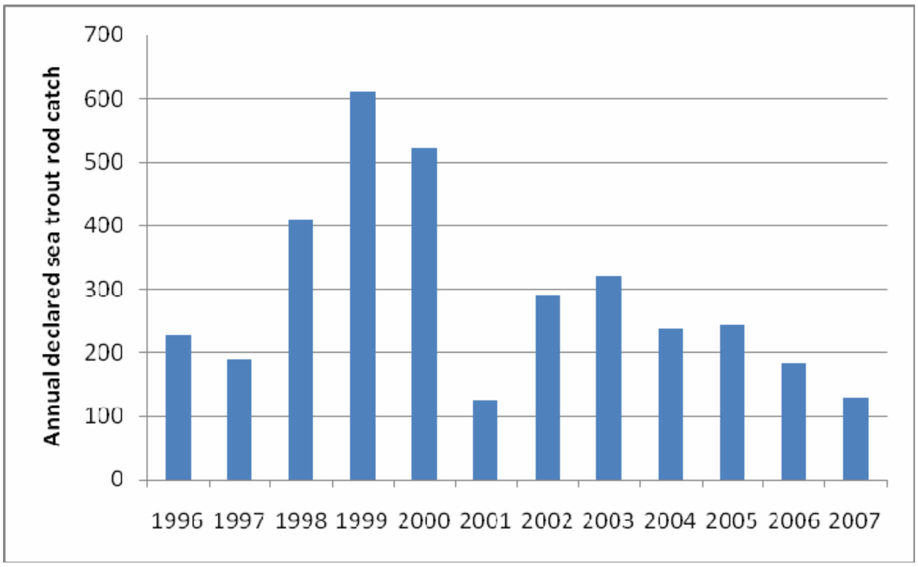


Figure 2.14 River Usk declared sea trout rod catch between 1996 and 2007

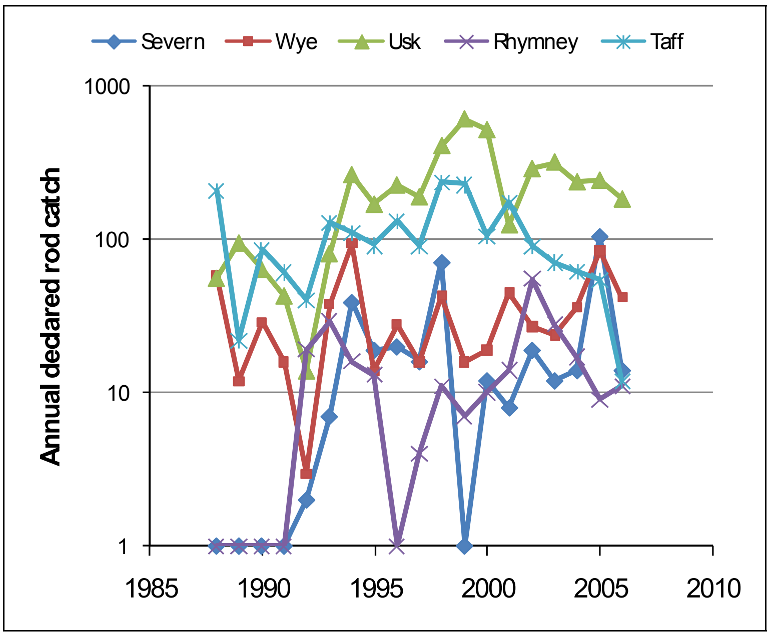


Figure 2.15 Variation in declared sea trout rod catch (n+1) from principal Severn Estuary rivers, note log scale.

Coalfield rivers

Sea trout rod catches on the River Taff have shown a decreasing trend since 2001 with catches usually below 100 (Figure 2.16). The greatest declared rod catches were in 1998 and 1999 at over 200 fish.

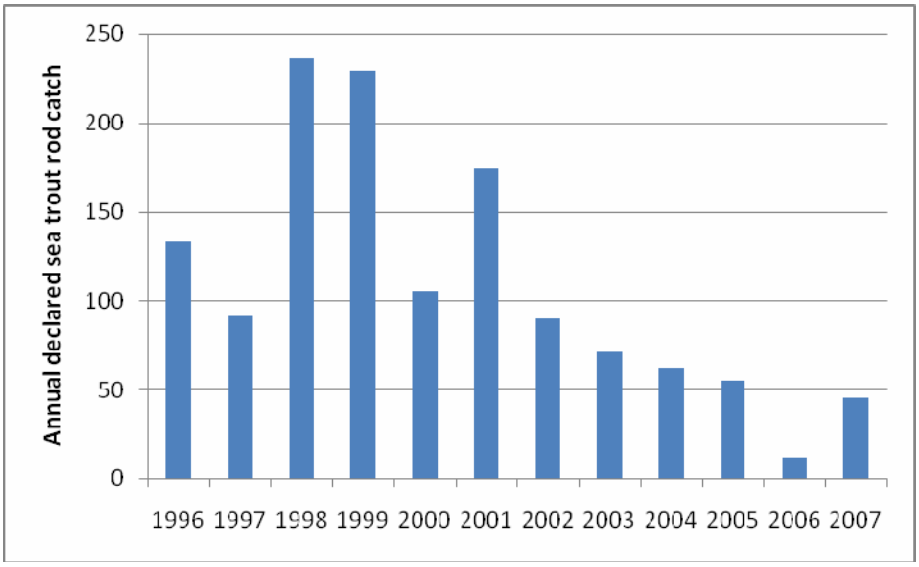


Figure 2.16 River Taff declared sea trout rod catch between 1996 and 2007

Future stock trends

Predictions of salmon stock performance into the future are given in the EA SAPs for individual rivers. The method used, outlined in EA/CEFAS (2008), is based on Bayesian analysis of egg deposition estimates from the previous 10 years. Extrapolation of the 20th percentile line is used to indicate future stock performance.

The CL is set from the overall relationship between spawning stock (or egg equivalents) and adults (or egg equivalents) returning as their progeny. By definition a (just) compliant stock is one in which the egg deposition (or spawning escapement) is at or above the CL level for 80% of the time on average, i.e. 4 years out of five. Thus the CL is the 20%ile of the escapement distribution (with Standard Distribution, SD) during a particular test period (10 years). Correspondingly, the average stock level in that period is the 50%ile and this level is termed the Management Target (MT).

Concerns over River Wye salmon stocks have been expressed for several years and this river has been consistently below its

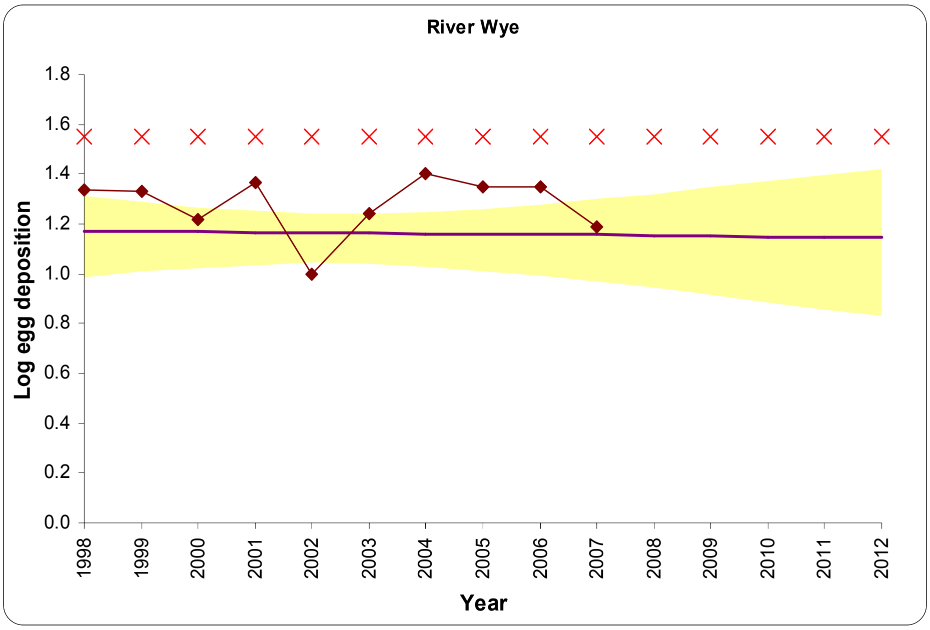
Conservation Limit for the last 10 years. A continued minor reduction over the next five years is predicted (Figure 2.17). Byelaws specific to the River Wye were introduced in 2003 to aid salmon survival through the fishing season. In the past, rod catches of up to 8,000 (1967) salmon have been recorded on the River Wye in comparison to the 2007 catch of 675 individuals. These historical records give an indication of the potential of the River Wye salmon stocks into the future.

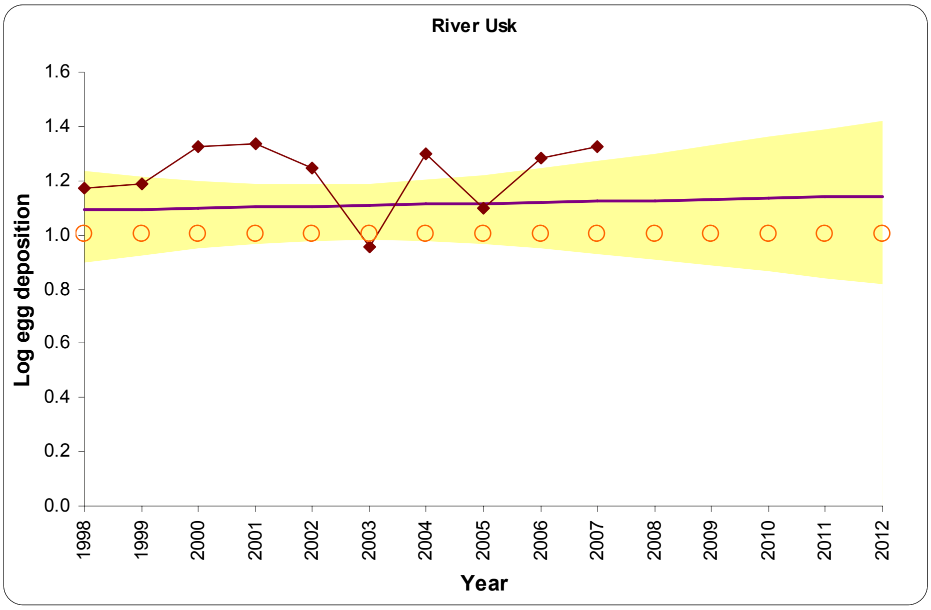
A long-term decline in MSW numbers has been observed in the River Usk, with a modest post 1999 improvement since the drift net buyout. The Conservation Limit of 350 eggs per 100 m^{-2} has been achieved during the last 10 years. Future status of the River Usk is uncertain (the Conservation Limit lies between the 5 and 95% probability levels of estimated egg deposition) with a slight upward trend predicted (Figure 2.17). Recent records of salmon rod catch (2004) on the River Usk are similar to the maximums recorded in the past. The potential for further stock improvement on this river is therefore currently uncertain.

Having failed to meet its Conservation Limit between 1997 and 2001, River Severn compliance is also predicted to be uncertain, with a slight upward trend to 2012 (Figure 2.17). Historical salmon rod catches on the River Severn have peaked at approximately 2,000 (1972) in comparison to a 2007 catch of 280 individuals. Historical records can therefore also give an indication of the potential of salmon stocks in the River Severn.

A Conservation Limit of 219 eggs per 100 m^2 has been set for the combined catchments of the Taff and Ely. The rivers have failed to meet this Conservation Limit since 1997 (Figure 2.17) with a downward trend predicted into the future based on data to 2006. It may be however that with recent improvements (discussed above) this trend could be reversed in the future.

The Water Framework Directive and its target for rivers to meet good ecological status by 2012 will undoubtedly require action to be taken on rivers currently failing this target. This is likely to include measures such as habitat enhancement, fish pass development and further reductions in exploitation where possible. These measures are not taken into consideration when predicting conservation limit compliance into the future but will be designed to improve fish stocks and as such will influence future stock trends.


River Wye
Log egg deposition
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year


River Usk
Log egg deposition
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1998
1999
2000
2001
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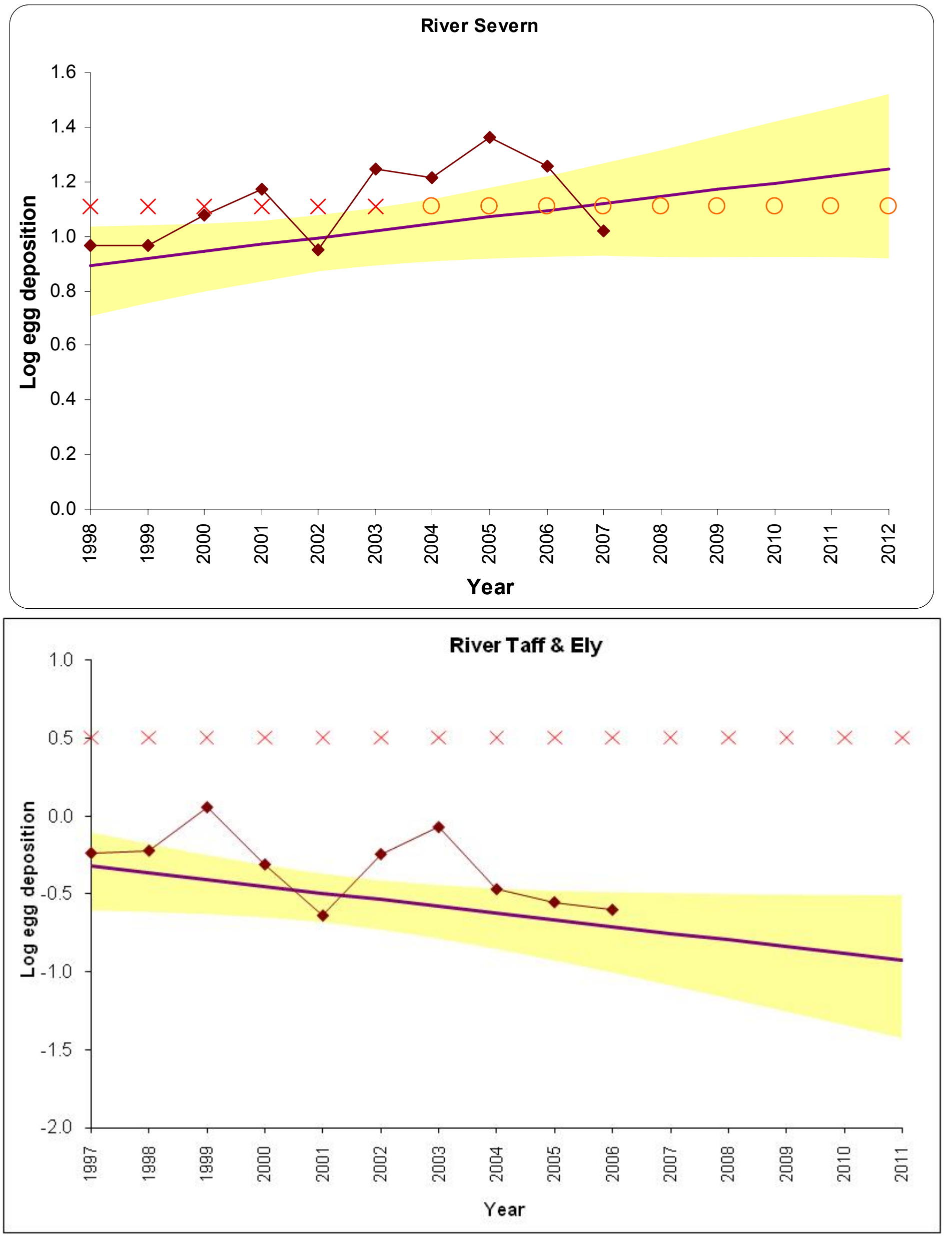

Figure 2.17 Trend lines of egg deposition in the Rivers Wye, Usk, Severn and Taff and Ely, showing linear projections to 2012.

The data are the 20%ile values of previous 10 yr estimated egg deposition. 5% (denoted by X) to 95% (denoted by O) probability intervals are shown and the horizontal lines are the Conservation Limits for each river. Data and graphs provided by the EA National Salmon team.

Shad

Allis shad are rare in the UK with no known spawning populations left. Historical UK-wide recordings of allis shad are shown in Figure

2.18. Within the Severn catchment historical records of allis shad on the Rivers Wye and Usk exist and there have been several recordings in the estuary (Figure 2.19). Although unproven it has also been inferred that the River Tamar and Solway Firth area may also support populations of allis shad (Hillman 2003). The last four rivers known to support a spawning population of twaite shad are the Rivers Tywi, Usk, Wye and Severn (including its tributary the River Teme) (Aprahamian *et al*. 1998a). The presence of three of these remaining spawning populations being within the Severn Estuary and the close proximity of the River Tywi places twaite shad at particular risk as there is potential for the entire UK population to be adversely impacted by a STP. Fewer historical UK recordings exist for twaite shad than for allis shad (Figure 2.20), however twaite shad has been recorded on more occasions within the Severn catchment (Figure 2.21). Although a rare species within the UK Twaite shad can be observed in some number on the Rivers Usk, Wye and Severn with, at times, shoals of hundreds of fish. SAC classification was described in Section 2.1.

Freshwater shad population data are largely restricted to spawning distribution surveys carried out intermittently in the River Wye and River Usk. Limited adult run size data from River Wye fish counters indicate an estimate of the number of shoals passing through the counter but do not provide individual run count information. Juvenile data were collected on the River Wye in 1979 and 1980 and again for SAC condition assessment monitoring on the Rivers Wye and Usk in 2005 and 2006 (Noble *et al*. 2007). No juvenile assessment had been undertaken previously on the River Usk.

River Usk

Spawning distribution surveys were undertaken during 1990, 1994, 1997, 1999, 2003 and 2004. The number of sites at which eggs were found ranged from 1 in 1994 to 18 in 2003. The most recent juvenile survey (summer 2006) gave an average density of 1.4 individuals 100 m^{-2} (Noble *et al.* 2007) based on a catch of seven individuals (all from Newbridge on Usk).

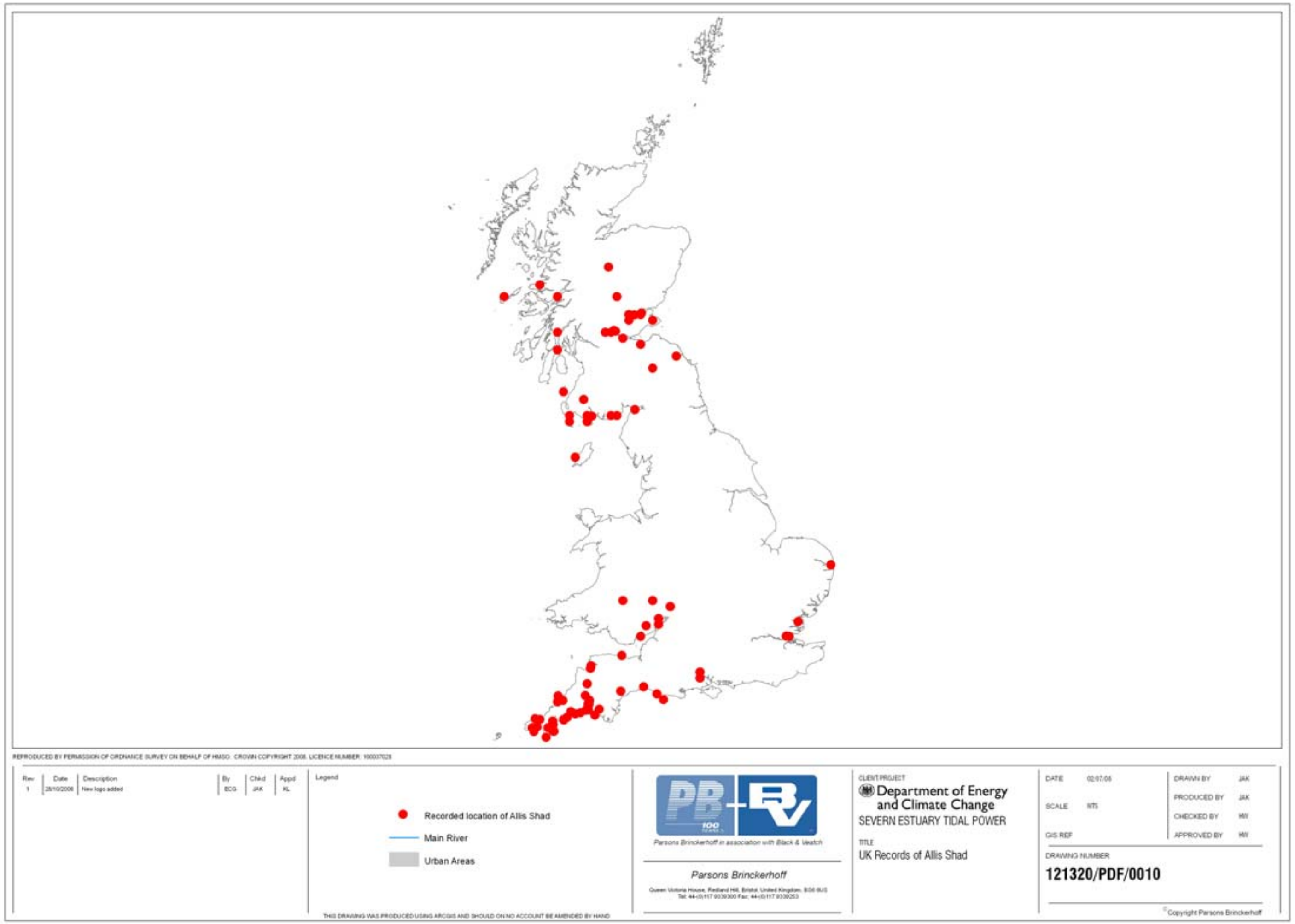

Figure 2.18 Recordings of allis shad throughout the UK (based on NBN Gateway data)

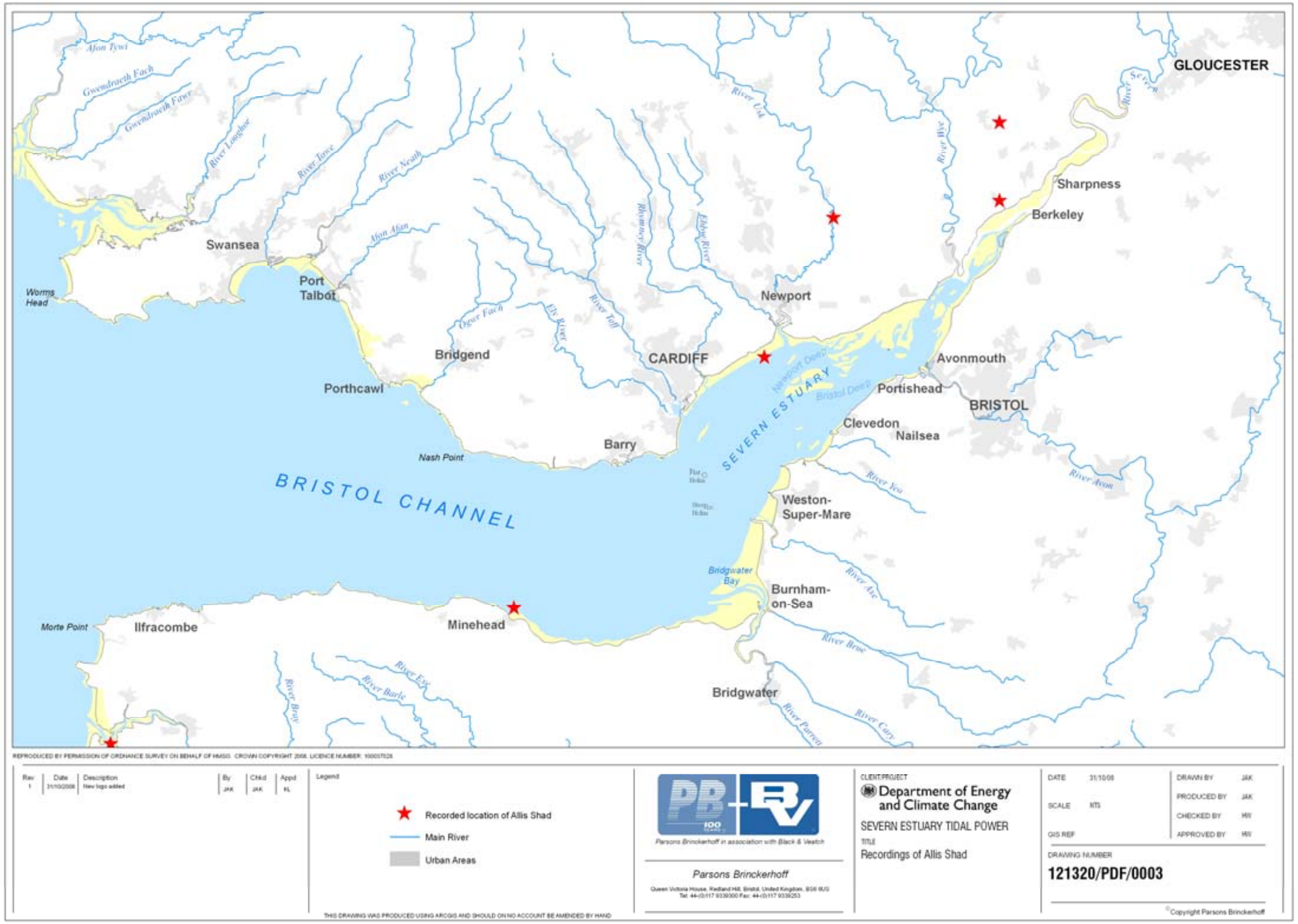

Figure 2.19 Recordings of allis shad around the Severn Estuary (based on NBN Gateway data)

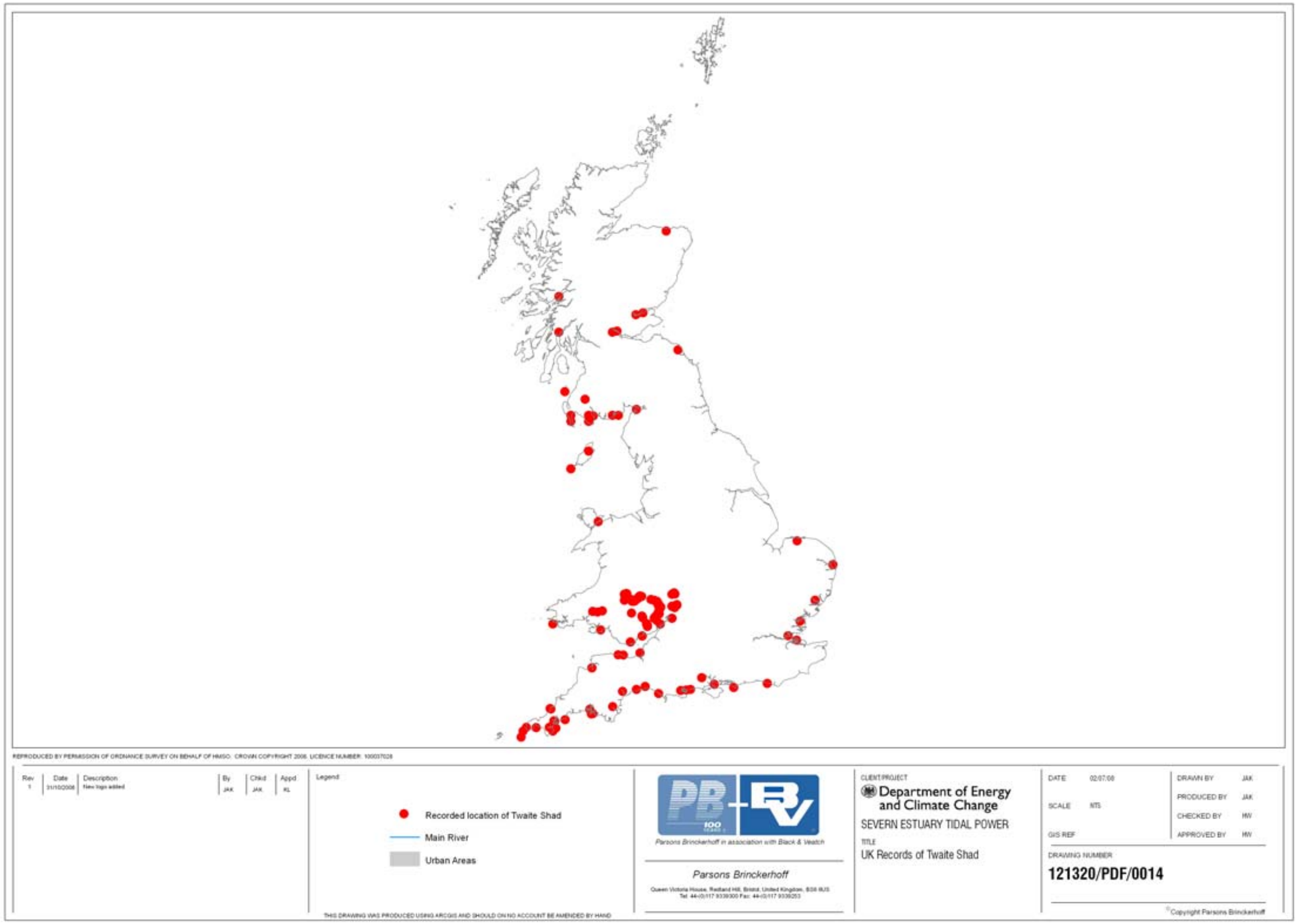

Figure 2.20 Recordings of twaite shad throughout the UK (based on NBN Gateway data)

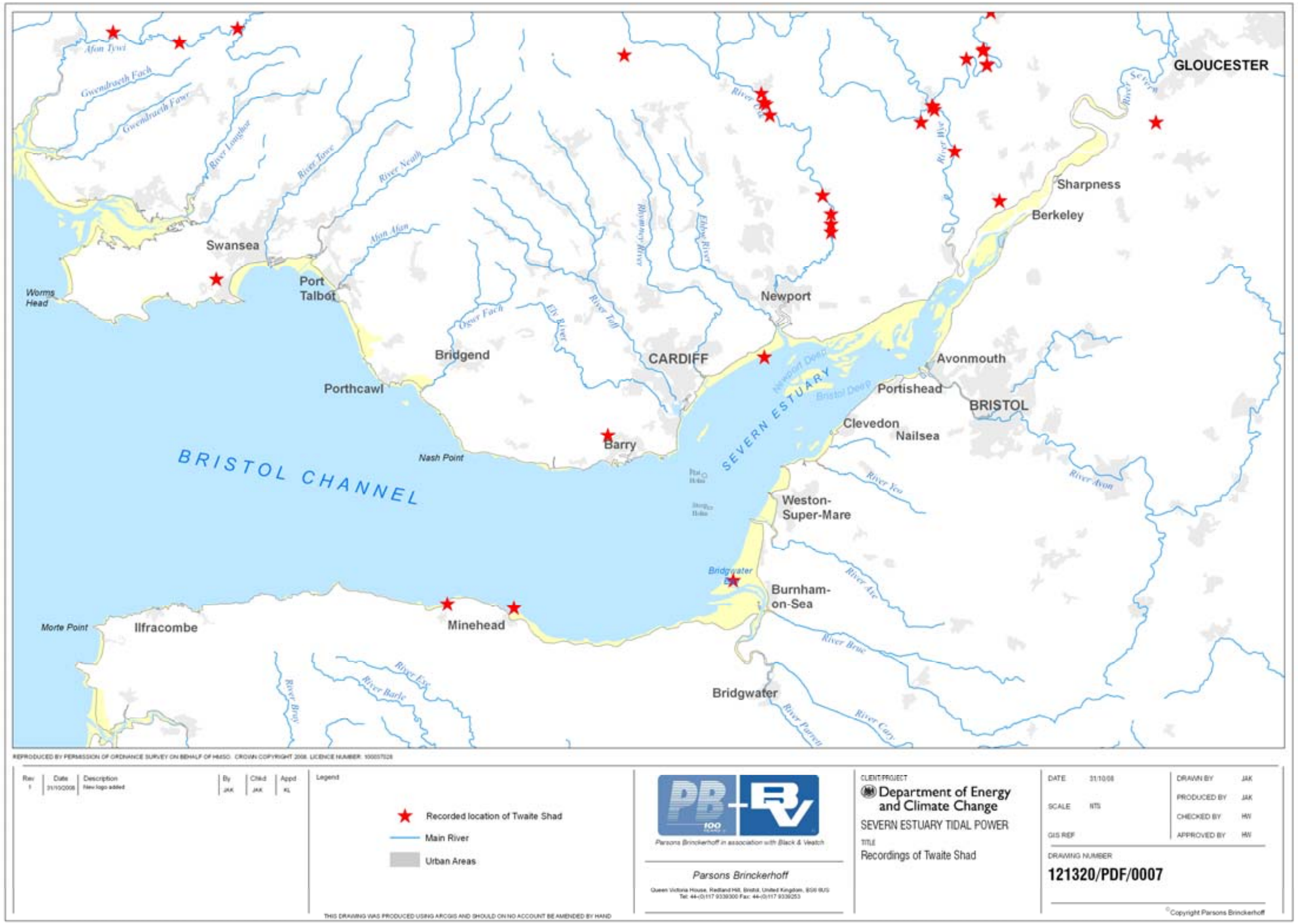

Figure 2.21 Recordings of twaite shad around the Severn Estuary (based on NBN Gateway data)

River Wye

Shad egg surveys were undertaken during 1980, 1997, 1999, 2003 and 2004, and the number of recorded egg sites varied from a low of 4 sites in 1997 to a high of 19 sites in 2004 (Noble *et al*. 2007). Data on shad shoals from the fish counter at Redbrook on the River Wye are available for 1999, 2000, 2002 and 2003. The number of shoals observed ranges from 187 in 2003 to 952 in 2000 (Noble *et al.* 2007). However, the equipment used does not give an accurate or comparable estimate of adult run size between years, therefore population performance cannot be determined from these data sets.

Juvenile shad data from 1981-82 indicate large inter-site and inter-annual variability, and so contribute little to estimates of population performance. Catches during the 2005 survey year were very low, at just 2 individuals. In the 2006 survey however, a total of 375 fish ranging in density from 5.3 to 92.3 individuals 100 m^{-2} were caught across four sites.

Other Severn Estuary rivers

Spawning populations of twaite shad are known to exist on the River Severn and its tributary the River Teme. A number of weirs on this system now restrict the extent of spawning distribution with Powick weir on the River Teme and Diglis weir at Worcester on the River Severn believed to be the extent of upstream migration in particular during low flow years (Aprahamian *et al*. 1998a).

Severn Estuary

The population of adult twaite shad migrating through the Severn Estuary on their freshwater spawning phase was sampled between 1979 and 1996 from catches within the salmon putcher nets operating near Lydney (Aprahamian & Aprahamian 2001). Taking into account changes in putcher trap design, the greatest catches were recorded in 1994 and 1982 with the lowest number recorded in 1985 (Figure 2.22). The number of juvenile twaite shad entrained annually into Hinkley Point B Nuclear Power Station was also recorded over a similar period from 1981 to 1996, with annual catches ranging from less than 10 during 1981, 1982, 1987, 1988, 1991 and 1993 to over 100 in 1989 (Aprahamian *et al*. 1998a). Comparison with environmental factors indicated a positive correlation between recruitment and temperature, and a negative correlation between recruitment and flow and rainfall (Aprahamian & Aprahamian 2001).

Sampling for juvenile twaite shad was also carried out between 1979 and 1981 at Elmore, Framilode and Newnham and at Oldbury Nuclear Power Station between 1979 and 1980 (Aprahamian, 1988). Juvenile shad were found to be present in the estuary from July before emigrating seaward in autumn. A portion of these fish were then found to re-enter the estuary the following April-May and remain until late summer/early autumn.

Other sources of shad data within the Severn Estuary are largely restricted to entrainment catches from the power stations located throughout the estuary. Juvenile twaite shad were collected from the screens of Oldbury on Severn Power Station during the period 1972 to 1977 and 1996 to 1999 (Potter *et al*. 2001). Mean annual catches decreased slightly from 2.6% of the total catch in the 70s to 0.8% in the 90s. This downward trend in percentage representation was contradictory to the increase in the total catch between the two periods. However whether total shad catch actually declined or has just not increased at the same rate as other marine and estuarine species is unclear.

