The Biology and Conservation of the Fish Assemblage of the Severn Estuary (cSAC)

D J Bird

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CRYNODEB GWEITHREDOL

Aber Hafren yw’r aber mwyaf ond un yn y DU. Mae wedi cael ei ddynodi’n yACA oherwydd ei fod yn cynnwys mathau o gynefin a rhywogaethau sy’n brin neu o dan fygythiad yn Ewrop, gan gynnwys y pysgod esgynnol y llysywen bendoll a llysywen bendoll yr afon, y wangen a’r herlyn. Mae gwastadeddau llaid a thywod rhynglanwol helaeth yn cynnal niferoedd mawr iawn o infertebratau benthig, pysgod a phoblogaethau o bwysigrwydd rhyngwladol o adar hirgoes. Cofnodwyd dros gant o rywogaethau o bysgod o Aber Hafren a’i ymestyniad morol, Môr Hafren. Mae’r rhan fwyaf o’n gwybodaeth am gymuned pysgod yr aber yn dod o’r unigolion sy’n cael eu dal ar y sgriniau mewnlifoedd dŵr oeri a ddefnyddir yn y gorsafoedd pŵer ar hyd glannau Cymru a Lloegr. Mae amlder pysgod yng ngorsaf bŵer Hinkley Point, a saif ar ymyl atfor yr aber ym Mae Bridgewater, wedi cael ei fonitro ers dros 25 mlynedd ac mae cofnodion tebyg ar gael o orsaf bŵer Oldbury o’r 1970au a’r 1990au. Defnyddiwyd y data hwn i ddisgrifio bioleg ac ecoleg y rhywogaethau mwyaf niferus o bysgod a chramenogion yn yr aber.

Mae samplau gorsafoedd pŵer wedi ei gwneud yn bosibl egluro ffactorau sy’n effeithio ar amrywiadau tymhorol a blynyddol yn amlder rhywogaethau unigol. Y patrwm o amlder pysgod sy’n dod i’r amlwg yw un lle mae tonnau o rywogaethau gwahanol yn dod i’r aber ar ôl ei gilydd ar adegau penodol o’r flwyddyn. Mae’r newidiadau tymhorol hyn i’r casgliad o bysgod yn hynod gyson, ond gall amlder rhywogaethau unigol amrywio’n sylweddol o flwyddyn i flwyddyn gan ddibynnu ar lwyddiant bridio, ychwanegu pysgod ifanc, newidiadau i’r tymheredd, halwynedd a llif dŵr croyw. Mae’r rhywogaethau mwyaf niferus o bysgod yn cynnwys, yn bennaf, pysgod ifanc rhywogaethau morol sy’n defnyddio’r aber fel magwrfa. Oportiwnwyr aberol morol yw’r enw ar y rhain. Mae categorïau cylch-oes eraill yn cynnwys rhywogaethau'r môr a rhywogaethau dŵr croyw sy’n crwydro i ddyfroedd aberol o dro i dro, a rhywogaethau esgynnol a disgynnol sy’n defnyddio’r aber fel llwybr mudo. Mae’r adroddiad yn adolygu bioleg ac ecoleg 27 o rywogaethau sy’n dibynnu ar yr aber am o leiaf ryw ran o’u cylch oes, ac yn ystyried y ffactorau sy’n effeithio ar eu hamlder tymhorol, eu twf, eu hymddygiad a’u statws cadwraethol.

Trafodir y rhesymau posibl am y cynnydd sylweddol yn amlder pysgod sydd wedi digwydd yn raddol ers y 1970au ac yn gyflymach ers 2002. Efallai bod y ffaith bod ansawdd y gwaddod a’r dŵr yn yr aber wedi gwella, yn enwedig o ran halogi â metelau trwm, yn esbonio’r cynnydd yn niferoedd y pysgod yn rhannol, ond mae codiadau yn nhymheredd y dŵr yn gysylltiedig â newid yn yr hinsawdd yn debyg o fod yn arwyddocaol iawn. Mae ffactorau eraill a all effeithio’n andwyol ar y gymuned pysgod a bygwth ei sefydlogrwydd yn cynnwys y cynnig i adeiladu morglawdd ar draws yr aber. Bydd hyn yn effeithio ar ddosbarthiad y gwaddod ac yn amharu ar weithgaredd mudo rhywogaethau gwarchodedig. Un achos pryder penodol yw’r posibilrwydd o farwolaethau wedi’u hachosi gan dyrbinau. Mae hyn yn debyg o fod yn arwyddocaol iawn i rai rhywogaethau mudol a hefyd i’r oportiwnwyr aberol morol sy’n symud i mewn i’r aber ac allan ohono’n dymhorol. Mae’r adroddiad yn cloi trwy roi crynodeb am iechyd y casgliad o bysgod yn yr aber ac mae’n gwneud argymhellion ar gyfer rheolaeth a chadwraeth yr aber yn y dyfodol.

EXECUTIVE SUMMARY

The Severn Estuary is the second largest estuary in the UK and has been designated a cSAC because it contains habitat types and species that are rare or threatened in Europe, including the anadromous river and sea lampreys and the twaite and allis shads. Extensive intertidal mud and sandflats support vast numbers of benthic invertebrates, fish and internationally important populations of wading birds. More than a hundred species of fish have been identified from the Severn Estuary and its seaward extension, the Bristol Channel. Most of our knowledge of the estuary's fish community comes from individuals entrained on the cooling water-intake screens used at power stations sited along the English and Welsh shores. Fish abundance at Hinkley Point power station situated at the seaward margin of the estuary in Bridgewater Bay, has been monitored for more than 25 years and similar records are available from Oldbury power station from the 1970s and 1990s. These data have been used to describe the biology and ecology of the more abundant species of fish and crustaceans in the estuary.

Power station samples have enabled factors that affect seasonal and annual variations in the abundance of individual species to be elucidated. The pattern of fish abundance that emerges is one in which sequential waves of different species enter the estuary at specific times of year. These seasonal changes in the fish assemblage are remarkably consistent, but the abundance of individual species can fluctuate markedly from year to year depending on breeding success, juvenile recruitment, changing temperatures, salinity and freshwater discharge. The most abundant species of fish consist primarily of the juveniles of marine species that utilise the estuary as a nursery that are termed marine estuarine-opportunists. Other life-cycle categories include marine stragglers and freshwater species that occasionally stray into estuarine waters, and anadromous and catadromous species that use the estuary as a migratory corridor. The report reviews the biology and ecology of 27 species that are dependant on the estuary for at least some part of their life-cycle and considers factors affecting their seasonal abundance, growth, behaviour and conservation status.

Possible reasons for the marked increase in fish abundance that has occurred gradually since the 1970s and more rapidly since 2002 are discussed. The fact that sediment and water quality in the estuary has improved, particularly with regard to heavy metal contamination, may partly explain the increase in fish numbers, but increases in water temperature linked to climate change are likely to be very significant. Other factors that may adversely affect the fish community and threaten its stability include the proposal to construct a barrage across the estuary that will affect the distribution of sediment and interfere with the migratory activity of protected species. Of particular concern is the potential for turbine-induced mortality that is likely to be very significant for some migratory species and also for those marine estuarine-opportunists that show seasonal movements in and out of the estuary. The report concludes by summarising the health of the estuarine fish assemblage and makes recommendations for its future management and conservation.

1 INTRODUCTION

1.1 Scope of the report

The importance of the Severn Estuary as a habitat for wading birds and waterfowl has long been recognised and is reflected in the protection it currently enjoys. Under the International RAMSAR Convention on wetlands, the estuary is regarded to be of international importance. Additionally, under the EC Directive on the Conservation of Wild Birds (79/409/EEC), the Severn Estuary and upper Severn Estuary are designated as Special Protection Areas (SPAs). Apart from birds, the region also supports a number of migratory fish species that in recent years have declined in abundance and distribution and this has contributed to the area's designation as a Candidate Special Area of Conservation (cSAC) because it contains habitat types and/or species that are rare or threatened in Europe (Table 1.1). In the British context, Bridgwater Bay, the Severn Estuary and the upper Severn Estuary are SSSI and Bridgwater Bay and several other sites along the River Severn above the estuary are Nature Reserves. The Natural Environment and Rural Communities (NERC) Act requires the National Assembly for Wales to publish a list of habitats and species which "*are of principal importance for the purpose of conservation biodiversity*" in Wales. Under Section 42 of the act, 19 marine habitats and 55 marine species are listed of which the majority are also UK marine BAP habitats and species which occur in Wales.

Table 1.1. Relevant species of fish occurring, or potentially occurring, in the Severn Estuary and associated rivers that are protected under various environmental designations. Note that the common sturgeon and smelt or sparling are not presently known to occur in the estuary. RAMSAR – wetland of international importance designated under the Ramsar Convention; SSSI – Site of Special Scientific Interest; cSAC – candidate Special Area of Conservation; UK BAP – UK Biodiversity Action Plan.

Fish species	Severn Estuary RAMSAR	Severn Estuary SSSI	Severn Estuary cSAC	River Usk SAC	River Wye SAC	UK BAP
Sea lamprey *Petromyzon marinus*	✓	✓	✓	✓	✓	✓
River lamprey *Lampetra fluviatilis*	✓	✓	✓	✓	✓	✓
Twaite shad *Alosa fallax*	✓	✓	✓	✓	✓	✓
Allis shad *Alosa alosa*	✓	✓	✓	✓	✓	✓
Atlantic salmon *Salmo salar*	✓	✓		✓	✓	✓
Sea trout *Salmo trutta*	✓	✓				✓
European eel *Anguilla anguilla*	✓	✓				✓
Common sturgeon *Acipenser sturio*						✓
Smelt (Sparling) *Osmerus eperlanus*						✓
Estuarine fish population in general	✓		✓			

In view of the significance of the region as a wildlife habitat, the countryside Council for Wales (CCW) and Natural England (NE) are currently developing conservation strategies for the Severn Estuary. Under the *Life in UK Rivers project* within the Natura 2000 network of protected European sites, a number of significant reviews have been completed on the ecology and habitat requirements of migratory species of lampreys, shad and salmon in estuaries. (Hendry & Cragg-Hine 2003; Maitland & Hatton-Ellis 2003; Maitland 2003). Under the same initiative, there are also comprehensive reports concerning the monitoring of these species (Harvey & Cowx 2003; Hillman et al. 2003; Cowx & Fraser 2003).

Apart from migratory species, considerably less information is available for the large number of other fish that occur in the estuary. This review focuses on the ecology of fish that use the estuary for a *significant* part of their life-cycle. The main aims of the report can be summarised as follows:

- to identify those species for whom the estuary is required for the completion of their life-cycle
- to review the information available on dietary and habitat requirements
- to review what is known about the environmental factors that normally regulate spatial and seasonal aspects of the ecology and biology of individual species
- to consider the anthropogenic factors that could adversely affect individual species and/or the fish assemblage in general
- to assess the health of the fish population in the estuary and to make recommendations on future management and conservation.

1.2 The Severn Estuary

Covering an area of 557 square km, the Severn Estuary is Britain's second largest estuary and has second highest tide in the world which can exceed 14.5 m. At spring tides, the Severn may be tidal up as far as Upper Lode Lock at Tewkesbury. A combination of these high tides and the funnel shape of the Bristol Channel leads to the formation of the Severn bore, a tidal wave that can reach 2 m in height (Langston et al. 2003). River Severn accounts for 25% of freshwater flow into the estuary (10^{10} m^3 y^{-1}) and more than a dozen other rivers contribute to the remaining 75%. Of these, the Wye and Usk are notable because they have their own SAC status (Table 1.1).

A proposal to harness the extreme tidal conditions by building a barrage across the estuary was originally proposed in 1981 and led to a number of environmental studies concerning the estuary's physical and ecological characteristics (Department of Energy 1989). As a consequence of the numerous studies undertaken at that time, the Severn Estuary and Bristol Channel is one of the best understood estuarine systems in the UK (Glover 1984). In 2007, a report by the Sustainable Development Commission (Sustainable Development Commission 2007b) revived the potential of using tidal power for energy generation. In a related report, the environmental impact of building a barrage across the Severn Estuary has been reviewed (Sustainable Development Commission 2007a).

1.2.1 Physical characteristics

The physical characteristics of the estuary have been studied over many decades in considerable detail (Bassindale 1943). These investigations have been partly driven by concerns about the level of contamination in the estuary emanating from industrial effluent or discharged from Sewage Treatment Works (STWs) along the Welsh and English coasts. Work completed as a result of these concerns has led to a good understanding of the hydrodynamics (Uncles 1984) and sedimentation processes in the estuary. These are the primary drivers that define the region's intertidal habitats that range from rocky shores in some parts of the estuary and the establishment of mudflats and sandflats at other locations (Dyer 1984; Kirby 1994). These markedly different substrata largely determine the abundance and distribution of organisms in the estuary (Uncles 1983) and to some extent, the distribution of the fish that feed on them.

In sub-tidal regions of the estuary, the extreme sediment mobility severely limits colonisation by benthic invertebrates. Large areas of the bottom consist of bedrock or fluidised mud (Kirby & Parker 1983) and few organisms are capable of living under these conditions (Kirby et al. 2004). In more stable marginal areas however, extensive mudflats and sandflats support vast numbers of benthic invertebrates and these in turn provide food for fish and internationally important numbers of wading birds and wildfowl (Ferns 1984).