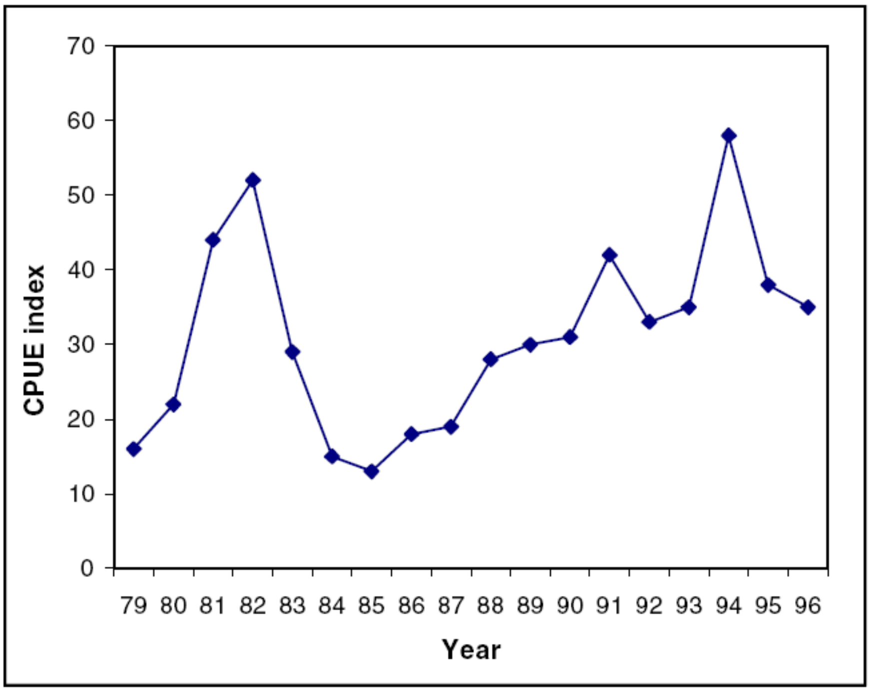

Figure 2.22 The CPUE index of female twaite shad caught in the Severn Estuary between 1979 and 1996 (taken from Aprahamian & Aprahamian 2001).

Quantitative monthly sampling of entrained fish at Hinkley Point B Nuclear Power Station since 1980 (Henderson *et al*. 2007) gives an indication of juvenile twaite shad population trends throughout the last two and a half decades. Greatest catches occurred between 1989 and 1991 (Figure 2.23) correlating with the Oldbury Power Station data of peaks in recruitment during these warm summer years. Catch fluctuations throughout the sampling period make future predictions of population performance difficult.

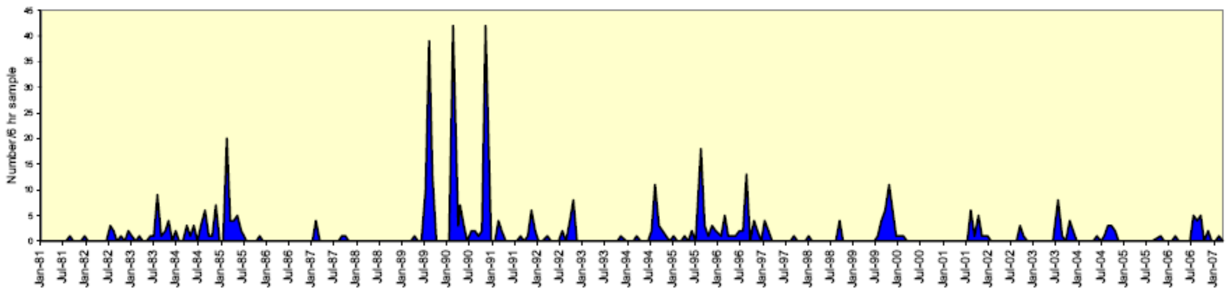

Figure 2.23 Entrainment of juvenile twaite shad into Hinkley Point B Nuclear Power Station over 6 hour sampling periods between 1981 and 2007 (taken from Henderson *et al*. 2007).

<u>*Lamprey*</u>

Over half of the 20 England and Wales SAC designations for the presence of lamprey species are situated on the Welsh coast including the Rivers Wye and Usk. The Severn Estuary itself is also a cSAC for the presence of river and sea lamprey. The most recent condition assessment round in 2007 classified all but the River Usk as unfavourable for river lamprey and all but the River Wye as unfavourable for sea lamprey. The River Usk has the greatest *Lampetra* spp. ammocoete (river and brook lamprey ammocoetes cannot be distinguished apart in the field and as such are termed collectively as *Lampetra* spp.) population across all British SAC rivers designated for the species, while the River Wye has the greatest sea lamprey ammocoete population of all British SAC's designated for its protection (APEM 2007).

Historical UK-wide records of sea and river lamprey are shown in Figure 2.24 and Figure 2.25 respectively. In the Severn Estuary, sea lamprey have been recorded on the Rivers Usk, Wye and Severn (Figure 2.26) whereas river lamprey recordings are more widespread (Figure 2.27).

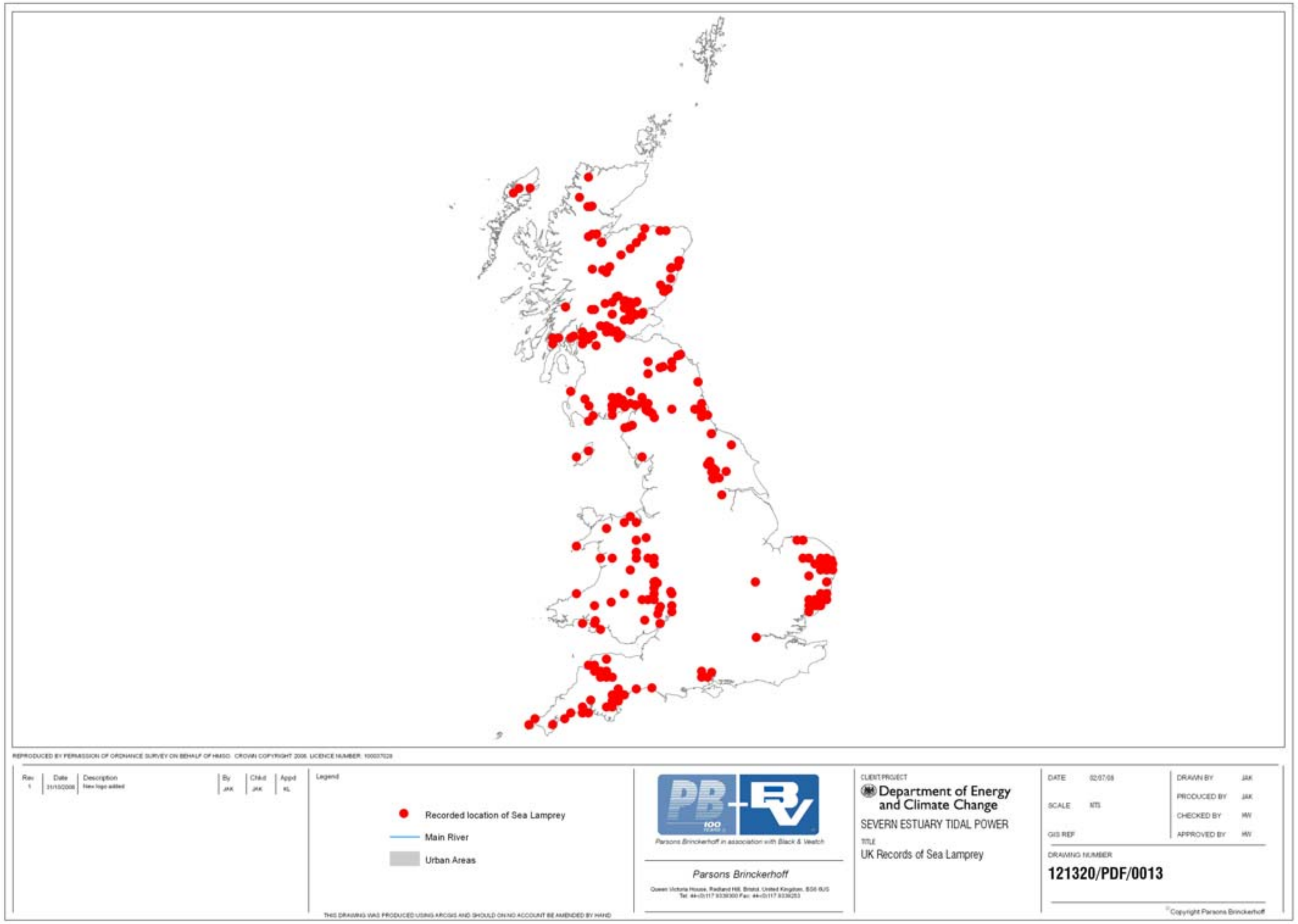

Figure 2.24 Recordings of sea lamprey throughout the UK. Data from NBN Gateway and APEM surveys

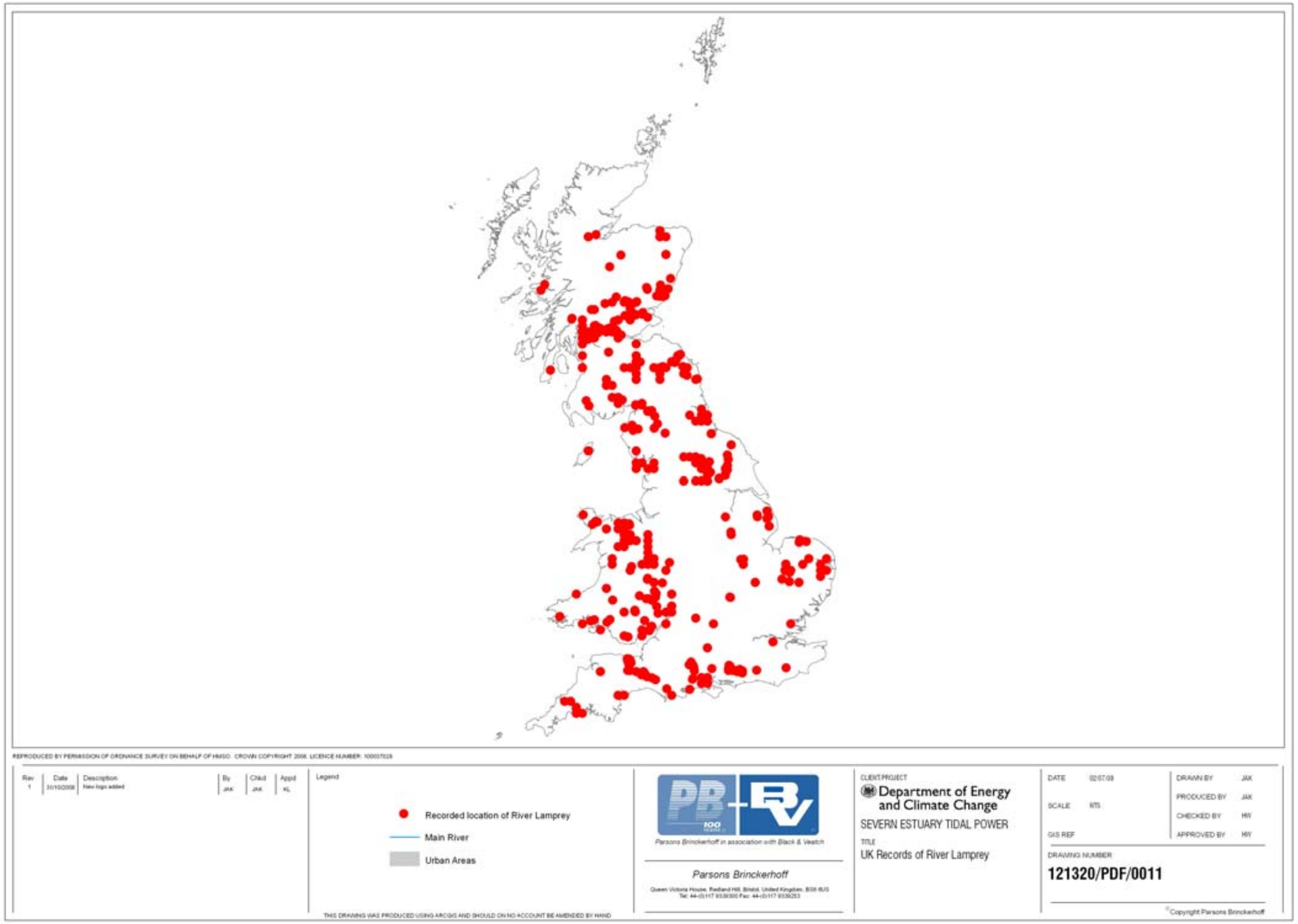

Figure 2.25 Recordings of river lamprey throughout the UK. Data from NBN Gateway and APEM surveys

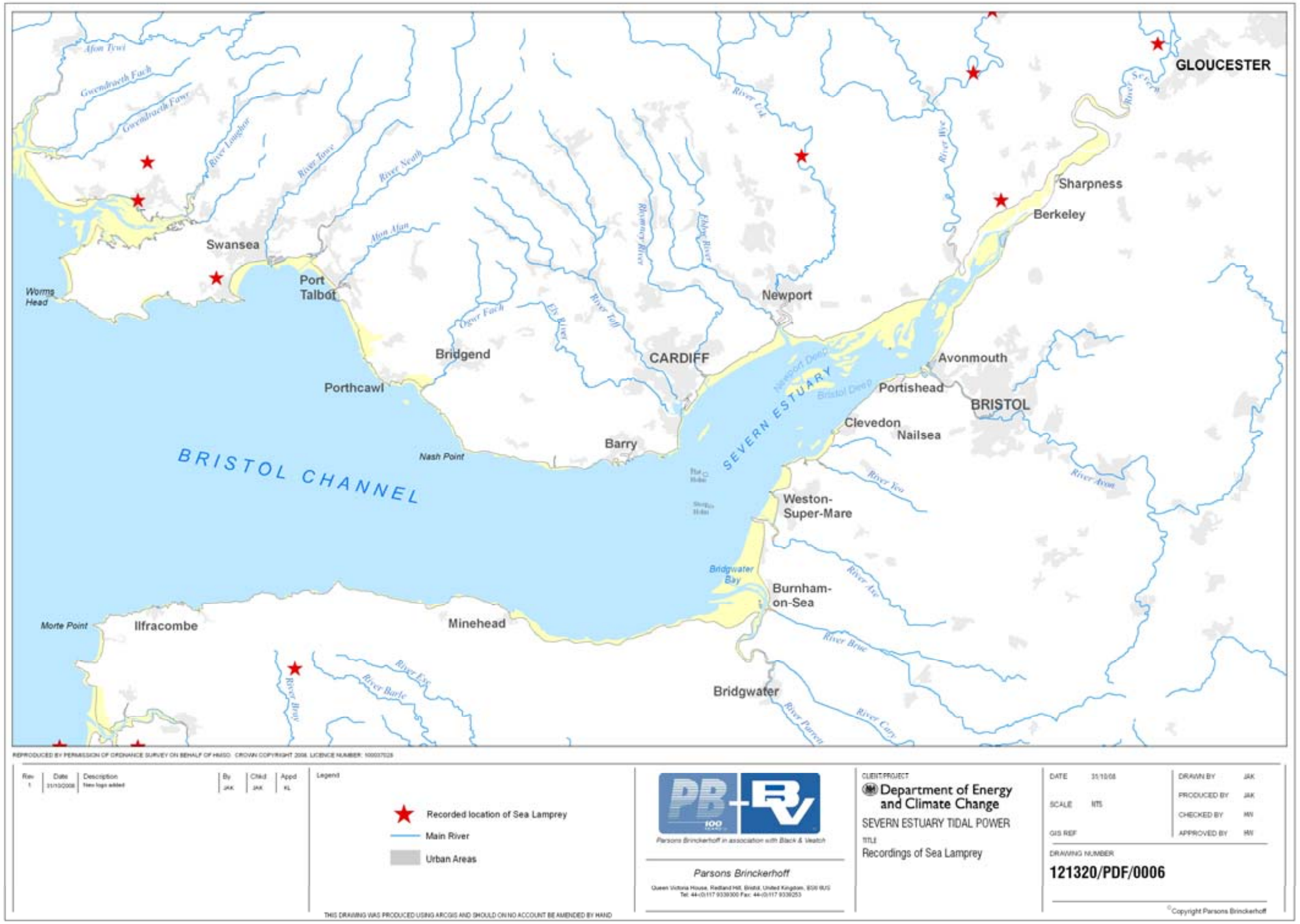

Figure 2.26 Recordings of sea lamprey around the Severn Estuary. Data from NBN Gateway and APEM surveys

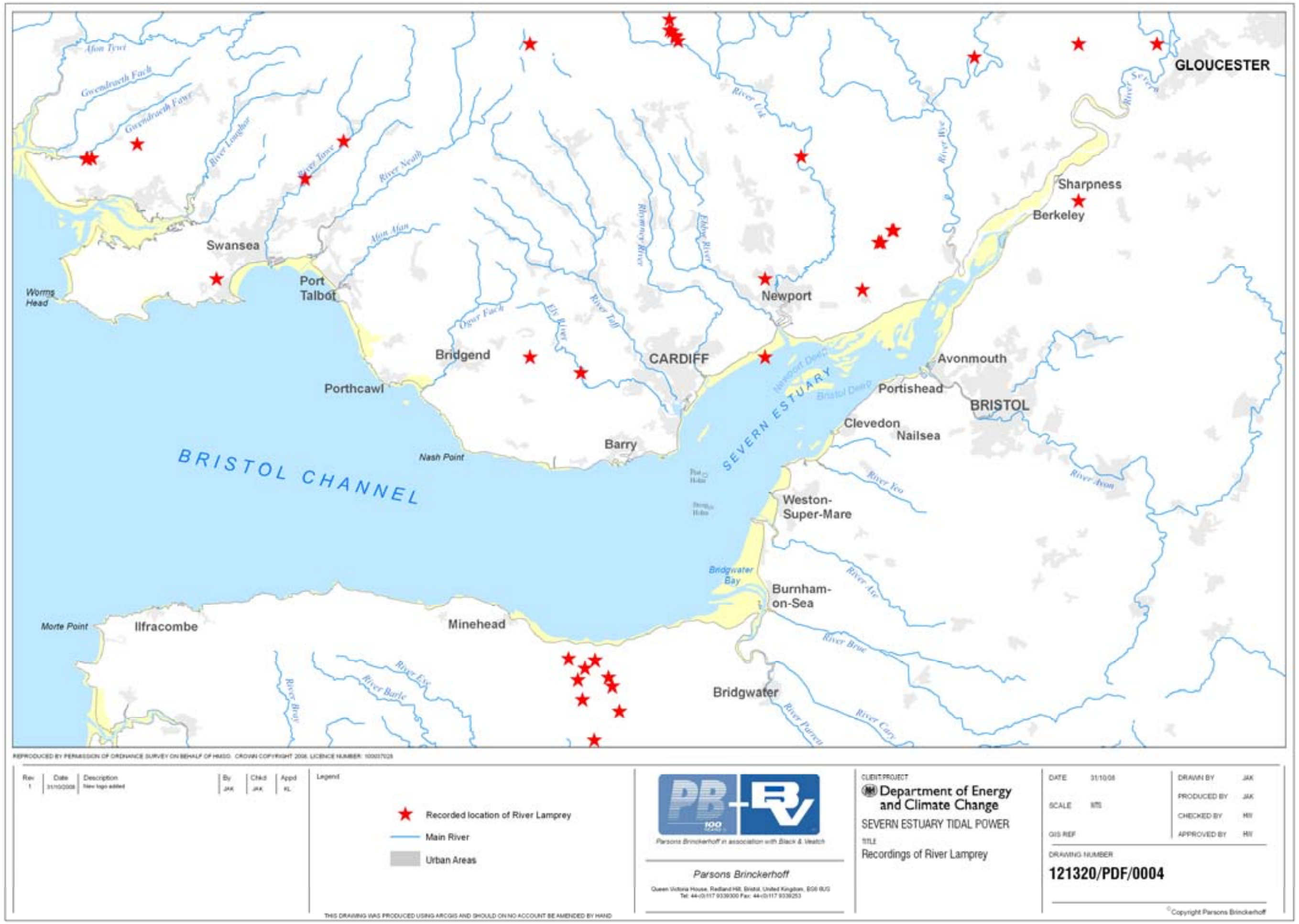

Figure 2.27 Recordings of river lamprey around the Severn Estuary. Data from NBN Gateway and APEM surveys

No commercial lamprey landings are known within the Severn Estuary and its tributaries, however historical accounts of incidental catches within putcher ranks and eel nets exist.

River Usk

Lamprey data for the River Usk date back to the 17th Century. Historical data consist primarily of anecdotal accounts and more recently incidental species catches from EA migratory salmonid surveys (Harvey *et al*. 2006). The first known dedicated lamprey survey was undertaken by APEM in 1998 (Cragg-Hine *et al.,* 1999). A total of 44 sites were surveyed using semi-quantitative point sampling electric fishing. *Lampetra* spp. ammocoetes were recorded at 31 of the sites and sea lamprey ammocoetes were recorded at five sites. A repeat survey in 1999 at a reduced number of sites (9) recorded *Lampetra* spp. ammocoetes at all sites with total ammocoete densities ranging from 1.16 to 5.23 m^{-2}. Sea lamprey ammocoetes were recorded at four sites.

The EAW 3 year fisheries monitoring programme included two years of semi-quantitative lamprey ammocoete electric fishing surveys over 2004 and 2005 and three years of adult sea lamprey spawning surveys between 2003 and 2005 (EAW 2004 & 2005). *Lampetra* spp. ammocoetes were recorded at all sites surveyed during both survey years. Sea lamprey ammocoetes were recorded at 12 sites in 2004 and 15 sites in 2005. Spawning locations, at 12 sites, were identified from downstream of Llantrisant to upstream of Crickhowell.

The most recent lamprey survey was undertaken in 2005 on behalf of CCW (Harvey *et al*. 2006). The study involved quantitative and semi-quantitative sampling of 35 sites of which five were within optimal and 30 within sub-optimal habitat throughout the catchment. *Lampetra* spp. ammocoetes densities ranged from 39 to 171 m^{-2} within optimal habitat and from 0 to 56 m^{-2} within sub-optimal habitat. Sea lamprey ammocoetes were recorded at five of the sub-optimal sites surveyed and three of the optimal sites with densities ranging from 0 to 29 m^{-2}. No sea lamprey were recorded upstream of Brecon weir suggesting that this structure may be a barrier to migration for anadromous lamprey. Recently (July 2008) sea lamprey have been observed spawning at Trostrey Weir (G.Mawle, *pers.comm.*).

River Wye

Historical anecdotal accounts and data for lamprey populations on the River Wye date back to the 17th Century (Harvey *et al*. 2006). The first dedicated lamprey survey was undertaken in 1996 during a survey of selected English rivers for lamprey (APEM 1996). Semi-quantitative sampling of 20 sites across the catchment recorded *Lampetra* spp. ammocoetes at 12 sites and sea lamprey at 2 sites.

The most recent lamprey survey was in 2005 (Harvey *et al*., 2006), and included the quantitative assessment of 54 sites, of which 6 were within optimal habitat. *Lampetra* spp. ammocoetes densities ranged from 0 to 45 m^{-2} within optimal habitat and from 0.19 to 76 m^{-2} in sub-optimal habitat. Sea lamprey were recorded at 3 optimal and 10 sub-optimal sites with densities ranging from 0.41 to 74 m^{-2}.

Other Severn Estuary rivers

Dedicated lamprey surveys for the purpose of population assessment are largely restricted to the SAC rivers designated for lamprey species. River lamprey are known to spawn within the River Severn downstream of Tewkesbury weir near Gloucestershire (Bird 2008), although survey data detailing populations do not appear to exist. During the increased freshwater flows of the 1988 winter a net fisherman caught several hundred sea lamprey transformers in one night (Bird *et al*. 1994), the largest on record within Severn Estuary tributaries.

Severn Estuary

Data from the Severn Estuary are restricted primarily to entrainment catches. Data from Oldbury Power Station between 1972 to 1977 and 1996 to 1999 have been analysed by Potter *et al*. (2001). Mean annual river lamprey catches during the period 1972 to 1977 represented 0.7% of the total. The annual mean catch between 1996 and 1999 decreased to 0.1% of the total species catch. Although not quantified, sea lamprey catches were observed to be greater during the 70s period than the 90s. This decline is contradictory to the overall abundance of fish within the catches which exhibited a marked increase. This increase has been largely attributed to improvements within the estuary in terms of their spawning, larval survival and recruitment.

Quantitative lamprey data are restricted to a dataset of just one year for the majority of lamprey rivers in the UK. It is therefore not possible at this stage to confidently determine the trend of either river or sea lamprey populations into the future.

Eel

The coastline of the Bristol Channel forms a large funnel in the path of larvae and migrating glass eel and the south-westerly orientation along with the high tidal range likely results in the large numbers of eel that enter the Severn. The Severn represents a major component of the UK eel stock with the glass eel fishery a major source of glass eel recruitment within England (White & Knights 1997a, Knights *et al.* 2001, Walker & Pawson 2006) with initial numbers being dependent on variations in Atlantic currents carrying larvae. Eel are distributed throughout the catchment, although few penetrate the source streams rising from the Cambrian Mountains, and they are reported as absent from the rivers draining the Birmingham urban area (Walker & Pawson 2006).

The eel fisheries (yellow, silver and glass) on the River Severn exist under licence from the EA. Walker & Pawson (2006) report that in 2005 there were 413 licence holders, the majority of which were elver dip nets (402). There is no monitoring of glass eel recruitment that is independent of the fisheries on the River Severn. Figure 2.28 illustrates the glass eel fishing capacity for England and Wales, and the trend in the River Severn is reported as similar to that illustrated here (Walker & Pawson, 2006).

For yellow and silver eel, data for England and Wales indicated that CPUE varied between 100 and 210 kg/instrument during the period 1983 to 1999, then decreased sharply to 25 kg in 2003 after which an increase was observed. The trend in the Severn may reflect these data, although it accounts for only a small fraction of the data analysed and the fisheries are relatively small.

Fishing effort (as measured by the number of licences sold) on the River Severn between 2002 and 2004 is shown in Table 2.6, which also illustrates the variability in catch between years.

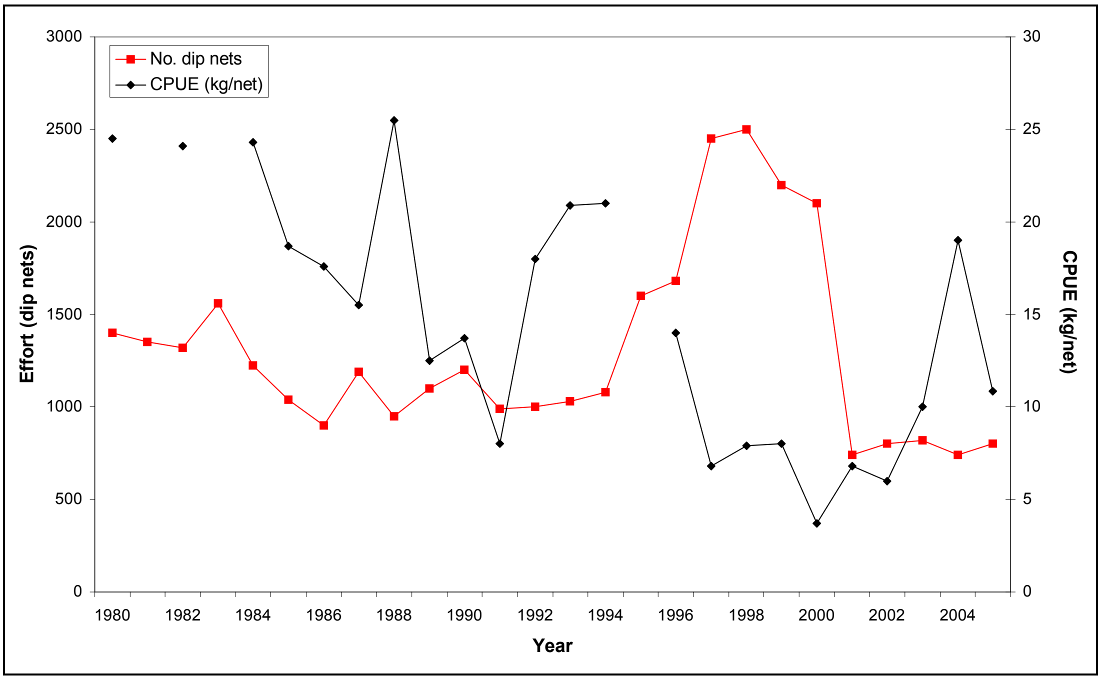

Figure 2.28 Glass eel fishery effort in England and Wales, 1980-2005. CPUE is based on Customs & Excise export estimates. Data taken from Walker & Pawson, 2006.

Table 2.6 Fishing effort for eel for the period 2002 to 2004. Data are from EA records as presented in Walker & Pawson (2006).

	2002		2003		2004	
	Licensed nets/traps	Catch (kg)	Licensed nets/traps	Catch (kg)	Licensed nets/traps	Catch (kg)
Glass eel	569	290	487	877	513	577
Yellow/silver eel	80	156	53	980	47	569

The EA fisheries statistics for 2006 provide data for eel and elver licence sales and catches. The data, available at the scale of the 'south west', are shown below in Table 2.6. While not directly comparable with the data above for the River Severn, the 2006 data results show an average of just 2.5 kg/net for elvers, and 12.8 kg/instrument for yellow eel and 3.9 kg/instrument for silver eel. As the River Severn will be the river with the highest catch returns, it is likely that the addition of other sites is responsible for the low catch statistics.

Table 2.7 EA data on eel and elver licence sales and catches for 2006 in the South West region. * denotes where a specific instrument is not designed to catch a particular life stage.

Instrument	Number	Elver catch (kg)	Yellow eel catch (kg)	Silver eel catch (kg)
Small wingless traps (group 10)	22	*	2	0
Fyke nets	510	*	6786	1108
Gloucester wing net	0	*	0	0
Fixed trap	5	*	75	916
Elver dip net	197	483	*	*
Eel trawl net	0	*	0	0
Total	**734**	**483**	**6863**	**2024**

Walker & Pawson (2006) indicate that declared catches of glass eel in the Severn Estuary have fallen from ca. 60 tonnes in the late 1970s, to less than 1 tonne between 2002 and 2004. While the annual catch varied widely between 1972 and 1983 (ca. 10 to 70 tonnes) as the catch declined so did the variation. These data should be considered in light of the fact that Customs and Excise data indicate substantial under reporting of the catch, which is likely masking trends in population densities

Historically, Walker & Pawson (2006) report that the yellow and silver eel fisheries were small: ca. 20 fishermen catching ca. 5 t/yr in the 1980s, 13 fishermen catching ca. 9 t/yr in the 1970s. Only anecdotal evidence is available pre-1970, with given values of an average nightly catch for the 1930s of ca. 500 kg compared with 75 kg in 1976.

Data on eel production in the River Severn are also available from surveys carried out at 93 sites by Aprahamian (1986) during 1983 and 1984. Age structure, growth, density, biomass and production were described. These surveys found that upstream of Worcester, in the Teme and Avon catchments, there were a higher proportion of older fish which partly reflected the greater proportion of females in the population in these regions. Males were found to predominate in the population downstream of Worcester. The greatest densities and biomass of eel were found in the lower reaches of various small rivers and brooks flowing directly into the River Severn downstream of Worcester.

An extensive programme of recent surveys funded by DEFRA included the River Severn as previous survey data were available. Thirteen lower Severn sites were fished for yellow eel in 2002, 2003 and 2004, with nine common to all surveys between 1993 and 2004

(Bark *et al*. 2007). No indication of a trend in population density, biomass or structure was apparent, although considerable interannual variability (as much as 25% difference between years) existed. Bark *et al*. (2007) interpreted this as evidence that despite the 70% reduction in glass eel recruitment, recruitment is still sufficient to supply the carrying capacity of the lower reaches of the river and lowland tributaries feeding the upper estuary/tidal section of the River Severn. These authors noted the male-domination within these lower reaches and lowland tributaries of the River Severn, providing further evidence in support of high recruitment. The upper freshwater reaches of the River Severn, reported as being female-dominated, were not studied therefore recruitment to these areas is less well known.

Regarding future trends, European-wide data from ICES shows a drastic decline in eel recruitment since the end of the 1970s, with glass eel recruitment dropping to just 1 – 5% of historic levels (pre-1980). Current ICES scientific advice is that the stock is outside safe biological limits and that existing fisheries are not sustainable (ICES 2007). The European Community has proposed a recovery plan be developed for the whole stock of European eel and that exploitation and other human activities affecting the stock be reduced as much as possible. As such procedures for the development of Eel Management Plans were entered into force by the European Council in September 2007; with implementation measures to begin in 2009 (EC Council Regulation No. 1100/2007/ Establishing measures for the recovery of the stock of European eel). Eel Management Plans should aim to provide an escapement of silver eel biomass that is at least equal to 40% of the potential escapement to be expected in the absence of anthropogenic influences. Further protection will come from CITES; as from March 2009 the European eel will be on the Appendix II list that deals with "species not necessarily threatened with extinction, but in which trade must be controlled in order to avoid utilization incompatible with their survival".

As data from commercial catches of glass eel in the River Severn appeared to show only a 70% decline (Bark *et al*., 2007) over the same time period that ICES studied, these authors suggested that the European-wide decline may have been overestimated, although they did note large declines in recruitment in other UK rivers. Implementation of the Eel Management Plans and CITES listing together with improvements in water quality have the potential to promote a return of European eel stocks. The draft Eel Management Plan for the Severn River Basin District concludes that downstream of

Worcester the eel population is at carrying capacity; while the middle reaches of the Severn and Avon catchments were likely below carrying capacity.

The apparent disparity in eel recruitment between the lower estuarine tributaries and the inner catchment should be noted. High recruitment in the tributaries (high population, male-dominated) alongside reports that the inner catchment is sparsely inhabited by a female-dominated population suggests that barriers to migration are the key factors responsible for the reduced number of eel in the inner catchment. Improving access is under consideration in the current draft of the Severn River Basin District Eel Management Plan as part of the aim to meet the EU escapement target of at least 40% of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had impacted the stock. This obviously has major implications when considering the potential development of another barrier on the River Severn. Because the River Severn has remained an area of high glass eel recruitment, capable of supporting a fishery, it will be key in the European-wide implementation of EC Council Regulation No. 1100/2007. The regulation will require the fishery to make available 60% of its catch for use as restocking material across Europe. Therefore, maintenance of high recruitment on the River Severn will be a pivotal feature of the European wide recovery plan. Accordingly the effect of a tidal barrier will need to be carefully assessed with regard to upstream (passive and active) and downstream migration, and the area of suitable habitat available for elver maturation after any hydrological changes.

Sturgeon

There are no formal records of common sturgeon populations within the Severn Estuary itself or the UK as a whole. Sturgeon although listed on the UK BAP as a priority species is classed within it as a 'priority species not recorded in the last 10 years'. The British Marine Life Study Society has collated a number of records. The most recent account was made by the EA of a fish caught between Newport and the Severn Bridge in the late 1980s. Numerous other records exist for the Rivers Severn and Wye dating back to 1718. There are no data on sturgeon spawning in the Severn Estuary rivers. Individuals have, however, been observed as far upstream as Shrewsbury on the River Severn.

Estuarine and marine species

Numerous studies have been conducted of the fish community of the Severn Estuary and the Bristol Channel (e.g. Parker-Humphreys 2004). Long-term sampling programmes of fish species entrained by power station intakes in the estuary and inner channel exist. Further studies assessing the aquatic ecology of the area were commissioned by the DOE in the 1980s to determine the feasibility of constructing a tidal barrage in the Severn Estuary and Bristol Channel. Monitoring of water quality and aquatic ecology in the area has also been undertaken as part of the National Marine Monitoring Programme (NMMP) which was initiated in the late 1980s and has now become the Clean Seas Environmental Monitoring Programme (CSEMP). In response to the Water Framework Directive a programme of Transitional Water fish surveys by the Environment Agency also commenced in 2007. As a result information is available regarding species richness, community composition and population dynamics (e.g. Claridge *et al*. 1986, Potter *et al*. 1986, Potter *et al*. 2001, Henderson *et al*. 2007). Further studies examining life history traits and migratory movements of specific fish species, including those of commercial interest (Holden & Williams 1974, Ajayi 1982, Claridge & Potter 1983, Henderson & Holmes 1990, Ellis & Shakley 1997, Henderson & Seaby 2005) have also been used as data sources.

Bristol Channel

A comprehensive source of information for species richness in the inner Bristol Channel comes from the entrainment data-set at Hinkley Point B Power Station in Bridgwater Bay (Figure 2.29) where monthly records began in 1981. Between April 2006 and March 2007, 29 fish species were caught (Henderson *et al*. 2007), and the number of species caught each year has ranged from 33 in 1982 to 46 in 1998 (Henderson 2007). The ten most abundant species recorded to date at this location are:

- Sand goby
- Sprat
- Whiting
- Poor cod
- Dover sole
- Pout
- Common sea snail
- Bass
- Flounder

- Dab

A beam trawl study of demersal fish and invertebrates within the Bristol Channel (Ellis *et al*. 2000) found that an assemblage of dab, plaice, sole and common starfish dominated sites within Camarthen Bay on the north bank of the Bristol Channel. A distinct transition occurred to an assemblage dominated by sole, pout and spider crab within southern sections of the outer estuary near Ilfracombe (Ellis *et al*. 2000).