1.2.2 Habitats & communities

The exceptional turbidity in the estuary results in high concentrations of suspended solids and this provides an excellent environment for microbial growth (Joint 1984). Nutrient levels and loadings are high for an estuary in the UK, but the turbidity limits light penetration and so primary productivity is severely restricted. Our knowledge of the composition of the zooplankton, including the eggs and larvae of fish, is based mainly on surveys carried out in the 1970s (Russell 1980; Williams 1984). These studies show that, as in the majority of temperate estuaries, salinity is the most important variable affecting zooplankton distribution and largely explains the observed seasonal patterns in abundance (Williams 1984). The zooplankton is dominated by calanoid copepods, but in the summer in some parts of the estuary, mysids may contribute a major part of the zooplankton biomass (Williams 1984).

Although strong currents and high turbidity severely limit the development of sub-tidal benthic communities (Warwick 1984), the extensive intertidal areas of mudflats, sandflats, saltmarsh and rocky shores support various communities of invertebrates (Boyden et al. 1977). With respect to rocky shores, it has been shown that the number of species of plants and animals declines with distance up the estuary (Crothers & Hayns 1994). Intertidal mudflats support high densities of invertebrates (Buck 1993) and there are large fringes of cord grass (*Spartina sp.*) and an important eel grass (*Zostera sp.*) bed near the second Severn crossing. Salt marshes occur on both sides of the estuary, mainly in the central reaches flanked by wide intertidal mudflats (Potts & Swaby 1993). Other work has described the intertidal zonation of animals and plants and the benthic ecology of the estuaries of major rivers that enter the Severn Estuary (Morrisey et al. 1994; Moore & Little 1994). For a comprehensive review of the intertidal habitats in the region, the reader is referred to the excellent summary provided by Langston et al. (2003).

2 THE FISH ASSEMBLAGE

2.1 Sampling techniques

The use of conventional fish sampling techniques in the Severn Estuary is extremely difficult because of the large expanses of inaccessible mudflats and the macro-tidal conditions. A traditional fishery for salmon, now no longer in existence, used a battery of basket-work traps known as putchers to catch migrating salmon and these also caught twaite shad, sea lampreys and even the occasional sturgeon (Hardisty 2006). Nets stretched across the River Severn have also been used to catch migrating eels and lampreys in the past. There are a few small commercial fisheries remaining that employ drift nets or beach seines at accessible sites to catch mainly flatfish (Sustainable Development Commission 2007a).

Most of our knowledge of the fish in the Severn Estuary and Bristol Channel comes from data obtained from fish entrained on the cooling-water intake screens at various nuclear power stations sited along the shore (Figures 2.1; 2.2). Two sites in particular (Oldbury and Hinkley Point) have provided detailed accounts of seasonal changes in fish numbers and species composition over several decades and these data form the basis for most of the information in the present report. Power station sampling has been an invaluable technique for studying the fish communities of other estuaries in the UK, including those in the Thames (Araujo et al. 1999) and Humber estuaries (Marshall & Elliott 1998).

(a) (b) (c)

Figure 2.1. Cooling-water intake screens employed at nuclear power stations on the Severn Estuary and Bristol Channel. Water is pumped from the bottom of a water reservoir through a metal mesh screen (a) mounted on large revolving wheels (b). With each revolution, any debris caught on the screens is washed off into mesh cages from which any entrained fish can be recovered (c).

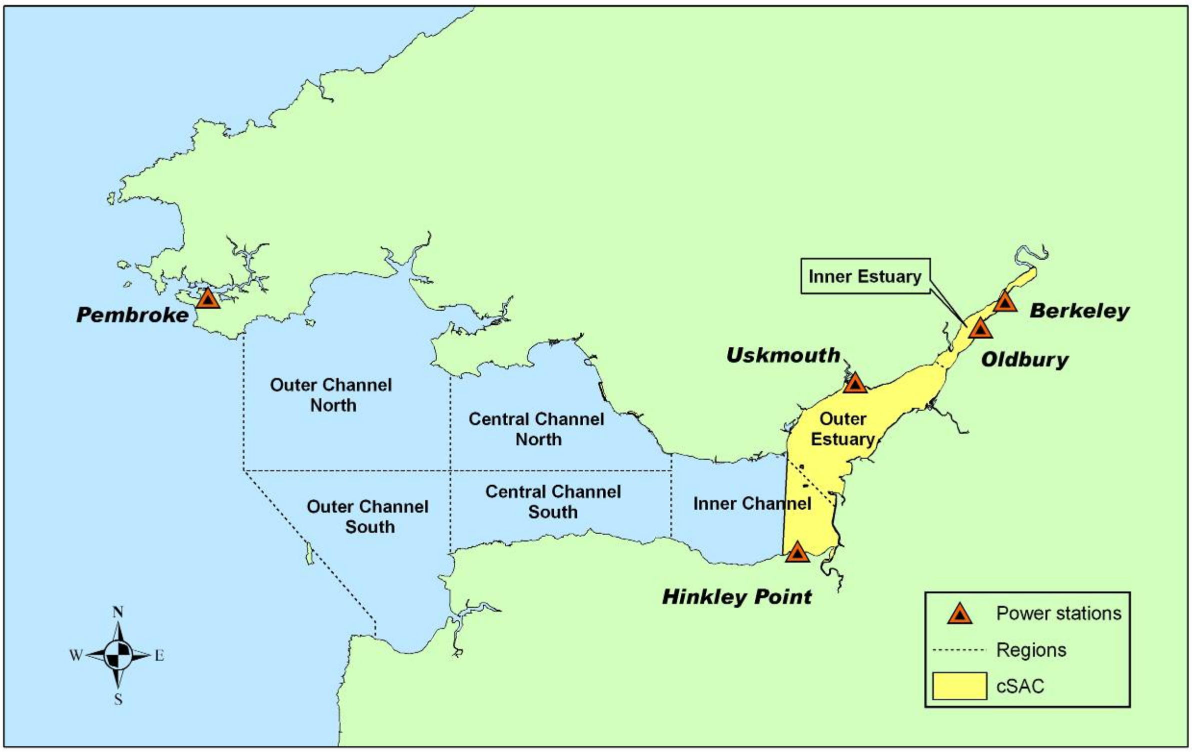

Figure 2.2. Locations of nuclear power stations that have been used to obtain information on the abundance and seasonality of plankton, macro-invertebrates, lampreys and fish in different regions of the Severn Estuary and Bristol Channel. After Claridge et al. (1986).

2.2 Number of fish species

Establishing the number of species of fish that are present in the Severn Estuary is not straightforward because it depends partly on how the area of the Severn Estuary is delineated. The upstream limit has sometimes been defined by the weirs at Maismore or at Tewkesbury on the River Severn, but the Severn Estuary cSAC does not extend this far upstream and ends adjacent to Frampton-on-Severn, several kilometres downstream of these weirs (Figure 2.3). Similarly, the seaward margin of the Severn Estuary where it merges with the Bristol Channel has been variously defined. In the past, this border has been indicated by a straight line that passes between the islands of Steep Holm and Flat Holm (Claridge et al. 1986). On other maps the border between these regions is drawn further seaward (Potts & Swaby 1993). To add to this complexity, the region defined by the Severn Estuary cSAC extends even further towards the ocean to include Bridgwater Bay (Langston et al. 2003). These differences in the way the estuary has been defined are important because information on the fish assemblage based on catches from Oldbury for example, will be quite different from one that also includes data from Hinkley Point, which some would regard as part of the Bristol Channel. In the present study, the Severn Estuary is defined as the region designated by the cSAC (Figure 2.3).

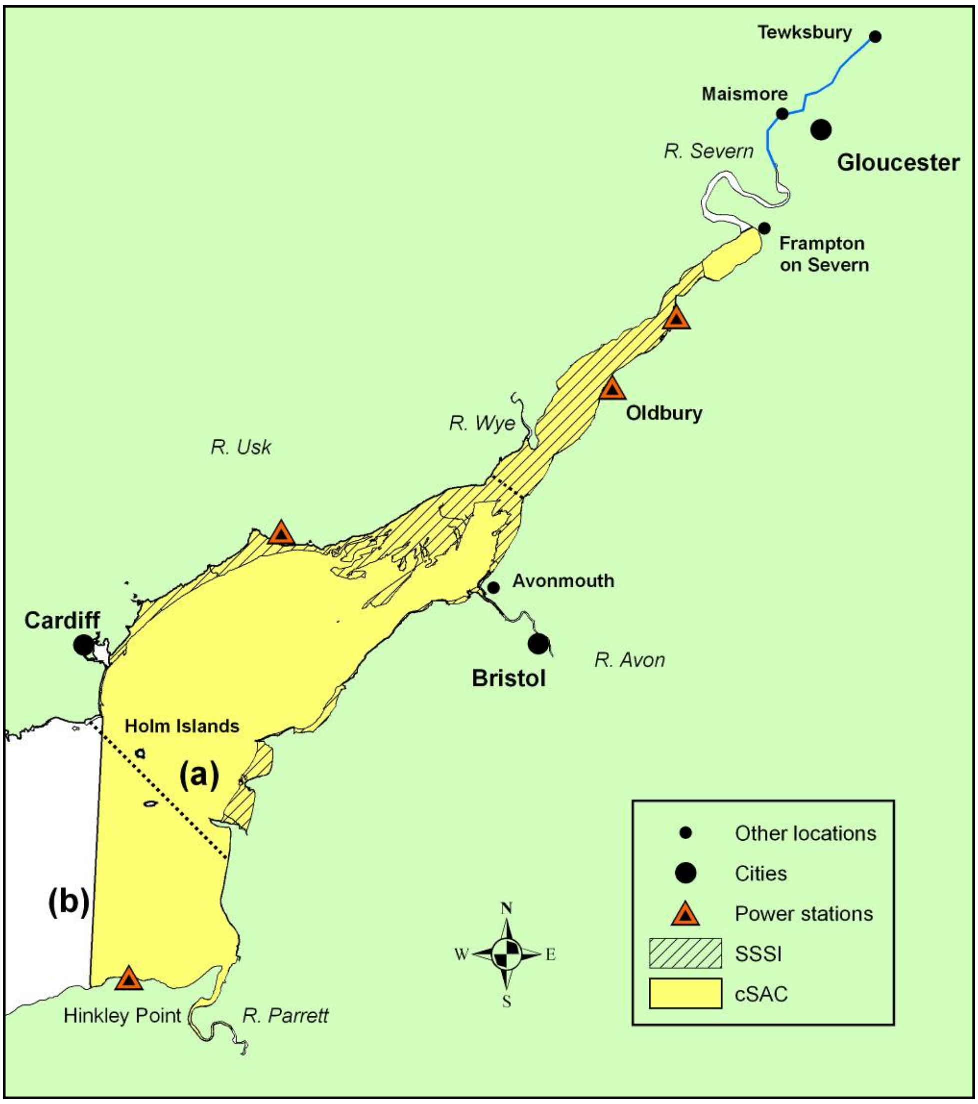

Figure 2.3. The Severn Estuary showing areas of SSSI and cSAC designations. The point at which the seaward margin of Severn Estuary becomes the Bristol Channel has usually been defined as indicated by line (a) that passes between the Holm Islands. The Severn Estuary cSAC designation shown by line (b) extends to include Bridgewater Bay and the power station at Hinkley Point.

There are records of fisheries dating back to the 15th Century (Natural Environment Research Council 1972; Severn Tidal Power Group 1989b; Potts & Swaby 1993), but the first reliable accounts are from the late 1800s (Day 1890; Day 1897). Other pioneering studies were completed in the 1930s and 1940s (Matthews 1933; Lloyd 1941) but more recent reports of fish species and their abundance are all based on samples obtained from power stations. Data from Oldbury power station, in the upper Severn Estuary, spans periods from 1972-1977 and 1996-1999 (Claridge et al. 1986; Potter et al. 2001). A separate, virtually unbroken data set on crustaceans and fish is available from Hinkley Point 'B' power station in Bridgwater Bay that began in 1980 (Henderson et al. 1984) and is still continuing. Data collected prior to the year 2000 for this site are contained in a number of annual reports (Henderson et al. 1984; Henderson 1992; Henderson & Holmes 1992; Henderson & Seaby 1993; Seaby & Henderson 1994; Seaby & Henderson 1995; Seaby & Henderson 1996). Records from 2000 onwards are accessible from Pisces Conservation Ltd. (www.irchouse.demon.co.uk). This unique data set, spanning a quarter of a century, represents one of the largest time series for an entire animal community anywhere in the world. The fact that power station samples have contained almost the complete list of known inshore fish suggests the technique is highly effective for sampling fish communities (Henderson 1989) although it is possible that some very rare species remain unrecorded.

The number of species recorded for the Severn Estuary has been reported as 111 by Potts & Swaby (1993). This represents a cumulative total species list for the estuary that includes part of Bridgwater Bay (Potts & Swaby 1993). Some of these species are not normally associated with estuaries and are probably accidental marine visitors that have been included in the species list for completeness. Thus, the basking shark (*Cetorhinus maximus*) and sunfish (*Mola mola*) are extreme examples that must only have been observed in the estuary very rarely (Potts & Swaby 1993). Henderson has recorded 82 species at Hinkley Point (Kirby et al. 2004). Claridge et al. (1986) list a total of 97 species of fish that they obtained from five power stations in the Severn Estuary and Bristol Channel in the 1970s. Of these, 78 species were described from Oldbury (Potter et al. 1986) and 66 species from Hinkley Point (Claridge et al. 1986; Potter et al. 1986). Although these latter authors recorded species that were common to both sites, those unique to Oldbury tended to be species typical of freshwater habitats while those only found at Hinkley Point were usually associated with the marine environment. This partly explains the reason for the differences in the total number of species recorded by different authors. Whatever method is used to determine the total number of species present in the estuary, it is clear that the fish assemblage in the Severn Estuary is one of the most diverse in the U.K. (Potts & Swaby 1991)

Additional species, not previously reported for the region, continue to be added each year. A good example is the Zander (*Stizostedion lucioperca*), a freshwater predatory fish originally introduced into lakes in the Bedfordshire area between 1878 and 1950 (Smith & Briggs 1999) and first recorded in the Severn Estuary at Oldbury in the 1970s (Potter et al. 2001).

2.3 Life-cycle characteristics

Fish are highly mobile and move up and down the estuary with the changing tides and seasons. Many species can tolerate high turbidity and a wide range of temperatures, salinity and oxygen concentrations. Schemes have been developed to separate fish into different categories based on their biology and ecology (Perkins 1974). In the Severn Estuary, they have been characterised according to their life-cycle characteristics and ecology using the following definitions (Claridge et al. 1986; Potter et al. 1986; Lenanton & Potter 1987):

- **Marine (M):** typically breeding in marine environments outside estuaries. Note that because Claridge et al. (1986) regarded Hinkley Point as outside the estuary, this category is helpful to distinguish fish caught only at Hinkley Point, but even at this site, this group are never abundant. The category contains species that are generally intolerant of reduced salinity and do not therefore turn up in samples from the inner estuary at Oldbury.

- **Marine Stragglers (MS):** marine species abundant in marine environments but occurring infrequently in the Severn Estuary and not known to enter other estuaries in the British Isles in large numbers. These species have occasionally been recovered from both Hinkley Point and Oldbury.

- **Freshwater (F):** typically occurring and breeding in fresh water.

- **Marine Estuarine-Opportunistic (MEO):** marine species found in large numbers in the Severn Estuary and other British estuaries.
- **Estuarine (E):** typically occurring and breeding in estuaries.

- **Anadromous (A):** migrating from the sea into fresh water to breed.
- **Catadromous (C):** migrating from fresh water into the sea to breed.

Species characterised as marine (M) *e.g.* Brill (Figure 2.4), or marine stragglers (MS) are listed in Table 2.1. As these fish normally spend their entire life-cycle in the sea and only occasionally enter estuaries, they have only a minor role to play in the estuarine ecosystem. Thus, only four species, the conger eel, Norway pout, red mullet and plaice; are ever caught in numbers exceeding about 10 per year in power station samples. They probably have little impact, either as prey or as predators on other estuarine species. While they add to the biodiversity of the fish assemblage, their main populations occur in the sea. They will therefore not be seriously affected by changes in estuarine habitat, contamination or other anthropogenic or environmental factors that may impact on populations of those species that are more intimately dependent on the estuary.

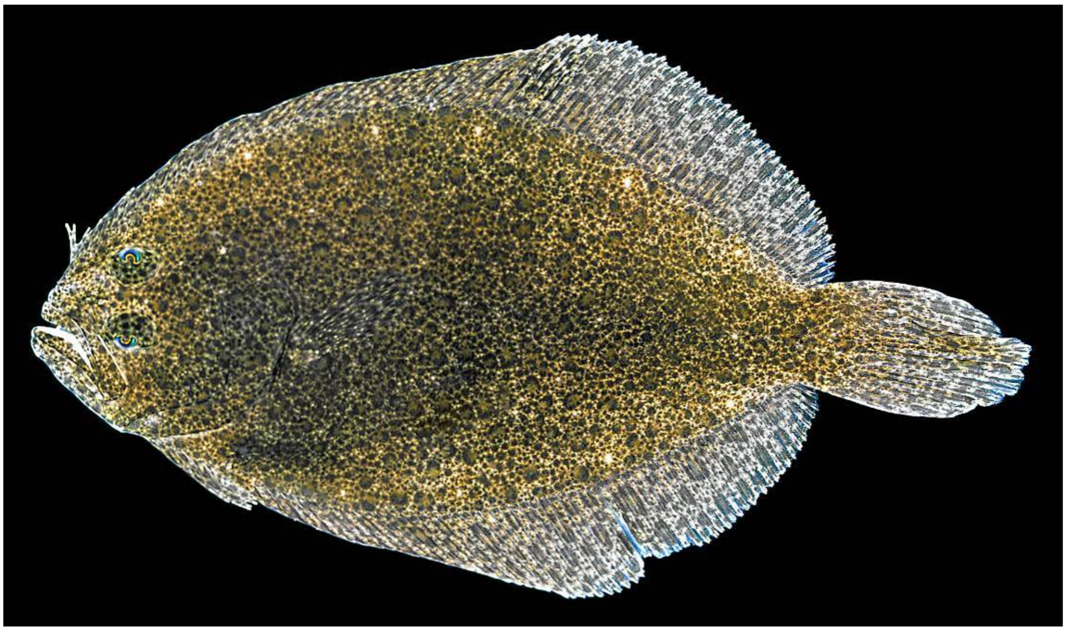

Figure 2.4. The brill (*Scophthalmus rhombus*) is an example of a predominantly marine species (M) that occasionally enters brackish water in small numbers. *Photograph David Bird.*

A similar situation applies to species categorised as freshwater (F) by Claridge et al. (1984). These are listed in Table 2.2 and will be recognised by fisherman as characteristic of freshwater environments in which they normally live and breed. The specimens recovered at Oldbury and/or Berkeley power stations are presumably fish that have inadvertently been swept downstream and entered brackish water. The numbers of freshwater species recovered at Oldbury is always low, and usually related to increases in fresh water discharge in the spring and autumn months after heavy rain. The only exception to this generalisation concerns the three-spined stickleback which occurs in considerable numbers at Oldbury and can be regarded as both a freshwater and an estuarine species (see section 4.13). With respect to the conservation and protection of the Severn Estuary cSAC, these primarily freshwater species are of little consequence since they do not contribute significant numbers or biomass to the estuarine fish assemblage. Most individuals breed and spend their entire life in fresh water.

The remaining species of fish recorded for the Severn Estuary rely on the estuary for some aspect of their life-cycle (Table 2.3). As a result of this dependence, these species are often the most vulnerable to anthropogenic and environmental factors that could affect the habitat and ecology of the estuary. For this reason, this group is the primary focus of this report. For anadromous (A) and catadromous (C) species, the estuary provides a connecting corridor between fresh water and marine habitats that is critical for the completion of the life-cycle. Marine estuarine-opportunistic (MEO) fish are all marine species who spend the first few years of life in the sheltered waters of the estuary where suitable food is abundant and there are fewer predators. The Severn Estuary ranks as one of the top ten estuaries in the UK for the number of marine estuarine-opportunistic species it supports (Potts & Swaby 1993). Marine estuarine-opportunists can be present in the estuary in very large numbers at particular times of year. Finally, there are just a few species that spend their entire life-cycle within the estuary (E). The most important factors that could adversely affect the fish population are discussed in Section 3 and each of the estuarine-opportunistic species is discussed individually in Section 4.

Table 2.1. Species of fish typically occurring and breeding in marine environments. Those assigned to a marine life-cycle category (M) have not been recorded in the Severn Estuary from power stations upstream of Hinkley Point. Those species regarded as marine stragglers (MS) have been recovered from Hinkley Point but have also occasionally been recorded at Oldbury and Berkeley power stations in the inner Severn Estuary. Rare (+), regularly caught (++), common (+++). Adapted from Claridge et al. (1986).

Family	Species	Common name	Life-cycle category	Occurrence
Scyliorhinidae	*Scyliorhinus stellaris*	Nurse hound	M	+
	Scyliorhinus caniculus	Lesser-spotted dogfish	MS	+
Carcharinidae	*Galeorhinus galeus*	Tope	M	+
Squalidae	*Squalus acanthias*	Spurdog	M	+
Rajidae	*Raja undulata*	Undulate ray	MS	+
	Raja montagui	Spotted ray	M	+
	Raja clavata	Thornback ray	MS	+
Clupeidae	*Engraulis encrasicholus*	Anchovy	MS	+
	Sardina pilchardus	Pilchard	MS	+
Gonostomatidae	*Maurolicus muelleri*	Pearl-side	M	+
Argentinidae	*Argentina sphyraena*	Argentine	M	+
Congridae	*Conger conger*	Conger eel	MS	++
Syngnathidae	*Syngnathus acus*	Great pipefish	MS	+
	Entelurus aequoreus	Snake pipefish	MS	+
	Nerophis ophidion	Straight-nosed pipefish	M	+
Gadidae	*Micromesistius poutassou*	Blue whiting	MS	+
	Trisopterus esmarkii	Norway pout	MS	++
	Gadus morhua	Cod	MS	+
	Merluccius merluccius	Hake	MS	+
	Molva molva	Ling	MS	+
	Raniceps raninus	Tadpole fish	MS	+
	Gaidropsarus vulgaris	3-bearded rockling	MS	+
Zeidae	*Zeus faber*	John Dory	M	+

Family	**Species**	**Common name**	**Life-cycle category**	**Occurrence**
Carangidae	*Trachurus trachurus*	Horse mackerel	MS	+
Mullidae	*Mullus surmuletus*	Red mullet	MS	++
Labridae	*Crenilabrus melops*	Corkwing	MS	+
	Ctenolabrus rupestris	Goldsinny	MS	+
	Labrus bergylta	Ballan wrasse	MS	+
	Centrolabrus exoletus	Rock cook	MS	+
Ammodytidae	*Gymnammodytes*	Smooth sand eel	MS	+
	Ammodytes tobianus	Sand eel	MS	+
Trachinidae	*Echiichthys vipera*	Lesser weever	MS	+
Scombridae	*Scomber scrombrus*	Mackerel	MS	+
Gobiidae	*Crystallogobius linearis*	Crystal goby	MS	+
	Aphia minuta	Transparent goby	MS	+
	Buenia jeffreysii	Jeffreys' goby	MS	+
	Gobius paganellus	Rock goby	MS	+
Callionymidae	*Callionymus reticulatus*	Reticulated dragonet	MS	+
	Callionymus lyra	Dragonet	MS	+
Blenniidae	*Blennius gattorugine*	Tompot blenny	M	+
Mugilidae	*Chelon labrosus*	Thick-lipped grey	MS	+
Triglidae	*Eutrigla gurnardus*	Grey gurnard	MS	+
	Trigloporus lastoviza	Streaked gurnard	MS	+
	Aspitrigla cuculus	Red gurnard	MS	+
	Trigla lucerna	Tub gurnard	MS	+
Agonidae	*Agonus cataphractus*	Hook-nose	MS	+
Cyclopteridae	*Cyclopterus lumpus*	Lumpsucker	MS	+
Gasterosteidae	*Spinachia spinachia*	15-spined stickleback	MS	+
Bothidae	*Scophthalmus maximus*	Turbot	MS	+
	Scophthalmus rhombus	Brill	MS	+
	Zeugopterus punctatus	Topknot	MS	+
	Arnoglossus laterna	Scaldfish	MS	+
Pleuronectidae	*Limanda limanda*	Dab	MS	+
	Pleuronectes platessa	Plaice	MS	++
	Glyptocephalus cynoglossus	Witch	MS	+

Family	Species	Common name	Life-cycle category	Occurrence
Lophiidae	*Lophius piscatorius*	Angler fish	MS	+

Table 2.2. Species of fish typically occurring and breeding in freshwater (F) that have been recovered from the water intake screens of power stations at Oldbury and/or Berkeley in the inner Severn Estuary. Rare (+), regularly caught (++), common (+++). Adapted from Claridge et al. (1986).

Family	Species	Common name	Occurrence
Cyprinidae	*Cyprinus carpio*	Carp	+
	Gobio gobio	Gudgeon	+
	Tinca tinca	Tench	+
	Carassius carassius	Crucian carp	+
	Carassius auratus	Goldfish	+
	Abramis bjoerkna	Silver bream	+
	Alburnus alburnus	Bleak	+
	Abramis brama	Bronze bream	+
	Rutilus erythophthalmus	Rudd	+
	Rutilus rutilus	Roach	+
	Leuciscus cephalus	Chub	+
	Leuciscus leuciscus	Dace	+
Percidae	*Perca fluviatilis*	Perch	++
	Stizostedion lucioperca	Zander	+
Gasterosteidae	*Gasterosteus aculeatus*	3-spined stickleback	+++
	Pungitius pungitius	10-spined stickleback	+

Table 2.3. Species of fish that are dependent on the estuary for some part of their life-cycle. Those that use the estuary as a migratory corridor may be anadromous (A) or catadromous (C). Others, termed marine estuarine-opportunistic (MEO) are primarily marine but depend on the estuary for some aspect of their life-cycle. A few species normally live and breed only in estuaries (E). Rare (+), regularly caught (++), common (+++). Adapted from Claridge et al. (1986).