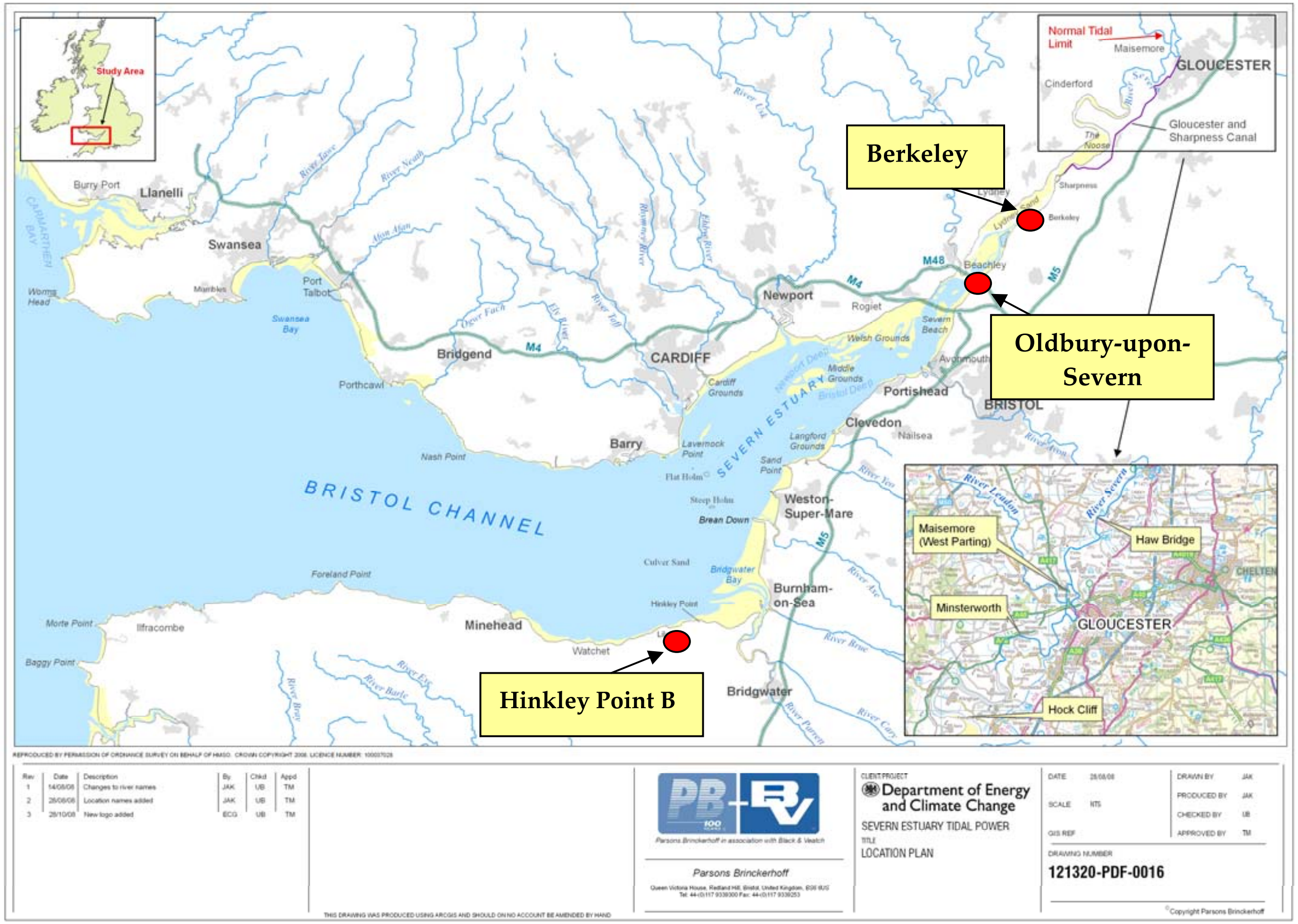

Figure 2.29 Positions of Hinkley Point B in the Bristol Channel, and Oldbury-upon-Severn, Uskmouth and Berkeley power stations in the Severn Estuary at which sampling of fish at intakes has been conducted.

Severn Estuary

The Hinkley Point B entrainment records are complemented by similar records for the Oldbury-upon-Severn Power Station within the inner Severn Estuary, and occasional records from intake screens at Berkeley Power Station (~7 km upstream of Oldbury-upon-Severn) and Uskmouth Power Station at the mouth of the River Usk on the north bank of the outer Severn Estuary (e.g. Claridge *et al*. 1986), (Figure 2.29). The fish assemblage recorded at these power station intakes between 1972 and 1977 (a total of 78 species), was very similar to that of the inner Bristol Channel (Potter *et al*. 1986), (Table 2.1), (see Section 2.1, Existing Baseline, Marine & Estuarine Fish for further details).

The ten most abundant species at Oldbury-upon-Severn, between 1972 and 1977, in order of decreasing abundance were:

- Sand goby
- Whiting
- Flounder
- Bass
- Sea snail
- Poor cod
- Thin-lipped grey mullet
- Twaite shad
- Eel
- Herring

As in many other estuaries, the fish assemblage within the inner Severn Estuary is dominated by a relatively small number of species with high abundances. The majority are marine migrants (8 of the 10 species), and two are diadromous (twaite shad and eel), (see 'Migratory Fish' section).

There was considerable interannual variation in the abundance of each species, however, flounder, whiting, sea snail (all marine migrants) and eel (catadromous) were always one of the ten most abundant species. Additionally, each year, the sand goby complex (consisting of *P. minutus* and *P. lozanoi* which cannot be readily differentiated in the field) and whiting comprised most of the fish sampled, each contributing just under 30% of the total catch (Claridge *et al*. 1986). As the periods of sampling conducted at Hinkley Point B and Oldbury-upon-Severn Power Stations differed a direct comparison between sites is not possible. However, a study conducted in 1989 suggested that the overall species diversity of fish assemblages within these waterbodies had remained stable over the previous 50 years (DOE 1989).

Of the species within the estuary protected under the UK BAP (see 'Baseline Receptor' section), the marine stragglers (blue whiting, hake, horse mackerel, ling and saithe) were only caught in low numbers in the Bristol Channel and the Severn Estuary (Potter *et al*. 1986, Henderson 2007). The remaining five BAP species, (cod, herring, plaice, sole and whiting), were marine migrants and these were caught relatively frequently (Potter *et al*. 1986, Henderson 2007). The latest report summarising 2006/07 catches between April at Hinkley Point B describes temporal patterns for these five marine migrant BAP species since 1981, (Henderson *et al*. 2007), on which the summaries below are based.

- Cod: Numbers have generally increased since 1986. Peak abundances were recorded between 1990 and 2000.

- Herring: The 2006/2007 season included the greatest single catch. Data suggest that abundance is increasing.

- Plaice: Plaice is the least common of the flatfish sampled at this location. Only a few individuals usually present in a 6 hr sampling period.

- Sole: This species consistently has a high abundance within the Bristol Channel.

- Whiting: Abundance peaked in the late 1990s and continues to be one of the most abundant species recorded at Hinkley Point B.

Future Trends

In common with many UK estuaries, water quality improvements through the implementation of regulations to reduce the discharge of contaminants into the Severn Estuary have had beneficial effects on the fish community. Although the major species have changed little over the past few decades, the abundance of many species (including bass, Dover sole, herring, Norway pout, sprat, sand goby, thin-lipped grey grey mullet and whiting) increased considerably between the 1970s and late 1990s. Over the same period flounder, poor cod and sea snail declined in abundance (Potter *et al*. 2001). It is unclear whether abundances of numerous species are likely to continue to increase. This does not appear to be the case for the Bristol Channel as interannual differences in abundances for key species appear to have remained relatively consistent since the late 1990s (Henderson 2007).

The fish population within the Severn Estuary is dominated by 0+ individuals. A high recorded abundance of 0+ individuals could partly be due to the main method of sampling (power station intakes preferentially sample juvenile fish), however, the relatively low level of commercial fishing activity within the inner Bristol Channel and Severn Estuary provides further evidence that juveniles are far more abundant than adult fish. This could be partially due to the predominance of small invertebrates (mainly meiofauna, and smaller than average macrofaunal specimens) as a food source. While ideal for juveniles, these may not be sufficient for macrobenthivorous adult fish.

The community composition of key fish species has not changed considerably over recent decades (Henderson *et al*. 2007). However, two main discrete changes have been observed in the fish community as a whole including an increase in species abundances in the late 1980s, and an increased frequency of southern warm water species since the early 1990s which is thought to be due to environmental change (Henderson 2007). The trophic structure of the estuary alters seasonally in relation to the species composition of the fish fauna. Due to the turbidity of the water and instability of the substrate there is little opportunity for planktonic or benthic primary production, and the food web is based on dissolved organic carbon transported downstream by rivers flowing into the estuary and heterotrophic microbial activity. Mysids are relatively abundant providing food resources for species feeding on mobile epifauna. The key prey item is the common shrimp which is the only crustacean abundant throughout the entire year (Henderson *et al.* 1992). This provides a year-round food source for juvenile fish within the estuary and is particularly important for 0+ whiting (Henderson & Holmes 1989). Geomorphological processes are expected to determine benthic invertebrate communities to a large extent, and the grazing activity of common shrimp on muddy substrates could also potentially prevent other invertebrates establishing communities.

Overall, the fish fauna and community structure of the Severn Estuary is considered to be typical of British and North Eastern European macro-tidal estuaries (e.g. Andrews *et al*. 1982). However, it does not have a smelt population which is usually found within similar estuaries in the UK. Fish assemblages within major UK estuaries are of significance when considering the resilience of fish fauna to perturbation, as levels of perturbation within many UK estuaries have been historically high. The fact that many estuaries have experienced major perturbation at some point but have returned to a similar community structure with the same dominant species, indicates that the current organisation appears to be a naturally occurring stable state (Henderson *et al*. 1992).

2.1.3 Sensitivity of receptors to change

For the purposes of scoping, the identification of potentially significant issues to be taken forward into phase 2 of the SEA have been identified using an initial assessment of the sensitivity of each receptor and the magnitude of change to which it is exposed. The methodology for identification of potentially significant issues is set out in Annex 1. Sensitive receptors are identified below.

In some cases, relevant receptors and their sensitivity can be identified at this scoping stage. For other receptors, at this stage there is far greater uncertainty as to receptor sensitivity, and their exposure to effects from tidal power options. In these cases it has not been possible to reach consensus on receptor sensitivity at this scoping phase. It will therefore be necessary to review receptor sensitivity once short-listed options are identified, and in the light of feedback during SEA Scoping consultation.

Sensitivities of receptors were determined based on a combination of the importance of the receptor (i.e. whether it is of international, national or local conservation importance), and the vulnerability of the receptor to environmental change (i.e. is it in declining, stable or favourable condition and dependant on a narrow, medium or wide range of environmental conditions), (see Annex 1: Table 1).

Diadromous species

Depth of knowledge of the estuarine behaviour of diadromous species is highly variable. Aspects of migratory behaviour relevant to the assessment of effects of a tidal barrage include the seasonal and diurnal timing of: routes taken through the estuary, position in the water column, evidence of natal homing and straying, passive and active transport methods and swimming ability. Information regarding each of these behavioural aspects is briefly described below for the migratory species. Table 2.8 summarises the assessment process for the sensitivity classification of each of the diadromous fish species.

Most fish use a number of environmental cues to initiate migration, with tidal regime, freshwater discharge and water temperature known to be key. All of the migratory species will therefore be sensitive to changes in any of these environmental conditions to varying degrees, with consequences for access to spawning and nursery areas, recruitment success, survival and dispersal. Additionally, each species will also have seasonally varying physiological sensitivities to changes in water quality in the estuary. Relevant information on these aspects is also briefly detailed below for the migratory species.

Table 2.8 Assessment process for sensitivity classification of each of the diadromous fish species

Fish species	Life stage (moving u/s or d/s)	Level of protection	Population Status	Impacts					Sensitivity
				Alterations to migratory cues	Disruption to route of passage	Habitat change	Water Quality	Angling	
Atlantic salmon	Smolts (d/s) Spawning adults (u/s) Kelt (d/s)	International	Unfavourable	✓	✓		✓	✓	**H** Based on international importance and high vulnerability
Sea trout	Smolts (d/s) Spawning adult s (u/s) Kelt (d/s)	National	Stable/increasing	✓	✓		✓	✓	**M** Based on national importance and medium vulnerability
Shad	Juveniles (d/s) Spawning adults (u/s) Spent adults (d/s)	International	Unfavourable	✓	✓	✓ (juveniles)	✓	✓?	**H** Based on international importance and high vulnerability
Lamprey	Transformers (d/s) Adults (u/s)	International	River lamprey unfavourable in Wye SAC and sea lamprey unfavourable in Usk SAC	✓	✓	✓	✓		**H** Based on international importance and high/medium vulnerability
Eel	Glass eel /elvers (u/s) Yellow eel (resident) Silver eel (d/s)	International	Currently outside safe biological limits	✓	✓	✓	✓	✓	**H** Based on international importance and high vulnerability
Sturgeon	Juveniles (d/s, resident) Adults (resident, u/s and d/s)	National	No population is known currently	✓	✓	✓	✓		**H** Based on national importance and high vulnerability

Atlantic salmon and sea trout

The sensitivity of salmon to environmental change is considered to be **High**. This classification has been based partly upon its international importance as an Annex II feature of the River Wye and Usk SAC's. Further, the populations in the River Usk and Wye were classified as being in unfavourable condition during the 2007 condition assessment. In addition to the sensitivity of salmon it may also be necessary to consider freshwater pearl mussel populations within tributaries of the Severn Estuary such as the River Wye which depend upon salmon to complete their life cycle.

The sensitivity of sea trout to environmental change is considered to be **Medium**. Although not an internationally protected feature they are listed under the UK BAP as a priority species. As coastal and estuarine movements of sea trout are believed to be even more extensive than salmon, stocks and fisheries may be vulnerable.

Adult salmon migrate into UK estuaries and rivers on their spawning migration throughout the year generally peaking between July and October. The Rivers Severn, Wye and Usk are renowned for their current (or historical) spring run of large salmon, occurring January to May. Most salmon die after spawning, but a small proportion (5-10%) return to sea between December and April, at which stage they are known as kelts. Upon entering coastal waters cues for navigation become more dependent on tidal flow, possibly involving some form of selective tidal stream transport. At some undetermined stage in the coastal phase, and by mechanisms that are not fully understood, salmon home to the chemical signature of their natal river presumably borne by freshwater flows (Hasler 1966, Arnold 1974).

Homing behaviour in salmon is not exact, and straying is a normal property, enabling them to colonise new rivers and to maintain a low level of gene flow between populations (Thorpe 1994, Quinn 1993). Straying extent, normally very low, is variable and depends upon the source of the strays, proximity and similarity of donor and receiving rivers, and the population level of indigenous salmon in the colonised river. Significant mixing of natal river water occurs in the Severn Estuary; this and the funnel form of the estuary may be responsible for the comparatively high degree of population exchange and mixing, at least in the estuarine approaches to these rivers (Swain 1982, Aprahamian *et al*. 1998b, Solomon 1988).

The single most important factor influencing salmon movement into estuaries from the sea is river flow. All studies have shown that, at any season, higher than average freshwater flows induce more salmon into an estuary (e.g. Hayes 1953, Huntsman 1948, Jackson & Howie 1967, Banks 1969, Stasko 1975, Clarke *et al*. 1991, Smith *et al*, 1994, Purvis *et al*. 1995, Solomon *et al*. 1999). Low flows often lead to their departure and extended absences of many weeks (Potter 1988, Clarke *et al*. 1991, Smith *et al*. 1995, Solomon *et al*. 1999) which, under extreme conditions, can lead to mortality (Clarke *et al*. 1991, Solomon & Sambrook 2004).

A range of salmon behaviour has been described across the various estuaries studied, but there are some common features. In a review of tracking studies (Milner 1990) a generic model emerged of salmon behaviour changing on passage from sea to river. Tidally directed movements were strongest in the lower to middle reaches of estuaries, with fish moving upstream on the flood tide and back on the ebb tide, or delayed while moving up or downstream, if suitable areas were present. In the higher reaches of estuaries there was a general tendency for tidally directed movements to be replaced by positive upstream swimming in response to river flow through orientation and positive rheotaxis (Arnold 1974).

The degree of ebb tide upstream movement is a critical issue, not well-described. While cessation of upstream movement has been observed in the lower Usk estuary (Aprahamian *et al*. 1998b), this may reflect the local conditions and is not a universal pattern. This variability may depend on factors such as position in the estuary, water velocity, freshwater influence, size and maturation state.

Tracking studies show that adult salmon migrate mainly in the upper 6 m of the estuary occasionally diving to depths of up to 28 m, probably orientating by vertical salinity gradients (Smith *et al*. 1995, Westerberg 1982). Their lateral position in estuaries is rarely reported but it seems that salmon (Brawn 1982, Preide *et al*. 1988) and sea trout (Milner 1992) use most of the channel width, taking advantage of faster flows in the direction of their travel because it is more energetically efficient (Harden Jones 1968, Arnold 1974). Frequency of river entry is greatest at night, with this effect being strongest at low river flow and almost absent at high river flows (e.g. Smith & Smith 1997, Solomon *et al*. 1999).

The few studies of migratory behaviour of kelts in freshwater or estuarine environments suggest that residency is brief, only one to two tidal cycles. Movement appears controlled predominantly by freshwater flow and occurs primarily at night (Purvis *et al*. 1995, Bendall *et al*. 2005). Wild smolt migration through the Conwy Estuary, North Wales, has been shown to be predominantly by nocturnal, selective ebb tidal transport, with some variation in different parts of the estuary (Moore *et al*. 1995). In the Usk estuary tidal variation in power station catches were used to infer that smolts migrated seaward on the ebb tide and at night (Aprahamian & Jones 1997).

Swimming speeds influence fishes' ability to pass barriers and negotiate currents, so are relevant to tidal range structures. Absolute swimming speed is size dependent. Wild 12 cm smolts have been found to maintain sustained speeds of 85 cms^{-1} equating to 7.1 bls^{-1} (Peake & McKinley 1998). A sustained swimming speed of 75 cms^{-1} is a recommended indicative critical speed for engineering design purposes (Clough *et al.* 2004). Burst speeds are higher, and for wild adult Atlantic salmon (fork length 51.2 ± 2.3 cm) swimming speeds of up to 4.13 ms^{-1} or 8.35 bls^{-1} were observed in flume studies (Colavecchia *et al*. 1998). Above a threshold of 1.92 ms^{-1} however, a shorter distance was traversed and no individuals were able to ascend the flume.

Sea trout biology is broadly similar to salmon (Crisp 1999, Harris & Milner 2006). Adult sea trout arrivals are more clumped into the summer months than salmon. Sea trout have higher rates of straying amongst adjacent rivers and possibly a lower dependency on flows for river entry. Sea trout often spend extended periods in estuaries, in some cases never going to sea, thus multiple spawning is common and they show correspondingly higher post spawning survival rates. As a result, during their life cycle sea trout will make more use of estuaries than salmon. The sea trout stocks of the Rivers Severn and Wye particularly, and the Usk to lesser extent, are notoriously small for their river's size. The reasons for this are unclear but might be due to the energy budget/survival tradeoffs of migration influenced by the location of nursery areas in these rivers, coupled with feeding opportunities and survival risks in the inner estuary.

Migrating migratory salmonids undergo major physiological change on passing between salt and freshwater, due to salinity effects on gills, which effectively reverses osmotic direction (Hoar 1953). As a result they are sensitive to additional environmental physicochemical stressors. Of these, water temperature, dissolved oxygen concentrations and heavy metal toxicity are thought particularly important and their effects are interrelated.

Migratory salmonids are more sensitive to higher temperatures than non-migratory salmonid fish. The preferred temperature for Atlantic salmon lies between 9 and 17°C (Alabaster & Lloyd 1980). Where salmon inhabit waters in which sustained natural summer temperatures are 20-21°C, any increase in temperature could be detrimental (Alabaster & Lloyd 1980).

Salmon are sensitive to low levels of DO, but can acclimatize within a few hours. Acclimation to increased salinity increases resistance to low DO, with the median threshold concentration for survival in freshwater being about 3.3 mg/l compared with 2.6 mg/l in 30-80% seawater (Alabaster & Lloyd 1980). For adult migrant migratory salmonids passing through an estuary during the summer months, the DO concentrations at the 50th and 5th percentile should be 5 and 2 mg/l respectively. However, other factors such as temperature, length of deoxygenated zone, will also play a role in determining whether low DO concentrations form a barrier to migration or not. For young fish higher percentiles for DO may be necessary.

Cadmium, zinc and copper are common industrial pollutants, with a history of high contamination in the Severn Estuary. They are toxic to fish in soluble form, and their toxicity is influenced by temperature, salinity, hardness, DO and pH (Alabaster & Lloyd 1980). However, intake is primarily controlled by food concentrations (Pentreath 1994) with the metal burden accumulating in the gills, liver and kidney where, at high concentrations, damage may result.

Summary

Salmon are considered to have a **High** sensitivity, while the sensitivity of sea trout is considered to be **Medium**. Adult salmon migrate into the Severn Estuary in spring, mainly within the upper 6 m of the water column, with river flow being the most important factor influencing their entry to the estuary. Sea trout on the other hand may never leave the estuary. Migratory salmonids are very sensitive to high temperatures, and low DO concentrations.

Shad

The sensitivity of allis and twaite shad to environmental change is considered to be **High**. This classification has been based partly upon their international importance as Annex II features of the River Wye and Usk SAC's and the Severn Estuary cSAC. All SAC's in the recent condition assessment round were classed as unfavourable for both allis and twaite shad populations.

The adult freshwater spawning migration of twaite shad commences in April and May and continues for a period of 2 to 3 months with fish entering the rivers in waves between 05:00 and 20:00 hours (Aprahamian *et al*. 2003a). In freshwater, shad migrate close to the river bed (Clabburn 2002 cited by Aprahamian *et al.*, 2003b), but putcher rank catches suggest that they move in the upper water column in the estuary (Miran Aprahamian *pers. comm*). The twaite shad population contains repeat spawners, the downstream migration of spent adults on the River Wye occurs in June and July. Peaks in movement occurred around dawn to dusk and were reduced between 21:00 and 03:00 (Gregory & Clabburn 2003). They remain within the estuary until autumn (Miran Aprahamian *pers. comm.*).

The seaward migration of juvenile shad starts in the autumn with most having left by the end of October. The juveniles move throughout the water column with a preference for the surface layers (Castlenaud *et al*. 2001 cited by Aprahamian *et al*. 2003b). Catches from the intake screens of Oldbury-upon-Severn, Berkeley and Hinkley Point Power Stations suggest that some juvenile individuals over winter in the river and begin their seaward migration the following spring and early summer upon a rise in water temperature (Claridge & Gardner 1978). This sampling was however undertaken at only one point and as such Aprahamian (1988) suggests that the converse may also be true, with 1 year old shad making an onshore migration from the estuary during the spring period.

Shad populations are genetically structured, with a pattern of population isolation by distance (Alexandrino *et al*. 2006). The British population represents a distinct group in comparison to other Atlantic twaite shad populations (Alexandrino *et al*. 2006). Three distinct British population groups were defined; Tywi, Usk and the Severn group for the Wye, Teme and Severn rivers (Alexandrino *et al*. 2006). It was recommended that these three population groups be taken forward as distinct conservation management units. Straying shad from other European countries such as France however, may be seen within UK waters including the Severn Estuary. Despite no allis shad individuals being represented within the assessment of the genetic structure of UK shad populations, allis shad haplotypes were found in samples from each of the twaite shad populations (Alexandrino *et al*. 2006). This suggests past or present hybridisation or introgression between the two species. The extent of introgression was greater within those populations located further seaward (Rivers Tywi and Usk) than those further upstream the estuary (Rivers Wye and Teme). This may be as a result of populations of allis shad existing, and/or having existed, within these rivers in greater numbers and/or greater straying of continental allis shad into those rivers encountered first.

Shad are particularly sensitive to physical damage and scale loss. During seaward migration juveniles exhibit a heightened sensitivity to acute handling and confinement stress (Shrimpton *et al*. 2001 cited in Zydlewski *et al*. 2003) following a gradual loss of ability to regulate ions in freshwater (Zydlewski *et al*. 2003). A reduced swimming performance has also been observed during this phase of seaward migration (Zydlewski *et al*. 2003). Burst speeds of adults were determined to be approximately 20 cms^{-1} and sustained speeds had a median of 58 cms^{-1} and a 90^{th} percentile of 46 cms^{-1} (Clough *et al*. 2004).

There is very little information regarding the sensitivity of shad to decreases in water quality and exposure to contaminants (Bird 2002). For adult shad

Alosa fallax, Maes *et al.* (2007) inferred from their study that the level of dissolved oxygen required to ensure passage upstream through the estuary needed to be greater than 5 mg/l. In the River Elbe, juveniles (0+) were found to avoid areas of low dissolved oxygen (<4 mg/l) with the greatest catches in areas with DO levels between 4 and 5 mg/l (Möller & Scholz 1991). As there is limited data specific for the shad species it is therefore necessary to infer responses and effects from some of the other more studied migratory teleosts such as salmon as described above. The sensitivity of shad to environmental change will be further assessed within the development of life cycle models within phase 2 of the SEA. Apsects of increasing instantaneous mortality on the shad population will be taken into consideration during this assessment including work undertaken by Aprahamian (1988b)

Summary

Both allis and twaite shad are considered to have **High** sensitivity. Spawning adults migrate upstream from April to June; fish utilise the bottom waters in rivers, while the estuarine movements are less well known. Spent adults return downstream from June to July. Juvenile seaward migration is autumnal, with fish utilising the upper water column within the river, although estuarine movement is less well known. Three genetically distinct shad populations inhabit the waters potentially affected by any barrage development. Shad are sensitive to physical damage, but little is known of their sensitivity to water quality.

Lamprey

The sensitivity of river and sea lamprey to environmental change is considered to be **High**. This classification has been based partly upon their international importance as Annex II features of the River Wye and Usk SAC and the Severn Estuary cSAC. Sea lamprey populations within the River Usk, and river lamprey populations in the River Wye have also been classified as in unfavourable condition within the 2007 condition assessment round.

Adult sea lamprey migrate into estuaries and freshwater during the spring and usually spawn within the riverine environment between the months of May and June. Upon hatching lamprey larvae (ammocoetes) reside burrowed within riverine sediment for up to six years before beginning their seaward migration as macropthalmia or transformers. Sea lamprey reside at sea for a period of approximately two years before returning to estuarine and freshwaters during their spawning migration.

River lamprey adults spend the majority of their one to two year adult life stage within coastal and estuarine waters and may never leave their natal estuary. They begin their freshwater spawning migration between October and March prior to spawning in March and April. River lamprey ammocoetes reside within the freshwater environment for approximately four and a quarter years before transforming and beginning their seaward migration.

Both species have been observed to migrate predominantly during the hours of darkness, peaking approximately two hours after nightfall and ceasing by about 02:00 (Hardisty & Potter 1971). During daylight hours light is avoided by seeking out resting places under rocks and amongst tree roots.

Upon transformation at the end of the ammocoete life stage the macropthalmia drift downstream with numbers typically peaking between September and October and again between April and May. Evidence suggests that this migration takes place predominantly during the hours of darkness 19:00 to 07:00. There are conflicting accounts of their position within the water column. The majority of accounts however, concur that migration is concentrated to the mid channel, following the greatest flow as seen with other seaward migrating juveniles (Empson & Meredith 1987).

Both species cease feeding upon beginning their upstream spawning migration which is coupled with many body systems operating at a reduced capacity or shutting down completely. River and sea lamprey spawn once and then die and as such do not make a downstream migration as spent adults.

Although it is known that lamprey adults migrate into rivers using a migratory pheromone, there is evidence to suggest that this is not river-specific homing (Rodriguez-Munoz *et al.* 2004). Recent research on sea lamprey adults has shown that migrating adults respond to a pheromone released by ammocoetes. This allows migrating adults to assess that a river is suitable for spawning by the presence of existing larval populations.

Homing in river lamprey populations has also been assessed (Gaudron & Lucas 2006). Preliminary findings indicated that river lamprey adults are also attracted to larval pheromones during the early migratory phases. It is therefore suggested that anadromous lamprey adults exhibit weak homing behaviour at best. In addition to homing behaviour and larval pheromone attraction, environmental cues such as reduced river discharge, water quality and pollution events are also likely to have a bearing upon determination of spawning river selection.

There is little information available as to the movement of adult or transformer lamprey through estuaries although it is known that the adult spawning migration is triggered by increases in freshwater discharge coinciding with periods of high tide. In light of the relatively poor swimming ability of adult lamprey it is likely that selective tidal stream transport is used as a method of traversing the estuarine environment during hours of darkness. During ebb tides and daylight periods it is likely that resting areas are sought deeper within the water column (Potter & Huggins 1973).

River lamprey entrainment data from Oldbury Power Station during the period 1972 to 1977 indicated that migration from the estuary into freshwater began earlier during high freshwater discharge years and later during low flow autumns and winters. Migration was found to consist of two peaks of differing size class. The migration of the larger typical form peaked in November where as the smaller 'praecox' form peaked in February. Migration began when temperatures had fallen to below between 12 and 16°C (Abou-Seedo & Potter 1979). Lamprey transformers and upstream migrating river lamprey adults ('praecox' form) were caught by trawl between Gloucester and Tewkesbury during the spring of 1970, 1971 and 1972 (Potter & Huggins 1973). All individuals were caught during night trawls, with no lamprey in daytime trawls.

All species and life stage of lamprey adopt the anguilliform (lateral undulatory) mode of swimming, an inefficient mode resulting in lamprey being poor swimmers (Dauble *et al*. 2006). Dauble *et al*. (2006) reported the burst speeds of juvenile Pacific lamprey (*Lampetra tridentata*) as ranging from 56 to 94 cms^{-1} with a mean of 71 ± 5 SD cms^{-1} or an average of 5.2 s^{-1} bl. Sustained (aerobic) swimming speeds over a 5 minute test interval ranged from 0 to 46 cms^{-1} with a median of 23 cms^{-1}. Swimming ability studies on post transformed American sea lamprey exposed to velocities of 30 to 60 cms^{-1} at temperatures of between 5 and 15°C determined endurance times of between 10 and 1,625 seconds with larger individuals exhibiting the higher times (Beamish 1978). A review of spawning migrating, non-feeding American sea lamprey adults concluded that burst swimming speeds of up to 3.9 ms^{-1} could be attained for a few seconds (Hunn & Youngs 1980). The comparability of these data to the European sea lamprey form however is questionable due to the smaller size seen in adults of the American form. A number of authors have described a burst and rest behaviour of adult lamprey in attempting to pass an obstruction (Lucas *et al*. 2006). During the rest period they appear to attach to the structure using their oral disc exhibiting little sign of physical movement, concluded as a period of physiological recovery. The time spent during this resting recovery period has been shown to increase with cumulative burst movements (Quintella *et al*. 2004, 2005).

A paucity of knowledge regarding lamprey behaviour and populations remains in the UK and extends to the level and response to environmental change. The morphological changes exhibited during the spawning migration phase in particular will alter the sensitivity of lamprey to environmental change. Knowledge gathered during recent years, suggests that migratory adult lamprey are probably highly sensitive to toxins and low DO due to a number of morphological factors including; on the whole less sophisticated body systems than teleosts, reduced body system capacity and shutting down during the spawning phase, absorption of lipids releasing toxins into the bloodstream, increased oxygen demand from muscle respiration and a limited ability to produce enzymes in response to organic contamination (Bird 2002).

Problems associated with poor water quality and in particular low oxygen sags within estuaries and the lower river have been coupled with perceived declines in lamprey populations within rivers throughout the UK. In light of potential summer water quality sags, migrating adult sea lamprey are the most likely to be affected during their migratory period of between March and June (Bird 2002).

Summary

Lamprey are considered to have **High** sensitivity. Adult sea lamprey migrate into estuaries and freshwaters in the spring, while adult river lamprey may never leave their natal estuary, and migrate upstream between October and March. Migration of all species within the river is predominantly nocturnal. Data on water column location is conflicting for rivers, and virtually unknown for estuaries. Migrating adults are believed to be sensitive to toxins and low DO.

Eel

The sensitivity of eel to environmental change is considered to be **High**. Although not a feature of any Natura 2000 sites, eel are considered to be under threat and have seen a significant decline in stocks. ICES state that the European eel stock is outside safe biological limits. In 2007 the European Community entered into force a Europe-wide recovery plan (EC Council Regulation No. 1100/2007/) with implementation measures to begin in 2009. Each Member State is required to establish national Eel Management Plans which will aim to achieve an escapement of silver eel to the spawning population that equals or exceeds a target set at 40% of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences (e.g. fishing, water quality or barrier to migration) had impacted the stock. In 2009 eel will also be added to CITES Appendix II list which details species in which trade must be controlled.

Eel pass through four developmental stages during their life cycle. European eel (*Anguilla anguilla*) are believed to breed in the Sargasso Sea, oceanic currents transport the larvae (planktonic leptocephali) to the continental shelf, where they metamorphose into glass eel (White & Knights 1997ab). Glass eel become pigmented elvers when they enter estuaries after which some actively migrate inland to complete the growing stage (yellow eel) whilst others remain in salt or brackish water along the coast. Females remain in fresh water for a longer period than males (Aprahamian 1988a) and tend to grow and mature in upper reaches of watersheds whereas males tend to remain in the downstream reaches (Tesch 1977, Boubèe & Williams 2006). Transformation into silver eel occurs prior to the downstream migration back to spawning grounds at sea. Males mature earlier (< 45 cm length at > 4-6+ years) while the females mature later at between 6-15+ years (Knights *et al*. 2001). On the Severn, Aprahamian (1986 & 1988a) found that males matured between the ages of 4 and 20 years with a mean age of 11.9 years and that it was feasible for eels to reach the required size of between 29-44 cm length within four or five years. It was not until around age seven however that a relatively large proportion of River Severn male eel began to mature. The pattern found for females in the catchment was that at or after 13 years a considerable proportion of the female population matured and emigrated (Aprahamian 1988a). The mean age and size at emigration for females in the Severn was found to be 17.8 years and 65 cm (range 35-84 cm) (Aprahamian 1986 &1988a).

Glass eel are reported as being predominantly benthic in coastal/estuarine habitats, and negatively phototaxic. During the day they remain in deeper waters with low light intensity (Tesch 1977). Timing of upstream migration is probably determined by water temperature, with initiation in the Spring triggered by temperatures in excess of 10-11°C, and peak migration occurring at temperatures above 15-16°C (White & Knights 1997a and references therein). These higher temperatures are usually coincident with lower river discharge rates. Elvers are usually found in greater numbers in larger rivers, as higher flow rates are more attractive to immigrants (White & Knights 1997a). Increasing population density and competition are active promoters of upstream migration, although this can be inhibited by natural and man-made barriers (Knights *et al*. 2001). High recruitment with low mortality would be expected to produce high population densities dominated by smaller eel and males, whereas low recruitment would likely be reflected by lower stock densities composed of larger eel, the majority of which would be female (Knights *et al*. 2001).

Large numbers of glass eel enter the Severn Estuary between February and April. They have limited energy reserves, and must feed before metamorphosing into elvers (White & Knights 1997a). Migration occurs at night with the young eel travelling upstream, usually at the surface, using selective tidal stream transport and keeping close to the river bank (Sinha & Jones 1986, White & Knights 1997ab). Some juveniles resume upstream migration after one or more years in estuarine habitats. Young eel that metamorphose into yellow eel while still in brackish waters do not appear to develop a drive to migrate further upstream, and this may explain why yellow eel are so numerous in the extensive brackish regions of large rivers. Based on 1991 – 1993 survey data, White & Knights (1997a) reported passive tidal transport of glass eel up the Severn as low. A considerable time delay between the initial passive migration and the arrival of active migrants suggested that migration up the estuary was slow, so enhancing losses to predation and other natural mortality factors.

Downstream migration by the mature silver eel begins in early autumn and is strongly nocturnal as only the smaller, younger eel are diurnal. There is evidence that silver eel will avoid artificial light from land, and during brighter nights may prefer to migrate at greater water depths (Tesch 1977).

The swimming performance of elvers, investigated by McCleave (1980), indicated that they would not be able to make headway against water currents in excess of 50 cms^{-1}. At water temperatures between 11.1 – 13.3°C, elvers averaging 7.2 cm length could swim for ca. three minutes at a water speed of 3.5 bls^{-1}, this decreased logarithmically to 0.7 minutes at 5.0 bls^{-1}, with another decrease to 0.27 minutes at 7.5 bls^{-1}. Endurance swimming tests of small and medium eel (120-300 mm fish) indicated that at water temperatures of 10-15°C, water velocities greater than 0.2 ms^{-1} reduced the amount of time that individuals spent swimming to virtually nil, equating to an upper quartile of 1.5 bls^{-1}. Eel over 300 mm length would continue swimming until water velocities of ca. 0.55 ms^{-1} were reached, equating to an upper quartile of 1.5 bls^{-1}. At higher water temperatures (> 15°C) small eel performed similarly, while the larger eel improved, and remained swimming up to velocities of 0.7 ms^{-1}, equating to an upper quartile of 2.5 bls^{-1}. It was suggested that eel were not comfortable with sustained swimming, as they consistently tried to escape the experimental flumes during these experiments (Clough *et al*. 2004), although the natural behaviour of eel may have been a contributory factor to this observation. For elvers of *A. anguilla* burst speeds of 350 to 600 mms^{-1}, dependent on body length, have been reported (Clough & Turnpenny 2001, Clough *et al*. 2002). Burst speeds of larger eel have been reported as 1.15 ms^{-1} for 200 mm fish, 1.25 ms^{-1} for 400 mm fish and 1.35 ms^{-1} for 600 mm fish (Clough & Turnpenny 2001, Clough *et al*. 2002).