Family	**Species**	**Common name**	**Life-cycle category**	**Occurrence**
Petromyzontidae	*Petromyzon marinus*	Sea lamprey	A	+
	Lampetra fluviatilis	River lamprey	A	+++
Clupeidae	*Alosa alosa*	Allis shad	A	+
	Alosa fallax	Twaite shad	A	+++
	Sprattus sprattus	Sprat	MEO	+++
	Clupea harengus	Herring	MEO	+++
Salmonidae	*Salmo salar*	Salmon	A	++
	Salmo trutta	Trout	A	+
Anguillidae	*Anguilla anguilla*	European eel	C	+++
Syngnathidae	*Syngathus rostellatus*	Nilsson’s pipefish	MEO	+
Gadidae	*Merlangius merlangus*	Whiting	MEO	+++
	Trisopterus luscus	Bib	MEO	+++
	Trisopterus minutus	Poor cod	MEO	+++
	Pollachius pollachius	Pollack	MEO	++
	Ciliata septentrionalis	Northern rockling	MEO	++
	Ciliata mustela	5-bearded rockling	MEO	++
Percichthyidae	*Dicentrarchus labrax*	Bass	MEO	+++
	Pomatoschistus microps	Common goby	E	+++
	Pomatoschistus minutes *Pomatoschistus lozanoi*	Sand goby complex	MEO	+++
	Gobius niger	Black goby	EST	+
Mugilidae	*Liza ramada*	Thin-lipped grey	MEO	+++
Atherinidae	*Atherina boyeri*	Sand smelt	E & M	++
Liparidae	*Liparis liparis*	Sea snail	MEO	+++
Gasterosteidae	*Gasterosteus aculeatus*	3-spined stickleback	E & F	+++
Pleuronectidae	*Platichthys flesus*	Flounder	MEO	+++
Soleidae	*Solea solea*	Dover sole	MEO	++

2.4 Changes in seasonal abundance

One of the most striking features about the fish composition of the estuary is the remarkably consistent cycles of abundance that occur each year. Using multi-dimensional scaling (MDS) ordination techniques, it has been demonstrated that these changes are largely caused by sequential immigration and emigration of different species, particularly marine estuarine-opportunistic species, and were not driven by variations in water temperature, salinity or freshwater discharge from the river (Potter et al. 1986; Potter et al. 1997; Potter et al. 2001). The number of species recorded each month at Oldbury peaks in the autumn and early winter and falls to its lowest levels in the late spring and summer (Claridge et al. 1986; Potter et al. 2001). The proportional contribution of the most abundant marine estuarine-opportunistic species also changes in a regular annual sequence so that each species contributes its highest proportion to the total catch at a characteristic time of year (Table 2.4). For example, the highest proportion of sprat occurs in early September and this is followed by sequential waves in abundance of herring, bass, poor cod, bib, whiting, thin-lipped mullet and sea snail (Figure 2.5).

Table 2.4. Aspects of the biology of the 16 most abundant species of fish collected from Oldbury power station from 1972-1977. The dominant year class (typically >90% of all the ages classes present) are indicated in bold. Very occasional specimens of older year classes have not been included. Adapted from Potter et al. (1986).

Species	Peak spawning time	Peak abundance at Oldbury	Modal length class at peak abundance (mm)	Year class or stage present
Sand goby (*P. minutus*)	Mar-May	Jan	50-52	**0+ 1+**
Sand goby (*P. lozanoi*)	Apr-Jun	Jan	38-40	**0+ 1+**
Whiting	Apr	Sep-mid Nov	85-89	**0+** 1+ 2+
Flounder	Mar & Apr	late Jun-Aug	40-44	**0+** 1+ 2+ 3+
Bass	May	Sep	45-49	**0+** 1+ 2+ 3+
Sea snail	Jan-Mar	Dec-mid Jan	65-69	**0+**
Poor cod	Mar-May	Sep-mid Oct	65-69	**0+** 1+ 2+
Thin-lipped mullet	May & Jun	late Sep-early Dec	45-49	**0+** 1+ 2+
Twaite shad	May & Jun	Aug & Sep	35-39	**0+** 1+
European eel		Nov	270-350	all ages
Herring	Mar & Apr	Aug & Sep	60-64	**0+** 1+
Sprat	Mar & Apr	late Jul-early Sep	40-44	**0+** 1+
3-spined stickleback	Apr-Jun	Dec-Mar	42-46	**0+** 1+ 2+
River lamprey	Mar & Apr	Oct-Jan	260-320	migrant stages
Bib	Mar-May	Sep-mid Oct	70-74	**0+** 1+ 2+
Common goby	Jun & Jul	Dec-Mar	25-39	**0+ 1+**

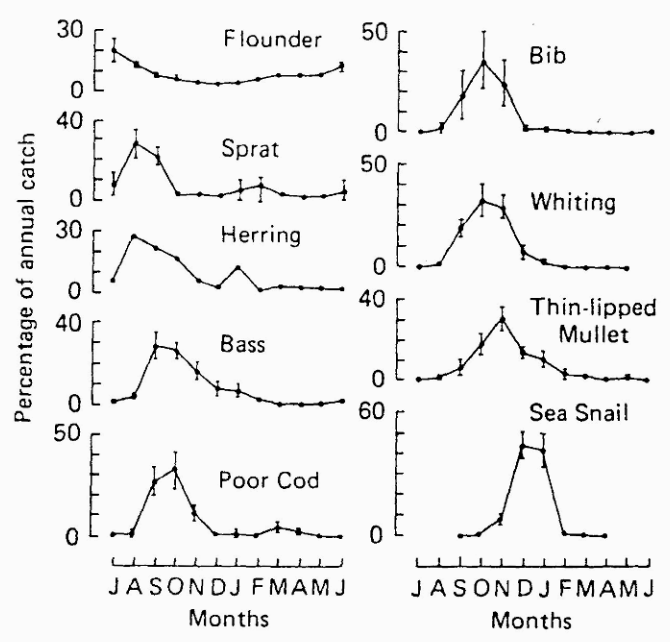

Figure 2.5. The mean percentage catch of nine of the most abundant estuarine-opportunistic marine teleosts collected in each month from Oldbury power station. From Claridge et al. (1986).

In other parts of Europe, fish communities that have been described for estuaries and brackish water habitats include North Bull Island in Ireland (Koutsogiannopoulou & Wilson 2007), the Zeeschelde and Scheldt estuaries in Belgium (Maes et al. 1998; Maes et al. 2005) and the Mondego (Leitao et al. 2007) and Tejo estuaries in Portugal (Salgado et al. 2004). In all these accounts, emphasise is placed on the seasonal pattern of abundance in fish species and the predominance of the youngest year classes at specific times of the year. These studies provide overwhelming evidence that many marine species of fish use estuarine habitats as nursery areas for the youngest year classes. This is especially true for members of the Clupeidae and Gadidae as well as a few other species such as bass and sea snails, which dominate the fish community in the autumn and winter.

2.5 Changes in annual abundance

In addition to cyclical changes in the number of fish in the estuary with season, there are also annual fluctuations in the abundance of many species (Figure 2.6). These inter-annual changes are only detectable because of the existence of long-term data sets that allow numbers to be monitored over several years. For example, data on total annual catches of fish at Oldbury, after adjustment to a common sampling effort, demonstrate that fish abundance was far greater in the 1990s than the 1970s (Potter et al. 2001). This was mainly attributed to increases in the numbers of sand goby, whiting, bass, thin-lipped grey mullet, herring, sprat and Norway pout (Table 2.5). A number of factors are probably responsible for these observed increases, but any improvement in habitat or environmental quality is likely to be of general benefit to all fish. There is circumstantial evidence that the observed increase is probably a direct result of reduced environmental contamination although other factors, such as increasing water temperatures due to climate change, may be significant (see Section 3).

For some species, it has been possible to tease out the important drivers involved in interannual variation. For example, although the annual recruitment of bass is highly variable, increases in abundance have been correlated with exceptionally warm years (Henderson & Corps 1997). On the other hand, the abundance of the sea snails has been shown to vary inversely with water temperature (Henderson & Seaby 1999).

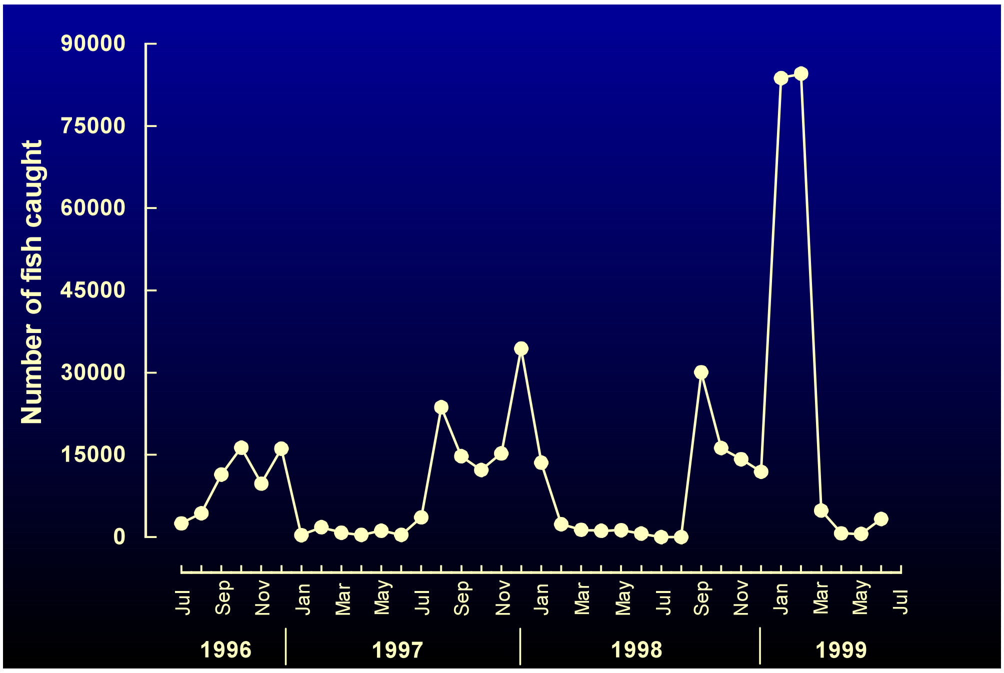

Figure 2.6. The total number of fish caught each month on the water-take screens at Oldbury power station between 1996 and 1999 show marked differences in abundance. See Potter et al. (2001) for further details.

Table 2.5. Ranks, mean annual abundances and percentage contributions of the most abundant species of fish collected at Oldbury in the five years between July 1972 and June 1977 and between July 1996 and June 1998, and the proportional difference between the mean abundances in the former and latter periods. Adapted from Potter et al (2001).

Common name	**1972/1977**			**1996/1998**			**Difference**
	Rank	**Mean**	**%**	**Rank**	**Mean**	**%**	
Sand goby	1	8572	29.2	1	36129	37.7	+4.2
Whiting	2	8294	28.2	3	17714	18.5	+2.1
Flounder	3	2896	9.9	7	1899	2.0	-1.5
Bass	4	2156	7.3	2	22585	23.6	+10.5
Sea snail	5	1980	6.7	8	1466	1.5	-1.4
Poor cod	6	846	2.9	17	35	<0.1	-24.2
Thin-lipped mullet	7	779	2.7	6	2477	2.6	+3.2
Twaite shad	8	776	2.6	11	729	0.8	-1.1
European eel	9	737	2.5	10	949	1.0	+1.3
Herring	10	574	2.0	9	1444	1.5	+2.5
Sprat	11	360	1.2	4	5402	5.6	+15.0
3 spined stickleback	12	254	0.9	14	178	0.2	+1.4
River lamprey	13	191	0.7	16	109	0.1	-1.8
Bib	14	182	0.6	13	184	0.2	0
Common goby	15	149	0.5	15	159	0.2	+1.1
Norway pout	20	48	0.2	5	2944	3.1	+61.3
Dover sole	17	75	0.3	12	345	0.4	+4.6
Total (all species)		**29366**			**95828**		

These datasets are also invaluable for detecting subtle long-term trends. Over short periods of a few years, such small changes are difficult to separate from the noise of other factors such as variable annual recruitment, but over periods of a decade or more, clear trends emerge. Thus, the gradual decline in the numbers of river lampreys and European eels using the estuary becomes clearly evident, although the causes for their decline is not always easy to establish with any certainty (Maitland & Lyle 1990; Maitland & Lyle 1991).

3 ANTHROPOGENIC & ENVIRONMENTAL CONCERNS

3.1 Contamination

Early comprehensive accounts of the contaminants entering the Severn Estuary, as well as a number of other significant papers on the Severn Estuary, were published in a special edition of the Journal *Marine Pollution Bulletin* (Morris 1984; Owens 1984). Since that time, many other studies have reviewed sources and distribution of estuarine contamination (Harper 1991; Vale & Harrison 1994; Little & Smith 1994; Ellis 2002; Bird 2002) and these have been recently reviewed and summarised by Langston et al. (2003). Large estuaries are attractive to industrial development because they provide a source of water for industrial processes, a suitable sink for the discharge of industrial effluent and port facilities for the transport of bulky raw materials and finished products (Figure 3.1). Estuaries tend to be bordered by large towns and cities that require the appropriate infrastructure to service the population (*e.g.* roads, energy production, STWs) and these are an important additional source of contamination. Until the 1970s, the major pollution impact on estuarine organisms in most estuaries was probably caused by poorly treated sewage that led to low oxygen concentrations (Matthiessen & Law 2002). In the Severn Estuary however, the high turbidity helped minimise this impact, and it was metal contamination that was of more serious concern. Under the National Water Council classification system, the water in the upper estuary is designated mainly of good quality while the middle and lower estuary are regarded as fair quality (Sustainable Development Commission 2007a).

3.1.1 Metals

In the Severn Estuary, there is a tendency for point sources of metal contamination to be diluted and widely distributed by the strong tidal currents. Nevertheless, some regions remain relatively highly contaminated because many metal ions show a pronounced tendency to bind to sediment particles. The highest levels of metals tend to be associated with the finest sediment fractions because of their larger surface area and binding characteristics (Duquesne et al. 2006). There remains a legacy of contamination in the sediments that will continue to pose a potential threat to the biota for decades, but the ultimate fate of metals in the estuary depends on a number of factors, of which sediment stability is probably the most important. In areas of sediment erosion, contaminated materials are dispersed widely and are eventually carried out of the estuary. In regions of deposition however, fine particles gradually accumulate so that highly contaminated sediment becomes overlaid by cleaner material.