The European eel population is most likely panmictic (Dannewitz *et al*. 2005, in Aprahamian *et al*. 2007). Spawning occurs in the Sargasso Sea and oceanic currents control the distribution of larvae, accordingly larvae of any given brood have the potential to contribute to the population in any river throughout the distribution range. Homing behaviour towards a particular river is therefore unlikely. Instead, elvers become rheotactic when they encounter freshwater mixed with seawater, and they attempt to swim against the ebb current towards the freshwater source. As salt content increases towards high tide the eel cease active swimming and are passively carried by the tide (Creutzberg 1961 in Tesch 1977). Homing behaviour towards the Sargasso Sea is poorly understood as the transoceanic migration by adult silver eel occurs at depth in the ocean and routes, mechanisms and behaviours are largely unknown (Tesch 1977).

Eel sensitivity to changes in both water quality and climate change is likely to differ depending on the life-cycle stage. Significant water quality effects are likely to include water temperature, water depth, together with dissolved oxygen concentrations and pollutant load. Eel are amongst the most tolerant fish with regard to low DO, able to migrate though localised areas of low DO (Maes *et al*. 2007). They are also resilient, often surviving injuries that would be fatal to other species (Tesch 1977). However, sublethal concentrations of a wide range of contaminants are reported to have consequences on the physiology of eel, which may be more sensitive to pollutants than other species (Bruslé 1994 in Feunteun 2002).

Eel are sensitive to changes in water temperature, as this appears to be a key trigger for initiating and halting migration, both up and downstream. Therefore changes in both water velocity and depth capable of changing water temperature could potentially affect on eel behaviour and recruitment. High temperature is also associated with outbreaks of disease in eel (Tesch 1977). Changes in water velocity have the potential to affect on migratory behaviour. Higher current velocities (and possibly the increase in turbidity associated with such flows) frequently enhance downstream migration of silver eel (Tesch 1977).

Data presented in Fuenteun (2002) suggest that a high body fat content and long life cycle combined with a predominantly benthic nature as they mature, results in eel accumulating loads composed of various contaminants. However there is no evidence of mortality resulting from such loads outside of major accidents. Pesticides have been shown to disrupt metabolism in European eel; contamination load was related to pathological lesions in North American eel populations and organochlorine contamination may be linked to oocyte diameter. As silver eel do not feed on their transoceanic migration to the Sargasso Sea their fat stores are used for swimming energy and gonad maturation. Therefore, the quantity of contaminants accumulated during maturation is likely to play an important role in breeding success, larval survival and migration success of glass eel and elvers.

As eel are particularly sensitive to sediment-based contamination loads, eel could be potentially sensitive to any disturbance of sediments. Such events (natural or anthropogenic) can change the chemical properties of sediments (e.g. pH and redox potential) and promote the mobilisation of contaminants.

Oceanic climate change has the greatest potential to affect eel populations by affecting on the growth and development of larvae in the Sargasso Sea. Increasing water temperature appears to lead to a reduction in productivity in sub-tropical areas resulting in less food for the larvae (Knights 2003). Changes to oceanic currents could also affect the transport rates of larvae to UK shores. While changes to water temperature in nearshore areas could affect the timing of their upstream and downstream migrations, eel are possibly less vulnerable to continental climate change than other species as they are tolerant of a wide range of environmental conditions.

Summary

Eel are considered to have a **High** sensitivity. Upstream migration of glass eel begins in spring, using the bottom waters of the estuary. Water temperature is the critical factor that determines the onset of migration. Downstream migration by adults occurs at night in the autumn, with eel using the bottom waters of rivers and estuaries. Eel are sensitive to water temperature, and sediment-based contaminant loads.

Sturgeon

The sensitivity of sturgeon to environmental change is considered to be **High**. Although no populations of sturgeon are currently known to exist within the UK they are being considered alongside other protected species in light of the species inclusion on the UKBAP priority species list. Additionally the Severn Estuary is the most likely site of any UK reintroduction project and their is a possibility of strays from the reintroduction programme on the Gironde entering the Severn Estuary. If sturgeon were to establish within the Severn Estuary they would undoubtedly be afforded international protection. Overall sturgeon are of international importance, are known to be sensitive to environmental change, and have the possibility of coming into contact with a STP scheme.

After spawning common sturgeon adults rapidly migrate back to the sea until ready to spawn again, and as a result will use the estuarine environment as a migratory route to freshwater spawning grounds. Sturgeon are repeat spawners with males spawning approximately every 1 to 2 years and females every 3 or more years (Rochard *et al*. 1990). Currently the only known European populations reside within the Gironde-Garonne-Dordogne Basin in France and the Rioni Basin in the Black Sea. French authorities managed to artificially spawn fish in 2007 and as a result stocked 9,000 juveniles in September 2007 into the Gironde. Adolescent sturgeon spend up to 8 years in the estuarine environment and are known to move to other estuaries during this phase. As such, adolescent sturgeon from this population may stray into the Severn Estuary in the future and will require protection during their residence.

Summary

Sturgeon are considered to have a **High** sensitivity. No population is known to currently exist in the Severn Estuary, but any introduced population or straying continental individuals would be afforded international protection.

Estuarine and marine species

When considering the sensitivity of the fish species within the Severn Estuary to change it is important to assess a number of key characteristics of the functional groups utilising the estuary. In particular, factors influencing the effects of environmental change on fish species include the route and depth of passage of individuals through the estuary, the transit time and residence time of species within the estuary, seasonality of presence/absence, and the influence of tidal transport on larval and juvenile movement. Each of these aspects is addressed in turn below for each of the EUFGs. Other relevant environmental parameters such as water quality, habitat availability and abundance of prey items are considered within the Environmental and Social Impact Assessment section of the Scoping Report.

EUFGs include a wide range of fish species with varying levels of sensitivity to change. Therefore, it has been decided to class the groups as a whole based on the species with greatest sensitivity which has been assessed by considering the importance of the receptor and the vulnerability of species to environmental change. Table 2.9 summarises the assessment process for the sensitivity classification of each of the estuarine fish species.

Table 2.9 Assessment process for sensitivity classification of each of the estuarine fish species

Fish species	Life stage (moving u/s or d/s)	Level of protection	Population Status	Impacts					Sensitivity
				Alterations to migratory cues	Disruption to route of passage	Habitat change	Water Quality	Angling	
Marine Migrants (sensitivity based on UK BAP species: cod, herring, plaice, sole and whiting)	Predominantly juveniles	National	Stable	✓	✓	✓	✓	✓	**M** Based on national importance and medium vulnerability
Marine stragglers (sensitivity based on UK BAP species: blue whiting, hake, horse mackerel, ling & saithe)	Adults Juveniles	National	Stable	✓	✓	✓	✓	✓	**M** Based on national importance and medium vulnerability
Freshwater stragglers	Adults Juveniles	Local	Stable	✓	✓	✓	✓	✓	**L** Based on local protection and medium vulnerability
Estuarine species	Adults Juveniles	Local	Stable	✓	✓	✓	✓	✓	**L** Based on local importance and medium vulnerability

<u>*Marine Migrants*</u>

For marine migrants the most sensitive species following these criteria are the protected UK BAP species cod, herring, plaice, sole and whiting. Consequently the sensitivity of marine migrants to environmental change is considered to be **Medium.** The national importance of the estuary as a nursery area remains unclear for many of the marine migrant species in terms of the contribution of juveniles from the estuary to UK adult stocks.

This group of fish species comprises the greatest species richness and abundance of fish within the Bristol Channel and Severn Estuary. In general, the majority of marine migrant fish species recorded are dependent on the estuarine environment for juvenile development and juveniles enter the estuary in large numbers each year, as illustrated by the predominance of 0+ fish sampled within the inner Severn Estuary (Potter *et al*. 1988, Henderson & Holmes 1991, Symonds & Rogers 1995). Thin-lipped grey mullet and flounder are tolerant of low salinities and can swim much further upstream than most of the other marine migrants. Consequently, thin-lipped grey mullet and flounder can be found up to the tidal limit of the River Severn and further upstream on occasion. Most species tend to move towards deeper water in the winter during the adult phase, however, sprat do the reverse and seek out shallower water (Potter & Claridge 1985, DOE 1989). Therefore, in common with other marine migrants, sprat spawn outside the estuary, but it is one of the few species of fish which occurs as adults within the Severn Estuary in any notable numbers.

The route and depth of passage of these marine migrant species within the estuary is expected to be largely correlated with their preference for pelagic habitat, or habitat closer to the sediment/water interface and can be related to the feeding guild to which they belong. Most of these marine migrant species feed on benthic meio- and macrofauna (~40% of marine migrant species) with a relatively high proportion of hyperbenthivorous-piscivores (~30%) (Section 2.1.1). Overall, it is expected that most of the marine migrant species would travel close to the channel/estuary bed during migration to the estuary and when they are within the estuary. Monitoring on the Thames Estuary indicates that juveniles of numerous species actively use tidal transport and tend to move within shallow water along the estuary margins, for example flounder (Colclough *et al.* 2002)

It is generally considered that marine migrant juveniles within the Severn Estuary are largely spawned within or outside the Bristol Channel in spring. However, the larval migration time and timing of subsequent recruitment differs among marine migrant species, which is at least partly related to mode of transport (Potter *et al*. 1986). For example, it is thought that very small individuals of bass, herring and sprat move relatively rapidly up the estuary via passive and selective tidal transport, whereas larger whiting juveniles are able to actively migrate upstream or downstream and may take longer to reach the estuary (Potter *et al*. 1986). The time taken from spawning in the Bristol Channel to 0+ recruits appearing in the inner estuary can range considerably among species (Claridge *et al*. 1986).

These 0+ individuals are transported from spawning areas in the Bristol Channel or beyond and enter the estuary in large numbers, often remaining for just a few weeks. The period of peak abundance, however, differs among species. For example, in the 1970s peak abundances for flounder were in June/August, for herring and for sprat they were in August/September; bass and poor cod were found in largest numbers in September/October; for pout, whiting and thin-lipped grey mullet abundance was greatest in October/November and the abundance of sea snail peaked in December/January (Claridge *et al*. 1986). Although there can be considerable variation in the number of individuals successfully recruiting to the estuary each year, there is no evidence to suggest the seasonality of recruitment of species has changed over subsequent decades (Henderson *et al*. 2007). The outcome of this is a distinct, highly consistent, cyclical change in the fish assemblage within the inner Severn Estuary resulting in gradual variation in community composition and the relative abundance of dominant species throughout the year. Therefore if detrimental conditions are present in the Severn Estuary (e.g. reduced water quality or contaminated sediments) exposure of the more abundant fish species to these conditions is likely to be short-term so negative effects are reduced when compared to long-term residence.

Potter *et al*. (2001) examined interannual variation in the strength and timing of recruitment of key species in the inner Severn Estuary in relation to water temperature and salinity. No correlation between annual variation in peak abundance among eight of the most numerous marine migrant species (bass, herring, whiting, sea snail, sprat, poor cod, pout, thin-lipped grey mullet) was found, and there was also no relationship between the number of recruits and water temperature or salinity for these species. Consequently, the timing of recruitment of 0+ fish for these species is likely to be related to environmental conditions outside the inner estuary area, such as variation in the strength of currents used for larval transport and environmental change at spawning sites (Potter *et al*. 2001).

Some studies have noticed an effect of temperature, however, on certain species in the Bristol Channel. For example, higher than usual numbers of the marine migrants bass, herring, pout and sole were caught in Bridgwater Bay following the unexpectedly high water temperatures of the 1988-89 winter (Holmes & Henderson 1990, Henderson & Seaby 2005). When comparing sole abundance in Bridgwater Bay with the abundance of 95 other species across a 24 year period, the only significant positive correlation was with the numbers of bass (Henderson & Seaby 2005), and this is a species for which a relationship between higher temperatures and increased recruitment rates has been established (Holmes & Henderson 1990).

The utilisation of estuarine environments indicates marine migrants are generally tolerant of the high turbidity levels found within them. It is therefore considered that the main effect of changes in turbidity would relate to differences in productivity of the system (if any) and subsequent effects on the food chain as opposed to direct physical impacts on marine migrant fish. Most marine and estuarine fish are also tolerant of a wide range of DO levels. Bivalve molluscs and some annelids tend to accumulate contaminants which can gradually become more concentrated moving up the food chain and reach high levels in top predators. Heavy metals can become concentrated in some marine migrant species e.g. flounder, and vitellogenin production by male flounder has been demonstrated following exposure to oestrogenic compounds (Kleinkauf *et al.* 2004).

Environmental change can also affect the availability of prey items for marine migrants and other fish species. Juvenile whiting in particular has a very close association with their preferred prey, the common shrimp, *Crangon crangon*. This shrimp is one of the few species to remain within the inner Bristol Channel during the winter months as female shrimp within the upper estuary conduct seaward spawning migrations to seek salinities >12 (Henderson & Holmes 1989). It is thought that juvenile whiting migrate throughout the area in relation to shrimp movements and there is evidence for a strong positive correlation between whiting and shrimp abundance (Henderson & Holmes 1989). Such migrations in relation to prey availability can contribute to variation in recruitment patterns of various species to the Bristol Channel and Severn Estuary and clearly any change in numbers of shrimp or similar prey items would be expected to have an influence on the population dynamics of their predators. Habitat changes could result in an increase in the homogeneity of bottom sediments within the estuary, and this could potentially result in a greater mean size of invertebrate individuals. Such a shift could result in a significant proportion of invertebrates being too large for consumption by small juveniles, although the potential sensitivity of juvenile marine migrants to such a change in prey size remains to be clarified.

Consequently, as described above, the Severn Estuary represents a seasonally compartmentalised ecosystem with different seasons supporting different age cohorts of a given fish species, dominated by juveniles of marine migrant species. There is very little interaction between each seasonal component and the effects of short-term seasonal impacts (e.g. duration of a couple of months) could be confined to a relatively small number of species with little effect on the marine migrant functional group as a whole (Henderson *et al.* 1992). However, the benefits of such compartmentalisation would no longer be evident in the presence of long term impacts (e.g. over a year).

Marine Stragglers

The allocation of the magnitude of sensitivity to change for marine stragglers has been based on the BAP species blue whiting, hake, horse mackerel, ling and saithe. Overall, therefore, it is considered that marine straggler species would have a **Medium** sensitivity to environmental change within the Severn Estuary. In general marine migrant species are far more abundant than marine stragglers in the estuary. However, the marine stragglers are more speciose and account for just under two thirds of the species recorded. Consequently, marine stragglers form an important component of the fish assemblage within the estuary.

Marine stragglers consist of a wide range of fish species primarily representing benthic and demersal species although some are pelagic such as anchovy, horse mackerel and pilchard. In common with marine migrants many of the marine straggler species consume benthic meio- and macrofauna as at least a partial component of their diet (~50% of species). It is likely that the majority of marine stragglers would be found on or just above the channel/estuary bed during migration and once in the estuary.

Data for marine stragglers regarding larval transit time, residence time and seasonality is not entirely relevant for an assessment of baseline fish communities within the estuary. This is because these species usually breed entirely within marine environments and larvae or adults do not consistently enter estuaries, and they do not require estuarine habitats for development. There is little information available regarding effects of changes in water quality and habitat availability on marine stragglers, although it is expected that there would be considerable interspecific variation in the sensitivity of these species to such changes.

Freshwater Stragglers

The sensitivity of populations of freshwater stragglers to changes in the environmental conditions would be **Low** as none of these species are of national conservation importance and populations are likely to be stable.

Within low salinity waters in the upper estuary some freshwater species may be present, constituting a relatively large number of species found in low numbers. It is considered that the main factor influencing movement of freshwater species into the estuary is the extent of freshwater entering the estuary from the Rivers Severn, Wye and Usk. With a downstream shift of the saline/freshwater interface, there is greater potential for more freshwater straggler species to be found, and they would be likely to be present in greater numbers. These species also exhibit a wide range of sensitivities to variations in water quality. Specific information regarding the sensitivities of these species to variations in different water quality parameters within estuarine environments is lacking, however, it is thought that cyprinids would be most likely to be tolerant of low levels of DO than species preferring faster flowing water.

Estuarine Species:

Species belonging to this EUFG are considered to have a **Low** sensitivity to environmental change. There is a consensus that four of the species expected to be present within the Severn Estuary are considered to be truly estuarine in that they can live and breed within the Severn Estuary (black goby, common goby, sand smelt and worm pipefish). It remains unclear if sand goby is a marine migrant or estuarine resident (e.g. Franco *et al*. 2008), however sand goby individuals are more numerous than common goby and for the purposes of this paper this species is also considered likely to be an estuarine resident. It is also important to note that differentiating sand and common goby is difficult and individuals may have been incorrectly identified in the past. Sand smelt has been recorded relatively frequently within the inner Severn Estuary. However, sand goby and common goby are likely to be within the top 15 most abundant species (Potter *et al*. 1986), and both continue to be one of the more numerous fish species within the estuary. In general, These species are expected to use a wide range of habitats within the estuary.

Recreational Angling

As "receptors" fisheries will tend to follow the sensitivities and vulnerabilities of target fish species (see above). However, they have responses to environmental change in their own right, as the physical conditions for fishing, such as infrastructure, tidal patterns, access and availability alter.

2.2 Sources of data

Data and information used within this review have been obtained from various sources including data and reports produced by the statutory bodies (EA, CCW and NE), local, national and international government bodies and consultancies. Although a call for evidence has been submitted to all relevant parties requesting data be supplied for use within this SEA scoping paper, there are a number of resources outstanding.

Consultation has been made with experts on each of the fish species and information gathered as part of this exercise has been included and taken into consideration throughout this topic paper.

Individual sources of data and information have been detailed throughout the report and a comprehensive reference list is given at the end of this document.

2.3 Assumptions and limitations

Diadromous species

Information regarding the behaviour of each of the migratory fish species and their various life stages which are likely to influence the assessment of effect and the feasibility and design of potential mitigation and compensation measures have been collated and summarised within this topic paper. The information available on the behaviour of each of the migratory fish species and life stages is widely variable. The greatest information exists for the more commercially important migratory salmonids with data lacking for the rarer and more cryptic species such as lamprey and shad. Table 2.10 and Table 2.11 give a brief description of the information available both specifically for the Severn Estuary and also its tributaries in general. The extent of knowledge and information available has been ranked as follows; 0 = almost none, 1 = little, 2 = moderate, and 3 = substantial. The first ranking represents what we know specifically in the context of the Severn Estuary and its tributaries. The score in brackets represents what is known for the species and life stage in general. Where information is lacking it has been possible in some cases to gain knowledge from surrogate species, but even so such information is unlikely to be directly comparable with the situation within the Severn Estuary.

Significant knowledge gaps regarding migratory behaviour exist for all species, particularly shad and the two lamprey species, both in terms of the Severn Estuary and its tributaries and the species in general. Consistent knowledge gaps exist for a number of aspects of ecology and behaviour; the route of passage through the estuary, depth of passage, tidal transport, swim speed, transit time, residence time within the estuary, diurnal timing, seasonality, migratory cues, homing behaviour and stock status. As noted in Section 2.2, many of the behavioural responses and traits vary greatly with estuary type (size, structure, hydrography), with location, with season and with fish age, size and maturity. Thus, while some generic points can be transposed from studies elsewhere, in most cases estuary and site specific studies are required to describe adequately the processes in order to reduce uncertainty in predicted responses. Whilst some aspects of the behaviour of these species (i.e. residence time, transit time) may change as a result of the STP, others may remain similar e.g. depth of passage. The role of ecosystem modelling should be considered as a potential tool for structuring knowledge and answering carefully specified questions. While not covered here a review of international work in this rapidly developing field would be valuable to cover elsewhere in the overall assessment.

Estuarine and marine species

Long-term sampling at power station intake sites has provided important and informative data sets regarding fish communities within the inner Bristol Channel and Severn Estuary. Although collation of such data has numerous benefits it is important to be aware of the limitations of the data provided. As with the majority of estuarine fishing techniques, the intakes are selective, sampling species swimming within a relatively small area near the location of the intakes. Pelagic species are likely to have a better chance of avoiding the intake and would be under-sampled in relation to benthic species. When comparing assemblages caught within different power station intakes it is important to understand the differences in their locations, which can introduce bias to the potential range/abundances of fish species caught due to the preferences of different species for different habitat types e.g. salinity tolerances, deeper or shallow waters, and the depths at which different species swim in the water column. In general it is also expected that these power station intakes are more likely to capture juveniles than adults for most fish species due to the slower swimming speed of juveniles and their consequent increased susceptibility to entrainment.

Evidently, it is necessary to complement sampling at these intakes with other survey methods to gain a more representative understanding of the fish community within a wide range of areas of the inner Bristol Channel and Severn Estuary. EA surveys commenced in 2007 to monitor the status of fish communities in Transitional Waters for the WFD. These surveys utilise a multi-method approach following the techniques in Coates *et al*. (2007) and will provide valuable new data sets for estuarine fish assemblages. When examining information from different data sources, however, it is important to understand sampling bias of the relevant techniques. For example, the capture efficiency of a 4 m beam trawl for juvenile plaice ranged from 33% for 10 mm fish, 57% for 50-60 mm juveniles and to 46% for 70 mm juveniles (e.g. Lockwood 1974, Kuipers 1975). Comparison with studies using a 2 m beam trawl indicates that the catches are greater with the larger and more efficient beam trawls (Edwards & Steele 1968). Another study identified that by modifying the tickler chains with heavier spiked chains, the catch efficiency for juvenile flatfish increased by a factor of almost two (Rogers & Lockwood 1989).

CEFAS have conducted annual sampling within the Bristol Channel since 1993 using a 4 m beam trawl. Although this again provides useful data this selective technique is specifically designed to target benthic and demersal fish species of commercial importance. Overall, there is a lack of information regarding pelagic species within the Bristol Channel and Severn Estuary.

Table 2.11 gives a brief description of the information available for fish species belonging to each of the EUFGs within the Severn Estuary and estuaries worldwide, using the 0 to 3 scoring system outlined above.

There is a wide range of fish species within each of the estuarine use functional guilds, exhibiting a variety of behaviours and patterns of habitat use. In general, however, information is available for the categories used to head Table 2.11 for most of the more abundant marine migrant species found within the Severn Estuary, and other estuaries worldwide. As much of the information for the Severn Estuary has been derived from studies of fish catches at power station intakes the limitations outlined above apply to these data sets. Significant knowledge gaps exist predominantly for marine stragglers especially in terms of spawning location, route of passage, tidal transport, transit time, residence time, seasonality, and stock status. Further information is also required for spawning location, route of passage, transit time, tidal transport and stock status of estuarine species, which live and breed within the Severn Estuary. In terms of the freshwater stragglers, although a considerable amount of information is available regarding their behaviour in rivers, little is known of their status and behaviour in estuaries.

As mentioned above for diadromous fish species, it is possible that the behaviour of these marine and estuarine species could be different in the Severn Estuary than in other estuaries worldwide due to the specific environmental conditions provided by the Severn Estuary. Consequently, appropriate caution should be applied to the interpretation of results from other estuarine studies. It is worth noting, however, that the WFD protocols which have been developed over recent years (Coates *et al*. 2007) are based on data collected in over 40 estuaries within England and Wales (in addition to European intercalibration excercises), and hence results from these surveys should be comparable across different estuaries.

Table 2.10 Migratory species knowledge table (work in progress)

	Life stage	Route of passage	Depth of passage	Tidal transport	Swim speed	Transit time	Residence time	Diurnal timing	Seasonality	Migratory cues	Homing /Straying	Stock status	Feeding ecology
Atlantic Salmon	Adult	**1(1)** net/putcher captures indicate marginal passage on ebb of some fish, flood routes not known, likely everywhere with suitable depths, but clearly restricted as channels form. Some grey lit. tracking in 80s and re Cardiff Bay Barrage, but uninformative re main estuary. CEFAS studies exist on salmon passage in Fowey and recent unpublished work on the River Tyne. Putcher catch is more an indication of tidal transport than a selected migratory route. Main landward movement is partially a function of location of main tidal flow, but weather patterns are also relevant as fish appear to be in different locations depending on wind direction (and pressure?). Late 70s and early 80s tracking will not help (technology was too poor). Some observations available from Cardiff Barrage tracking studies.	**1(2)** no studies on Severn. Net capture indicate some surface (e.g. 1-2 m) movement, surface swimming with short dives (to orientate by salinity profiles?) may be common process, seen elsewhere, e.g. River Dee, Fowey(?). Large CEFAS unpublished data set on the depth of passage of salmon in the River Tyne obtained using acoustic depth transmitters.	**1(2)** recognised general mechanism of upstream movement, modified by position in estuary (cf FW flow). Upstream passage on ebb seen in Usk Estuary. Putchers catch fish dropping back in ebb. River Usk and River Taff tracking does indicate use of virtually all tidal states for landward travel at times, but the relative importance is not clear, and these observations may be influenced by the precise location in which they were made.	**0(2)** no direct studies in Severn. Some elsewhere. Some very coarse observations from River Taff studies.	**0(2)** estuarine specific, dependent upon dimensions, structure and holding areas, coupled with season/maturity of fish, river flows and timing of entry with respect to tidal cycle (NB "entry" hard to define on Severn.. Studies elsewhere. CEFAS have some limited upublished data on the movements of salmon in relation to water temperature in Rivers Tyne and Avon. Some very limited observations on "absence time" of salmon available from the River Taff after tagging and relocation to the estuary, plus approach to and entry to the Cardiff Barrage fish pass.	**0(2)** see transit time. Studies elsewhere: extended (days-weeks in estuaries with holding areas; also offshore departures and extended delays induced by low flows and high temp. Likely to vary seasonally (shorter near autumn)	**0(1)** highly variable depending on location in estuary	**2(2)** inferred from net/putcher and rod catches (thus constrained by season). No direct estuarine out of season obs.	**2(2)** principles known from several studies; but mechanism of changing relative importance of cues during sea-river transition not known. Freshwater influence and season/maturity critical. Highly complex due to number of rivers and degree of mixing of flows.	**2(2)** tagging studies show extensive interchange amongst all Severn Estuary adult migrant stock, giving mixed stock fisheries	**2(2)** adult stock fairly well described from catch and other stock assessment methods record for 50+ years on main rivers + River Taff trap data	**0(0)** likely stop feeding (maturation-linked) in coastal waters or somewhere in outer estuary?
	Smolt	**1(1)** no direct observations. Power station samples show marginal passage of some. Seaward movement in main channel close to surface (River Conwy, River Test, River Tawe, River Fowey). Movement close to estuary bank during flood.observations of smolt entrainment at old Uskmouth Power Station (plus others), plus by-catch from elver nets indicates at least some shore-oriented movement.	**0(2)** tracking studies elsewhere show changing behaviours, dependent upon location in estuary; surface movement preferred, with tidal variation to select tidal transport	0(2) tracking studies elsewhere show tidal transport important mechanism, likely for Severn.	0(1) tracking studies elsewhere show combination of active and passive movements, actual swimming speeds in estuary little studied.	**0(2)** tracking studies elsewhere show dependent upon estuary length and structure. Normally, as fast as possible e.g. 1-3 tidal cycles, to avoid predation?	**0(1)** tracking studies elsewhere show no residence (see transit time). Feeding unknown. Residence time short but dependant upon estuary length and topography.	**0(2)** nocturnal in upper reaches, less so lower down or with later running smolts, which also move in day	**2(2)** If assume no extended residence time then presence in estuary follows passage through rivers , which is well described (April-June range), but nothing known about autumn smolt possibility. Smolts were caught at Uskmouth from January to June, and some were seen in November and December	**0(1)** principles known from several studies; cues to initiate smolting and then migration occur in FW, others that may act in estuary not investigated (cues for what?)	0(0) probably not relevant, smolts are on their way to sea and not expected to go up other estuaries, although may be a sheltering mechanism, straying is an adult returnee issue	1(1) inferred from juvenile and adult assessments; but weak links; no direct observation on smolt runs. Some relative ests from River Usk from power station data.	**0(0)** could be significant if arrival is synchronised with feeding opportunities, and prey species are themselves affected by a barrage.
	Kelt	**0(0)** not studied. Some limited CEFAS unpublished data for River Tyne.	**0(0)** not studied	0(1) studies elsewhere indicated tidally direct movement coupled with active swimming	**0(0)**	**0(1)** some studies elsewhere show rapid passage 1-3 tidal cycles.	**0(0)** feeding residence possible in outer estuary (wherever that starts?), durations not known, but see transit time)	**0(0)** ?	1(1) inferred from spawning; starts post spawning (November) but end is less clear, maybe May - no reported observations - check early net catch records. Some observations from Taff tracking plus "bycatch" of kelts in Wye and Usk rod fishery	0(0) Post spawning (in FW) behaviour; so not thought relevant to estuary , unless feeding and further sea ward is initiated by external cues	0(0) probably not relevant, kelts are on their way to sea and not expected to go up other estuaries, although may stray during early feeding	1(1) kelt stocks poorly described in rivers and therefore similar for estuary, standing stock in any month not known	**0(0)**
Shad	Adult	**0(0)** No information found. By-catch in some putcher ranks gives some evidence	**0(1)** Lower half of the water column - in river. Upper half of water column in estuary.	**0(0)** No information found	2(2) Burst and sustained swimming speed info. Based on River Wye caught fish.	**0(0)** No information found	**0(0)** No information found	1(2) In rivers adult shad migrate predominantly during the day (05:00 to 20:00). **Riverine info. only.**	**2(3)** Fish arrive in freshwater from April to May. Extends into June. May be present in the estuary before April.	**2(2)** Onset when temperatures reaching 10 to 12°C.	**2(2)** Genetic diversity study on individuals from the Rivers Wye, Usk, Severn and Tywi.	**1(1)** Fish counter on River Wye and salmon putcher nets. Wye counter no longer in operation (stopped in 2006).	See Aprahamian 1988.
	Juvenile	**0(0)** No information found	**1 (1)** Throughout the water column with preference for surface layers.	**0(0)** No information found	0(1) Reduced swimming performance in latter portion of seaward migration.	**0(0)** No information found	**2(2)** July to October. Some over winter.	**0(0)** No information found	**2 (2)** Autumn, majority left the estuary by end of October. Some over winter in river. Power station entrainment. Age 1+ re-enter the estuary the following spring (April/May) and stay until the autumn.	**1(1)** Temperature cue for seaward migration data from power station entrainment. Associated with a decline in temp below 19°C and ceasing at 9°C. Discharge alone not a cue.		1(1) Condition assessment monitoring and power station entrainment data.	See Aprahamian 1988.
	Spent	**0(0)** No information found	**0(0)** No information found	**0(0)** No information found	2(2) Burst and sustained swimming speed info. Based on River Wye caught fish.	**0(0)** No information found	**0(0)** No information found	**1(1)** Dawn to dusk. Acoustic counter on River Wye.	**2(2)** June to July. Acoustic counter on Wye. Spent fish remain in estuary until the autumn.	**0(0)** not studied	**2(2)** Genetic diversity study on individuals from the Rivers Wye, Usk, Severn and Tywi.	**1(1)** Fish counter on River Wye. Counter no longer in operation.	See Aprahamian 1988.
Sea Lamprey	Transformer	**0(1)** Concentrated in mid channel following greatest flow.	**0(1)** Conflicting accounts. Mid and bottom water column suggested by some and throughout water column by others.	**0(1)**	**0(1)** Anguilliform mode, poor swimmers. Data available for post transformed American sea lamprey.	**0(0)** No information found	**0(1)** Reside at sea for adult life stage.	**0(2)** 19:00 to 07:00. **Riverine info only.**	**1(2)** September to October and April to May.	**0(1)** Increased freshwater discharge.		**0(0)** No data known.	
	Adult	**0(0)** No information found	**0(0)** Deep water resting areas sought during daylight and ebb tides. Tagging study on the River Mondego.	**0(1)** Selective tidal stream transport used	**0(1)** Anguilliform mode, poor swimmers. Data available for American sea lamprey adults.	**0(0)** No information found	**0(1)** Reside at sea for adult life stage.	**0(2)** Nocturnal approximately 2 hrs after nightfall and ceasing by 02:00. **Riverine info only.**	**1(2)** Migrate into estuaries in spring and into rivers by May to June.	**0(1)** Increased freshwater discharge coinciding with periods of high tide.	**0(1)** Genetic diversity between Spanish rivers.	**1(1)**	**0(1)**
River Lamprey	Transformer	**0(1)** Concentrated in mid channel following greatest flow.	**1(1)** Conflicting accounts. Mid and bottom water column suggested by some and throughout water column by others. Surface elver trawls in Severn caught individuals.	**0(1)**	**0(1)** Anguilliform mode, poor swimmers. Data available for Pacific lamprey transformers.	**0(0)** No information found	**1(1)** Spend majority of adult life stage in coastal and estuarine waters. May never leave natal estuary.	**1(2)** 19:00 to 07:00. Elver trawls in Severn caught individuals during night hours only.	**1(2)** September to October and April to May.	**0(1)** Increased freshwater discharge.		**2(2)** Power station entrainment data	
	Adult	**0(0)** No information found	**1(1)** Surface elver trawls in Severn caught individuals.	**0(1)** Selective tidal stream transport used	**0(1)** Anguilliform mode, poor swimmers. Behaviour attempting to pass an obstruction has been observed. Cumulative burst and rest periods.	**0(0)** No information found	**1(1)**. Spend majority of adult life stage in coastal and estuarine waters. May never leave natal estuary.	**1(2)** Nocturnal approximately 2 hrs after nightfall and ceasing by 02:00. Elver trawls in Severn caught individuals during night hours only.	**2(2)** Autumn and Spring from October to March. An autumn and spring population exist in the Severn (praecox and normal form).	**1(1)** Increased freshwater discharge coinciding with periods of high tide. Earlier during high water freshwater discharge and late during low flow years. Onset of migration begins when temperatures fall below 12 to 16°C.	**0(1)** Tagging and tracking studies on the Rivers Ouse and Derwent.	**1(1)**	**0(1)**
Eel	Glass / elver	**0(1)** Keep close to river bank - on ebb tid. More spread out across the estuary on flood.	**1(2)** Are predominantly benthic in coastal/estuarine habitat remain deep in water column where light intensity is low. Migrate at surface from estuarine to freshwater.	**1(2)** Selective tidal stream transport.	**2(2)** Eel are poor swimmers. Burst swimming performance data available.	**1(1)** Migration up the estuary is considered to be slow.	**1(2)**. Some remain in brackish water where they mature.	**1(2)**. Negatively phototaxic.	**2(2)** Between February and April. Migration extends in to May. Elver fishing commences in January and can continue into June.	**1(2)** Initiation and cessation triggered by temperatures in excess of 10 to 11°C.	**1(2)** Homing behaviour is considered unlikely. Oceanic currents control the distribution of larvae. Assumed to be panmictic	**2(2)** Commercial fishery.	White & Knights, 1997a. Severn. Knights, 2003. Sargasso sea
	Silver	**1(1)** Unknown	**1(1)** Some information available from tracking studies.	**1(1)**	**2(2)** Eel are poor swimmers. Burst and sustained swimming performance data available.	**1(1)** No information	**1(1)**	**1(2)**. Strongly nocturnal. Only smaller, younger eels are diurnal.	**1(2)**. Early autumn. August to November	**1(2)**		**1(1)** No information - have to assess from yellow eel status.	
Sea trout	Adult	**0(1)** tracking in Glaslyn Estuary showed use of channels and over flooded sand banks	**0(1)** surface preference, diving not tested - too few obs	**1(1)** TP observed elsewhere	0(1) speed over ground and swimming speeds crudely inferred from current speeds.	**0(1)** probably size for size similar to salmon, apart from feeding fish (see residence)	**1(1)** spend considerable time on coastal and estuarine waters, feeding, durations not known, but mainly summer months elsewhere	**0(1)** qualitatively day and night passage. CEFAS unpublished data on the River Tyne.	**2(2)** inferred from net/putcher and rod catches (thus constrained by season). No direct estuarine out of season obs.	**0(1)** assume similar in principle to salmon, but note difference in marine migration and coastal/estuarine residence	**0(1)** Straying more extensive than salmon	**2(2)** Sea trout are comparatively rare in Severn Estuary rivers. Adult stock fairly well described from catch record for 30+ years on main rivers + River Taff trap data	**0(1)** feeding expected in estuary
	Smolt	**0(1)** no direct observations.	**0(1)** similar to salmon	**0(2)** tracking studies elsewhere show tidal transport important mechanism, likely for Severn.	**0(0)**	**0(1)** likely similar to salmon upper reaches	**0(1)** post smolts may spend extended periods in estuarine habitats before seaward migration (or FW return), cf Glaslyn and elsewhere. Plus brown trout as "slob trout may spend extended periods before FW return - BUT NB sea trout rarity in Severn Estuary - at the moment.	**0(1)** Similar to salmon (Rivers Fowey & Conwy).	**1(1)** Initial presence in estuary follows passage through rivers , which is less well-described than for salmon (April-June range), but nothing known about autumn smolt possibility.	**0(1)** principles known from several studies; cues to initiate smolting and then migration occur in FW, others that may act in estuary not investigated (cues for what?)	**1(2)** extensive straying of post-smolts likely	**1(1)** inferred from juvenile and adult assessments; but weak links; no direct observation on smolt runs. Some relative est for Usk from power station data.	**0(1)**
	Kelt	**0(0)** not studied	**0(0)** not studied	**0(1)** studies elsewhere indicated tidally direct movement coupled with active swimming	**0(0)**	**0(1)** some studies elsewhere show rapid passage 1-3 tidal cycles.	**0(1)** feeding residence likely in outer estuary (wherever that starts?), durations not known, but see transit time)	**0(1)** elsewhere (River Tyne) nocturnal on ebb. CEFAS published data for River Fowey.	**1(1)** inferred from spawning; starts post spawning (November) but end is less clear, maybe May - no reported observations - check early net catch records, will last longer than salmon, probably	**0(0)** Post spawning (in FW) behaviour; so not thought relevant to estuary , unless feeding and further sea ward is initiated by external cues	**0(0)** probably not relevant, kelts are on their way to sea and not expected to go up other estuaries, although may stray during early feeding	**1(1)** kelt stocks poorly described in rivers and therefore similar for estuary, standing stock in any month not known	**0(0)**

0 - No information known
1-Little information known
2-Moderate information known
3-Substantial information known
First No-Severn (brackets No. -Elsewhere/general)

Table 2.11 Marine and estuarine species knowledge table (work in progress)

Estuarine Use Functional Group	Key Species	Spawning location	Predominant lifestage	Route of passage	Depth of passage	Tidal transport	Transit time	Residence time	Seasonality	Stock status	Feeding ecology
Marine Migrants	Sand goby, whiting, cod, flounder, bass, sea snail, herring, sprat, poor cod, sole, thin-lipped mullet	1(1) Within or seaward of inner Bristol Channel but generally lack of specific data. Location data are available for bass in Severn Estuary.	2(2) Based on sampling at power station intakes very high percentage of juveniles (~70-80%), other evidence suggests very high numbers of juveniles, and importance of Severn Estuary as a nursery for marine migrants.	1(1) Little information available. Data available for bass to indicate main feeding and growth areas for individuals migrating to Severn Estuary are in unstratified water less than 50 m deep.	1(1) Mainly demersal species but also some pelagic species such as sprat, herring and thin-lipped grey mullet. Depth of movement of specific species could be predicted based on preferred feeding modes, although little information regarding possible ontogenetic shifts (e.g. whiting are thought to change from pelagic to demersal habitat at a certain size).	1(1) Some information available for transportation methods of larvae of some key species. e.g. herring, sprat and bass are very small when they reach the estuary and likely use passive and selective tidal transport. Species with larger larvae within the estuary such as whiting are more likely to actively migrate through the water column. Distributions of bass eggs and larvae could be accounted for by passive drift in deeper waters. For adults some species e.g. mullet are likely to move with the tide, data lacking for most species. During seaward migration herring may get washed up and down the Bristol Channel and Severn Estuary.	2(2) Inferred from larval sampling in Bristol Channel and catches at power station intakes. Information available for time taken from spawning to reach the estuary for key species e.g. flounder, sprat, herring, bass, poor cod, pout, whiting, thin-lipped mullet, sea snail. Annual migrations for most species.	2(-) Inferred from catches at power station intakes. Information available for residence time of species in the estuary (predominantly juvenile fish) for key species e.g. flounder, sprat, herring, bass, poor cod, pout, whiting, thin-lipped mullet, sea snail. Usually ranges from a month to three months.	2(2) Species lists for inner Bristol Channel and inner Severn Estuary available from long-term sampling at power station intake. Clear seasonal use of estuary by marine migrants, considerable variation among species in terms of months when present/absent within the estuary.	2(2) Relative abundance data based on counts derived from long-term sampling at power station intakes available for most species found in the inner Bristol Channel and inner Severn Estuary. Limited data regarding benthic and demersal species derived from beam trawling in the Bristol Channel. Although some pelagic species were sampled by intakes, no data were found for pelagic species within the middle of the Bristol Channel and Severn Estuary.	2(2) Majority of species feed on benthic invertebrates and/or large mobile invertebrates and fish. Numerous sources of information are available regarding feeding ecology of individual species.
Marine Stragglers	Blue whiting, dab, hake, horse mackerel, ling, saithe, anchovy, angler fish, small-eyed ray	1(1) Within or seaward of inner Bristol Channel but lack of data regarding specific spawning areas.	0(0) No information found to suggest if mainly juveniles or adults in the estuary	0(0) No information found.	1(1) Little information available. Mainly demersal species likely to be associated with the estuary bed but also some pelagic species such as anchovy, horse mackerel and pilchard.	0(0) No information found regarding movement of larval or adult marine stragglers into the estuary. Maximum expected penetration into the estuary could be predicted partly in relation to salinity profile of estuary as marine stragglers tend to remain in waters of with salinity close to seawater and tend to remain within the lower estuary.	0(0) No specific information found. Occasional and irregular movements of species into lower parts of estuary.	0(0) No specific information found. Most marine stragglers found in small numbers and intermittently. Is likely that residence time will vary considerably among species and is not dependant on reproductive requirements.	1(1) Some information from power station intakes based on small numbers of individuals caught. In general, no expectations of seasonal use of the estuary.	1(1) Relative abundance data based on counts derived from long-term sampling at power station intakes available for most species found in the inner Bristol Channel and inner Severn Estuary. No data regarding stock status of most of these species in offshore and mid channel waters. Some qualitative data for dab in the Bristol Channel.	**2(2)** Majority of species feed on benthic invertebrates and/or large mobile invertebrates and fish. Numerous sources of information are available regarding feeding ecology of individual species.
Estuarine Species	Common goby, sand smelt	0(0) Within Severn Estuary, although no data providing spawning locations.	2(2) Both juveniles and adults present in the estuary	0(0) No information found.	2(2) These species are expected to be closely associated with the estuary bed as they move around the estuary.	0(0) No information found regarding how these species move in relation to tidal movements.	N/A	2(1) Year-round	2(1) Year-round	2(1) Count and relative abundance data derived from long-term sampling at power station intakes in the inner Bristol Channel and inner Severn Estuary.	2(2) Common goby are a benthic species and mainly consume meiofauna within bottom sediments. Sand smelt can be considered to be hyperbenthivorous-zooplanktivores and feed mainly on zooplankton and small mobile invertebrates found on or just above the sediment. Information is available for other species.
Freshwater Stragglers	Perch, brown trout, roach, bronze bream, carp, silver bream, rudd, crucian carp, dace, ten-spined stickleback	0(0) Primarily spawn within Rivers Severn, Usk, Wye and Avon and other smaller rivers (estuary) and River Parrett (for freshwater stragglers in Bridgwater Bay). Exact locations not known.	0(0) No information found to suggest if mainly juveniles or adults in the estuary	0(0) No information available. Could be partially predicted based on feeding mode and expected depth in the water column preferred by different species, and tidal movement of freshwater/saline interface.	1(1) These species have a wide range of feeding preferences. Distance into which species penetrate estuary is dependent on extent of freshwater plume. Surface/pelagic species expected to remain within freshwater plume in upper layers, benthic species may remain closer to the estuary bed. All species would move up and down estuary (and vary depth in water column) in relation to tidal movement of plume.	0(0) No specific information found regarding movement of larval or adult freshwater stragglers into the estuary. However, predictions can be made based on movement of freshwater/saline interface throughout the estuary, as salinity expected to be key factor in limiting penetration of freshwater stragglers into the estuary.	0(0) No specific information found. Occasional and irregular movements of species into upper parts of estuary.	0(0) No specific information found. Most freshwater stragglers found in small numbers and intermittently. Is likely that residence time will vary considerably among species and is not dependant on reproductive requirements.	1(1) Some information from power station intakes based on numbers of individuals caught. Most species caught in small numbers, although three-spined stickleback have been recorded in large numbers at Oldbury. In general, numbers within inner estuary increase in autumn and winter due to greatest river discharge and lower salinities during these seasons.	1(1) Relative abundance data based on counts derived from long-term sampling at power station intakes. Species usually sampled in low numbers, with exception of three-spined stickleback which was sampled in large numbers in the inner estuary. No information regarding numbers mid estuary.	2(2) Numerous sources of information are available regarding feeding ecology of these freshwater fish species.

0 - No information known
1-Little information known
2-Moderate information known
3-Substantial information known
First No-Severn (brackets No. -Elsewhere/general)

SECTION 3

ENVIRONMENTAL AND SOCIAL ISSUES

3 ENVIRONMENTAL AND SOCIAL ISSUES

3.1 Key environmental and social issues

3.1.1 Introduction

The feasibility study is considering a number of potential tidal power schemes. These include schemes identified by the Sustainable Development Commission in its 2007 study, schemes submitted in response to the Call for Evidence, and other schemes identified during the SEA study. Phase 2 impact assessment work will focus on the shortlisted schemes, or combinations of schemes, when known.

For the purpose of scoping, a range of options has been used that represents the spread of issues that may arise from the development of tidal power in the Severn Estuary. The range comprises a large barrage constructed across the wider region of the Estuary, a small barrage constructed across the narrower region of the Estuary, and a land connected lagoon constructed on one or other side of the Estuary. These options have been used to help identify the issues which could arise from tidal power on the Severn so that these can be considered in phase 2. This does not presuppose that these, or any other options, will form the shortlist of options that will be considered in phase 2 of the SEA.

3.1.2 Relevant changes to environment from tidal power options

The key changes to the environment of the Severn Estuary due to the construction of a STP option of any form are likely to affect migratory and estuarine fish in a number of ways to varying degrees depending upon the sensitivity of the species and life stage. Such changes to the environment are likely to include alterations to the tidal regime, freshwater discharge, water quality, intertidal habitat and route of passage. The severity of such effects are likely to be dependent upon the type and position of the different barrage options within the estuary, the permeability of the structure, the types of turbines proposed, the extent of water quality related issues and the presence/absence of fish passage solutions.

Although the specific changes will vary depending on the different STP schemes there are a number of effects expected to be common to all options. Each of these issues and associated effects will initially be discussed in generic terms to provide an assessment which is expected to be applicable to each of the likely STP designs to varying degrees. However, following each section, information is also presented for a representative range of STP options to indicate any specific considerations relevant to that design.

Alterations to migratory cues

Most migratory fish species rely on freshwater discharge as a migratory cue. The release of freshwater discharge into the estuary downstream of a STP structure will be delayed during times of impoundment. Depending upon the number of rivers impounded and the volume of their freshwater flow in relation to the overall freshwater input into the estuary and the length of time of impoundment, migratory behaviour may be disrupted and/or delayed. Additionally the delay to migration caused by a STP resulting in a potential pooling of migrants up or downstream of the structure may have indirect consequences such as increasing predation rates through predator attraction and increasing exposure to reduced water quality.

Migratory fish in particular salmonids are strongly influenced by tidal movement once they leave coastal water and enter the estuarine environment (Milner, 1990). Their behaviour changes again when they identify a freshwater cue and begin to swim actively against the flow. The points at which these alterations to migratory behaviour take place are likely to be specific both for individual estuarine/freshwater environments and species. Any alterations to tidal and potentially freshwater patterns are likely to alter the point at which behavioural changes take place. Migratory behavioural changes resulting from a STP have the potential to negatively impact upon the success and survival of migratory fish species.

For fish which display natal homing behaviour, such as Atlantic salmon and shad, STP may further delay migration by disrupting their ability to locate their natal rivers contained within freshwater discharge. Reduced mixing upstream however and a downstream movement of the surface freshwater wedge may aid natal river identification and decrease transit time and straying upstream of the STP option.

Large barrage

A large barrage proposal is likely to be downstream of most of the major Severn Estuary rivers it is therefore considered that the majority of migratory species entering these rivers will be affected by a reduction in freshwater inflow. Impacts upon tidal patterns within the estuary as a whole are also likely to occur with a large barrage and as such has the potential to result in changes to migratory behaviour with associated impacts.

Small barrage

A small barrage proposal is likely to encompass fewer rivers and as such migratory species from rivers downstream of the structure are not likely to be as affected by the reduction in freshwater and therefore a reduction in migratory cues. The position of a small barrage within the upper reaches of the estuary has the potential to result in changes to the transition of migratory behaviour from estuarine to freshwater environments.

Land connected lagoon

The extent of the effect from a land connected lagoon will depend upon the number and size of the rivers which it encompasses. Reduced freshwater input from encompassed rivers is likely to hinder species migrating into them. The presence of a land connected lagoon within the Severn Estuary has the potential to alter both tidal and freshwater patterns and as such has the potential to alter the migratory behaviour of fish currently utilising these patterns.

Disruption to route of passage

The placement of a STP option within the Severn Estuary will result in effects to fish passage and movement both for the seasonal migration of diadromous species and the daily movement of estuarine species. Potential effects will stem not only from the presence of a physical barrier but also the turbines associated with this barrier. In addition to disruption of passage within the estuary itself a STP may further affect migratory passage through potential alteration of the tidal limit decreasing periods during which passage over weirs such as Tewkesbury on the River Severn is possible. This has the potential in particular to affect species such as shad. In light of the new fish passage regulations due in April 2009 which require the consideration of the passage of all fish species it will be necessary to consider the passage of both migratory, estuarine and freshwater straggler fish species past the STP.

In a high tidal range and strong excursion environment such as the Severn Estuary, upstream migrants are likely to use tidal stream transport as a mechanism of moving up the estuary. An STP option across the estuary will alter this tidal regime and potentially as a result the mechanism and rate of upstream movement of migratory fish. Furthermore, as discussed above migratory fish are likely to change their behaviour as they move into the estuary from coastal waters, through the main estuary and into the inner estuaries and freshwater environments. Changes to the tidal and freshwater patterns as a result of a STP structure will further the negative impacts to migratory behaviour and resultant impacts upon individuals and populations. Such changes to migratory movement may result in delay and increased passage time which subsequently has the potential to result in further effects including increased predation and extended exposure to any changes to water quality.

Turbine passage related effects

Fish injury and mortality from turbine passage can result from a number of mechanisms including physical effect with turbine structures resulting in strike from runner blades, stay vanes, wicket gates and draft piers and grinding and abrasion from passing through gaps between fixed and moving structures. In addition to these mechanical sources, injury can also result from pressure changes, shear stress, turbulence and cavitation. Types of injury include decapitation, lacerations, bruises, severing, haemorrhaging, popped and missing eyes, ruptured swim bladder, flared and torn opercula and skeletal fractures. In addition to direct effects, indirect effects may also affect the survival of turbine passed fish. The main indirect effect associated with passage is the disorientation resulting from movement through the turbulent area downstream of the turbine resulting in increased risk of predation. The osmotic stress caused by scale loss and epithelium damage may also result in indirect fish mortality as a result of increased susceptibility to disease and pathogens in particular of migratory individuals which are already under osmotic stress from ionic imbalances due to the transition from marine to freshwater environments and *vice versa*. The probability and severity of injury occurring will vary between the different species and life stages, as well as turbine design and configuration.

Shear stress

When a fish passes between two adjacent water masses moving at different velocities, due to the viscosity of the water, force is exerted on the fish, known as shear stress (Nietzel *et al*., 2000). The extent of injury suffered is dependent upon the size of the fish, its sensitivity and the way in which the force strikes the fish (Nietzel *et al*, 2000). Force that strikes a small area will have greater pressure and will result in more damage than the same force hitting the entire side of the body. The extent of damage resulting from shear stress is therefore dependent upon the location on the body and the area over which it manifests itself. Greatest rates of shear strain will occur in narrow boundary layers near surfaces such as near the blade tip and hub. Shear stress within the boundary layers of the turbine may be as much as 5000 Nm^{-2} although it is estimated that they will be lower than 500 Nm^{-2} throughout the majority of the turbine structure (Nietzel *et al*., 2000). During laboratory studies on the effects of shear on fish the incidence of bent and bruised opercula and damaged and missing eyes predominated (Nietzel *et al*., 2000). Of the species tested (rainbow trout *Oncorynchus mykiss*, spring and fall Chinook salmon *O. tshawytscha*, American shad and steelhead *O. mykiss*) American shad juveniles were found to be the most sensitive species to shear stress with strain rates of 517 $cm^{-1}cm^{-1}$ and above resulting in significant injury and mortality. Mortality rates of up to 20% were also seen in 'control' fish highlighting the sensitivity of this life stage to any handling. All individuals tested died with exposure to a strain rate of 1,008 $cm^{-1}cm^{-1}$. Of those fish that were not injured or killed, an increased susceptibility to predation was observed in comparison to control fish. Trials undertaken on migratory salmonids at shear stresses equivalent to 600 cm/s/cm observed little scale loss, no loss of mucous coating, no other apparent injuries and no mortality (Turnpenny *et al*. 1992).

During exposure of age 0 and 1 fish to a high velocity jet to determine the effects of shear stress and turbulence, injuries were found to be rare below 9 ms^{-1} in all species except American shad (Guensch *et al*. 2002). Major injuries in the migratory salmonids were observed at velocities of 12 ms^{-1} and above, with mortality occurring at 18 ms^{-1}. Injuries included eye, operculum, isthmus and gill damage. Physical injuries were greatest within age 1 fish due to their greater mass whereas age 0 fish exhibited higher frequencies of inertial stress and disorientation as a result of their lesser mass.

Trials on the effect of shear stress on juvenile Pacific lamprey (*Lampetra tridentata*) found that strain rates up to 1,830 cm/s/cm which are known to kill salmon resulted in no incidents of injury or death (Moursund *et al*. 2003). It has been suggested that this hardiness is due to the physiology of lamprey which are flexible and do not have the vulnerable structures of teleosts such as scales, a bony skeleton, operculum, large eyes or a swimbladder.

Mechanical injury

The rate of fish strike by a turbine blade is dependent upon the ratio of the length of the fish and the distance between successive blades termed 'water length' (Davies 1988). The first model to determine the probability of blade strike was developed by Von Raben in 1957 and has since been expanded upon by a number of subsequent authors (Deng *et al*. 2005). In addition to strike other mechanical injuries include abrasion and grinding and slap by the turbine blade surface. Turbine variables influencing the rate of blade strike include the length of the blade, rotational speed, discharge through the runner and velocity of effect. Biological variables include fish length, mass, stiffness and fish sensitivity which is specific to species and life stage. Those fish passing near the blade tips suffer a higher strike rate than those passing mid blade or near the hub. It is considered that surface orientated fish have a higher probability of receiving mechanical, pressure and force related injuries as they are likely to pass close to the blade tip.

Pressure

The pressure of water changes as it passes through a turbine, increasing within the intake casing and then rapidly decreasing as the water passes through the turbine blades, exhibiting its lowest pressure near the blade tip (Becker *et al*. 2003, Davies 1988). The rapid change in pressure can result in rupture of the swim bladder and the formation of gas bubbles within the fishes blood vessels and eyes (Turnpenny *et al*. 2000, Abernethy & Amidan 2001). Literature suggests however that the pressure changes associated with low head turbines such as those proposed for the Severn Estuary would not result in significant stress or injury to fish (Turnpenny *et al*. 2000).

Cavitation

An additional pressure effect is associated with the formation of bubbles within the low pressure zones around the runner blades leading edge (Davies 1988). When these bubbles collapse they cause a wave of high pressure which can result in damage such as haemorrhaging and eye popping on contact with a fish.

Indirect effects

Investigations to assess the effect of turbine passage on the escape behaviour of fish through observation of the c-start behaviour are inconclusive. Although some studies have observed alteration in escape behaviour including both an absence of the c-start movement and a decrease in response time (Cada *et al*. 2003) others have determined no significant difference between turbulent treated and control fish (Cada *et al*. 2006). Any disorientation resulting from turbulence downstream of the turbines or inertial stress from shear force, in particular with the smaller mass juveniles, may result in both migration delay and increased predation. Furthermore where minor and major injuries are sustained, increased susceptibility to pathogens and disease may further reduce the survival success of turbine passed individuals. Observations of mortality at hydroelectric plants have indicated predation mortalities of up to 33% of salmon smolts due to disorientation at the outflow in comparison to 10-19% from turbine passage mortality (Long *et al*., 1986 cited in Wye & Usk Foundation, 2008). At the La Rance Barrage predation of small disorientated shoals of clupeids by gulls and bass have been observed (Solomon, 1988, cited in Wye and Usk

Foundation, 2008). During migration some species may be more susceptible to damage and indirect stresses due to natural changes in their ionic balance and in the case of juvenile shad the development of scales. During the smoltification process the scales of migratory salmonid smolts become loose (Handeland *et al.* 1996) and are easily dislodged, exposing the delicate epithelium. Depending on the extent of injuries, indirect stresses may consist of pathogenic infection and increased risk of predation as a result of osmotic stress, which occurs when the epithelium becomes damaged. The maximum degree of scale loss tolerated by smolts is thought to be between 20 and 30% (Kostecki *et al*. 1987).

In addition to indirect survival effects, reproductive success in particular of migratory adults may be indirectly affected as a result of turbine and sluice injury. Investigations upon the effects of stress on teleosts have seen an increase in the hormone cortisol, other glucocorticoids and elevated glucose levels. A common response to stress in fish is the diversion of energy away from reproduction to cope with the stressor. This may result in the reabsorption of eggs and/or their reduced fitness. Therefore were a spawning adult to successfully make it past the STP option and to spawning grounds if it has been subject to stress during this process spawning success may be reduced.

Sluice passage

It is expected that sublethal injuries such as scale loss, fin damage and surface abrasions could all be sustained during passage through the STP sluice gates on the flood tide. As with injuries sustained from turbine passage this may result in indirect effects such as mortality and increased predation. Due to the high tidal excursion experienced in the Severn Estuary there is potential that migratory fish may pass through the sluices numerous times during their passage through the estuary. Similarly estuarine resident species are likely to pass through sluices many times during their period of residence.

Noise and vibration

Operational sources of underwater noise and vibration from a STP scheme are likely to be primarily generated from turbine and sluice operation. Information relating to the underwater acoustic effects of the STP proposals is currently unavailable and no data regarding comparable studies of sound emittance from a tidal barrage are believed to exist. As such further investigations are required before a full assessment of impacts could be undertaken (see Noise and vibration Topic Paper for further information).

The hearing capability of fish is dependent upon the physiology of individual species in terms of both the presence/absence of a swimbladder and the connection between the swimbladder and inner ear. Species fall into three broad categories; *non-specialists* which have no swim bladder, *generalists* which have a swimbladder but no special connection between it and the inner ear and *specialists* which not only have a swimbladder but also a connection between it and the inner ear which can extend their upper hearing ability by several kilohertz.

Clupeiformes fall within the *specialist* category and as such can hear sound over a far greater range than other fish species. Shad as well as other alosids appear to also be unique in that they can detect sound of far higher frequencies than other hearing specialists. Although not investigated to date, due to the hearing sensitivity of shad there is also potential that they can detect infrasound frequencies.

Salmon are classed as hearing *generalists* and as such cannot hear high frequencies within the ultrasound band but are able to hear low frequency sound and infrasound.

As lamprey lack a swimbladder they fall within the *non-specialist* hearing group. There is potential however that lamprey may be able to hear infrasound which works upon the basis of particle acceleration and therefore targets the inner ear. The hearing of lamprey is complicated, by the fact that they do not have otolith organs and no known work has been undertaken on the response of lamprey to sound in relation to their statoliths and labyrinth organs.

Eel which have a swimbladder but no connection to the inner ear as with salmon are classed as hearing *generalists*. There is evidence however to suggest that they can hear infrasound (Sand *et al*., 2000).

A frequency weighted scale currently exists for the assessment of behavioural and audiological effects of underwater noise upon marine animals from man-made underwater noise, the dBht (Species) (Nedwell *et al*. 2007). The dBht (Species) scale measures the perceived loudness of a sound to a specific species through a process of passing the sound through a filter mimicking the hearing threshold of the species. A dBht (Species) value can therefore be calculated corresponding to the likely loudness of the man-made sound to the species. This scale however, is reliant upon knowledge regarding the hearing threshold of the species. This is determined primarily through the availability of an audiogram either behavioural or from an auditory brainstem response.

Although audiograms have been produced for a number of the more high profile marine and estuarine fish species there are likely to be few for the diadromous species passing through the Severn Estuary. Audiograms are available for salmon however, they are not considered to be currently available for sea trout, eel, shad or lamprey. It may be possible to infer some knowledge for some of the species from surrogates, for example extensive work has been undertaken on American shad.
Due to the *specialist* hearing capacity of shad and as a result the large range over which they can hear, migratory shad life stages are considered to be most at risk of disruption from noise and vibration.

Potential effects from tidal power generation in the Severn Estuary

The generic tidal power options considered within this assessment generate are expected to generate power only on the ebb cycle. As such downstream migrating diadromous fish and moving estuarine fish will be at greatest risk of injury and mortality as a result of turbine passage. Within the Severn Estuary those migratory life stages at greatest risk will include juvenile shad, spent adult shad, lamprey transformers (river and sea lamprey), silver eel and salmon and sea trout smolts and kelt. Small individuals with a low mass such as juvenile shad will be subject to high inertial stress and resultant disorientation delaying migration and increasing predation. Larger individuals including spent shad, kelt and silver eel will have a higher probability of being struck by the turbine blades and as such will be at a greater risk of mechanical injury and mortality. The extent of injury resulting from mechanical contact will vary depending upon the physiology, stiffness and sensitivity of the species and life stages. Flexible species such as lamprey and eel will be less susceptible to injury from mechanical contact. Injury rates within lamprey will be further reduced due to their physiology in particular the lack of a swimbladder, scales, a bony skeleton and large eyes. Due to their small size, flexibility and robust physiology, lamprey transformers are likely to be the least susceptible to sustain major injury from mechanical and pressure effects. The delicate nature of spent and juvenile shad has the potential to result in high rates of mortality as a result of mechanical contact and pressure forces during turbine passage. The size and sensitivity of spent shad is likely to result in them being at greatest risk during downstream turbine passage. Numerous turbine passages of downstream migrants may occur as a result of the high tidal excursion within the Severn Estuary.

Due to both the strong tidal excursion within the Severn Estuary and the planned pumping regime at the end of the flood tide there is also potential for upstream migrating fish (adult shad, lamprey, salmon and sea trout and elvers/glass eel) to pass through the turbines during operation. The number of passages made through the turbines will depend upon the transit and/or resident time of the individual, its migratory behaviour during estuarine movement and the tidal excursion at the point of the STP option. This information is largely unknown for the migratory and estuarine species within the Severn Estuary. As with downstream migrating fish, the probability and extent of turbine injury will be dependent upon the size, stiffness and sensitivity of the species/life stage. Due to their small size and flexibility elver/glass eel are considered to be at least risk of major injury and mortality from turbine passage. Sensitive species such as shad are likely to be at greatest risk of major injury and mortality.

The depth within the water column at which the fish are migrating will further influence the probability and extent of physical and pressure injuries. Surface orientated fish that will be drawn down or dive to pass through the turbines will be at greatest risk of passing the tip of the blade and would therefore be at greatest risk of mechanical and pressure injury, disorientation and mortality. Information regarding the preferred position of the majority of the migratory fish within the water column of the Severn Estuary is limited or unknown.

Migratory fish species are considered to have the greatest potential of receiving turbine passage related injury as a result of their directed movement through the estuary. Indirect negative effects as a result of injury are also likely to be greater for migratory fish due to osmotic stress, physiological change and energy loss exhibited during the migration and spawning period. Those species that are repeat spawners have the potential to be greatly affected due to cumulative turbine passages throughout the adult life stage.

Juvenile marine migrants predominate within the estuarine fish assemblage within the Severn Estuary. The small size and low mass of these individuals is likely to result in relatively infrequent incidents of mechanical injury with inertial stress and disorientation being the dominant turbine passage negative effects for these life stages during their movement throughout the estuary. As with the migratory fish species, due to the high tidal excursion in the Severn Estuary, juvenile estuarine species may pass through the turbines numerous times during their residence period in the estuary. If, however, some fish species were to remain within the estuary for a year or longer (e.g. flounder) then increased size of individuals would make it more difficult to avoid injury on return to the sea.

The rate and extent of turbine related injuries is also known to be further influenced by the efficiency of operation in particular on tidal power schemes where head changes over the operating period. At the end ranges of turbine operation injury and mortality from pressure change, shear stress and turbulence is likely to increase (Cada unknown). Incidence of cavitation within the turbines are also considered to increase during these low efficiency periods (Davies 1988). The differing fish mortalities seen between the La Rance and Annapolis Royal tidal power schemes has been attributed at least in part to the differing operation regimes between the sites (Davies 1988). Operation at La Rance is controlled by computer with optimum efficiency being maintained wherever possible and cavitation believed to be absent (Davies 1988). Cavitation is known however to exist within the Annapolis Royal turbine (Davies 1988).

Large barrage

The extent of disruption to route of passage from a large barrage depends upon its location and the number, type and design of turbines and sluices proposed. Potential injury rates for migratory fish passing through a turbine will differ depending upon turbine type, runner blade diameter and rotation speed. Mortality rates for a bulb turbine 9m in diameter were tested and modelled by Turnpenny (1998). Aspects taken into consideration included rapid pressure change, shear stress, turbulence, cavitation and runner blade strike. Injury rates predicted are as follows: 40% for adult salmon (100 cm), 10% for salmon smolts (15 cm), 28% for adult eel (70 cm) and 53% for juvenile shad (7 cm). No information appears to be available for adult shad, elvers/glass eel, sea trout or lamprey transformers or adults.

Due to the likely location of a large barrage option downstream of the majority of the major rivers in the Severn Estuary including the River Usk and Wye SACs it is considered likely that the majority of migratory fish entering and leaving the Severn Estuary will pass the barrage either through the sluice gates or the turbines. Other migratory individuals straying from rivers such as the Tywi SAC may also pass through the barrage during this period. The high tidal excursion experienced within the estuary has the potential to result in numerous turbine passages for both up and downstream migrating fish.

Small barrage

The extent of disruption to route of passage from a small barrage will depend upon the same factors as those identified above for a large barrage. Turbines used on a small barrage may comprise of bulb turbines as discussed above although a smaller diameter would likely be used, straflo turbines or another technology type. Information regarding the predicted injury rates from passage through straflo turbines for each of the migratory species does not appear to be available. Any information on surrogate species (American shad, American eel, migratory salmonids and lamprey) from the prototype turbine at Annapolis however would give an indication of potential turbine injury rates for a straflo turbine. Information regarding injury rates for the Annapolis turbines however, does not appear to be readily available.

A small barrage is unlikely to encompass all of the Severn Estuary rivers. There is however known to be a high rate of straying of migratory fish within the Severn Estuary due in part to the high degree of mixing of natal river water (Swain 1982, Aprahamian *et al.* 1998b, Solomon 1988). Migratory species from rivers likely to be downstream of the structure such as the Usk, Avon, Tywi, Tawe and Ogmore must therefore also be considered as having the potential to be affected. Depending upon the transit time of migratory fish from the estuary to the rivers there is potential for numerous turbine passages to be made due to the high tidal excursion observed within the upper reaches of the Severn Estuary.

Land connected lagoon

As with the barrage options the extent of effect from a lagoon proposal will depend upon its size, location, turbine and sluice type and number. This is likely to vary greatly between different proposals and as such it is not possible at this stage to determine the potential rates of injury and mortality for fish passing through the turbines. The likelihood of turbine passage will largely be dependent upon the positioning of the lagoon/s within the estuary and the number of rivers that each encompasses. Furthermore the positioning of the turbines and sluices will be fundamental in determining the extent of effect with regards to rivers outside of the lagoon perimeter but in close proximity.

The intertidal habitat within the lagoon is also likely to be a suitable nursery area for both estuarine fish species and diadromous species such as juvenile shad, elvers and lamprey transformers which may reside within the estuary for a protracted period. These individuals may therefore pass into the lagoon and exit via the turbines and have the potential to do this many times during their residency.

Were migratory fish species to enter a lagoon they may remain within the impoundment for an unknown period of time. This period of impoundment within the lagoon would represent a delay to migration and may negatively impact upon the migratory success and survival of the individuals effected.

Were more than one lagoon option to be taken forward in parallel, cumulative negative effects to the fish populations would greatly increase with the majority of migratory and estuarine fish being subject to entering the lagoons and passing through the turbines upon exit, potentially on a twice daily basis.

Habitat Changes

Physical effects upstream (landward) of the STP Scheme

It is predicted that minimum water depths post-STP could potentially increase on both neap and spring tides (with a greater increase on springs) for about 50-60 km upstream of the STP option (depending on the scheme, see sections below for further details) (ABPMer 2008a). It has been estimated in the past that the post-STP low water level would be equivalent to the current mid water level and the high water level would also decrease, in addition the timing of high and low tide within the estuary would change (BES 1992). As mentioned earlier, the relative proportion of subtidal and intertidal habitat within the estuary could change.

A principal consequence of this would be that large areas of habitat which are currently exposed at low tide would be permanently submerged. This could have implications for fish which utilise shallower near-shore waters as availability of this habitat would increase and access to prey items in these areas would be available throughout the tidal cycle. The composition of invertebrates in these areas would change from intertidal organisms to those which can tolerate permanent submersion although this is not likely to reduce the abundance of prey items available to benthic feeding fish. Species such as shad however are unlikely to be affected by these changes in invertebrate composition as, if like herring, *Alosa pseudoharengus,* they are not behaviourally or morphologically adapted for feeding on benthos (Aprahamian 1988b). Overall, this change could reduce inter- and intraspecific competition for food and space in these shallower waters. However, it is known that some intertidal areas such as saltmarshes are extremely valuable habitats within the Severn Estuary. When submerged they provide important feeding grounds for juvenile fish and a refuge from predation (Colclough *et al*. 2005) and turbulence (Neumeier 2007). The high saltmarsh is a particularly important feeding area for juvenile bass which is a species of commercial importance (Colclough *et al*. 2005). In addition, it is considered, based on expert opinion, that intertidal saltmarshes could also potentially be utilised by estuarine resident diadromous species such as juvenile shad, river lamprey and yellow eel, and are of prime importance for juvenile marine migrants. There is however no current known evidence to support this. There is now evidence that new saltmarsh can be designed to optimise its utilisation by fish (Coates *pers. comm.*). Further to providing important foraging areas, saltmarsh also has an important role in nutrient cycling and CO_2 sequestration within estuaries (Colclough *pers. comm.*).

The permanent submersion of areas of saltmarsh would cause the saltmarsh vegetation to die and degrade and would greatly change the community composition of invertebrates present. In addition to loss of a vital habitat, this would affect fish in the short-term as bacterial degradation of the vegetation would lead to increased biological oxygen demand and potential anoxia in surrounding waters. Further modelling is necessary to quantify accurately the area of saltmarsh which is likely to be lost post-STP. It would be particularly useful to gain an understanding of the respective importance of different intertidal and subtidal habitats to diadromous species such as shad and eel, and to marine and estuarine fish (especially juveniles). For example, it has been found that the fish productivity of intertidal habitat in the Forth Estuary was twice that of nearby subtidal areas (Elliott & Taylor 1989). Further research of this nature is required to help quantify the potential effect of an estimated decrease in intertidal habitat and accompanying increase in subtidal habitat on fish productivity.

The strong tidal currents within the Severn Estuary currently separate coarser from more fine, muddy sediments. Sediment type is an important factor in influencing distribution of benthic organisms on the estuary bed and coarse sediments are not readily colonised by many invertebrate species. As this sediment separation is also combined with regular sediment resuspension caused by tidal movement, there is a depauperate subtidal invertebrate community within the Severn Estuary. Individuals generally have a smaller than average mean size for most invertebrate species and are of ideal size for consumption by very small juvenile fish. One potential consequence of the reduced tidal flows and decreased bed shear stress post-STP is that the less pronounced sorting of different sediment types would result in a more homogenous sediment regime. These sediments would provide more stable habitats and could result in an increase in the mean size of individuals, and potentially greater invertebrate diversity. Although an increase in invertebrate biomass would often be predicted to be beneficial to adult fish, an important consideration is that very small juveniles may not be able to consume the larger invertebrate prey items. This would potentially reduce prey availability for juvenile shad, estuarine yellow eel, elvers, estuarine river lamprey (other diadromous species would not be feeding in the estuary) and juvenile marine migrants. Such a change could have repercussions for the suitability of the Severn Estuary as a nursery area. Geomorphological modelling is needed to clarify predicted changes in sediment type within the estuary.

The reduced tidal range caused by enclosure of the estuary via the STP option could potentially increase localisation of wave energy dissipation in shallow water. This could affect levels of siltation and intertidal erosion (ABPMer, 2008b). Further research is required, however, before this can be confirmed and patterns may vary seasonally as currently during the summer months the intertidal zone tends to accumulate muddy material which is then eroded during periods of increased wave action (e.g. winter storm events). It is unclear how variation in the deposition/accretion regime could affect fish communities within the estuary, although any resultant changes to the invertebrate community could have knock-on negative effects for any diadromous species feeding in the estuary and other benthic feeding fish.

Physical effects downstream (seaward) of the STP option

There would be an increase in mean depth downstream of the STP option but this would be to a lesser extent than upstream, declining to a negligible change in mean depth ≤20 km downstream for all schemes (see sections for each STP scheme below for more detail) (ABPMer 2008a). In addition, immediately downstream of the STP flow speeds are predicted to be reduced during both spring and neap tides for the majority of the tidal cycle (ABPMer 2008a).