Metal contamination has important implications for the benthic organisms that live within the sediment and on the fish that feed on them. Compliance with Environmental Quality Guidelines (EQAs) under the EC Dangerous Substances Directive is generally good although Cu levels are close to the EQS at a number of sites. In the 1960s, particular concern was expressed about the amount of Cd present in the estuary, since it was then considerably higher than in most other industrialised European estuaries while in 1996 and 1998 there were failures for Zn around Avonmouth (Severn Tidal Power Group 1989a).

Bioaccumulation of metals occurs widely in invertebrates but the ecological significance is uncertain (Bryan & Langston 1992). Heavy-metal concentrations have been measured in limpets (*Patella vulgata*) (Noël-Lambot et al. 1980), brown shrimp (*Crangon crangon*) (Culshaw et al. 2002) and some fish from the region (Hardisty et al. 1974a; Badsha & Sainsbury 1977; Badsha & Sainsbury 1978; Rotchell et al. 2001; Bird et al. 2008). Levels of Cd in brown shrimp can still be 100 times higher than values reported for other European coastal waters (Culshaw et al. 2002). Although concentrations of Cd and other metals in sediments still often exceed proposed sediment guidelines, they only occasionally exceed levels that might have adverse measurable effects on the biota (Langston et al. 2003). There are now good indications that levels of Cd and other metals are declining in sediments (Duquesne et al. 2006) and in the biota, *e.g.* seaweed (Martin et al. 1997).

Figure 3.1. Industrial complexes at Port Talbot. *Photograph David Bird.*

3.1.2 Organic contaminants

Polycyclic Aromatic Hydrocarbons (PAHs) are present but only locally elevated from sources such as fossil fuel combustion, shipping, urban run-off, STWs and various point sources from industrialised areas (Law et al. 1997; Woodhead et al. 1999). Mostly this is anthropogenic, but local coal and oil-bearing strata probably also make a contribution (Langston et al. 2003). Some PAHs in sediments may exceed probable effects levels with consequences for benthic invertebrates and fish.

The *Sea Empress* oil spill in 1996 triggered a broad range of chemical and biological effects monitoring. Dab and plaice collected in the vicinity of Milford Haven showed clear evidence of elevated liver enzyme activity induced by the oil (Kirby et al. 1999). Benthic and migratory species of fish are especially vulnerable to oil spills and the estuary has many potential sources of hydrocarbon contamination. However, as past oil spills, including the *Sea Empress* have shown, under appropriate conditions, PAHs and related compounds do not tend to persist in the environment in the same way metals do and the energetic conditions in the estuary will help to minimise the long term impact of any hydrocarbon contamination.

Metabolites of PAHs have been detected in the bile of European eels from the estuary but concentrations were similar to those in eels from the Thames estuary and much lower than detected in the same species from more industrialised estuaries in the UK (Ruddock et al. 2002; Ruddock et al. 2003).

Pesticide and herbicides levels are not presently a problem. Organochlorine pesticides occasionally occur in sediments or benthic fish such as European eels, while PCB contamination is largely related to past industrial activity at Newport on the Usk. Organically bound tritium in sediments and benthic biota in the Cardiff area are a result of industrial discharge but the assimilation pathways are not understood (Langston et al. 2003).

Despite continuing improvements in water quality, especially for Cd, it is uncertain what effect this will have on the biota. The reported decline in European eel and twaite shad populations is at odds with general perceptions about recovery and improving water quality (Langston et al.

2003). This may be insignificant when compared with other factors such as fishing pressure, natural population variability and the issues discussed in the following sections.

3.1.3 Endocrine disruption

A survey of oestrogenic compounds in UK estuaries and coastal waters revealed that some heavily industrialised estuaries in the UK contained compounds that were oestrogenic to flounders (Allen et al. 1999). Thus, in the Mersey estuary, vitellogenin plasma concentrations, normally only present in maturing female fish, have been found to be elevated in male and immature female flounder, indicating that these fish had been exposed to natural and synthetic oestrogens and/or xenoestrogens (Kleinkauf et al. 2004).

There is no specific information for any species of fish in the Severn Estuary, but endocrine disruption may be important for migratory species, especially downstream of STWs, since these are believed to be a significant source of oestrogenic and other endocrine disrupting compounds (Allen et al. 1999). It has been suggested that marine fish that are top-predators may also be susceptible to endocrine disruption due to biomagnification of organochlorine pesticides. Processes such as smoltification, metamorphosis, and hermaphroditism, may be particularly susceptible to endocrine disruption, but this has not been adequately studied (Matthiessen 2003).

Despite the lack of information on endocrine disruption in fish from the region, there is recent evidence that normal gonadal development of male estuarine clams (*Scrobicularia plana*) is occurring extensively at sites in Southwest UK, with populations exhibiting varying degrees of intersex (ovotestis). The intersex condition has been observed in more than two-thirds of the populations screened and was highest in clams from the Bristol Channel and Severn Estuary (Langston et al. 2007). It is very likely similar endocrine disruption will be occurring in fish from these sites, but this has not been studied.

3.2 Climate change

Water temperature has a significant influence on the life of fish. Since the majority of fish cannot regulate their body temperature, the temperature of the surrounding water largely determines their metabolism. Moreover, temperature and salinity are primary determinants of oxygen tension in water. In warm saline conditions, oxygen availability may become a limiting factor for some species, especially those such as salmonids that have a high oxygen demand. Temperature therefore profoundly influences virtually every aspect of a fish's life, determining their growth rate, migratory activity and timing of sexual maturity. Many fish do not feed at all during the winter while others will migrate to colder, deeper water during the summer months. It has recently been proposed that temperature resource partitioning is a significant factor driving the temporal changes in species abundance in estuaries (Attrill & Power 2004).

The effects of global increases in temperature are therefore likely to have a significant impact on the distribution of many fish species and there are already indications that this has affected the fish assemblage in the Bristol Channel (Genner et al. 2004; Henderson & Seaby 2005a). It has been suggested that the increasing trend in the number of fish caught each year at Hinkley Point could be related to increased temperature, decreased salinity and the North Atlantic Oscillation and that these changes are a consequence of climate change (Henderson 2007; Henderson et al. 2007b). Henderson and colleagues have predicted that a 2°C increase in inshore seawater temperature would enhance total species richness of fish in Bridgwater Bay by 10%, although most of this gain would be due to "*warm water tourists*". Species near the northern limit of their distribution, such as sole and bass, have already shown dramatic increases in numbers (Figure 3.2) while those at their southern limit, such as the sea snail and dab have declined (Henderson 2007; Henderson et al. 2007a; Henderson et al. 2007b). Climate-driven changes in rainfall patterns since 1999 have tended to increase river discharge with concomitant increases in the amount of detritus entering the estuary. It has been suggested that the resulting enhanced productivity might explain why some cold water species such as cod and other gadoids (Figure

3.2), have also increased in abundance in recent years (Henderson 2007). Establishing the impact of climate change on fish assemblages will be difficult to determine and is likely to be the result of a complex interplay of factors, but there is no doubt that climate change has the capacity to significantly impact fish communities.

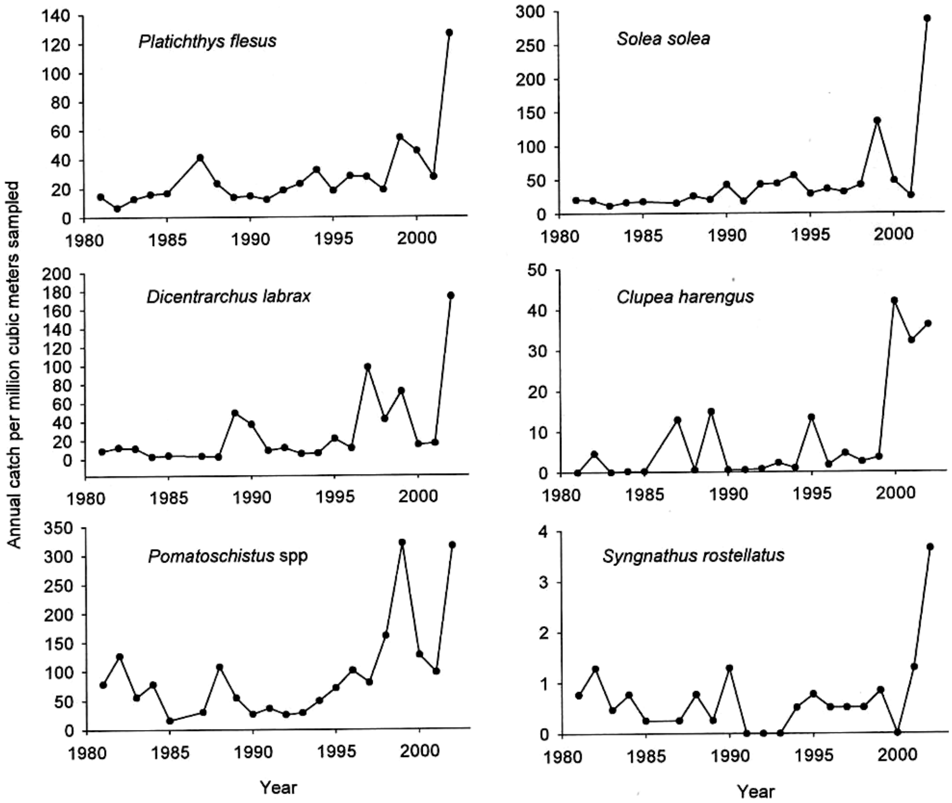

Figure 3.2. Examples of fish species, collected from Hinkley Point power station, that have shown increases in annual abundance. Modified from Henderson et al (2007b).

3.3 Sediment disturbance

Sedimentary layers have been used to trace the historical legacy of coal production and heavy metal contamination in the estuary from pre-industrial times through to the present-day (French 1993a; French 1993b). This is only possible because at some sites, *e.g.* salt marshes, sediment accumulation remains undisturbed. Over time, contaminated sediments from past industrial activity are overlaid by cleaner material, eventually making heavy metals and other contaminates unavailable to the biota. Problems can arise however, if sediments are subsequently disturbed, for example, by the development of docks, jetties and barrages or through dredging activity.

In a study of heavy metal concentrations in brown shrimps, Culshaw et al. (2002) found some of the highest concentrations of Cd, Cu and Zn in shrimp from Oldbury. At this site, regular dredging is used to maintain the depth of a reservoir of cooling water just offshore. Re-mobilisation of contaminated sediments at this site may partly explain the observed elevated metal levels in shrimp and this could, through bioaccumulation, increase metal contamination in fish feeding on them.

Sediment extraction has been identified as a cause for concern, especially when it has involved riverine sands and gravels which are essential habitats for several migratory species including lampreys, shad and salmonids. Loss of spawning habitat has been highlighted as one of the causes for the decline of shad in European rivers.

3.4 The Severn Barrage

The environmental impact of the original proposal to build a barrage across the Severn Estuary (Figure 3.3) are summarised in several government reports (Severn Barrage Committee 1981; Department of Energy 1989; Severn Tidal Power Group 1989a; Severn Tidal Power Group 1989b). Stimulated by the need to increase the proportion of energy obtained from renewable sources, the Sustainable Development Commission (SDC) has recently published a major assessment of the potential of tidal power in the UK (Sustainable Development Commission 2007b). This initiative includes a review of two proposals for a Severn barrage – the Cardiff-Weston barrage and The Shoots or English Stones barrage (Sustainable Development Commission 2007a). The implications of a barrage for the fish assemblage in the estuary are based mainly on studies undertaken for the original proposals in the late 1980s.

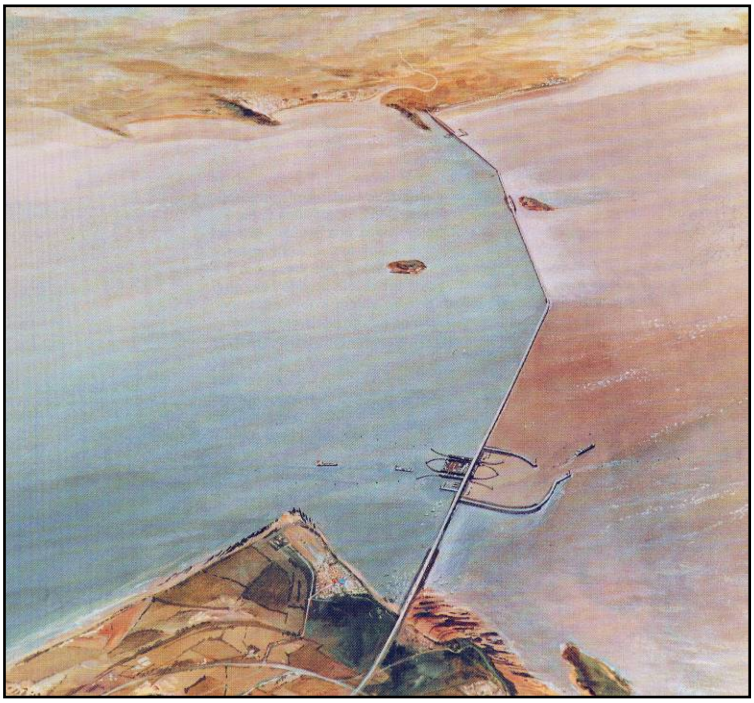

Figure 3.3. Artists impression of the Weston-Cardiff Severn barrage originally proposed in 1981. From Department of Energy (1989).

The environmental effects of relevance to fish in the estuary are similar for both schemes and are summarised in the following sections.