The main effect of the STP option on the seaward side would be to deflect and dissipate the energy of the tidal current. This may result in a decreased level of suspended solids immediately downstream of the STP option and result in deposition of fine sediments over the current rocky habitat. Such a change could influence invertebrate communities, potentially promoting the survival of suspension feeders within a localised area downstream of the STP option which would have a subsequent potential effect on the distribution of fish species in the area. However, the likelihood of this change occurring needs to be clarified via further modelling. The dissipated tidal energy could also lead to increased erosion of intertidal areas immediately downstream of the STP option, although again the magnitude of this effect (if any) is unknown and should be examined further.

Specific information for different tidal energy schemes

Large barrage

At a large barrage which typically might adopt an alignment between Brean Down and Lavernock Point, for example, minimum water depths are expected to increase by about 2 m on neap tides and 5 m on springs up to 40 km upstream, although 60 km upstream any difference would be negligible. Downstream differences would be less noticeable with minimum depths increasing by up to 0.5 m on springs near the barrage but there would be no change beyond approximately 20 km downstream. Immediately downstream of the barrage flow velocities could be expected to be halved during spring and neap tides for most of the tidal cycle (from 2 ms^{-1} to 1 ms^{-1}), this magnitude of reduction in flow velocity would be evident as far west as Nash Point. Upstream flow velocities would be reduced from 2.5 ms^{-1} to 0.5 ms^{-1} around Newport/Avonmouth on spring tides, and near Berkeley spring tide flows would be ~1/3 of their current speed (from 1.5 ms^{-1} to 0.5 ms^{-1}), and neap tide flows would be halved (ABPMer 2008a). In particular these changes would result in increased stability of the pools of fluid mud on the estuary bed which are present following neap tides (ABPMer 2008a). Negative effects on fish are expected to follow those outlined in the sections above.

Small barrage

For a small barrage such as that, for example, following an alignment from Severn Beach to Caldicot, modelling has predicted minimum water depths to increase up to 20 km upstream of the barrage by about 2 m on neap tides and 7 m on spring tides. At a distance of 50 km upstream (which represents the tidal limit) any differences would be negligible (ABPMer 2008a). Downstream of the barrage there would be a similar increase in minimum depth which would be 1 m on springs and there would be no change 20 km downstream (ABPMer 2008a). Flow speeds downstream of the barrage to Clevedon are expected to decrease. Although a decline is expected in both flood and ebb velocities it is expected that the ebb tide velocity would exhibit the greatest reduction when compared with the pre-barrage scenario (ABPMer 2008a). It is predicted that this reduction in ebb flow rates would lead to increased deposition within the basin (ABPMer 2008a). Negative effects on fish are expected to follow those outlined in the sections above.

Land connected lagoon

There is little information available regarding the potential effects of land connected lagoon impoundment on water quality or changes in habitat. One potential effect is that the presence of the lagoon will increase the speed of water flow through the main channel in the estuary. This could potentially have an effect on the movement of fish species including diadromous species migrating through the estuary i.e. fish would move faster with the flow and would experience greater resistance when swimming against it. The overall effects of this for fish, however, remain to be clarified. This increased water velocity could also increase levels of suspended sediment within the channel although it is not clear if this would have any effects on the invertebrate community within this area of the channel (which currently is a predominantly rock bed), or if it would have any effect on fish within the channel.

It is not known how fish would react to the presence of a lagoon impoundment. If they avoided entering the lagoon it would essentially represent a substantial loss of potential estuarine habitat for fish species (primarily feeding grounds for juvenile shad, estuarine yellow eel, elvers, estuarine river lamprey and suitable nursery habitat for marine migrants). It is possible that some fish may swim into the lagoon at a small size and then be less likely to swim back out past the lagoon wall when they are larger if they actively avoid the turbines. Individuals remaining within the lagoon in this manner would alter migration patterns of diadromous species and of marine migrant species using the lagoon. The tidal and sedimentation regime in the lagoon, and associated benthic invertebrate community also has the potential to change, producing an environment which differs from the current estuarine habitat, which could further influence fish communities within the area. The presence of a lagoon in some situations could also lead to loss of areas of saltmarsh which, as explained earlier, is an important habitat for a number of fish species. Conditions within the lagoon, however, are likely to be more sheltered than in the main estuary which could be of benefit when considering their potential function as a nursery area. A key issue, however, is the negotiation of turbines between the lagoon and main estuary as discussed in the 'Disruption to route of passage' section below.

Lagoons are expected to have a high flushing coefficient and water quality in the lagoon should be similar to the main estuary (ABPMer 2008a). Within the lagoons there may be a decrease in levels of suspended solids, although it is not clear if this would be sufficient to promote primary productivity within the lagoon, and hence the nature of this potential effect on the invertebrate community and fish is not yet known. The presence of tidal lagoon barrages on both sides of the estuary would further increase the velocity of water travelling through the main channel and the levels of suspended solids in the water column, which may increase the potential for negative effects on fish movement.

Water Quality Effects

There are a number of potential key changes to the water quality of the Severn Estuary following operation of the STP option which are expected to have direct and indirect effects on the fish community of the Severn Estuary. In summary, the key considerations are changes in salinity, temperature, suspended solids, dissolved oxygen and concentrations of pollutants.

Salinity

Due to the reduced tidal movement of water behind the STP scheme, freshwater from the rivers is expected to remain at the surface for a longer distance downstream within the estuary and the dense saline wedge would be likely to penetrate further upstream on flood tides. Consequently, following operation of STP it is predicted that there would be a downstream shift in the position of the saline water/freshwater interface at all stages of the tide. Salinity profiles play a key role in determining the distribution of fish throughout the estuary with species having different salinity tolerance/optimal ranges.

The direct effects of salinity on migrating salmon have rarely been studied and records of salinity, if made, are not usually reported. The most focused study is that of Smith *et al*. (1995) in the Aberdeenshire Dee. Much of the Dee Estuary is a harbour and strongly stratified, with a salt wedge extending for some 3 km of a total estuary length of 5.8 km. In the heavily modified, deepened channel of the River Dee salmon tended to remain in deeper, high salinity water for much of their time in the lower estuary, during estuarine migration. Clearly, salmon, sea trout and other diadromous species such as shad, lamprey and eel which migrate between saline and freshwater are well adapted to salinity change.

Marine stragglers are generally intolerant of reduced salinity (Franco *et al*. 2008). In contrast, many of the marine migrants can be found in waters with a wide range of salinities, for example Nilsson's pipefish can breed in water of relatively low salinity, and thin-lipped grey mullet can actively migrate to areas of low salinity including upstream of the tidal limit. Sand smelt which has resident populations within the Severn Estuary can occur in fully marine and freshwater environments in addition to the brackish waters of the estuary (Bird 2008). Although most fish species found in relatively large numbers within estuaries are extremely well adapted to variations in salinity, a period of gradual adjustment or acclimation may be needed for euryhaline fish to tolerate large changes (Claireaux *et al*. 1995). Cod are predominantly marine and are usually found in higher salinities than those experienced in estuaries. Lowering salinity from 30 to 26 was found to increase active oxygen consumption and heart rate in Atlantic cod, however, after a transitory period fish chose to remain in the lower salinity water (Claireaux *et al*. 1995). Although diadromous fish species are capable of osmoregulating in both fresh and saline waters, a number of physiological adaptations are required during the transitory process. As such they may be sensitive to sudden changes in salinity.

Regardless of their EUFG, individuals of most fish species near the saline water/freshwater interface are expected to move up and downstream in relation to the tidal excursion (Colclough *pers. comm.)* Overall, interactions between an altered saline regime within the estuary and fish communities are likely to be complex, however, in general it is expected that there could be a change in the distribution of fish species within the estuary resulting in an increase in the diversity of freshwater stragglers (e.g. three-spined stickleback, roach, carp etc.) at sites further downstream than those at which they are currently found and marine species (marine migrants, estuarine species and potentially some marine stragglers) could also penetrate further upstream than they do currently (Bird 2008). This increase in diversity could also potentially be associated with greater fish abundance within certain areas.

One potential concern within enclosed bodies of water is the development of saline stratification within the water column. Following the operation of the STP option the effects of the flood tide (especially on a spring tide) and associated water movement within the estuary would still be considerable. Saline stratification of the estuary is not expected on spring tides but during summer low flow conditions it may occur for short periods during neap tides (BES 1992, ABPMer 2008a) and such stratification can have implications for DO levels. Although salinity changes could be expected to influence the distribution of fish species and their invertebrate prey items, they are not predicted to inhibit passage of any diadromous species through the estuary. It is also likely that any changes in salinity would not influence the survival of diadromous species which feed and reside in the estuary, or have detrimental effects on the survival of marine species.

Temperature

There would be a likely decrease in water movement within the estuary following STP operation, and a potential for shallowing of the estuary basin if rates of sediment deposition were to increase (although modelling is required to clarify this). Both of these factors could contribute to an increase in mean water temperature within the estuary, especially during summer months. If there were changes in water temperature it could have significant implications for a number of species.

Temperature changes can have an effect on migratory fish species. Migratory salmonids can be relatively sensitive to high temperatures, with a range of 9 - 17°C being preferential for Atlantic salmon (Alabaster & Lloyd 1980). However, salmon have been shown to tolerate higher temperatures in estuaries when required (Alabaster & Gough 1986). It is known that adult twaite shad enter the Severn Estuary when the water temperature is 10.6-

12.3°C (Aprahamian 1988b). Upstream migration of elvers in the River Severn appeared to be triggered by temperatures greater than 10-11°C, with migration peaking at temperatures greater than 15-16°C (White & Knights 1997a). High temperatures have also been implicated in the outbreak of disease in eel (Tesch 1977).

It is known that annual patterns of fish community composition within the Severn Estuary are more closely related to influx of juvenile marine migrants at certain times of year, and subsequent emigration, than temperature and other environmental factors (Potter *et al*. 1986, 2001). However, variation in temperature can alter the water chemistry within the water column, and increases in temperature and salinity (alone or in combination) can lead to reduced DO levels in the water column (Bird 2008). Temperature changes can also affect metabolic rate of fish and growth rate, and can trigger key life-stage events (e.g. migration) in some species. Attrill & Power (2004), identified temperature-abundance relationships for 16 fish species from the Thames Estuary although such thermal resource partitioning in estuaries was found to have temporal rather than spatial dimensions. Although many species found in estuaries are likely to be tolerant of a wide range of temperatures, certain species can have specific temperature requirements. The maximum abundance of Nilsson's pipefish has been shown to occur at 14°C in the Thames estuary (Power & Attrill 2003) and bass begin to retreat from the Severn Estuary at water temperatures of 13-14°C (Kennedy 1972). Spawning of the freshwater straggler, three-spined stickleback, occurs mainly in April and May at a water temperature of about 14-18°C (Bird 2008). Elevated temperatures can also promote recruitment success of some species e.g. bass and sole (Holmes & Henderson 1990, Henderson & Seaby 2005) but may be detrimental for others such as the sea snail, which is at the extreme southern limit of its range in the Bristol Channel and Severn Estuary (Henderson & Seaby 1999).

Evidently, any long-term changes in temperature due to the presence of the STP option could have considerable implications for diadromous species passing through and utilising the estuary and for the estuarine fish assemblage as a whole, however, the extent of temperature change post-STP (if any) is yet to be determined. Any assessment of temperature changes and its resultant effects upon diadromous and estuarine fish species will need to take into consideration potential future alterations in the absence of a STP, in particular those resulting from climate change. Overall, it is expected that any immediate changes in mean water temperature in the estuary post-STP would not be sufficient to affect migratory or non-migratory fish within the estuary.

Suspended sediments

The Severn Estuary has a particularly high sediment load due to the high level of suspended solids from rivers entering the estuary, tidal flow rates and shape of the estuary (ABPMer 2008a). It has been predicted that reduction in ebb flow speeds upstream of the STP relative to flood speed would reduce bed shear stress by up to 10 times (DOE 1989). Although it has been suggested that this could result in increased rates of deposition (DOE 1989), other studies have suggested rates of erosion would increase and further clarification is required to understand the relative importance of these processes post-STP. The potentially reduced turbulence would also decrease the amount of resuspension of bed sediments. One theory predicts that turbidity within the estuary upstream of the STP option would be likely to be similar post-STP during flood tides, but could decrease considerably during neap tides (ABPMer 2008a).

Most adults of diadromous species passing through the estuary are not expected to feed heavily and changes in biota and food availability due to turbidity changes are not expected to affect these species. It is unclear what effects potential changes in the benthic community would have on juvenile shad, estuarine yellow eel, elvers and estuarine river lamprey which do feed within the estuary. The prime concern, however, with respect to some diadromous species (especially migratory salmonids) is that a decrease in turbidity would increase the susceptibility of migrating individuals to predation from marine piscivores (e.g. cod, pollack, bass). This is likely to be most evident in the waters immediately up and down stream of the STP option as migrating individuals may congregate behind the STP option while waiting for and identifying a suitable passage opportunity. With a combination of these aggregations and increased visibility for piscivores, predation levels of migrating fish could be higher post-STP.

Generally, estuarine fish are well adapted to survival in highly turbid environments and migratory species can readily pass through waters with high levels of suspended solids. The main effects of turbidity changes on estuarine fish would be due to the indirect effects on the estuarine food chain. If the turbidity decreased sufficiently to increase primary production due to greater light penetration of the water column and increased photosynthesis a number of changes could occur. Primarily, the increased food source could promote zooplankton growth and reproduction, resulting in higher zooplankton numbers (Glover 1984). If this occurred it would provide prey for species higher up the food chain including fish and suspension feeding invertebrates which are currently only present in low numbers in the estuary as the high turbidity levels reduces filtering efficiency (Glover 1984). Theoretically, these suspension feeders could also provide a rich new food source for adult and large juvenile fish potentially influencing the community of fish species present. It should be stressed, however, that this theory is currently under debate as although it is generally predicted that turbidity levels are likely to fall, the estuary would still be macrotidal and the decrease in turbidity may result in conditions characteristic of other estuaries in the UK (e.g. the Humber Estuary). Therefore, this could lead to slight increases in phytoplankton biomass but they would not necessarily result in the considerable changes to the ecosystem described above and the pre- and post-STP scenarios may be similar. In addition, the small invertebrates currently found in benthic sediments provide a good source of food items for juvenile fish, and a change in the benthic community may not necessarily be beneficial for small juveniles, especially if the size of invertebrates increases. Further geomorphological modelling is required to clarify the issue.

Dissolved oxygen

Alterations to DO levels within the estuary post-STP are complex and difficult to predict. It has been suggested that DO levels within the estuary could decrease on spring tides (ABPMer, 2008a). This is mainly due to resuspension of the near-bed fluid mud layer during spring tides (and to a lesser extent neap tides) which results in increased sediment oxygen demand due to greater bacterial activity within bottom sediments (Kirby *et al*. 2004). High suspended solid concentrations carried into the estuary on spring tides are also thought to be a cause (BES 1992). Consequently, when the degree of sediment input and resuspension is reduced post-STP, the extent of bacterial degradation could potentially be lowered resulting in improved DO levels. As mentioned above it is unlikely that turbidity would be reduced sufficiently for phytoplankton productivity to increase dramatically. If it did, however, then another important consideration is that this would lead to a higher biomass of organic material on the estuary bed for bacteria to degrade which could lead to lower DO levels. Modelling is required to confirm the likely changes in DO levels in the estuary post-STP.

Salmon are sensitive to low DO levels and this factor is of prime concern when assessing negative effects on a number of migratory species. Salmon can acclimatise rapidly, however, and in 30-80% seawater the threshold for survival for salmon is an oxygen concentration of 2.6 mg/l. In general DO within the estuary at the 50^{th} and 5^{th} percentile should be 5 and 2 mg/l, respectively (Alabaster & Lloyd 1980). Lamprey can also be affected by low oxygen sags, especially in summer when it is mainly sea lamprey which would be actively migrating through estuaries (Bird 2002). Shad have been found to avoid areas of low dissolved oxygen (<4 mg/l) with negative impacts on their migration through estuaries (Möller & Scholz 1991, Maes *et al.* 2007). Eel are very tolerant to low DO and can readily migrate through areas with low DO levels which is partly facilitated by the permeability of eel skin (Bird 2008).

If DO levels were found to decrease in areas of the estuary, mobile epifauna would be expected to move away from these areas and this would influence the distribution of fish consuming them (e.g. whiting which feed predominantly on common shrimp), (Henderson & Holmes 1989). Most marine and estuarine fish are tolerant of a wide range of DO levels and this factor is of prime concern when assessing negative effects on migratory species, especially migratory salmonids.

Modelling has indicated, however, that due to the level of turbidity remaining in the estuary post-STP and the flushing on each tide, low oxygen levels are unlikely (IMER 1982, Glover 1984). In addition, the reduced tidal mixing is likely to be counteracted by the increased ability of low salinity water to hold oxygen (solubility of oxygen in water increases with decreasing salinity) and overall there would be no significant change in oxygen concentrations (Bird 2008). It has also been suggested that even if oxygen levels were at 60-70% saturation during some periods post-STP it is not expected to put migratory fish at risk (Hull *pers. comm.*). Therefore, based on information available to date, changes in DO levels are not expected to have a negative effect on fish within the Estuary, including diadromous species. It would be beneficial, however, if further modelling could be conducted to confirm the above views regarding DO changes in the estuary post-STP.

Contaminants

Due to a history of pollution from industrial and urban wastewater discharges there are high concentrations of contaminants within sediments in the Severn Estuary. Diffuse pollution from agriculture and associated input of nutrients into the estuary has also increased considerably over recent times.

The current nutrient status within the Severn Estuary is described in ABPMer (2008a) although it is clear that further modelling is required to improve our current understanding of the quantities of contaminants entering the estuary and their rates of mobilisation. In summary, the concentrations of nitrates, phosphates and silicate decrease moving downstream along the estuary (Owens 1984) and nutrient concentrations have doubled over the last 20 years (ABPMer 2008a). Sediments within the estuary currently contain trace metals, heavy metals, radionuclides and organic pollutants (BES 1992). Sediments in the Bristol Channel and Severn Estuary have some of the highest concentrations of cadmium within the UK (DEFRA 2000).

Organic compounds from sewage and other sources discharged into the estuary are consumed by deposit feeders in the estuary which can provide a food source for fish utilising the estuary. Over-enrichment of such substances can lead to anoxia. Under the post-STP scenario, however, due to increased average near-shore water depths there would be an increase in initial dilution of individual discharges and reduced dispersion. In addition, any contaminants entering the surface layer of the water column would be carried further seaward than previously due to the increased downstream penetration of the surface water freshwater plume (Bird 2008). Overall, increased likelihood of anoxia is not expected therefore this is not likely to have a considerable effect on fish, although further modelling is required.

With regards to inorganic contaminants the main sources of exposure for fish is via ingestion or through the gill membrane. Currently, the high level of bed shear stress (especially on spring tides) constantly resuspends bottom sediments and promotes transfer of contaminants from sediment to the water column. These are then flushed out of the estuary on the ebb tide. Following operation of the STP option this resuspension of sediment would be less pronounced and in combination with the predicted increase in flushing time (ABPMer 2008a), the residence time of contaminants in the estuary could be greater post-STP (BES 1992). Such changes could lead to an increase in concentrations of contaminants within sediments, although as mentioned earlier it has been suggested that there could be more erosion than deposition and this would be elucidated via further modelling.

Soluble forms of cadmium are toxic to fish and are accumulated in the gills, liver and kidney. In Atlantic salmon the 5-day LC50 at 4°C and 10°C in freshwater has been measured at 1000 μg Cd/l and 50 μg Cd/l, respectively, with greater resistance noted for fish held at a salinity of 15 (Alabaster & Lloyd 1980). Zinc can cause asphyxia in salmon, and depending on the water hardness the maximum annual 95-percentile concentration for zinc in freshwater should not exceed 0.03-5 mg Zn/l. In saline environments, however, resistance to zinc concentrations is far greater and is maximised at a salinity of 31 (Alabaster & Lloyd 1980). Copper is also commonly present in polluted waters along with zinc. The maximum annual 95-percentile concentration for copper in freshwater should not exceed 5-112 μg Cu/l for migratory salmonids, although, as with other trace metals, salmon may be more tolerant of increased salinities (Alabaster & Lloyd 1980). Effects of trace metals on lamprey, eel and estuarine fish in general are less clearly defined although there may be behavioural in addition to physiological effects (Bird 2002).

There is little information regarding the effects of contaminants on most of the species recorded within the Severn Estuary. It is generally bivalve molluscs which accumulate toxins, although levels can also be high in some annelid worms (Crompton 1997). The degree to which an organism concentrates the pollutant varies according to both the pollutant and the species, however, if the toxin is not continuously excreted it will gradually accumulate within the organism during its life span. Fish consuming contaminated plants or animals are often unable to excrete the toxins themselves and, therefore, these conservative pollutants can bioaccumulate along the food chain up to the top predators. Heavy metals and metalloids including lead, mercury and arsenic can accumulate in the tissue of fish species including those of commercial importance. A study conducted in 1991 examined heavy metal concentrations in flounder (*Platichthys flesus*) in the estuary (Johnson 1992). It was found that over 90% of individuals comprising the largest size class exceeded the EC Environmental Quality Standard for mercury of 0.3 mg kg^{-1} fish wet weight. The presence of oestrogenic compounds can also result in endocrine disruption of marine fish, elevated levels of vitellogenin production have been recorded in flounder in the Mersey Estuary (Kleinkauf *et al.* 2004), and may be evident in top predators within the Severn Estuary although further research is required to clarify this.

Parsons Brinckerhoff (2008) suggests that it is necessary to determine dilution rates and the extent of the modification of spring-neap tidal cycle when assessing the likelihood of contaminants becoming more concentrated post-STP. Overall, it has been predicted that the concentrations of conservative pollutants (e.g. cadmium, nickel) could at worst double (ABPMer 2008a). In contrast, concentrations of non-conservative pollutants are unlikely to change (ABPMer 2008a). For the Severn Estuary, modelling indicated that the concentrations of both ammoniacal nitrogen and *Escherichia coli* (indicator of organic pollution), would be unlikely to change following operation of a STP option (BES 1992).

Consequently, it is considered that if concentrations of conservative pollutants did increase considerably this could have an effect on some fish species within the estuary, potentially including salmonids. Further modelling is required to increase understanding of any potential changes in volume of water within the estuary or possible altered salinity regimes in order to determine the potential for changes in concentrations of pollutants.

<u>Specific information for different tidal energy schemes</u>

Large barrage

Specific changes to water levels and velocity are indicated in the 'Habitat Changes' section. However, available information regarding the different STP options is sparse and at this stage scheme-specific assessments regarding changes in water quality are not possible.

Small barrage

Specific changes to water levels and velocity are indicated in the 'Habitat Changes' section. However, available information regarding the different STP options is sparse and at this stage scheme-specific assessments regarding changes in water quality are not possible.

Land connected lagoon

Some general information regarding changes in water velocity and flushing times is provided in the 'Habitat Changes' section. However, there is not enough information at present to make an assessment of specific changes in water quality following operation of tidal lagoons.

Angling

Freshwater angling

In terms of angling the most important rivers entering the Severn Estuary are the Rivers Usk, Wye and Severn each of which support migratory salmonids. The River Parrett is another major river which enters the inner Bristol Channel. Data regarding migratory salmonid angling effort within these rivers is available as annual declared rod days for salmon and sea trout, and the number of anglers declaring them (EA Fisheries Statistics published annually). These figures are however reliant on anglers making a return or accurately declaring days fished. In 2000 it was estimated that 442 anglers were fishing in the River Usk for an estimated 9,156 days in total (with a 5 year mean of 11,358 fishing days between 1996 and 2000). Greater numbers were recorded in the River Wye with an average of 1,712 anglers fishing between 1990 and 1994 (average of 22,080 fishing days), and 2,422 anglers in 1995 (21,030 fishing days), (EA 1997). The number of salmon rod days fished on the River Severn decreased from a range of 11,800-15,000 days between 1994 and 1998, to 4,000-7,000 days between 1999 and 2006. Migratory salmonid angling is extremely important to the region economically. The current average value per salmon, is estimated to be ~£9,000 for Wales (EA 2001), but this is only the value to fishery owners (the value of fishing rights), it takes no account of the value to anglers, the local economy or to the general public (G.Mawle, *pers.comm.*). The figure for the River Severn is around £1,000 (due to the predominance of coarse fishing in this river). In addition, some farmers are only able to retain land near the River Severn due to revenue from fishing and if that were to be reduced some farmers may be forced to leave the area. This could potentially have a great effect upon the wider UK and/or local economy.

Potential physical negative effects of tidal power generation in the Severn on salmon have been discussed earlier which could lead to loss of individuals. Further modelling to assess alterations to water quality and habitat changes post-STP is required to clarify if migratory fish species, including salmonids, would potentially be adversely affected by these changes. If there was an increase in availability of prey items this could potentially be beneficial for any migratory fish species if they were feeding during passage through the estuary. Overall, however, if a tidal power generation in the Severn were to have a negative effect on migratory salmonid movement/survival within the Severn Estuary this could influence migratory salmonid numbers and hence migratory salmonid angling success within the Severn Estuary rivers. Consequently, any loss of migratory salmonids, and other migratory species which are occasionally fished by anglers (e.g. eel) has both ecological and economic implications for the region. Furthermore, it is likely that were stocks of migratory angling species to be significantly reduced as a result of a tidal power generation scheme in the Severn that angling for these species would be restricted or stopped in order to conserve their populations. This having an even further economic effect.

Sea angling

The total annual catch in the Severn Estuary has been estimated in the past to be about 1000 tonnes (DOE 1989) although it is thought to have risen considerably over the past two decades. The main species considered to be targeted by anglers are bass, cod, whiting, grey mullet, flounder, sole, lesser spotted dogfish, small eyed ray, thornback ray, conger eel and ling which are also species of interest for commercial fishermen (DOE 1989). Shore and boat angling is popular, with rock stances giving best access to deeper waters and about 40 angling clubs fish in the Bristol Channel. Angling opportunities seaward of tidal power generation in the Severn are not expected to change considerably following operation of a tidal power generation scheme in the Severn in terms of availability of fishing areas (e.g. suitable sections of the intertidal zone are unlikely to change). However, if there was deposition of finer sediments over the rocky areas immediately downstream of a tidal power generation scheme in the Severn and colonisation by suspension feeders occurred, this could increase numbers of fish in a localised area resulting in richer angling grounds. However, further geomorphological modelling is necessary to confirm whether or not this would be likely to occur. Improved angling opportunities may also be created within the vicinity of turbine outfalls as a result of predatory piscivore fish being attracted by dead fish killed during turbine passage as well as those alive but disorientated.

Angling success is less consistent upstream of the possible position of a tidal power generation scheme in the Severn and access to suitable fishing areas is currently difficult due to extensive intertidal flats (DOE 1989). The expected post-STP increase in mean water level and decrease in tidal range within the Severn Estuary could therefore be beneficial for anglers if the area of the intertidal flat within the estuary was reduced, and if deeper water could be more readily accessed. This would be entirely dependant, however, on the extent of the changes post-STP and the current locations of suitable angling areas.

The above effects are mainly related to shore fishing and access to suitable angling sites. It is important to consider that about 30 charter vessels also operate in the Bristol Channel from ports near Ilfracombe and Swansea reaching fishing areas further offshore. Operation of a tidal power generation scheme in the Severn could restrict the passage of waves and wave height lee of the barrier would be influenced by reduced fetch lengths. Therefore, this could result in better sea conditions and more days may be suitable for boat based angling which would lead to potential increased revenue from fishing, although the likelihood of this occurring needs further investigation. Offshore angling is likely to be affected by any notable changes in the fish community within and outside the Severn Estuary due to operation of a tidal power generation scheme in the Severn. Although further modelling is needed to help accurately predict changes in the fish assemblages, a range of potential effects for fish communities are discussed in the 'Habitat Changes' section of this report. In addition, changes to the salinity regime would alter the distribution of freshwater and marine fish species which would be expected to increase species richness within areas of the estuary in which saline stratification is evident (as described in the 'Water Quality' section of this report).

Specific information for different tidal energy schemes

Large barrage

Specific changes to water levels and velocity are indicated in the 'Habitat Changes' section. However, available information regarding the different STP options is sparse and at this stage scheme-specific assessments of negative effects on angling are not possible.

Small barrage

Specific changes to water levels and velocity are indicated in the 'Habitat Changes' section. However, available information regarding the different STP options is sparse and at this stage scheme-specific assessments of negative effects on angling are not possible.

Land connected lagoon

Some general information regarding changes in water velocity and flushing times is provided in the 'Habitat Changes' section. However, there is not enough information at present to make an assessment of specific negative effects on angling following operation of tidal lagoons.

3.1.3 Potentially significant issues arising from tidal power options

There are various methods for scoping and the assessment method used in this paper is presented to show a clear process for the identification of significant issues that need to be considered within phase 2 of the assessment. All scoping methods have some limitations, and for this reason consultation is an important part of the process to ensure all significant issues are identified for phase 2.

Each of the above negative effects will occur in parallel and as such combined negative effects upon migratory and estuarine fish species will undoubtedly result. For example potential delay and disorientation resulting from turbine passage coupled with reduced turbidity and increased clarity is likely to result in indirect negative effects such as increased predation and subsequently increased injury and mortality. Furthermore, changes in water quality such as an extension of freshwater at the surface, an increase in temperature and increased concentrations of contaminants have the potential to stress migratory species undergoing osmotic and physiological changes. Any further stresses such as physical injuries from turbine and sluice passage are likely to exacerbate this stress and increase the level of resultant effect.

In addition to the combined effects of effects there is also potential for this to occur within effects. There is potential, for example, for fish to make multiple passages through turbines and sluices both throughout their life cycle and during one migratory period. There is also potential for cumulative injuries and stressors to not only reduce survival rates, for example from increased scale loss and resultant osmotic stress, but also reproductive success as a result of energy transfer from reproduction to survival and repair mechanisms.

The potential for successive negative effects and population losses during each life stage of migratory fish species will undoubtedly result in potential combined negative effects upon the overall population. For those species with important repeat spawner elements of their population, such as shad, cumulative and synergistic negative effects will have a greater effect upon the success and sustainability of the population.

It is not the intention to undertake an assessment of significance of negative effects at this stage. However a systematic process for the identification of significant issues that need to be considered within the main assessment has been undertaken. Potentially significant issues have been identified according to the definitions provided in Annex 1, Table 2 and are summarised in Table 3.1 below.

Upon consideration of the Natura 2000 sites within and connected to the Severn Estuary, the development of a tidal power scheme in this location is likely to contravene the targets set by the Habitats Directive. At this initial Scoping Phase of the SEA it is not possible to fully identify the extent to which the Directive will be contravened. As such no assessment can be made at this stage with regards to the implications of contravening the Directive or the extent of potential resulting penalties. Upon identification of a short list of STP options within phase 2 of the SEA and the provision of detailed scheme information, an indication of the extent of failure of the Habitats Directive and its possible implications will be made.

Alterations to migratory cues

Large barrage

- The likelihood of the migratory cues and natal homing of migratory fish species being disrupted by this scheme is **certain**.
- The duration of the disruption will be for the **lifetime** of the barrage and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).
- The frequency of disruption will be during each migratory cycle.
- There is some evidence to suggest that upon decommissioning of obstructions to passage excluded migratory species can return.

- Cumulative and synergistic negative effects will include effects upon multiple spawners as well as each of the relative effects acting in unison.

- The magnitude of negative effects upon the majority of migratory fish species will be **high**.

- A number of internationally protected migratory and estuarine fish species have the potential to be affected as a result of a large barrage scheme.

Small barrage

- The likelihood of the migratory cues and natal homing of migratory fish species being disrupted by this scheme is **certain**.

- The duration of the disruption will be for the **lifetime** of the barrage and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption will be during each migratory cycle.

- There is some evidence to suggest that upon decommissioning of obstructions to passage excluded migratory species can return.

- Cumulative and synergistic negative effects will include effects upon multiple spawners as well as each of the relative effects acting in unison.

- The magnitude of negative effects upon the majority of migratory fish species will be **high**.
- A number of internationally protected migratory and estuarine fish species have the potential to be affected as a result of a small barrage scheme.

Land connected lagoon

- The likelihood of the migratory cues and natal homing of migratory fish species being disrupted by this scheme is **probable**.

- The duration of the disruption will be for the **lifetime** of the lagoon and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption will be during each migratory cycle.

- There is some evidence to suggest that upon decommissioning of obstructions to passage excluded migratory species can return.

- Cumulative and synergistic negative effects will include effects upon multiple spawners as well as each of the relative effects acting in unison.

- The magnitude of negative effects upon the majority of migratory fish species will be **high**.

- A number of internationally protected migratory and estuarine fish species have the potential to be affected as a result of a land connected lagoon scheme.

<u>Disruption to route of passage</u>

The relative magnitude of this effect will depend largely upon the barrages position within the estuary. With regards to the migratory species the number of rivers upstream of the barrage will be critical in determining the level of effect upon the migratory fish populations. Negative effects will occur for both the populations within the rivers upstream as well as those downstream due to the straying nature of many of the migratory species.

<u>*Large barrage*</u>

- The probability of the route of passage of migratory and estuarine fish species being disrupted by this scheme is **certain**.

- The duration of the disruption will be for the **lifetime** of the barrage and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption will be during each migratory cycle with potentially numerous turbine passes due to high tidal excursion.

- There is some evidence to suggest that upon decommissioning of obstructions to passage excluded migratory species can return.

- Cumulative and synergistic negative effects will include effects upon each life stage including juvenile and adult, numerous turbine passes for multiple spawners as well as each of the relative effects acting in unison.

- The magnitude of negative effects upon the majority of migratory fish species will be **high**.

- Disruptions to route of passage and turbine injury/mortality will potentially be seen for both those populations from rivers upstream of the barrage as well as those below due to the straying nature of many of the species.

- The ecological value of the area affected is considered important in particular for lamprey, shad, migratory salmonids and eel. The shad population in particular is likely to be vulnerable as the entire UK population has the potential to be affected to varying degrees.

- A number of internationally protected migratory and estuarine fish species have the potential to be affected as a result of a large barrage scheme.

Small barrage

- The probability of the route of passage of migratory and estuarine fish species being disrupted by this scheme is **certain**.

- The duration of the disruption will be for the **lifetime** of the barrage and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption will be during each migratory cycle with potentially numerous turbine passes due to high tidal excursion.

- There is some evidence to suggest that upon decommissioning of obstructions to passage excluded migratory species can return.

- Cumulative and synergistic negative effects will include effects upon each life stage including juvenile and adult, numerous turbine passes for multiple spawners as well as each of the relative effects acting in unison.

- The magnitude of negative effects upon the majority of migratory fish species will be **high**.

- Disruptions to route of passage and turbine injury/mortality will potentially be seen for both those populations from rivers upstream of the barrage as well as those below due to the straying nature of many of the species.

- The ecological value of the area affected is considered important in particular for lamprey, shad, migratory salmonids and eel. The shad population in particular is likely to be vulnerable as the entire UK population has the potential to be affected to varying degrees.

- A number of internationally protected migratory and estuarine fish species have the potential to be affected as a result of a small barrage scheme.

Land connected lagoon

- The probability of the route of passage of migratory and estuarine fish species being disrupted by this scheme is **probable**.

- The duration of the disruption will be for the **lifetime** of the lagoon and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption will be during each migratory cycle with potentially numerous turbine passes due to high tidal excursion and straying and residence.

- There is some evidence to suggest that upon decommissioning of obstructions to passage excluded migratory species can return.

- Cumulative and synergistic negative effects will include effects upon each life stage including juvenile and adult, numerous turbine passes for multiple spawners as well as each of the relative effects acting in unison.

- The magnitude of negative effects upon the majority of migratory fish species will be **high**.

- Disruptions to route of passage and turbine injury/mortality will potentially be seen for any straying and migrating individuals.

- The ecological value of the area affected is considered important in particular for lamprey, shad, migratory salmonids and eel. The shad population in particular is likely to be vulnerable as the entire UK population has the potential to be affected to varying degrees.

- A number of internationally protected migratory and estuarine fish species have the potential to be affected as a result of a land connected lagoon scheme.

<u>Habitat Changes</u>

The relative magnitude of this effect will depend largely upon whether a barrage scheme or tidal lagoon scheme is selected. More detail is currently available regarding the potential effects of the barrages on estuarine habitat than is available for the tidal lagoon options. Consequently, the assessment below is based on relevant information available for the barrage options and expert judgement.

<u>Large barrage</u>

- The likelihood of changes in habitat type/availability affecting fish communities within the Severn Estuary due to the scheme is **certain**.

- The duration of the disruption will be for the **lifetime** of the barrage and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption depends on the periods when marine migrants, marine and freshwater stragglers and diadromous species are within the estuary.

- It is expected that upon decommissioning of the barrage some changes to habitat would be reversible. Loss of saltmarsh, however, is likely to be a long-term loss of habitat.

- Cumulative and synergistic negative effects will include effects upon each life stage including juveniles and adults, and numerous estuary passes for multiple spawners as well as each of the relative effects discussed for changes to habitat acting in combination.

- The magnitude of negative effects upon the majority of fish species including migratory fish species is expected to be **medium**. If there is a considerable loss of intertidal saltmarsh habitat which is currently used by protected species e.g. estuarine yellow eel and juvenile shad, then the magnitude could be **high.**

- Effects of changes to habitat on fish communities in the estuary would primarily be evident within the estuary. Loss of juveniles could have knock-on negative effects on marine migrants downstream of the barrage. Similarly, there could be negative effects on population size of subsequent generations of diadromous species in the rivers flowing into the estuary.

- The ecological value of the area affected is considered important in particular for lamprey, shad, migratory salmonids and eel. The shad population in particular is likely to be vulnerable as the entire UK population has the potential to be affected to varying degrees. The estuary is valuable as a nursery area for marine migrants.
- A number of internationally protected migratory and estuarine fish species have the potential to be affected as a result of a large barrage scheme.

Small barrage

- The likelihood of changes in habitat type/availability affecting fish communities within the Severn Estuary due to the scheme is **certain**.

- The duration of the disruption will be for the **lifetime** of the barrage and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption depends on the periods when marine migrants, marine and freshwater stragglers and diadromous species are within the estuary.

- It is expected that upon decommissioning of the barrage some changes to habitat would be reversible. Loss of saltmarsh, however, is likely to be a long-term loss of habitat.

- Cumulative and synergistic negative effects will include effects upon each life stage including juveniles and adults, and numerous estuary passes for multiple spawners as well as each of the relative effects discussed for changes to habitat acting in combination.

- The magnitude of negative effects upon the majority of fish species including migratory fish species is expected to be **medium**. If there is a considerable loss of intertidal saltmarsh habitat which is currently used by protected species e.g. estuarine yellow eel and juvenile shad, then the magnitude could be **high.**

- Effects of changes to habitat on fish communities in the estuary would primarily be evident within the estuary. Loss of juveniles could have knock-on negative effects on marine migrants downstream of the barrage. Similarly, there could be negative effects on population size of subsequent generations of diadromous species in the rivers flowing into the estuary.

- The ecological value of the area affected is considered important in particular for lamprey, shad, migratory salmonids and eel. The shad population in particular is likely to be vulnerable as the entire UK population has the potential to be affected to varying degrees. The estuary is valuable as a nursery area for marine migrants.

- A number of internationally protected migratory and estuarine fish species have the potential to be affected as a result of a small barrage scheme.

Land connected lagoon

- The likelihood of changes in habitat type/availability affecting fish communities within the Severn Estuary due to the scheme is **certain**.

- The duration of the disruption will be for the **lifetime** of the lagoon and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption depends on the periods when marine migrants, marine and freshwater stragglers and diadromous species are within the estuary.

- It is expected that upon decommissioning of the tidal lagoon some changes to habitat would be reversible. Loss of saltmarsh, however, is likely to be a long-term loss of habitat.

- Cumulative and synergistic negative effects will include effects upon each life stage including juveniles and adults, and numerous estuary passes for multiple spawners as well as each of the relative effects discussed for changes to habitat acting in combination.

- The magnitude of negative effects upon the majority of fish species including migratory fish species is expected to be **medium**. If there is a considerable loss of intertidal saltmarsh habitat which is currently used by protected species e.g. estuarine yellow eel and juvenile shad, then the magnitude could be **high.**

- Effects of changes to habitat on fish communities in the estuary would primarily be evident within the estuary. Loss of juveniles could have knock-on negative effects on marine migrants outside the tidal lagoon. Similarly, there could be negative effects on population size of subsequent generations of diadromous species in the rivers flowing into the estuary.

- The ecological value of the area affected is considered important in particular for lamprey, shad, migratory salmonids and eel. The shad population in particular is likely to be vulnerable as the entire UK population has the potential to be affected to varying degrees. The estuary is valuable as a nursery area for marine migrants.

- A number of internationally protected migratory and estuarine fish species have the potential to be affected as a result of a land connected lagoon scheme.

Water Quality Effects

There would be variation in the degree of effects of changes in water quality among the various options for the barrage location and tidal lagoons. The following assessment of potential effects is based on the data available to date and expert judgement.

Large barrage

- The likelihood of changes in water quality affecting fish communities within the Severn Estuary due to the scheme is **probable.**

- The duration of the disruption will be for the **lifetime** of the barrage and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption depends on the periods when marine migrants, marine and freshwater stragglers and diadromous species are within the estuary.

- It is expected that upon decommissioning of the barrage some changes to water quality would be reversible.

- Cumulative and synergistic negative effects will include effects upon each life stage including juveniles and adults, and numerous estuary passes for multiple spawners as well as each of the relative effects discussed for water quality acting in combination.

- The magnitude of negative effects upon the majority of fish species including migratory fish species is expected to be **medium**.

- Effects of changes to water quality on fish communities in the estuary would primarily be evident within the estuary. Loss of juveniles could have knock-on negative effects on marine migrants downstream of the barrage. Similarly, there could be negative effects on population size of subsequent generations of diadromous species in the rivers flowing into the estuary.

- The ecological value of the area affected is considered important in particular for lamprey, shad, migratory salmonids and eel. The shad population in particular is likely to be vulnerable as the entire UK population has the potential to be affected to varying degrees. The estuary is valuable as a nursery area for marine migrants.

- A number of internationally protected migratory and estuarine fish species have the potential to be affected as a result of a large barrage scheme.

Small barrage

- The likelihood of changes in water quality affecting fish communities within the Severn Estuary due to the scheme is **probable.**

- The duration of the disruption will be for the **lifetime** of the barrage and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption depends on the periods when marine migrants, marine and freshwater stragglers and diadromous species are within the estuary.

- It is expected that upon decommissioning of the barrage some changes to water quality would be reversible.

- Cumulative and synergistic negative effects will include effects upon each life stage including juveniles and adults, and numerous estuary passes for multiple spawners as well as each of the relative effects discussed for water quality acting in combination.

- The magnitude of negative effects upon the majority of fish species including migratory fish species is expected to be **medium**.

- Effects of changes to water quality on fish communities in the estuary would primarily be evident within the estuary. Loss of juveniles could have knock-on negative effects on marine migrants downstream of the barrage. Similarly, there could be negative effects on population size of subsequent generations of diadromous species in the rivers flowing into the estuary.

- The ecological value of the area affected is considered important in particular for lamprey, shad, migratory salmonids and eel. The shad population in particular is likely to be vulnerable as the entire UK population has the potential to be affected to varying degrees. The estuary is valuable as a nursery area for marine migrants.

- A number of internationally protected migratory and estuarine fish species have the potential to be affected as a result of a small barrage scheme.

Land connected lagoon

- The likelihood of changes in water quality affecting fish communities within the Severn Estuary due to the scheme is **probable.**

- The duration of the disruption will be for the **lifetime** of the lagoon and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption depends on the periods when marine migrants, marine and freshwater stragglers and diadromous species are within the estuary.

- It is expected that upon decommissioning of the tidal lagoons some changes to water quality would be reversible.

- Cumulative and synergistic negative effects will include effects upon each life stage including juveniles and adults, and numerous estuary passes for multiple spawners as well as each of the relative effects discussed for water quality acting in combination.

- The magnitude of negative effects upon the majority of fish species including migratory fish species is expected to be **medium**.

- Effects of changes to water quality on fish communities in the estuary would primarily be evident within the estuary. Loss of juveniles could have knock-on negative effects on marine migrants outside the tidal lagoon. Similarly, there could be negative effects on population size of subsequent generations of diadromous species in the rivers flowing into the estuary.

- The ecological value of the area affected is considered important in particular for lamprey, shad, migratory salmonids and eel. The shad population in particular is likely to be vulnerable as the entire UK population has the potential to be affected to varying degrees. The estuary is valuable as a nursery area for marine migrants.

- A number of internationally protected migratory and estuarine fish species have the potential to be affected as a result of a land connected lagoon scheme.

Angling

Effects on angling of a barrage or tidal lagoon scheme are likely to differ greatly, especially with respect to changes in water level and access to current angling sites. However, little specific information is available regarding the effects on angling of the different schemes. Consequently, the assessment below is based on information available and expert judgement.

Large barrage

- The likelihood of negative effects on angling within the Severn Estuary and its associated rivers due to the scheme is **probable**.
- The duration of the disruption will be for the **lifetime** of the barrage and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).
- The frequency of disruption depends on the periods when species targeted by anglers are near angling grounds in the estuary.
- It is expected that upon decommissioning of the barrage negative effects on angling may be reversible where populations have not been lost locally or from the UK.
- Cumulative and synergistic negative effects will include effects upon all of the different species usually targeted by anglers including migratory and non-migratory species. It would involve considerations of economic, as well as ecological effects.
- The magnitude of negative effects upon angling is expected to be **medium**.
- Any negative effects on migratory fish would be evident in terms of catches at fishing sites within the rivers. Negative effects on marine and estuarine fish would be evident within the Severn Estuary.

- The value of angling is considered important. In addition to having recreational and social value, it is of economic importance for the region around the Severn Estuary river catchments and Severn Estuary.

- A number of species of migratory and non-migratory fish targeted by anglers have the potential to be affected as a result of a large barrage scheme.

Small barrage

- The likelihood of negative effects on angling within the Severn Estuary and its associated rivers due to the scheme is **probable**.

- The duration of the disruption will be for the **lifetime** of the barrage and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption depends on the periods when species targeted by anglers are near angling grounds in the estuary.

- It is expected that upon decommissioning of the barrage negative effects on angling may be reversible where populations have not been lost locally or from the UK.

- Cumulative and synergistic negative effects will include effects upon all of the different species usually targeted by anglers including migratory and non-migratory species. It would involve considerations of economic, as well as ecological effects.

- The magnitude of negative effects upon angling is expected to be **medium**.

- Any negative effects on migratory fish would be evident in terms of catches at fishing sites within the rivers. Negative effects on marine and estuarine fish would be evident within the Severn Estuary.

- The value of angling is considered important. In addition to having recreational and social value, it is of economic importance for the region around the Severn Estuary river catchments and Severn Estuary.

- A number of species of migratory and non-migratory fish targeted by anglers have the potential to be affected as a result of a small barrage scheme.

Land connected lagoon

- The likelihood of negative effects on angling within the Severn Estuary and its associated rivers due to the scheme is **probable**.

- The duration of the disruption will be for the **lifetime** of the lagoon and potentially permanent following its decommissioning in the case of populations (of species or genetically unique populations) becoming extinct locally or UK wide (10 years +).

- The frequency of disruption depends on the periods when species targeted by anglers are near angling grounds in the estuary.

- It is expected that upon decommissioning of the tidal lagoon negative effects on angling may be reversible where populations have not been lost locally or from the UK.

- Cumulative and synergistic negative effects will include effects upon all of the different species usually targeted by anglers including migratory and non-migratory species. It would involve considerations of economic, as well as ecological effects.

- The magnitude of negative effects upon angling is expected to be **medium**.

- Any negative effects on migratory fish would be evident in terms of catches at fishing sites within the rivers. Negative effects on marine and estuarine fish would be evident within the Severn Estuary.

- The value of angling is considered important. In addition to having recreational and social value, it is of economic importance for the region around the Severn Estuary river catchments and Severn Estuary.

- A number of species of migratory and non-migratory fish targeted by anglers have the potential to be affected as a result of a land connected lagoon scheme.

Table 3.1 Identification of potentially significant issues

Receptor & Sensitivity	Large barrage		Small barrage		Land connected lagoon	
	Description of Change & Magnitude	Significance	Description of Change & Magnitude	Significance	Description of Change & Magnitude	Significance
Shad - High	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue
	Changes to water quality - **High**	Potentially significant issue	Changes to water quality - **High**	Potentially significant issue	Changes to water quality - **High**	Potentially significant issue
	Changes to habitat - **High**	Potentially significant issue	Changes to habitat - **High**	Potentially significant issue	Changes to habitat - **High**	Potentially significant issue
	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue
	Angling - **Low**	Not significant	Angling - **Low**	Not significant	Angling - **Low**	Not significant
Lamprey – High	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue
	Changes to water quality - **High**	Potentially significant issue	Changes to water quality - **High**	Potentially significant issue	Changes to water quality - **High**	Potentially significant issue
	Changes to habitat - **High**	Potentially significant issue	Changes to habitat - **High**	Potentially significant issue	Changes to habitat - **High**	Potentially significant issue
	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue
	Angling - **Low**	Not significant	Angling - **Low**	Not significant	Angling - **Low**	Not significant
Salmon – High	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue
	Changes to water quality - **High**	Potentially significant issue	Changes to water quality - **High**	Potentially significant issue	Changes to water quality - **High**	Potentially significant issue

Receptor & Sensitivity	Large barrage		Small barrage		Land connected lagoon	
	Description of Change & Magnitude	**Significance**	**Description of Change & Magnitude**	**Significance**	**Description of Change & Magnitude**	**Significance**
	Changes to habitat - **High**	Potentially significant issue	Changes to habitat - **High**	Potentially significant issue	Changes to habitat - **High**	Potentially significant issue
	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue
	Angling - **High**	Potentially significant issue	Angling - **High**	Potentially significant issue	Angling - **High**	Potentially significant issue
Eel – High	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue
	Changes to water quality - **High**	Potentially significant issue	Changes to water quality - **High**	Potentially significant issue	Changes to water quality - **High**	Potentially significant issue
	Changes to habitat - **High**	Potentially significant issue	Changes to habitat - **High**	Potentially significant issue	Changes to habitat - **High**	Potentially significant issue
	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue
	Angling - **High**	Potentially significant issue	Angling - **High**	Potentially significant issue	Angling - **High**	Potentially significant issue
Sea trout – Medium	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue
	Changes to water quality - **High**	Potentially significant issue	Changes to water quality - **High**	Potentially significant issue	Changes to water quality - **High**	Potentially significant issue
	Changes to habitat - **High**	Potentially significant issue	Changes to habitat - **High**	Potentially significant issue	Changes to habitat - **High**	Potentially significant issue

Receptor & Sensitivity	Large barrage		Small barrage		Land connected lagoon	
	Description of Change & Magnitude	**Significance**	**Description of Change & Magnitude**	**Significance**	**Description of Change & Magnitude**	**Significance**
	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue
	Angling - **High**	Potentially significant issue	Angling - **High**	Potentially significant issue	Angling - **High**	Potentially significant issue
Sturgeon – High	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue
	Changes to water quality - **High**	Potentially significant issue	Changes to water quality - **High**	Potentially significant issue	Changes to water quality - **High**	Potentially significant issue
	Changes to habitat - **High**	Potentially significant issue	Changes to habitat - **High**	Potentially significant issue	Changes to habitat - **High**	Potentially significant issue
	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue
	Angling - **Low**	Not significant	Angling - **Low**	Not significant	Angling - **Low**	Not significant
Estuarine fish species - Medium	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue	Changes to migration cues - **High**	Potentially significant issue
	Changes to water quality - **Medium**	Potentially significant issue	Changes to water quality - **Medium**	Potentially significant issue	Changes to water quality - **Medium**	Potentially significant issue
	Changes to habitat - **Medium**	Potentially significant issue	Changes to habitat - **Medium**	Potentially significant issue	Changes to habitat - **Medium**	Potentially significant issue
	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue	Disruption to route of passage including turbine passage - **High**	Potentially significant issue

Receptor & Sensitivity	Large barrage		Small barrage		Land connected lagoon	
	Description of Change & Magnitude	**Significance**	**Description of Change & Magnitude**	**Significance**	**Description of Change & Magnitude**	**Significance**
	Angling - **Medium**	Potentially significant issue	Angling - **Medium**	Potentially significant issue	Angling - **Medium**	Potentially significant issue

3.2 Scope of Assessment Proposed in Phase 2

3.2.1 Introduction

Based on the review of existing information and the potentially significant environmental issues, the following suggestions are made in relation to the scope of the assessment under phase 2.

At this stage, these proposals are suggestions. A prioritised programme of SEA phase 2 studies will be developed, taking into account the key environmental risks across all topics. The programme will reflect the strategic nature of the study and will not address local issues.

The programme will also be based in part on responses to the consultation on the scoping report and supporting topic papers.

3.2.2 Potentially significant issues to be considered

In light of the protected status either internationally or nationally of all of the migratory fish species and a number of the estuarine species within the Severn Estuary the following negative effects are considered to be potentially significant;

- Alterations to migratory cues and their associated potential negative effects upon the migratory and estuarine fish populations.
- Disruption to route of passage including turbine passage related negative effects.
- Effects upon diadromous and estuarine fish populations with regards to changes in intertidal habitat availability and quality.
- Effects upon diadromous and estuarine fish populations with regards to changes to water quality.
- Effects upon freshwater and sea angling and their associated socio-economic issues.
- These potentially significant issues within the Phase 2 assessment will be set in the context of EU eel regulations escapement targets, salmon conservation limits and management targets and Habitats Directive favourable condition assessment targets as detailed within Table 4.2.

3.2.3 Suggested data collection

There are many studies that could be suggested that would help fill our knowledge gaps and elucidate mitigation and compensation measures as identified in this paper. These studies would all aid the assessment of an STP project. Indeed, many may over time prove essential to understand fully the risks to fish prior to the implementation of a scheme.

However, studies progressed in Phase 2 of the SEA need to be prioritised towards informing the high-level decision-making entailed within the SEA and wider Feasibility Study; whilst still contributing to subsequent assessment of the potential effects and solutions for a specific STP project.

The following section describes those desk studies that it is suggested are undertaken within the investigation period of SEA Phase 2. Field studies will also be essential before any STP option can be taken forward. Whilst it is highly desirable that field studies are undertaken at the earliest opportunity so as to inform the option development process, there is a need for desk based reviews to be undertaken first and the findings of such incorporated into future field investigations. There are also technical and practical considerations that restrict the feasibility of field studies within the timeframe available for Phase 2 of the SEA. For example, most field techniques that could be used to explore areas of uncertainty in this case, will require a significant period of methodological development, and any reliable results would therefore be unlikely to be forthcoming within the next year. For completeness however those field studies considered as priorities for future stages of the assessment process are identified.

Suggested Phase 2 data collection – desk based

Turbine passage study

Although technologies designed to reduce fish injury and mortality are emerging, in particular from the US and Canada, it may not be feasible to implement these within the designs of a tidal power project in the Severn Estuary. As such it is suggested that engineers and fish specialists liaise regarding possible design alterations to reduce fish damage and loss. Desk based investigations would be undertaken to examine the possible bypass measures and turbine design alterations. This would include discussions with those currently developing and investigating emerging technologies overseas. In the first instance this study would be largely desk based with fisheries specialists and engineers interfacing.

Although outside of the scope of the suggested review outlined above, Phase 2 of the SEA process would likely further benefit from some aspects of turbine design modelling. This would provide a greater understanding of the pressure and turbulence conditions out with and within the turbines as well as the anticipated operation regime. Some of this knowledge may already exist however and it is not until the desk based investigation described here is completed that it will be possible to define the extent of such a modelling exercise.

Assessment of the economic impacts to fishing

Assessments of the values of the recreational (freshwater and estuarine), heritage net and commercial fisheries of the Severn Estuary are proposed. These assessments will cover the value of the fisheries to the netsmen and angling clubs only and will not include aspects of the socio-economic valuations of the fisheries. Information gathered from the assessments will be used to assess the potential economic impacts to these bodies from an STP scheme for determination of the requirement for compensation measures to be applied within option costing.

It is anticipated that information for this assessment will largely be gathered from existing published and grey literature. Where applicable for determination of approximate compensation costs an indication of the number of stakeholders will be made. Data collection regarding the economic value of the fisheries and impacts of fish population losses will include questionnaires and interviews with anglers, fishery owners and netsmen where appropriate. In addition to stakeholders, consultation will also be made with relevant local and national Environment Agency staff.

Assessment of current telemetry technologies

Telemetry can be defined as the science of conveying information from one location to another. With acoustic and radio telemetry, sound and radio waves are utilised respectively to convey that information. The respective technologies have different uses and capabilities. For instance in deep or highly conductive water, e.g. salt water, radio telemetry is not practical. However in shallow freshwaters radio telemetry is generally preferred.

Major advances in equipment and techniques took place during the 1980's as a result of the requirements of studies relating to hydropower dams. These advances have continued into the millennium and indeed miniaturisation and advancement in telemetry equipment is an ongoing and ever changing process.

The Severn Estuary is an inhospitable environment and the scale of the telemetry based investigations likely required is unprecedented. As such a thorough review of current telemetry technologies and the most recent advances made relating to their capabilities is required. In particular an understanding of the current sizes and functionality of Combined Acoustic and Radio Tags (CART) is essential to inform future field based work.

Studies to determine the feasibility, success and confidence of mitigation and compensation measures

The suggestions for Phase 2 studies given below relate to the feasibility, success and confidence of mitigation and compensation measures which are themselves discussed more fully within Section 5.1.

The confidence surrounding the success of a number of the mitigation and compensation measures have been ranked as being unknown or low. This is primarily because such measures have not been undertaken before on this scale or the techniques are novel. It is suggested within Phase 2 of the SEA process that studies are restricted to desk based investigations to help determine feasibility and potential of each of the mitigation and compensation measures. Based upon these investigations it may however be necessary after Phase 2 to undertake lab or field based studies to fully assess the confidence of their success. This is particularly important for protected fish species where mitigation and compensation measures are likely to be critical for the success of the STP option. Summaries of study suggestions for each mitigation/compensation measure are briefly given below. Suggestions for Phase 2 of the SEA are currently restricted to desk based assessments, within which recommendations for field and lab based studies will be identified where necessary:

- ***Sluice design and fish swimming speeds*** – A detailed literature review of possible fish sluice designs for each of the species and life stages to be protected is suggested. Such a review may include the assessment of solutions used on other schemes such as Annapolis Royal, the behaviour of the different species with regards to passage including swimming speeds, movement through dark, submerged tunnels and possible measures to attract fish to passages through/over sluices. This review will partly assist in the determination of placement and operation of sluices both vertically and horizontally as well as the assessment of feasibility and predicted success.

- ***Behavioural screening*** – A detailed literature review of the hearing threshold and other behavioural stimuli such as light sensitivity of the key fish species is suggested. The feasibility and physical positioning of behavioural screening however will largely be dependent upon the water velocities approaching the STP option. Although beyond the scope of this proposed desk based study it is likely that modelling of the velocities approaching each of the STP options will be required after Phase 2. From this review, the feasibility of the operation of fish deterrent technologies could be determined once fish swimming speeds are factored in (see below for further details).

- ***Fish transportation*** – A desk based assessment of the feasibility of transporting fish manually past the structure (capture and transport past the STP either up or downstream, to its destination river or the sea) is suggested. Investigations are likely to centre on examples from other installations, implications with respect to changes in osmotic balance and the feasibility of catching individuals within the Severn Estuary or tributary rivers for transportation purposes.

- ***Habitat enhancement/creation*** – A desk based review of fish habitat enhancement/creation is required for each of the different species and life stages to be protected, in particular those where populations are currently restricted such as shad. The habitat requirements of each of the species and life stages would need to be assessed along with the feasibility of implementation and its likely success. The desk based study would encompass rivers and estuary areas within the STP affected area as well as a number of primary sites identified outside of it to help understand the mitigation and compensation possibilities.

- ***Stocking*** – A desk based investigation is suggested to determine the requirements, feasibility, location (mitigation and compensation) and predicted success of rearing and stocking programmes (rearing fish within a hatchery and releasing them into a river) for each of the species of concern. For those species not currently stocked within the UK, including shad and lamprey, the study is likely to involve gathering information from other countries. Evidence for surrogate species which may act as analogues for those species potentially under threat within the Severn Estuary and estuary rivers will also be considered.

- ***Translocation*** – A desk based review is suggested to assess the feasibility, location and predicted success of translocation programmes (capture, transport and release/introduction of fish from one river catchment to another) for each of the protected species. Experience is likely to be gained from other countries and potentially surrogate species in particular those species for which a paucity of knowledge currently exists in the UK such as shad and lamprey.

- ***Pheromone release*** – Information is available regarding the potential for the use of pheromones to guide, attract and deter lamprey. There may however, be further potential for use of this technique with some of the other homing species. It is therefore suggested that a desk based review be undertaken to explore the potential opportunities of this technique with both lamprey and other species. Experience is likely to be gained from other countries as well as surrogate species.

- ***Fish herding*** – Following on from the study into behavioural screening it is suggested that an investigation be undertaken to determine the feasibility and likely success of fish herding as a possible mitigation measure.

- ***Additional sites for inclusion in the SAC list*** – It is suggested that a desk based review be undertaken to identify possible undesignated rivers which currently support populations of potentially affected species, which could be added to the SAC list. Data to inform this assessment are likely to originate predominantly from the NBN gateway, statutory and conservation bodies and consultancies. These data will be analysed to identify a number of primary sites for assessment.

- ***Life history model*** – It is suggested that life history models be developed for the key species that will potentially be affected by the STP to assist with the assessment of relative effects. It would be beneficial to determine where population pressures are likely to be greatest within a life cycle and understand the scale and cumulative impacts of losses on population dynamics. This knowledge will assist in the determination of relative effects of the STP at different life stages as well as the identification of protection, mitigation and compensation priorities. Such an assessment is likely to centre upon the protected species formulated from information held within published literature. Whilst the life history model for salmon is relatively well defined this is not the case for other species such as shad, lamprey and eel.

Suggested future (post Phase 2) data collection – field and laboratory based

Investigation into the behaviour of adult migratory species

A number of knowledge gaps regarding the behaviour of migratory fish species have been identified within the 'assessment of sensitivity of receptors to change' section of this topic paper. Shad are considered to be a priority species for investigation as they are at greatest risk of turbine related mortalities and due to their life history strategy which entails multiple repeat spawning. There is however a significant paucity of knowledge regarding their behaviour and critically the entire UK population of this internationally protected species is at risk. Lamprey and eel are also considered to be high research priority species predominantly due to the absence of data regarding the behaviour of these species in general and specifically within the Severn Estuary. It is therefore suggested that information generated from investigations into the migratory behaviour of these protected species is used to help determine turbine impacts.

As fish species are distinct and require different collection and monitoring techniques the studies are presented, and can be undertaken, as single subject studies. However it is suggested that the studies are undertaken as a rolling programme monitoring the different species as they migrate through the estuary.

For the assessment of migratory adult behaviour, tagging and tracking studies are suggested to determine the depth of their movement in the water column, position across the estuary and transit/residence time. However, due to the relative scarcity of knowledge and experience regarding the tracking of these species and the practical difficulty of working in the environment of the Severn Estuary, it has been suggested by the Environment Agency that preliminary investigations be undertaken in other estuaries that pose less practical difficulty. The specific estuaries recommended by the EA are the Eden and Ouse in particular for studies upon adult lamprey (river and sea) and silver eel. Investigations would include planning, developing and testing of suitable techniques, e.g. fish capture and tag attachment, as well as an initial fieldwork phase. Such work would aim to yield information on behavioural considerations that may be applicable to the Severn Estuary.

As outlined above, these preliminary investigations will not be undertaken within the SEA Phase 2. It should be noted however that the absence of this data collection within Phase 2 of the SEA may, depending on their likely success, limit the knowledge regarding the migratory behaviour of these species.

Although it may be feasible to develop understanding regarding the behaviour of some species from other UK estuaries it is suggested that following the preliminary investigations and development of the techniques for the tracking of these species, where possible, investigations are explored for the Severn Estuary. In particular it is suggested that investigations on shad not included within the preliminary study due to geographical restrictions are considered. Furthermore although valuable data and knowledge would undoubtedly be gathered from the suggested preliminary investigations, some aspects of behaviour may differ within the Severn Estuary.

Sampling of the ecology of the Upper Severn Estuary

Sampling of both the fisheries and invertebrate communities within the upper part of the Estuary is suggested. As this field work is not expected to take place within Phase 2 it should be noted, that the information will not be available for assessment within Phase 2 and as such mitigation and compensation measures in relation to this portion of the estuary may alter later within the SEA process once such data collection has been undertaken. Suitable sampling techniques may include fish trawls, fish traps and seines and collection of invertebrate core and grab samples. Mapping of sensitive habitat types within this area would also be undertaken within this assessment.

Investigation into the behaviour of juvenile migratory species

To gather knowledge to fill the gaps remaining regarding the behaviour of juvenile migratory fish species it is suggested that investigations to explore this aspect be considered in the future. Such investigations may include netting surveys of juveniles of each of the species to investigate their behaviour within the Severn Estuary or indeed other estuaries where possible with regards to the depth of movement in the water column, position across the estuary and transit/residence time. Whilst it is possible that following construction of an STP scheme and due to the modified nature of the estuary the transit/residence times of species may change, it is unlikely that aspects such as e.g. depth of movement would alter. Key species that may require field-based investigations after Phase 2 include: juvenile shad, lamprey transformers, elver and glass eel and salmon smolts.

Swimming speed laboratory based investigations

An understanding of the swimming ability of fish species during their different life stages is critical to assess the feasibility of fish passage and ultimately to the design of the deterrent systems. A desk review is proposed during Phase 2, but it may be necessary to supplement this after Phase 2 with laboratory-based investigations. As with migratory behaviour, shad are considered likely to be the research priority due to the risks to the UK population and the paucity of information currently available. Other species and life stages likely to benefit from subsequent laboratory investigations due to current lack of information include lamprey transformers and adults and silver eel.

SECTION 4

PROPOSED APPLICATION OF THE SEA FRAMEWORK

4 PROPOSED APPLICATION OF THE SEA FRAMEWORK

4.1 Proposed SEA objectives

The use of SEA Objectives is not a requirement of the SEA Directive but is a recognised method of assessing the effects of a plan or programme. This technique is also proposed in UK Guidance. SEA Objectives usually reflect a desired direction of change, for example the maintenance of the favourable condition of conservation sites. It therefore follows that these objectives do not have to be met in full, but the degree to which they do provides a way of identifying preferences when comparing options.

The SEA Objectives have been developed in accordance with UK Guidance. The objectives were also derived using:

- The review of environmental plans and programmes conducted as part of scoping;
- The baseline data collation;
- The identification of environmental issues.

Each SEA Objective is supported by a series of assessment criteria and indicators. These are intended to provide more explicit explanation of how the performance of each short-listed option will be appraised against the SEA Objectives.

How the objectives, and supporting assessment criteria and indicators, have been derived in relation to this topic are described in Table 4.1 below.

Table 4.1 Derivation of SEA objectives for migratory fish, marine/estuarine fish and recreational fisheries

SEA Topic: Migratory fish, marine/estuarine and recreational fisheries	
Relevant International Plans, Programmes and Environmental Protection Objectives	The EC Directive on the Conservation of Natural Habitats and Wild Flora and Fauna (The Habitats Directive, 92/43/EEC) requires each Member State to prepare and propose a national list of sites for evaluation in order to form a European network of SCIs. Once adopted, these are designated by member States as SACs. The main objective of the Bern Convention is to conserve wild flora and fauna and their natural habitats, especially those species and habitats whose conservation requires the co-operation of several States. Particular emphasis is given to endangered and vulnerable species, including migratory species. The OSPAR Convention applies the ecosystem approach to the management of human activities. It is organised under six strategies, one of which is Protection and Conservation of Marine Biodiversity and Ecosystems. The EU Marine Strategy aims to achieve good environmental status of the EU's marine waters by 2021 and to protect the resource base upon which marine-related economic and social activities depend. The Freshwater Fish Directive requires Member States to designate freshwaters (including estuaries) needing protection or improvement to support fish life. The purpose of the WFD is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which: • Prevents further deterioration and protects and enhances status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems.

Relevant International Plans, Programmes and Environmental Protection Objectives (contd.)	• Aims to enhance protection and improvement of the aquatic environment, *inter alia*, through specific measures for the progressive reduction of discharges, emissions and losses of priority substances, and the cessation or phasing-out of discharges, emissions and losses of the priority hazardous substances. The Convention on Wetlands of International Importance was signed in Ramsar, in 1971. It is an inter-governmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources, as a means to achieving sustainable development throughout the world. It applies to estuarine fish communities and migratory fish species. Under EC Regulation 11000/2007 member states are required to prepare an Eel Management Plan for each catchment. The objective of the Eel Management Plan will be to reduce mortalities so as to permit the escapement to the sea of at least 40% of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had impacted the stock. Further relevant international legislation and planning policy to consider include: Environment 2010: Our Future Our Choice-EU Sixth Environment Action Plan; World Summit on Sustainable Development; The EC Urban Waste Water Treatment Directive; Nitrates Directive; Directive 2006/7/EC concerning the management of bathing water quality and repealing Council Directive 76/160/EEC; Convention for the Protection of the Marine Environment in the North-East Atlantic; Directive on Shellfish Waters (79/923/EEC); Bonn Convention on the Conservation of Migratory Species of Wild Animals; EU Biodiversity Strategy; UN Convention on Biological Diversity.
Relevant National/Regional Plans, Programmes and Environmental Protection Objectives	Consultation on Our Seas-a shared resource sets out a number of high level marine objectives including: • Achieving a sustainable marine economy • Using sound science responsibly

Relevant National/Regional Plans, Programmes and Environmental Protection Objectives (contd.)	• Healthy marine habitats occur across their natural range and are able to support strong, bio diverse biological communities and the functioning of healthy, resilient and adaptable marine ecosystems. A Better Environment, Healthier Fisheries: Better Fisheries for our nations sets a number of objectives: • Improve fish stocks and create a better environment for wildlife and people, • Provide more chances for people to fish and help fisheries perform better, and • Help sustainable fisheries boost the local economy. UK Marine Bill Consultation Document. The UK Government is committed to bring forward proposals for a Marine Bill that will introduce within its area of responsibility a new framework for the seas, based on marine spatial planning, that balances conservation, energy and resource needs. The key themes of the bill include; managing marine fisheries and improving marine nature conservation among others. The UK BAP has been prepared in response to Article 6 of the biodiversity Convention, to develop national strategies for the conservation of biological diversity and the sustainable use of biological resources. The overall goal of the UK BAP is 'To conserve and enhance biological diversity within the UK and to contribute to the conservation of global biodiversity through all appropriate mechanisms. The Countryside and Rights of Way Act extends the public ability to enjoy the countryside whilst also providing safeguards for landowners and occupiers. It creates a new statutory right of access to open country and registered common land, modernising the rights of way system, give greater protection to SSSIs, provide better management arrangements for AONBs, and strengthen wildlife enforcement legislation. Some species are protected under the Wildlife and Countryside Act as features of a SSSI (under s28) but are also protected in their own right under Schedule 5 (species other than birds specially protected under The Wildlife and Countryside Act, 1981), e.g. shad, sturgeon.

Relevant National/Regional Plans, Programmes and Environmental Protection Objectives (contd.)	The Swansea Bay Shoreline Management Plans has the following relevant objectives: • To maintain and where possible improve access to the foreshore for fisheries activities. • To minimise and mitigate against any adverse effects on the fishing industry and other developments and the operation of water/power company infrastructure. Further relevant UK plans, programmes and environmental protection objectives to consider include: the Water Resources Act; Asset Management Plan Programme; Salmon and Freshwater Fisheries Act; SAPs (Usk, Wye & Severn); Eel Management Plans; Cleaner Coasts Healthier Seas: Working for a better marine environment 2005-2011; Conserving Biodiversity-The UK approach; Natural Environment and Rural Communities Act 2006 . For England they include: Water Resources for the Future: A Strategy for England and Wales; Planning Policy Statement 9: Biodiversity and Geological Conservation; Planning Policy Guidance Note 20: Coastal Planning; Our Environment: Our Future-The Regional Strategy for the South West Environment 2004 - 2014; Action for Biodiversity in the South West-A Series of Habitats and Species Plans to Guide Delivery; The Severn Estuary Shoreline Management Plan. For Wales they include: Environment Strategy for Wales; People Places Futures - Wales Spatial Plan; Planning Policy Wales; CCW Core Management Plans (Including Conservation Objectives) for Rivers Usk, Wye and Tywi; Severn River Basin District Significant Water Management Issues; Priority Habitats of Wales; Wales Biodiversity Framework; TAN 5: Nature Conservation and Planning; TAN 14: Coastal Planning; Valuing our Environment: Economic Impact of the Environment of Wales; Welsh Water Monitoring Plan 2005-2010; Western Wales and Severn River Basin Management Plans; Monmouthshire Local Biodiversity Action Plan; Newport's Local Biodiversity Action Plan; Vale of Glamorgan Local

	Biodiversity Action Plan. The Severn Estuary Shoreline Management Plan. Numerous further regional and local planning policies are likely to be relevant to the scheme and will be identified by the policy team.
Potential Environmental Changes associated with Severn Tidal Power Development	Potential for disruption to migration as a result of alterations to migratory cues through changes to freshwater release. Route of passage of migratory and estuarine fish species will be disrupted through both the placement of the STP option and its turbines. Turbine passage has the potential to result in injury, mortality and indirect effects to migratory and estuarine fish species passing through them and adverse resultant effects to the population. Sluice passage may also result in fish injury and resultant adverse effects to the population. Changes to the tidal regime as a result of a STP option has the potential to change intertidal habitat currently utilised by migratory and estuarine fish species. Changes to water quality following construction of a STP option has the potential to affect directly and indirectly upon the migratory and estuarine fish populations. Effects will continue for the life time of the operation of the STP option and may remain following decommissioning. Effects identified above will occur to varying degrees with all proposed STP schemes. Scheme specific effects are identified within Section 3.1.