3.4.1 Water quality

Based on information in the SDC review (Sustainable Development Commission 2007a) the likely effects with respect to water quality are predicted to include:

- Reduction in the rates of longitudinal dispersion and the efficiency of absorption of oxygen from the air.
- Movement seaward of the freshwater/salt water interface by 5 to 30 km, depending on river flow.
- Up to a doubling of concentrations of conservative pollutants such as Ni and Cd.
- No significant change in the concentrations of non-conservative pollutants behind the barrage.
- No significant change in the number of bacteria near sewage outfalls.
- No significant change in the oxygen status. In spite of the reduced tidal mixing the system would tend to be capable of retaining more oxygen because of the associated reduced salinity.
- A reduction in the suspended sediment concentrations landward of the barrage.

The expected shift in salinity would profoundly influence the fish assemblage in the region. Many marine species would be expected to penetrate further up the estuary to the barrage and their abundance here would increase.

3.4.2 Intertidal mudflats & sandflats

The total area of intertidal mudflats and sandflats exposed at low water within the Severn Estuary has been estimated to cover an area of 20,958 ha (English Nature and the Countryside Council for Wales 2005). The construction of a barrage would reduce the tidal range upstream and could result in a loss of up to 30% of the intertidal habitat (Sustainable Development Commission 2007a). Although this might be expected to reduce the populations of benthic invertebrates on which many fish and birds rely, it has been suggested that the reduced turbidity and resulting bed stability would cause a shift from hard to soft bottom communities and lead to an increase in the biomass of suspension-feeding invertebrates (Department of Energy 1989). This form of increased productivity has been observed in La Rance (see next section) where there has been an increase in species diversity and abundance of invertebrates (Desroy & Retiere 2004)

3.4.3 Migratory species

Another significant concern about the barrage relates to its potential impact on migratory species of fish. Increased numbers of weirs and other migratory barriers have long been implicated as a contributing factor in the decline of anadromous species including lampreys and shads. There can be little doubt that migratory passageway problems are threatening a high proportion of European freshwater fishes (Northcote 1998). It should also be remembered that many marine estuarine opportunistic species, although not anadromous, still penetrate well into the estuary as part of their normal seasonal movements into suitable nursery areas. The impacts of migratory barriers in general are considered in detail in Section 5.1.

3.4.4 Turbines

For fish, the single most important problem arising from tidal power generation is the inevitable increased mortality caused by the passage of migratory fish through hydroelectric turbines. This was identified as a significant problem when the original barrage proposals were considered

(Department of Energy 1989) and has been highlighted again in the SDC review (Sustainable Development Commission 2007a). A study to identify factors causing injury to fish during turbine passage concluded that there was insufficient understanding of the specific injury mechanisms (Solomon 1988). Another report on the impact of the tidal barrage in the Rance basin on the northern coast of Brittany concluded that there is little evidence that turbine-related deaths have been a significant problem where migratory fish and cephalopods apparently pass through the turbines, or via sluice gates, unharmed (Retiere 1994). In contrast however, other evidence suggests that the La Rance barrage has had an impact on trout migration (SAGE 2004).

Fish passage studies conducted at the Annapolis Royal low-head tidal turbine in the Bay of Fundy in Canada also suggest turbine-related mortality can be significant (Dadswell & Rulifson 1994). At this site, mortality was estimated to result in 20-80% mortality per passage. The mortality rate depended on the fish species involved, fish size and the efficiency of the turbine operation (Figure 3.4).

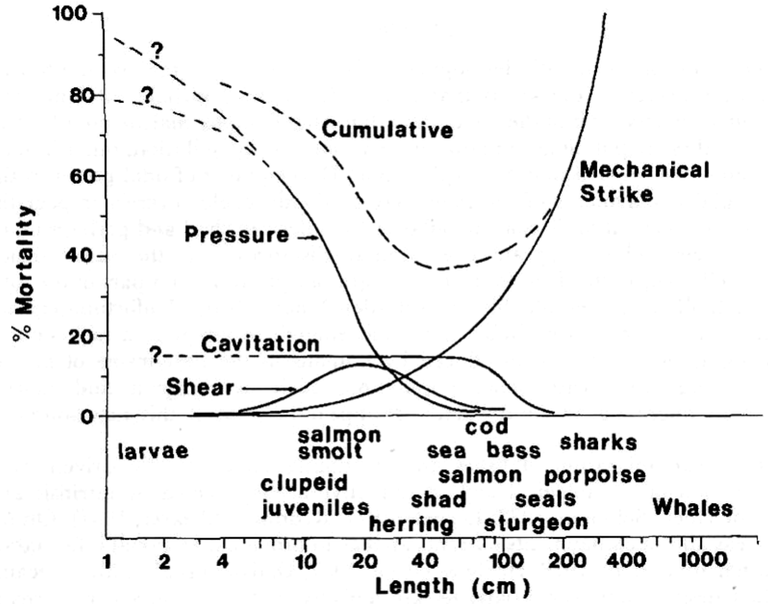

Figure 3.4. Hypothetical distribution of mortality and its causes from passage through hydraulic, low-head turbines in relation to body length. From Dadswell & Rulifson (1994).

Recently, additional work on the injury caused to fish by turbines has been simulated for various stress factors. Mortality due rapid pressure change, hydrologic shear stress and turbulence, cavitation and runner blade strike were each modelled separately (Turnpenny et al. 2000) and the results have led to greatly improved estimates of fish injury for key migratory species (Table 3.1).

Table 3.1. Predicted injury rates for fish passing through a Severn barrage turbine. From Sustainable Development Commission (2007a).

Fish (length)	Injury Rate
Adult salmon (1000 mm)	40%
Salmon smolt (150 mm)	10%
Adult European eel (700 mm)	28%
Juvenile shad (70 mm)	53%

The impact of hydroelectric power generation has been studied in migrating European eels in the River Meuse in the Netherlands using radio-telemetry. *Nedap* transponders implanted into silver eels enabled their movements to be monitored near the hydropower installations (Winter et al. 2006). This study demonstrated that migrating eels showed a reluctance to pass the turbines and subsequently suffered estimated turbine-related mortality of 16-26%.

Similar concerns about turbine-related mortality have been raised following proposals for other barrage schemes in Wales (Jones 1994). It is surprising therefore that in a study carried out as part of the Sustainable Energy Programme; conservation issues relating to the impact of a barrage on the fish assemblage were not mentioned (Taylor 2002).

The typical approach to mitigate against the impact of migratory barriers involves the construction of fish passes. With respect to the potential impact of a barrage, the SDC report provides a useful summary of the issues (Sustainable Development Commission 2007a):

"*Provision of large fish passes will be essential, however the design of a fish pass functioning in such an environment and facilitating tidal transport mechanisms is without precedent (neither Fundy, Annapolis, La Rance or the south Wales barrages attempt to do this). Although varying proportions of some species may find and use a fish pass, the success with which they will do so is not currently predictable. Given the varying behaviour and migration route of each species it is conceivable that a large number of passes of varying design would be needed. A substantial flow would be required through these passes in order to maximise attraction of fish, and the structures would therefore have to be very large indeed. Attempting to exclude fish by screening (behavioural or the highly impractical screening approach) would be highly unlikely to work at all (Environment Agency, pers. comm. 2007). The potential for fish to change their typical migration routes in response to a large scale obstruction would require further consideration in the context of a barrage".*

3.5 Industry-related fish mortality

Industrial changes in aquatic ecosystems, including cooling-water extraction, barriers to migration and turbine development, can all restrict or delay fish migration, increase predation, affect water quantity and quality, and subject fish to direct damage and stress. Schilt (2007) has reviewed attempts aimed at improving fish passage and protection near these facilities. Apart from modifications and additions to engineered structures, sensory stimuli such as light, sound, turbulence and electric fields have been used to influence fish distribution. In this context, it is noteworthy that at a hydroacoustic monitoring station on the River Wye, migrating shad would not pass the station when it was operating at 200 kHz, but were unaffected at 420 kHz (Gregory & Clabburn 2003). Measures designed to improve fish survival, such as spilling water at a dam to provide non-turbine passage, can sometimes cause other problems for fish such as higher dissolved gas concentrations downstream (Schilt 2007).

The number of fish killed annually by power station intake screens is considerable and has been estimated to exceed 10 million individuals at a power station located on the Ems Estuary in The Netherlands (Hadderingh & Jager 2002). Similar levels of mortality at Hinkley Point had led to concern that this level of entrainment could be detrimental to the fish population. Trials to evaluate the use of repellent sound fields to divert fish away from the power station intake were unsuccessful, in fact, the number of fish entrained increased (Turnpenny et al. 1994). More recent attempts at using sound as a deterrent have been more successful, decreasing the number of fish entrained by 60% (Maes et al. 2004). This technology may have important applications for deterring fish from entering turbine intakes if the Severn Barrage is built.

4 SPECIES DEPENDANT ON THE ESTUARY

4.1 Lampreys (Petromyzontidae)

Two anadromous species of lampreys use the Severn Estuary as a migratory corridor, the sea lamprey (*Petromyzon marinus*) and the river lamprey or lampern (*Lampetra fluviatilis*). The River Severn has always been an important river for both species and despite the extensive construction of weirs in the 19th century; it probably still supports the greatest number of sea and river lampreys of any northern European river. Other major tributaries of the Severn and several Welsh rivers also support significant lamprey populations (Hardisty 2006). Information about the status of both species in the region have been summarised in several reports (Harvey & Cowx 2003; Maitland 2003; Henderson 2003).

4.1.1 Sea lamprey (Petromyzon marinus)

Adult sea lampreys grow to about 91 cm and a weight of 2.5 kg. Information about the parasitic marine phase in the British Isles is poorly known except that they attack a wide range of fish including salmon, European eels, cod, haddock, basking shark and sturgeon (Wheeler 1969). Adult sea lampreys enter the Bristol Channel at the start of their spawning migration in the spring and are occasionally recovered from Oldbury in March. Spawning occurs in gravelly sections of streams and rivers in May and June when the water temperature reaches 15ºC (Hardisty & Potter 1971b). The adults excavate a shallow circular depression in the substratum, known as a redd and die soon after spawning. The eggs hatch into blind and toothless larvae that are quite unlike the adult and are carried downstream of the spawning site and burrow into silty deposits of the river. Here they remain for 5-6 years depending on the water temperature and food supply (Hardisty & Potter 1971a). They grow slowly, filter feeding on algae, diatoms and other organic detritus until they reach 150-200 mm, when they undergo a radical metamorphosis that begins in late summer and lasts for approximately four months. During this period the rudimentary eyes of the larvae become fully functional, a tooth-bearing oral disc develops and the body turns a silvery colour.

Figure 4.1. Young adult sea lampreys (*Petromyzon marinus*). These individuals were caught in the River Severn during their downstream migration. *Photograph David Bird.*

The newly metamorphosed young adult sea lampreys emerge from the substrate and begin a downstream migration to the sea in the autumn when rivers are in flood (Potter 1980). Very little is known about this stage in the life-cycle although it is believed that entry into salt water is an important stimulus for the onset of parasitic feeding.

Downstream migrants of this species are very occasionally recovered from intake screens at Oldbury in the autumn. However, in November 1988, several hundred recently metamorphosed sea lampreys (Figure 4.1) were caught by fishermen using nets across the River Severn during heavy freshwater discharge about 10 km above Gloucester just outside the tidal limits of the River Severn (Bird et al. 1994). The size of these individuals and the presence of digested material in their guts implied that they had already started to feed parasitically. It has been suggested that young adults may be carried back into freshwater, either attached to other migratory fish such as salmon (Banks 1969) or by strong tides, but it is also possible that they had already begun to feed in freshwater (Bird et al. 1994).

4.1.2 River lamprey (Lampetra fluviatilis)

Although the ecology of the river lamprey or lampern (Figure 4.2) is in many respects similar to that of the sea lamprey, there are important differences in the timing and detail of the different phases in the life-cycle. There are two distinct forms of the river lamprey, both of which occur in the Severn Estuary. The typical larger form feeds parasitically for about 18 months at sea, reaching a length of approximately 300 mm. The smaller *praecox* form however, spends only 12 months feeding as an adult and therefore rarely attains a length greater than about 240 mm. The main upstream migration of river lampreys peaks between October and January for the typical form, and between February and March for the *praecox* form (Abou-Seedo & Potter 1979). Fishes known to have been attacked by river lampreys are often migratory or brackish water species, such as the sea trout and shad (Figure 4.3), and this suggests that adult river lampreys do not move far from the coast during the adult feeding stage (Wheeler 1969).

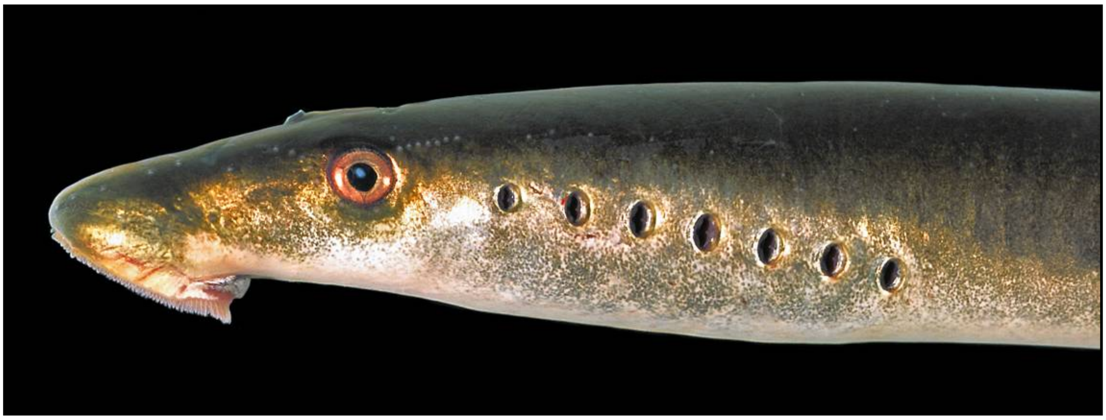

Figure 4.2. An upstream migrant river lamprey (*Lampetra fluviatilis*) recovered from the water intake-screens at Oldbury power station in the autumn. *Photograph David Bird.*

River lampreys require a gravel substrate in which to build their redds and spawning takes place in March or April when the water temperature is between 9 and 11ºC. Since river lampreys can be found in the estuary as early as July and as late as April, some individuals must spend several months in rivers before the water is warm enough to initiate spawning. River lampreys are known to spawn in gravelly sections of the River Severn below Tewkesbury weir near Gloucestershire. The larvae of river lampreys live in the soft deposits of streams and rivers where they feed on micro-organisms filtered from the water above their burrows (Moore & Potter 1976a; Moore & Potter 1976b). The larval phase lasts for just over four years (Hardisty & Huggins 1970). Newly metamorphosed downstream migrants appear in elver trawls (Potter & Huggins 1973) and can be collected from power station intake screens in the spring.

Figure 4.3. Dead specimen of a shad recovered from Oldbury power station that had been damaged by the feeding activity of a river lamprey. Note the central hole produced by the tooth bearing tongue-like piston of the lamprey and the small surrounding marks caused by the lamprey's oral disc teeth. *Photograph David Bird.*

4.1.3 Conservation issues: Lampreys

The decline in lamprey populations has been attributed to a number of causes. Dams and weirs that impede the upstream adult migration have undoubtedly been important and a tidal barrage would pose a serious threat to these ancient jawless fish. Based on recent estimates for a variety of fish species (Turnpenny et al. 2000), turbine-related mortality associated with a tidal barrage could be expected to be similar to that for eels which have a comparable shape and size *i.e.* about 28% per passage.

The loss or destruction of spawning sites is not likely to be a major problem because spawning lampreys require gravelly riverine habitats similar to those used by salmon and trout and these are generally well protected. The same cannot be said for the sediments in which the larvae occur and disturbance of larval beds by farm stock, and pollution from their urine and faeces, needs to be avoided if viable lamprey populations are to be maintained.

There is now evidence that adult sea lampreys select spawning rivers based on the odour of larvae that they contain and the bile acids released by the larvae are part of this pheromonal odour (Bjerselius et al. 2000). The chemical structure of the pheromone has been elucidated (Sorensen et al. 2003; Sorensen & Hoye 2007) so there is now the potential to use attractants to guide upstream migrating adults to suitable spawning sites. It is ironic that this has been suggested as a way of catching the landlocked form of the sea lamprey in the Great Lakes region of North America where this species is a serious pest (Smith 1972; Smith & Tibbles 1980), but the potential of pheromonal attractants for lamprey conservation has not yet been explored.

4.2 Shad (Clupeidae)

The biology of the twaite shad (*Alosa fallax*) and the allis shad (*Alosa alosa*) in European waters were the subject of an International Conference in France in 2001 at which the ecology and status of both species in Europe were reviewed (Bagliniere et al. 2001). Allis and twaite shad have declined across Europe and they are now absent from many rivers where they once flourished and supported thriving fisheries. A report on the ecological requirements of shad has also been produced under the LIFE in UK Rivers project (Maitland & Hatton-Ellis 2003) and other reports and extensive background information on these species are available elsewhere (Potts & Swaby 1991; Hillman et al. 2003; Maitland & Hatton-Ellis 2003; Henderson 2003).

4.2.1 Twaite shad (Alosa fallax)

The biology of the twaite shad in the Severn Estuary and River Severn has been the subject of a number of investigations (Claridge & Gardner 1978; Aprahamian 1988; Caswell & Aprahamian 2001; Aprahamian & Lester 2001; Aprahamian & Aprahamian 2001). Adult twaite shad enter the Severn Estuary between April and June with peak numbers observed in May when the water temperature is between 10.6 and 12.3ºC (Claridge & Gardner 1978; Aprahamian 1988). Males arrive first and tend to be smaller and younger (2-5 years old at maturity) than females (4-5 years old at maturity) (Wheeler 1969; Aprahamian 1988). The adults do not feed during their upstream spawning migration.

Twaite shad require areas of sand or gravel in which to spawn (Caswell & Aprahamian 2001) and only four rivers in the region provide suitable conditions that are known to support breeding populations. These are the Severn, the Wye, the Usk and the Twyi (Hillman et al. 2003). Spawning time varies between rivers so in the Wye for example, it occurs in mid-June but in the Severn it takes place later in mid-July (Aprahamian 1988). In the Severn, spawning occurs below the weir at Tewkesbury, probably because the volume of water over the weir is not sufficient for shad to migrate any further upstream and the fish therefore assemble here (Claridge & Gardner 1978). After spawning, the adults resume active feeding and migrate seawards. The eggs are demersal and hatch after four to eight days, depending on the water temperature (22-24ºC). The larvae migrate back downstream to the estuary and young 0+ fish first appear in samples at Oldbury in mid-July and reach a maximum abundance in September when the water temperature has declined to below 19ºC. The young migrate seawards out of the estuary in the autumn and by late August, they appear at Hinkley Point in the Bristol Channel (Claridge & Gardner 1978). Many 1+ fish re-enter the estuary in the spring and have been known to penetrate as far as Elmore, near Gloucester (Aprahamian 1988).

A study of another population of twaite shad in the Tagus Estuary in Portugal, found that adults included a higher proportion of fish in their diet than those from the Severn and Wye. This study also observed that, in spite if their adaptation to pelagic life, twaite shad in the Tagus Estuary feed on some benthic organisms, including the brown shrimp (*Crangon crangon*) (Assis et al. 1992).

Evidence of the timing and relative size of the annual migration of twaite shad into the Wye has been estimated through the use of a hydroacoustic fish counter. The Severn Estuary is one of few estuaries in Europe where young twaite shad have been recorded in any numbers (Potter et al. 1986; Potts & Swaby 1993) and juvenile twaite shad are about the tenth most abundant species at Oldbury (Potter et al. 2001). Based on corrected weekly samples from the water-intake screens at Oldbury power station, the mean annual abundance of 0+ and 1+ individuals was 737 between 1972 and 1977 and rose to 949 between 1996 and 1998 (Potter et al. 2001).

4.2.2 Allis shad (Alosa alosa)

In most respects, the life-cycle of the allis shad is very similar to that of its more common relative, except that the allis shad tends to be larger and migrate further upstream during their spawning migration.

Apart from the populations supported by the Usk and Wye, this species is rare in British waters (Maitland & Lyle 1990; Maitland & Lyle 1991). There are no confirmed spawning sites for allis shad in the UK (Maitland & Lyle 1990; Maitland & Lyle 1991). Adult individuals of this species have been recorded rarely from samples at Oldbury (Figure 4.4). Between July 1974 and April 1977 no juvenile specimens were observed at Oldbury power station (Claridge & Gardner 1978).

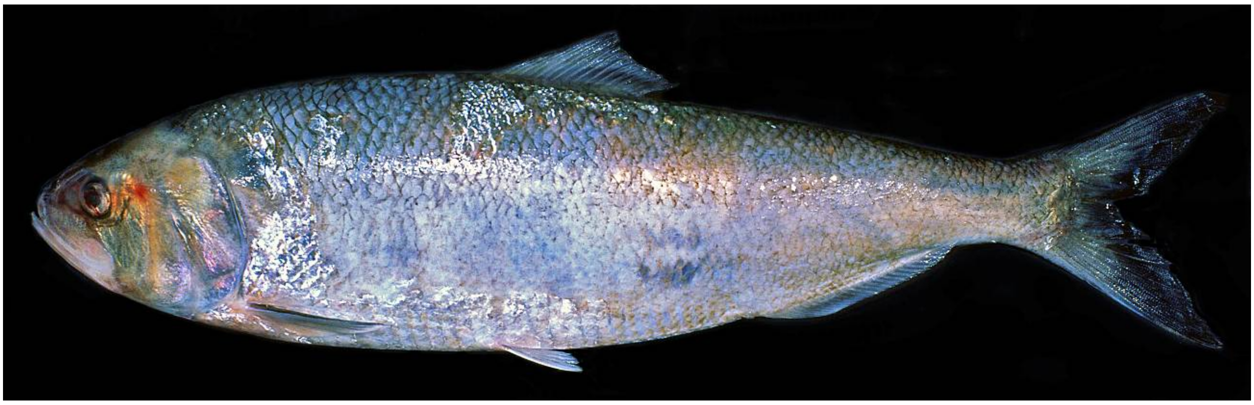

Figure 4.4. Rare specimen of an allis shad recovered from Oldbury power station. *Photograph David Bird.*

4.2.3 Conservation issues: Shad

In Northern Europe, the twaite shad is frequently reported on Southwest coasts, but it is claimed that populations have been badly affected by the pollution in river mouths (Wheeler 1969). Weirs and other migratory barriers such as the Crickhowell bridge footings on the Usk are believed to prevent shad from reaching suitable spawning sites and this has almost certainly contributed to their decline in the Severn and Usk but not in the Wye or Tywi (Maitland & Lyle 1990; Aprahamian & Aprahamian 1990; Maitland & Lyle 1991).

A combination of poor water quality, migratory barriers and the destruction of spawning sites have probably been the most important factors that have led to the decline and extinction of the allis shad in many European rivers (Lelek 1987). A recent publication draws attention to the need to protect migrating fish in the Usk and Wye (Mccoy 2005). Another report concerning the Usk cSAC, highlights the relatively poor swimming performance of shad and their behaviour during migration that makes this species especially vulnerable to many potential barriers to migration (Environment Agency 2004). The report states:

"Shad are strongly shoaling species and anything that disrupts this, such as areas of turbulent or highly aerated water, can disrupt shoaling and adversely affect migration. There are also limitations such as water depth and current velocity that might affect both swimming capacity and behaviour, and thereby the inclination to pass a limiting structure. If they encounter good flows then their migration will potentially distribute them throughout the available habitat, however a low flow period might constrain this by rendering otherwise insignificant structures, such as bridge footings, relatively impassable."

The construction of a barrage in the estuary would certainly have serious implications for these relatively rare species and carries a very high risk of very high mortality that could effectively eradicate the stock (Sustainable Development Commission 2007a). Turbine-related mortality has been estimated at 53% for juvenile shad and although no estimates are available for migrating adult shad, the mortality for Atlantic salmon which they resemble in shape and size, is expected to be 40% (Turnpenny et al. 2000).

4.3 Herrings (Clupeidae)

Fishes of this group are amongst the most important economically in the oceans. Not only are they heavily exploited commercially, but they are an important food item for larger fish. Juvenile clupeids are some of the most important components of temperate estuaries both in terms of numbers and biomass. At critical times in the year, the shoals are so vast that power station staff may be forced to shut down water-intake pumps to prevent blockages.

4.3.1 Sprat (Sprattus sprattus)

Sprats are small herring-like fishes with a maximum length of about 150 mm. Although they are predominantly a coastal species, they are tolerant of brackish water and can occur in large numbers in estuaries during the autumn and winter. Spawning occurs in the open sea in spring and summer between April and July and the eggs either float at the surface or in mid-water at a depth of 25-50m. The eggs hatch in three or four days and the larvae drift inshore where they feed mainly on the eggs and young of planktonic copepods such as *Calanus*, *Pseudocalanus* and *Temora*. Sprat grow rapidly and may reach 120 mm by the end of the first year and they usually become sexually mature in the second year of life when they are 130-140 mm long. Adult sprat feed mainly on planktonic crustaceans and fish larvae and rarely live for more than four years (Wheeler 1969).

Sprat once contributed significantly to the fishery of the Bristol Channel and Severn Estuary (Robertson 1938) and although this fishery has now declined, they remain an important component of the teleost fauna. They are present throughout the year and are consistently in the top 15 most abundant species present in the estuary. Based on the distribution of post-larval fish in plankton samples, Russell (1980) has suggested that sprat spawn between April and June in the region between Lundy Island and the Devon coast and also off the Gower peninsula. They were the most abundant of all teleosts in plankton samples taken in the spring and summer of 1974 (Russell 1980; Williams 1984). New 0+ recruits with a modal length class of 40-44 mm reach peak abundance at Oldbury in August and September before a second wave of larger, older fish (80-143 mm) appears between January and March (Potter & Claridge 1985). A comparison of data obtained from Oldbury have shown that sprat have increased in abundance by a factor of 1.3 between the 1970s and late 1980s (Potter et al. 2001).

4.3.2 Herring (Clupea harengus)

Based on meristic characteristics that include the number of vertebrae, fin rays, scales and gill rakers, herring can be divided into a large number of distinct races. Although the different races spawn at different times of the year and have distinct spawning grounds, they can be broadly grouped into those that spawn in the spring and those that spawn in the autumn. Newly hatched larvae feed initially on planktonic diatoms and flagellates but later progress to the eggs and larvae of copepod crustaceans and young fish, particularly juvenile sand eels. Adult herring also consume planktonic copepods, especially *Calanus* and *Temora*, and the abundance of these crustaceans is known to have an important influence on herring distribution and migration. Other significant components of the adult diet include the hyperid amphipods *Euthemisto* and *Hyperia*, euphausiids such as *Nyctiphanes* and *Meganyctiphanes* and mysid shrimps. The range of fish eaten by adults includes not only sand eels but also gobies and young whiting, herring and flatfish. Invertebrates such as arrow-worms (*Sagitta*), ctenophores (*Oikopleura*) and pteropods (*Limacina* and *Clione*) are also important in the adult diet (Wheeler 1969).