Potentially significant issues	Each of the effects identified have the potential to be adversely significant. International and national designations exist within the effected area for both migratory and estuarine fish species. All migratory fish species within the estuary are afforded a level of protection as well are a number of estuarine species.
Proposed SEA Objective **Proposed SEA Objective (contd.)**	To avoid adverse effects on designated wildlife sites for fish of international and national importance. To avoid adverse effects on the populations of other protected fish species and habitats. To avoid adverse effects on national and local biodiversity target features that include fish habitats and species. To avoid adverse effects on recreational and heritage fishing. To avoid adverse effects on commercial fish resources. To minimise the risk of introduction of non-native invasive fish species.

4.2 Proposed assessment criteria

For the proposed assessment criteria see Table 4.2 below.

Table 4.2 Proposed assessment criteria for migratory fish, marine/estuarine fish and recreational fisheries

SEA topic	SEA Objective	Assessment Criteria	Indicators
Migratory fish, marine/estuarine and recreational fisheries	To avoid adverse effects on designated wildlife sites for fish of international and national importance. To avoid adverse effects on the populations of other protected fish species and habitats. To avoid adverse effects on national and local biodiversity target features that include fish habitats and species. To avoid adverse effects on recreational and heritage fishing. To avoid adverse effects on commercial fish resources. To minimise the risk of introduction of non-native invasive fish species.	Will the option result in adverse impacts upon the favourable conservation status and hence integrity of status of internationally designated sites supporting fish? Will the option adversely affect the achievement of favourable conservation status for internationally and nationally important fish species or their capacity to recover if currently designated as in unfavourable condition? Will the option result in changes in the populations of designated fish species of national importance, i.e. SSSI features? Will the option maintain BAP fish species in line with UKBAP targets? Will the option affect other statutory or non-statutory wildlife sites important for fish?	Changes in designated features and designation status for fish. Abundance of populations of internationally and nationally important fish species. Changes in the range of internationally and nationally designated fish species. Changes in the physical (biological and chemical) parameters upon which the fish species rely'. Abundance of populations of fish species caught by recreational anglers. Abundance of populations of fish species caught in commercial fisheries.

SECTION 5

OTHER TOPIC ISSUES TO BE CONSIDERED IN PHASE 2

5 OTHER TOPIC ISSUES TO BE CONSIDERED IN PHASE 2

5.1 Consideration of mitigation and compensation

SEA is an iterative process of gathering data and evidence, assessing environmental effects, developing measures to prevent or reduce any adverse effects, then making recommendations to refine the plan in view of the predicted environmental effects, and the monitoring of significant effects of implementing the plan or programme. Significant adverse effects that cannot be prevented or reduced will also need to be avoided as fully as possible.

The international nature conservation importance of the Severn Estuary imposes specific obligations on consenting authorities in determining development consent applications. This includes consideration of the requirement for compensatory measures where internationally designated sites would be adversely affected. Given the potential scale of effects it is recognised that the requirements for compensatory measures could be substantial. The issue of compensatory measures is addressed in a separate report which sets out the further work to be done to determine whether tidal power development could be acceptable.

The 'preliminary review of possible mitigation and compensation requirements under the Habitats Directive' undertaken as part of the scoping Phase of the STP documented the many challenges in developing mitigation and compensation measures for the potential impacts of an STP scheme. The potential scale and unprecedented nature of measures required was highlighted along with the current low level of confidence in their effectiveness. It was determined that pending further evaluation of both the potential impacts and the mitigation and compensation opportunities it is not possible at this stage to categorically determine whether any STP scheme could or could not comply with the requirements of the Habitats Directive.

During the process of scoping the technical issues, measures to prevent, reduce or avoid effects are also starting to emerge, specifically in relation to this topic. These, and other not yet identified measures, will need to be considered in much more detail for their effectives and appropriateness in the next phase of work.

The outline mitigation and compensation measures that have emerged during scoping are summarised below.

5.1.1 Potential mitigation measures

Each of these measures may, in isolation, not be sufficient to fully mitigate against a given effect, however, it is the cumulative effect of these mitigation measures (and potentially in combination with compensation measures) which is important when assessing their potential to minimise any negative effects of the development. The potential to avoid effects and a confidence of effectiveness is given for each potential measure. This level of confidence represents the likelihood of the measure being successful in reducing effects assuming everything else being equal, it does not indicate a confidence in the measure being able to offer like for like mitigation.

Physical screening

Physical screening technologies although used widely on freshwater hydropower schemes to prevent fish ingress into the turbines and subsequently reduce fish injury and mortality have not been used on estuarine barrage hydropower schemes to date. The mesh size required is dependent upon the size and life stage of the species that needs protecting.

The use of small mesh sizes that would likely be required would need extensive cleaning to keep the screens clear. In addition, the screen throughput velocity would likely exceed the swimming ability of at least juvenile shad and lamprey transformers resulting in impingement upon the screens and subsequent mortality. It is considered unlikely that the installation of physical screening up and downstream of the turbines will be a successful protection measure within the environment of the Severn Estuary.

This mitigation measure could **partially** avoid effects from the STP option however, it is considered to have a **low** confidence of effectiveness.

Behavioural screening

Behavioural deterrents can substitute or supplement physical screening however they do not achieve the same level of exclusion as physical screens. Behavioural fish deterrents operate on the response of fish to stimuli such as sound and vibration, light, temperature, taste and odour, pressure change, touch, hydraulic shear, electrical and possibly magnetic fields. These senses can be used to help fish avoid the intake structure from which the stimulus is being projected. Systems reliant upon visual cues such as light deterrents however may not be effective within the turbid environment of the Severn Estuary.

Acoustic stimuli is the best understood of the behavioural screening technologies and has been found to be effective in reducing entrainment of hearing sensitive species such as shad. For example there was a 42% reduction in the passage of shad through the turbines of the Annapolis Royal barrage following installation of an acoustic fish diversion system. The effectiveness of acoustic deterrence however, is dependent upon the hearing ability of the fish and their swimming ability in relation to the attraction flow of the turbines and distance from stimuli. Such systems are relatively ineffective for hearing insensitive species such as lamprey.

Varying avoidance efficiency has been seen for electric, bubble and light technologies. Use of these technologies as a deterrent measure for the STP option would require considerable further investigation.

This mitigation measure could **partially** offset effects from the STP option however, it is considered to have a **low** confidence of effectiveness without fully understanding the responses of the species involved.

Fish passage solutions

Conventional fish passes are not suitable to the tidal environment therefore sluices and bypasses should be considered. Solutions must consider all fish species to be protected, the route and depth of passage of these species through the estuary, their swimming ability and willingness to pass through dark or narrow passages.

Given the presence of a large number of sluices within barrage structures, these could be designed to facilitate both upstream and downstream movements of fish. Adaptations could also be made to intake tunnel design to incorporate fishways in particular in the upper part of the structure for surface migrating downstream juveniles such as salmon smolts (Wye and Usk foundation, 2008). There is currently little understanding of how migratory and estuarine fish use the Severn Estuary during migration and other life cycle stages (swimming depth, position relative to shore line etc). Such information will be important in identifying sluice location, design and operation. It could also inform the location of turbines subject to engineering constraints. Pending further studies of the use of the estuary by migratory and estuarine fish the confidence of such measures being effective in mitigating effects is currently unknown.

This mitigation measure could **partially** avoid effects from the STP option however, the confidence of effectiveness is currently **unknown** without undertaking studies to further investigate individual species migratory behaviour and requirements.

Low-impact turbines

The requirement to reduce fish injury and mortality during turbine passage is paramount to the project. The development of a number of low-impact turbines that maintain efficient energy production is ongoing in the US and Canada.

Funded by the US Department of Energy the Advanced Hydro, Turbine System programme is exploring a number of innovative concepts. Contracts were awarded to Alden Research Laboratory Inc./Northern Research and Engineering Corporation and Voith Hydro Inc. ARL/NREC have produced a prototype which is currently undergoing trials. Voith have investigated how existing Kaplan turbine designs can be modified to improve efficiency and reduce environmental effects.

Natural Resources Canada and Rapid-Eau Technologies have also been involved in the development of a "vaneless" turbine aimed at minimising damage to passing fish. The predicted survival rate for this turbine was estimated at 93.3% based on a five blade runner and 96% for three blades.

On some smaller scale hydropower schemes, zig-zag wall designs have been used to direct migratory fish towards sluices and away from turbines. It is unclear whether such a design could be used for a large scale estuarine barrage, in particular as the cost implications could be large.

If generation is only taking place on the ebb tide it may be possible to reduce contact with mechanical parts during the flood filling phase by feathering the blades so that they are parallel with the water flow.

This mitigation measure could **partially** avoid effects from the STP option however, the confidence of effectiveness is currently **unknown** without identifying a specific technology or design adaptation.

Transporting fish past the barrage

There are examples in particular on riverine hydropower schemes in the US of migratory fish being trapped, collected and transported around a barrier. The trap and transport of salmon over barriers has also been carried out in Scotland and Scandinavia and trap-and-transport systems for eel are statutory requirements in some European countries. Major issues exist however, especially in relation to osmoregulation of the fish and sustainability of the operation, and there would inevitably be some degree of stress and damage to the fish caused by capture and handling.

This mitigation measure could **partially** avoid effects from the STP option however, the confidence of effectiveness is considered to be **low**.

Fish herding

Acoustic herding has traditionally been used in commercial fisheries to steer fish into nets. It may be possible to adapt this technique to decrease transit time of migrants passing through the estuary and thus through the barrage sluices within one flood tide. This would decrease the downstream movement of individuals with the ebb tide and resultant potential multiple passages through the turbines. The efficiency of such a technique would depend upon the hearing ability of the species targeted and the sound sources used.

This compensation measure could **partially** avoid effects from the STP option however, the confidence of effectiveness is currently **unknown**. A study to assess its efficacy would be required before this option could be implemented with any degree of confidence.

Habitat enhancement

Habitat enhancement within the rivers of the Severn Estuary has the potential to form a mitigation measure increasing the overall population within the rivers. It should be noted however that under the Water Framework Directive's objectives for rivers to meet Good Ecological Potential, enhancement initiatives are already under consideration to support the achievement of meeting the conservation objectives. As such, it is only improvement measurements beyond these that can be viewed as mitigation for a STP scheme. Increased access to spawning grounds improving reproductive success could be provided by the installation of fish passes on currently impassable weirs and the removal of weir structures. Potential spawning habitat itself could further be improved by rehabilitation works such as gravel cleaning. Measures to reduce sediment input including improved land management, grants to farmers and the introduction of river margin buffer strips could be increased to improve spawning and rearing habitat and as such enhance the stock status.

This mitigation measure could **partially** avoid effects from the STP option and previous schemes would suggest that the confidence of effectiveness is **medium** for some species such as salmon. For those species for which less information regarding their requirements is known such as lamprey and shad effectiveness is largely **unknown**.

Habitat creation, modification and ecological enhancement

For marine, estuarine, and freshwater straggler species habitat creation upstream or downstream of the barrage may be required. Mitigation in lagoons would primarily be based around habitat creation, habitat modification, and ecological enhancement within the lagoon boundary, also habitat enhancement outside the lagoons could be considered

Artificial irrigation of exposed areas could be used to create new intertidal habitat if required. For example, some saline lagoon habitat could be created by inundating an area during spring tides and allowing it to drain gradually. Managed realignments have proven to be successful at creating intertidal habitats which are effectively used by adult and particularly juvenile fish. Approximately 8,000 ha of suitable habitat is expected to be available for managed realignment projects in the Severn Estuary, therefore such projects should be supplemented by others outside the Severn Estuary to increase the amount of intertidal habitat that can be created to compensate the scheme.

It is unclear how much intertidal area would need to be created within the Severn Estuary to mitigate against loss of intertidal habitats due to operation of the STP option. Overall, this mitigation measure has the potential to **partially** avoid the effects of changes in habitat availability and is assigned a **low** level of confidence.

Turbine/sluice operation regime

Injury and mortality of priority species and life stages could potentially be reduced by amending the operating regime of the STP option including both turbine generation and sluice operation. Cessation of operation either seasonally and/or diurnally during peak migration periods could be built into the operating regime. Such measures however, are unlikely to prove feasible due to the differing periods of migration seen between different fish species and life stages of the same species (Table 5.1).

Table 5.1 Key fish movements throughout the year

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Salmon	Smolt												
	Adult	Spring run not common now					Main run peaks in Aug - Oct						
	Kelt												
Sea trout	Smolt												
	Adult							Main run peaks in summer months					
	Kelt												
Shad	Juvenile	Some over winter at mouth of river estuary			Overwintering juveniles go to sea spring and early summer				Move downstream in river and out to estuary/sea				
	Adult												
	Spent						Move down into estuary and may stay until Autumn						
Eel	Glass/Elver												
	Silver												
River lamprey	Adult										Move into estuary and upstream from Oct to March		
	Juvenile									Move downstream peaking Sep/Oct		autumn and spring and April/May	
Sea lamprey	Adult			Peak movement into rivers spring							Return to estuary autumn to spring		
	Juvenile									Move downstream peaking Sep/Oct		autumn and spring and April/May	

Key: Black = peak.

This mitigation measure could **partially** avoid effects from the STP option however; the confidence of effectiveness is currently **unknown** without confirming a specific regime and fully understanding the behaviour of the fish to be protected.

A principal aim of the STP option design should also be to minimise change to the natural estuarine regime (while still retaining the desired energy generation capability) so that subsequent changes to water quality are also minimised. Management of the timing of the tidal exchange and amount of water exchanged could at least partially manipulate water quality within the estuary.

Control of the tidal exchange could also influence the area of intertidal zone which is submerged at different stages of the tide (inundation regime). A decrease in intertidal habitats would be accompanied by an increase in the area of subtidal habitat. This could potentially be beneficial for fish if it provides an increase in habitat and prey availability. However, the relative productivity of different intertidal and subtidal habitats for fish remains to be clarified. In addition loss of certain types of intertidal habitat such as saltmarsh which provides a very specific intertidal habitat of particular benefit for juvenile fish could potentially have a negative effect on fish communities in the area. If productivity in the estuary did increase post-STP and invertebrates increased in size (see 'Habitat Changes' section) this is not necessarily a desirable effect. The Severn Estuary is currently unique due to its particularly low productivity, and the small invertebrates provide a food source for juvenile fish. It is important, therefore, to develop an operation regime (where possible) which aims to maintain this unique character during operation of the STP option.

There are currently considerable uncertainties associated with the expected morphological and ecological changes within the Severn Estuary post-STP. Consequently, this mitigation measure has the potential to **partially** avoid the effects of changes in water quality and habitat change and based on the information available to date is assigned a **low** level of confidence.

Stocking

Atlantic salmon stocks have been enhanced throughout Europe by hatchery rearing and smolt releases. Stocking of streams with salmon eggs and fry is also common in Scotland. Among many other examples, salmon fry are stocked in the River Trent Catchment as part of the salmon restoration programme and farmed smolts are released into the River Kennet. It should be noted however that the success of such projects is rarely investigated or demonstrated.

A stocking programme for river lamprey has been undertaken on Finnish rivers where spawning does not occur or is restricted.

Stocking of eel, based on the capture of wild fish, is undertaken in Europe and it is now increasingly being seen as a way to help the eel stock recover. Eel aquaculture techniques, where elvers are grown on in captivity, were developed in Japan and subsequently transferred to much of Asia. In Europe, many countries also adopt these techniques with Italy and France having a long history of eel aquaculture.

Where fish are translocated or stocked it is important to ensure that the stocked fish are representative of the donor population(s) in terms of its genetic composition and level of variability. Stocking can cause genetic changes which can reduce the quantity and quality of fish recruitment. If stocking is to be carried out it is important to introduce measures to protect natural populations and to recognise that stocking may have detrimental effects on these populations.

Stocking alone however would not be an effective mitigation measure in isolation as further measures would need to be taken to ensure that at least a proportion of the fish stocked were able to return unharmed.

This mitigation measure could **partially** avoid effects from the STP option and previous schemes would suggest that the confidence of effectiveness is **medium** for some species such as salmon and eel. For those species for which less information is known however, such as lamprey and shad effectiveness is largely **unknown**.

Improved access for anglers

If angling within the estuary was adversely affected by operation of the STP scheme this would have economic repercussions for the region. Further shore-based angling opportunities could be provided by developing new platforms/areas for anglers to fish from and potentially facilitating access to new fishing grounds/sites. Within tidal lagoons pontoons could be constructed from which anglers could fish, similarly barrage situated fishing platforms could also be constructed. This mitigation measure has the potential to **partially** avoid the effects on angling and is assigned a **medium** level of confidence.

Predator control

If migratory fish are delayed due to disruption to passage from the STP the potential exists that predation attempts on these fish may increase. Methods of predator control could be implemented as a mitigative measure to reduce this potential effect. Feeding aggregations of piscivorous waterbirds around structures such as dams are controlled, worldwide, using a number of methods. These methods generally involve scaring the birds using a variety of non-lethal harassment techniques such as noise generating scarers or encouraging aggressive birds such as gulls and pigeons. These deterrents however would need to be operated over a large area in order to be effective and could have unpredictable effects on other species. Roost management may also be an option where it is possible to cut down or modify roosting and resting sites to make the site less attractive.

Although birds are protected by law, there are provisions to be able to shoot (and kill) them under licence under certain circumstances for the purpose of preventing significant damage to fish stocks. Generally no licence is required to shoot simply with the intention of scaring however where the birds are SPA or SSSI interest features, this action may be considered a likely significant effect and may therefore need another form of permission. Such permission would be subject to the Habitats Regulations (Reg. 48) and therefore may need appropriate assessment.

Like birds, the most common methods used to control predation by seals at dams and barriers are non-lethal harassment techniques (firecrackers, rubber bullets, high-pressure water hoses) and acoustic deterrents.

Acoustic deterrent systems exist that are effective at keeping both birds and seals away from fish farms. Acoustic repellent systems emit random sounds underwater. The sound is extremely unpleasant to seals, fish however are not affected. In addition to the hydroacoustic element scarers also often comprise a coloured prism at the surface which rotates with the wind, reflecting light, which helps to deter birds such as eider ducks, cormorants and gulls.

This mitigation measure has the potential to **partially** avoid the effects on fish stocks and is assigned a **low** level of confidence.

5.1.2 Potential compensation measures

Whilst further study in phase 2 will explore the potential mitigation measures detailed above so as to elucidate the effectiveness of those measures, it is possible that when combined they may only partially avoid the potential effects from the STP option. As such compensation measures may be required. It should be noted that the potential compensation measures detailed below will require more detailed study to evaluate their potential effectiveness. These measures should therefore at this stage be seen as broadly illustrative and more detailed discussion / research is suggested during phase 2 of the project. Nonetheless it is fully understood that the task of compensating potential effects at the scale that may be required will be an extensive and serious undertaking and is unprecedented. Each of these compensation measures may, in isolation, not be sufficient to fully compensate against a given effect, however, it is the cumulative effect of these measures (and in combination with mitigation measures) which is important when assessing their potential to minimise any negative effects of the STP option. The potential to avoid effects and a confidence of effectiveness is given for each potential measure. This level of confidence represents the likelihood of the measure being successful in reducing effects assuming everything else being equal; it does not indicate a confidence in the measure being able to offer like for like compensation.

EC (2007) defines compensatory measures as being '*independent of the project (including any associated mitigation measures). They are intended to offset the negative effects of the plan or project so that the overall ecological coherence of the Natura 2000 Network is maintained*' (further information regarding compensation within UK and International legislation can be found within the Preliminary review of possible mitigation and compensation requirements under the Habitats Directive document).

Stocking

In addition to stocking migratory fish within the tributaries of the Severn Estuary affected by the STP scheme, stocking may also be used as a compensation measure. Fish originating from either the river to be stocked or those from the Severn Estuary could be introduced to rivers outside of the Severn Estuary to increase the overall population of that species within the UK.

Major efforts to culture American shad have been undertaken in North America and in the Allis Shad LIFE-Project there are plans to stock five million shad larvae in the River Rhine system. Although a similar operation outside the River Severn catchment could increase the potential for shad survival, the specific genetic populations could be lost.

The success and suitability of stocking compensation measures in increasing the population will depend upon any bottlenecks within the population and the carrying capacity of the receiving system, which should already be being managed to maximise the stocks within the river as per the species condition assessment/good ecological potential targets.

It should be noted however that due to the genetically unique fish populations potentially affected within the Severn Estuary SACs that stocking would not represent a like-for-like compensation measure for migratory fish.

This compensation measure could **partially** offset effects from the STP option and previous schemes would suggest that the confidence of effectiveness is **medium** for some species such as salmon. For those species for which less information is known however, such as lamprey, shad and eel effectiveness is largely **very low**.

Translocation

There is some evidence to suggest that shad can be translocated between rivers. For instance American shad have successfully been translocated from the east to the west coast of North America. Furthermore Atlantic salmon have been moved within and between catchments, regions and even continents to enhance stocks.

A large proportion of the stocking programmes undertaken for eel, use eel from other rivers and countries, for instance the Baltic area largely uses eel originating from western Europe.

There is strong glass eel recruitment in the Severn and as a result the river has provided eel for translocation programmes for a number of years. Recently the EA undertook the translocation of 63,000 elvers from the Severn Estuary to the River Aire at Rodley, Leeds.

Barriers to the downstream migration of European eel have been identified as one of the possible causes of the decline in stocks. As part of the recovery plan for eel the EA are required to prepare an Eel Management Plan for each catchment. The objective of the plan will be to reduce mortalities so as to permit the escapement to the sea of at least 40% of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had affected the stock. In addition, by mid 2013, 60% of eel less than 12 cm in length that are caught should be reserved for restocking purposes.

The suitability of a translocation programme would need to be assessed however with regards to the potential implications upon the existing ecology of the receiving river system.

This compensation measure could **partially** offset effects from the STP option and previous schemes would suggest that the confidence of effectiveness is **low** for some species such as eel. For those species for which less information is known however, such as lamprey and shad effectiveness is largely **unknown**.

Novel techniques – pheromone release

The Great Lakes Fishery Commission has undertaken extensive research over the last decade to investigate the possibility of the future application of sea lamprey pheromones as a population control mechanism. Olfaction is considered to be the key mechanism regulating the behaviour of sea lamprey with regards to migration and sexual maturity and possibilities exist to use cues as a conservation and compensation measure for STP effects.

Although information currently only exists for lamprey there may also be some potential for the development and application of synthetic pheromones for other natal homing species such as salmon and shad.

This compensation measure could **partially** offset effects from the STP option however, the confidence of effectiveness is currently **unknown**. A study to assess its efficacy would be required before this option could be implemented with any degree of confidence.

Additional sites for inclusion in the SAC list

It may be possible to identify rivers in the UK or indeed other parts of Europe that currently support populations of protected migratory fish species which do not have any international designation for their protection. There is some potential for suitable sites to be identified with the use of large scale UK data sets such as the NBN gateway. Consideration must be given to the source of the data however, as although it may present the record of individuals, a self-supporting breeding population cannot automatically be inferred. Caution must also be taken in particular with historical records before assuming correct identification. Species of lamprey for example are distinguished within this data set however, identification to species level in particular for the juvenile life stages is difficult, if not impossible at very early life stages, and may lead to misinterpretation.

Indeed the only confirmed historic breeding population of allis shad in the UK is the River Severn and beyond the three designated SAC sites and the River Severn the only known historical twaite shad spawning population has been in the River Thames. There is some evidence to suggest that there is a breeding population of allis shad in the River Tamar and Solway Firth area. Adults have been observed in the River Tamar and eggs potentially from allis shad have also been found although the species to which the eggs belonged could not be confirmed. No juveniles have been caught within this catchment and the success of any population is currently unknown. The River Tamar may however provide the most suitable river for compensation measures of shad within the South West of England. It may however be possible to identify sites within other European countries such as Ireland, France, Portugal and Spain. This would not however provide compensation for the loss of individual genetic strains present within UK populations.

Relatively little information is known regarding the stocks of lamprey species within SAC designated rivers in particular for sea lamprey and as such little conclusive information is likely to exist for currently non-designated river systems. However it is possible that following further investigations suitable sites may be identified within the UK.

Large populations of salmon are known to exist in non-designated rivers within the UK for example on the River Tyne. It may therefore be feasible to include additional sites to the SAC list for the protection and enhancement of this species.

It should be noted however that due to the genetically unique populations potentially affected within the Severn Estuary SACs that additional SAC site inclusion would not represent a like-for-like compensation measure for migratory fish. There is currently no clear process for designating additional non like-for-like SACs and this would need to be addressed as part of the wider feasibility study.

This compensation measure could **partially** offset effects from the STP option however, the confidence of effectiveness is considered to be **medium** within the UK for some species such as salmon although **low** for the rarer species such as shad and lamprey.

Habitat enhancement

It may be possible to compensate for fish losses from the Severn Estuary with the enhancement of stocks within other river systems through habitat enhancement. Habitat enhancement will mirror that described above as mitigation for within-river population improvements. This would however require a significant amount of monitoring to ensure that the objectives were met and would need to be fully functional prior to any losses caused by the proposal. It should be noted however that enhancement initiatives may already be planned or required to meet the conservation objectives/good ecological potential/status of the river and as such it is only improvement measures beyond these that can be viewed as compensation for a STP scheme.

This compensation measure could **partially** offset effects from the STP option and previous schemes would suggest that the confidence of effectiveness is **medium** for some species such as salmon. For those species for which less information regarding their requirements is known however, such as lamprey and shad effectiveness is largely **unknown**.

Habitat creation, modification and ecological enhancement

By creating or modifying habitats in other areas so as, for example, to develop suitable nursery grounds for juvenile and adult fish and diadromous species utilising estuarine habitats pre-STP it may be possible to compensate for fish losses from the Severn Estuary. Suitable areas may be located in the inner Bristol Channel, for example Bridgwater Bay, or habitat could also be reclaimed from further afield. Enhancements will mirror those described above as mitigation for within-river population improvements. A significant amount of monitoring would however be required to ensure that these measures were effective and they would need to be fully functional prior to any losses caused by the proposal.

Overall, this compensation measure has the potential to **partially** offset the effects of changes in habitat availability and is assigned a **low** level of confidence.

Improved access for anglers

Management to increase fishing opportunities for anglers via the creation of pontoons in suitable coastal areas or facilitating access to good fishing sites along other estuaries and rivers could be applied outside the Severn Estuary and rivers. Any sites developed outside the area, however, would reduce regional economic benefits. This compensation measure has the potential to **partially** offset the effects on angling and is assigned a **medium** level of confidence.

Monetary compensation

Monetary compensation should be considered for businesses negatively affected by the STP option (i.e. charter vessels, angling shops etc.). It is also suggested that financial compensation could be considered for fishery owners affected financially due to the loss of angling revenue resulting from the operation of the STP option.

This compensation measure has the potential to **partially** offset the effects on angling and is assigned a **medium** level of confidence.

5.2 Consideration of cumulative effects

There are a number of cumulative issues that need to be considered more fully with respect to the proposed options:

- The possible cumulative effects of combined STP proposals should be taken into account, for example, the effects of a large barrage in addition to a land connected lagoon would be greater than these options in isolation.

- The possible construction of a Swansea Bay lagoon (which is outwith the area considered in this SEA). This would potentially reduce the availability of habitat to fish utilising the estuary and could compound the effects of any further potential loss of habitat due to operation of the STP option.

- Other possible future tidal technologies, e.g. tidal stream proposals. This could lead to further change in the tidal flow regime of the estuary which could potentially increase overall effects of the STP option on fish.

- The possible 'Round 3' development of offshore windfarms in the Irish Sea. Generally it is considered that the distance of these proposed windfarms from the proposed barrage would preclude any considerable effects, however, if the construction and operation of the windfarm did have a negative effect on the population of one or more species it could exacerbate any change and/or stress in the population potentially resulting from the operation of the STP option.

- The possible construction of a new nuclear power station at Hinkley, Somerset. Entrainment of individuals within power station intakes could reduce numbers of individuals of numerous species during the period of power station operation. Although the numbers entrained are likely to be relatively small in relation to populations of various species as a whole, any loss of individuals would be over and above any potential losses due to the presence of the STP scheme.

Further potential 'in-river' issues will need to be considered for migratory species and these will be examined in more detail in phase 2 when more information is known. Once the STP scheme proposals are submitted, under the Habitats Regulations 'in combination' effects would also have to be considered. The implications of such 'in combination' effects are likely to have more significance to the scheme than cumulative effects assessment under the SEA process alone.

5.3 Trans-boundary effects

Due to the migratory nature of the majority of species under discussion within this topic paper and the fact that all but estuarine resident species spend at least part of their life cycle within the marine environment, consideration will have to be made regarding potential trans-boundary effects.

Close consideration must be given to eel owing to their current status and the legislation in place to try and conserve stocks, as discussed in Section 2.1.2. Implementation of the measures set out under the Council Regulation (EC) No. 1100/2007 for the recovery of the stock of European eel would need to be considered further in phase 2.

For those species that do not natal home or show limited natal homing any effect upon individuals moving through the Severn Estuary has the potential to effect upon the population as a whole. This population may represent a UK or European stock and as such may have wider effects upon the status of populations and designated sites within other countries. This has the potential for both conservation and designation implications including failure to meet directive targets such as favourable condition status.

Due to the size of the Severn Estuary elver population a large number of individuals from this stock are currently removed and translocated to other estuaries and rivers both in the UK and other European countries such as Sweden. Were the population within the Severn Estuary to reduce as a result of the presence of a tidal power scheme it may be necessary to limit or cease this measure. Reduced or ceased translocation could affect the success and continuation of those populations that are currently assisted having potential consequences upon their conservation designation in several countries.

The Severn Estuary supports large populations of several juvenile marine migrant fish and is an important nursery ground for many species. Therefore, considerable changes within the Severn Estuary could potentially affect UK populations of some species. For example, a large number of bass individuals spawn in the Irish Sea and Bristol Channel and adults which spent their time as juveniles within the Severn Estuary may emigrate to other parts of Wales, England, Scotland and potentially Ireland and contribute to adult stock throughout the UK. Even if a species is not designated as being of conservation importance, it should be considered important if, for example, 30% of UK adults of that species utilised the Severn Estuary as juveniles. There is currently little information regarding the relative contribution of the Severn Estuary stock to UK populations of different marine migrant species but such information would be particularly useful when assessing potential effects of the STP scheme.

For some species such as shad where known breeding rivers in the UK are limited it may be necessary to carry out compensation measures such as stock enhancement and designation of new SACs within other countries such as Ireland, Portugal, France and Spain. Compensation measures requiring other member states to take on the responsibility of new SACs however may be complicated and come up against opposition. In addition, although these measures may maintain numbers of shad individuals there would still be a loss of distinct genetic populations and high level decisions would be required to assess whether or not this was acceptable.

There are also a number of potential indirect effects upon the wider freshwater ecology of the rivers of the Severn Estuary as a result of the loss of a proportion of the diadromous fish populations. In particular but not exhaustively these may include the loss of a proportion of the nutrient inputs from fish that die after spawning and the interactions between diadromous species and other aspects of riverine ecology such as the life stage of freshwater pearl mussel. These wider indirect ecological aspects will be taken into consideration within phase 2 through interfacing with other Topic Papers such as freshwater and terrestrial ecology.

5.4 Monitoring strategy

To underpin the more detailed assessment that would be required for a development application, suggestions will be provided in the SEA on the nature, type and frequency of monitoring that might be required. It is noted that a significant monitoring programme would be required covering all receptors and for an extended period of time. This is necessary to provide a sufficient understanding of seasonal and annual variation to support impact assessment predictions.

In some cases, suggestions on the nature of such a monitoring programme have started to emerge during the scoping process. These measures are not needed directly for the main assessment phase of the SEA and will need to be considered in much more detail for their effectives and appropriateness in the next phase of work.

The outline monitoring measures that have emerged during scoping are summarised below.

To assess changes in fish populations and identify appropriate levels of mitigation and compensation from the installation of a STP scheme it will be necessary to monitor both migratory and estuarine fish population's pre and post construction. Sufficient post construction monitoring would be required to distinguish between temporary construction and longer term operation effects and assess the effectiveness of mitigation and compensation measures.

Where historical monitoring of a sufficient nature to determine a significant change exists, it is suggested that this monitoring be continued. For example, this may include for migratory fish species, a continuation of condition assessment monitoring within the riverine SACs and other major river systems such as the River Severn and Avon. However it is likely that this will need to be conducted on a more regular basis than the current 6 year cycle. Annual sampling would be suggested. Estuarine fish sampling is currently undertaken on the Severn Estuary as part of the WFD monitoring programme. These surveys employ a multi-method approach utilising seine nets, otter and beam trawls to examine fish assemblages within the estuary (Coates *et al*. 2007). A number of ecological measures are then assessed for fish assemblages caught and analysed to give an indication of the status of assemblages within the estuary (Coates *et al*. 2007). The number and location of sites sampled for the WFD programme, however, may not be sufficient in isolation to record fish communities within all key areas and habitats and include all fish species of interest. It may therefore be necessary to supplement this sampling with additional techniques, sites and where necessary frequency. In addition to those sites where effects may be felt it will also be necessary to monitor sites at which compensation measures have been implemented.

It is suggested that statistical tools such as Bohlin and power analysis are used to determine an appropriate number of sites to be monitored in order to detect a level 3 change equivalent to a halving or doubling of the population. A more robust approach could also be followed although understandably the more robust the approach the more resources would be necessary.

Although there are a number of limitations to the analysis and interpretation of the data sets in terms of identification of change and bias, due to the length of the data set it is suggested that power station entrainment monitoring be continued and data acquired for use within the suite of monitoring for the STP option.

For those mitigation and compensation measures for which confidence is currently unknown and indeed for those where a level of confidence has been applied in a precautionary way it is suggested that trials and monitoring programmes be initiated before STP implementation.

It should be stressed that the competent authorities involved will want to see all possible measures taken to ensure the protection of internationally and nationally designated species and habitats and all efforts undertaken to avoid any additional anthropogenic change and indeed a robust monitoring programme to confirm that mitigation and compensation measures are indeed effective.

SECTION 6

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SECTION 7

GLOSSARY

6 GLOSSARY

Assemblage	Collection of organisms of one type within a defined area
Benthic	Organism living in or on the bottom/sediment of a waterbody
Biodiversity	A measure of the relative diversity of organisms present within different ecosystems
Biomass	Total weight of organisms per unit area
Community	A defined assemblage of plants/animals, clearly distinguishable from other assemblages
Diadromous fish	Fish migrating from saltwater to freshwater
Diversity of species	Reflects both the number of species present in a community or assemblage and the proportion of the assemblage represented by each species
Epifauna	Animals living on the surface of a substrate (e.g. sediment)
Euryhaline	Marine organisms adapted to a wide range of salinity
Fry	Juvenile fish less than a year old
Indicator	A measure of variables over time, often used to measure achievement of objectives.
Intertidal	Area of sand and mud which is submerged by the tide for at least some time during the tidal cycle but is not covered by seawater at low tide
Leptocephali	The flat and transparent larva of the eel
Macrotidal	When discussing a tidal range in excess of 4 m
Objective	A statement of what is intended, specifying the desired direction of change in trends.
Piscivorous	Fish eating
Primary producer	Organisms forming the base of the food web within an ecosystem, which synthesise organic matter from inorganic materials (usually using sunlight) i.e. predominately plants and algae
Ramsar Site	Wetland of International Importance listed under the Ramsar Convention (International treaty for the conservation of wetlands, 1975)
Resident fish	Fish who are resident in the area for the whole of their lifecycle
Saltmarsh	Wetland existing in intertidal areas, dominated by characteristic communities of salt salt-tolerant plants
Scoping	The process of deciding the scope and level of detail of a SEA, including the environmental effects and alternatives which need to be considered, the assessment methods to be used, and the structure and contents of the Environmental Report
Smolt	Migratory salmonid fish ready for or on its migration from river to sea
Species richness	The number of species present in a community or assemblage
Subtidal	Deep permanent water channels that flow through intertidal areas

ANNEX 1 - METHOD FOR SCOPING OF SIGNIFICANT ISSUES

Table 1: Look-up for sensitivity of receptor (based on the feature/receptor that is the subject of the designation, not the designation itself)

		Vulnerability to environmental change		
		High e.g. receptor in declining condition &/ or dependent on narrow range of environmental conditions	Medium e.g. receptor stable condition &/ or dependent on moderate range of environmental conditions	Low – receptor in favourable condition &/ or dependent on wide range of environmental conditions
Importance of Receptor	International, e.g. SPA Feature	High	High	Medium
	National, e.g. SSSI feature	High	Medium	Low
	Local, e.g. LNR feature	Medium	Low	Low

Table 2: Look-up for assigning potential significance of issues

		Magnitude of environmental change			
		High (E.g. High probability (>90%), all (90%+) capacity of estuary to support receptor affected, long duration (10yr+), irreversible)	Medium (E.g. Moderate probability (50 - 90%), some (50 - 90%) capacity of estuary to support receptor affected, moderate duration (5 - 10yr), probably irreversible)	Low (E.g. Low probability (50 -10%), local effects, short duration (5-2yr), probably reversible)	Very Low (E.g. Low probability (<10%), local effects, short duration (<2yr), reversible)
Sensitivity of Receptor (see Table 1)	High	Potentially significant issue	Potentially significant issue	Potentially significant issue	Not significant
	Medium	Potentially significant issue	Potentially significant issue	Not significant	Not significant
	Low	Potentially significant issue	Not significant	Not significant	Not significant