Young herring remain in shallow water during the first two years of life where they grow to about 160-180 mm. It is during this period that they may enter estuaries where they frequently form mixed shoals with similar-sized young sprat and shad. The adults however, are primarily pelagic and found in offshore waters from the surface down to depths of 200 m.

4.3.3 Conservation issues: Herrings

Estuaries are extremely important nursery areas for juvenile clupeids. Their fast growth, early maturity and short lives are characteristics of *r*-selected species which tend to be less vulnerable to over-exploitation since they can recover quickly if fishing pressures are reduced. The future for herring and sprat lies in the proper management of marine adult stocks, but estuaries provide a relatively safe haven for new recruits and this should be recognised by those managing the fishery.

4.4 Salmon & Trout (Salmonidae)

The salmonids are a group of mainly freshwater or anadromous fish, many of which are of great economic importance. The rivers draining into the Severn Estuary support important populations of salmon and sea trout. Both species rely on the estuary to complete their life-cycle.

4.4.1 Salmon (Salmo salar)

The anadromous life-cycle of salmon is well known and has been intensively studied and reviewed and therefore will only briefly summarised here. Mature salmon spawn in winter, usually in November or December. The female excavates a redd in the gravel stretches of suitable rivers and is joined by the male who fertilizes the eggs as they are laid by the female. After spawning, the spent adults (now called *kelts*) move downstream through the estuary to the sea. Not all adult salmon survive the journey back to the ocean, but those that do may subsequently recover over a period of 5-18 months and embark on a second spawning migration. A few fish even manage a third spawning migration but very few manage a fourth (only 0.02% in the Wye). Details about the marine phase in the life-cycle are not well known, but young salmon and *mended kelts* are believed to range widely. While at sea, salmon feed on a variety of fish (*e.g.* herring, sprat, sand eel, mackerel, and various gadoids) and crustaceans (*e.g.* euphausiid shrimps, prawns, gammarid amphipods and various crabs).

The diet of young salmon (*parr*) in freshwater reflects the food available at different times of the year, but predominantly consists of aquatic insect larvae, with an increasing proportion of adult insects being taken at the water surface during the summer and autumn. Parr that grow rapidly may undertake their downstream migration as *smolts* at the end of their first year when they are 100-150 mm, but others remain in freshwater for two, three or exceptionally even four years before migrating.

Data on smolts collected from Oldbury and Berkeley power stations demonstrated that their abundance in the estuary peaked in autumn (October) and again in the spring (April & May) although they are present in all other months except July (Claridge & Potter 1994). It was estimated that the total number of salmon smolts entrained annually on the screens at Oldbury between 1972-1977 ranged from 92 to 791, with a mean of 405. Total estimated numbers at Berkeley ranged from 196 to 788 per annum (Claridge & Potter 1994). A study of catches at Uskmouth power station estuary indicated smolts prefer to migrate seaward through the lower Usk estuary during the night on an ebbing tide (Aprahamian & Jones 1997)

Fish returning to freshwater after spending a complete year and part of the following summer at sea are known as *grilse* and measure about 510 mm. Other fish that spend a further year at sea are known as *small summer fish* and weigh about 5.4 kg while those that spend three or more winters at sea are called *large summer fish* and weigh about 11 kg. When salmon re-enter freshwater on their spawning migration, the fact that their stomachs are invariably empty suggests that they do not feed in fresh water.

4.4.2 Trout (Salmo trutta)

Trout breed in winter from October to February, usually at temperatures of 5-10ºC. Sexual maturity occurs in males at two years and females at three years of age. Spawning always occurs on gravelly shallows in redds excavated by the female. The young fry hatch in about 40 days at 10ºC when they are 15-25 mm long. They begin to feed in four to six weeks once the yolk sac has been absorbed.

Sea trout are a migratory form of the brown trout that move downstream into estuaries as smolts when they are about 210 mm in length. Their diet at sea has not been much studied but is believed to include a range of fish species including sprat, young herring and sand eels as well as crustaceans such amphipods (*e.g. Corophium*), gammarids, decapods such as *Crangon* and mysid shrimps. Many of these prey items also occur in estuaries where sea trout are known to feed extensively.

4.4.3 Conservation issues: Salmon & Trout

The salmon is one of the most valuable food fish in the world and significant runs of salmon occur in the Wye, Usk, Taff and Ely. The fact that migrating salmon smolts were being killed by water-intake screens led to power station authorities installing smolt protection devices during the spring of each year in an attempt to allow these smolts to escape, but the effectiveness of these devices has been questioned (Mills 1989). The Environment Agency has indicated that the potential mortality caused by barrage turbines on salmon and sea trout populations would be high to very high and this would have serious implications for the status of the stock (Environment Agency pers. comm. Cited in Sustainable Development Commission, 2007a).

The Environment Agency has also investigated the potential impacts of climate change on salmon (Environment Agency 2005). A model has been used to predict growth rates for salmon in the southwest under a 'low emissions' and 'high emissions scenario'. The model predicted that salmon growth could significantly improve under a 'low emissions' scenario. Salmon were however likely to fall below current growth levels under the 'high emissions' scenario as temperatures exceed optimum levels in the latter half of this century.

4.5 Eels (Anguillidae)

The European eel (*Anguilla anguilla*) and conger eel (*Conger conger*) are the only members of this family to occur in estuaries. Both species are important carnivores in the trophic structure of the estuary.

4.5.1 European eel (Anguilla anguilla)

European eels are common in most rivers and their estuaries in northern Europe. There have been recent reviews of their life-cycle, evolution and reproduction (van Ginneken & Maes 2005) and habitat requirements (Knights et al. 2005). In estuaries, they bury themselves in sand or mud and emerge at night to feed. It has been suggested that most European eels in marine and estuarine environments are usually smaller males while those in fresh water are larger and female but this does not always appear to be true. European eels living in fresh water are known as *yellow eels* (Figure 4.5) where they appear to be they are relatively sedentary, especially in small catchments (Laffaille et al. 2005). When males reach a length >410 mm and females >540 mm, they begin migrating to the sea. At this time the eyes enlarge, the lateral and ventral surfaces become silvery and the gonads begin to develop. These *silver eels* are most abundant in estuaries in September and October. Few silver eels have ever been caught at sea, but it is known that spawning takes place in the spring and summer in the mid-Atlantic. Larval eels are thought to drift passively in ocean currents until they arrive on European coasts after two and a half to three years at sea. When 12-18 months old, the flattened *lepocephalus* larvae metamorphoses into a transparent *glass eel* while still in the ocean and a further transformation occurs when glass eels become pigmented as they enter estuaries, at which point they are known as elvers.

A study of the environmental factors affecting elvers and young European eels in the Severn and Avon rivers determined that a temperature of between 14-16°C was statistically the most robust predictor for upstream migration (White & Knights 1997). Growth rate and production of European eels in the river Severn and its tributaries have also been studied (Aprahamian 1986; Aprahamian 2000). European eels eat a range of benthic organisms that include crustaceans and small fish (Wheeler & Newman 1992)

Figure 4.5. The yellow form of the European eel (*Anguilla anguilla*). *Photograph David Bird.*

4.5.2 Conservation issues: European eels

The River Parrett, which enters the Severn Estuary at Bridgwater Bay, supports a small commercial eel fishery as well as the second most productive elver fishery in England (Langston et al. 2003). Elvers command an extremely high price in Japan and elsewhere and they are heavily exploited for export, probably often illegally. In 1975, the quantity of elvers caught was estimated to range from 25-100 tonnes per year but the level of exploitation has increased dramatically since that time (Aprahamian 1986). As a consequence, the days of elver-eating competitions held annually at Frampton-on-Severn are now consigned to the past (Figure 4.6).

Figure 4.6. Elver-eating competitions at Frampton-on-Severn in about 1975. *Photograph David Bird.*

The permeability of the skin of eels is an adaptation that enables them to survive under low oxygen tensions, but this can make them more vulnerable to environmental contamination when they bury in muddy substrates. Additionally, because they are large fish and high in the estuarine trophic structure, they are often selected as a species suitable for environmental monitoring programmes (Amiardtriquet et al. 1987; Barak & Mason 1990; Maria et al. 2004) In the Severn Estuary and its tributaries, European eels have been employed to monitor PCBs (National Rivers Authority 1995) and metabolites in the bile used to assess PAH exposure (Ruddock et al. 2002; Ruddock et al. 2003). The seasonal activity of detoxification enzymes (EROD) and metal binding proteins (MTs) have also been measured in European eels from the Severn Estuary (Rotchell et al. 1999; Rotchell et al. 2000; Rotchell et al. 2001; Bird et al. 2008). These studies indicate that the level of hydrocarbon and metal contamination present in the estuary is low when compared to that measured in European eels from more polluted estuaries, so it is unlikely that water or sediment quality in the Severn Estuary currently has a significant impact on the European eel population.

Barriers to the upstream migration of elvers and young eels may be important, but there seems little doubt that over exploitation of elvers is a primary cause for the dramatic decline in European eel numbers seen in the estuary, especially at Hinkley Point (Henderson et al. 2006). A life-cycle model of the European eel has suggested that even if fishing mortality was reduced to zero, recovery would be expected to take 70-80 years. The model predicted that a sustainable fishing regime at 10% of the current rate of fishing mortality could be achievable but full recovery could take more than 200 years (Astrom & Dekker 2007).

4.6 Pipefish (Syngnathidae)

Pipefishes are common inshore residents and four species have been recorded from the region. Three of these are classified as marine or marine stragglers and only Nilsson’s pipefish penetrates far into the estuary. Male pipefish develop a brood pouch in which the eggs and developing young are protected and nourished. They are rather feeble swimmers and live mainly amongst weed and algae. They have slender snouts and small terminal mouths so that they are entirely dependant on minute planktonic organisms.

4.6.1 Nilsson’s pipefish (Syngnathus rostellatus)

Nilsson’s pipefish is a widespread species found on sandy shores around the coast of the British Isles. The fact that it is capable of breeding in water of low salinity explains its common occurrence in estuaries. Adults mature at approximately 100 mm but can grow to a length of 170 mm. The large eggs (about 1.5 mm in diameter) can be found within the brood pouch of the male from June to August. The eggs hatch after three weeks incubation into miniature pipefish that are about 14 mm long. When released from the male's pouch, the young are pelagic at first but soon descend to the bottom to take up a benthic existence. This species feeds exclusively on small crustaceans, mainly copepods, mysids and immature decapods, but will occasionally take amphipods and small isopods (Wheeler 1969).

A study of Nilsson's pipefish in the Thames Estuary showed regular patterns of seasonal abundance occurred in the spring and autumn (Power & Attrill 2003). Their appearance in the estuary was related to temperature, with maximum abundance occurring when the water temperature was 14°C. Temperature and salinity together defined a niche space in which about half of all pipefish were sampled. Long term trends over 16 years suggested numbers had increased as organic pollution had declined, but had then decreased in the 1990s as a result of drought-induced increases in temperature (Power & Attrill 2003).

4.6.2 Conservation issues: Pipefish

Despite its relative abundance in estuaries, little is known about the biology and ecology of pipefish or their susceptibility to environmental disturbance. Their cryptic shape and coloration means that they are easily overlooked, but the lack of information is mainly due to the fact that pipefish are not commercially important. Nevertheless, Nilsson's pipefish may have a useful role for monitoring the effects of climate change and more generally for assessing the health of the fish assemblage in the estuary.

4.7 Cod fish (Gadidae)

The members of the cod fish family (Gadidae) are of the greatest economic importance since the group includes many species that are heavily commercially exploited (Wheeler 1969). Collections from Oldbury between 1972 and 1977 yielded 47,783 gadoids representing 13 species and together these species contributed between 11.0 – 41.3% of the total catch per year (Claridge & Potter 1984). Of these, seven species can be regarded as marine stragglers (Table 2.1) and as they are never abundant, and can complete the whole of their life-cycle outside of the estuary, they are not considered further. The remaining six species are all marine estuarine-opportunistic and comprise the Northern rockling, five-bearded rockling, whiting, bib, poor cod, and pollack (Table 2.2). With the exception of the Northern rockling, which is most common between January to March, the other five species all reach maximum abundance at Oldbury between September and November each year.

4.7.1 Whiting (Merlangius merlangus)

Whiting are shallow water gadoids that are particularly abundant in the North Sea where they are found at depths of 30 to 100 m. The peak spawning period differs between populations but occurs sometime between January and July. Young fish grow to approximately 150 mm in their first year, 220 mm in their second year and 300 mm in their third year. Females tend to be larger than males and may attain a length of 530 mm by their time they are seven or eight years old (Wheeler 1969).

Young whiting are commonly found in estuaries, which they use as a nursery. They are frequently present in samples collected from power station intake screens and in most years, they are the second or third most abundant species at Oldbury and Hinkley Point (Claridge et al. 1986; Potter et al. 1986). Tens of thousands of fish are entrained on the water-intake screens in the autumn so the total number of whiting that must enter the estuary each year must be vast.

The greatest number of larval whiting appeared in plankton samples taken in the Bristol Channel in 1974 in mid-April with lower numbers present in May and June (Russell 1980). Data from the 1970s show that young 0+ fish first appear at Oldbury in mid-July and it has been suggested that unlike some other estuarine species, whiting reach their nursery areas by means of active migration rather than passive larval drift (Gordon 1977). At Oldbury, in August, young 0+ whiting have a standard length of 58-62 mm and this increases rapidly to reach 96-99 mm by November before growth slows down over the winter. A similar pattern is observed at Hinkley Point where 0+ fish grow from approximately 58 mm to 115 mm over the same period (Potter et al. 1988). The proportional contribution of the 0+ year class invariably exceeds 99% of the total whiting catch with very few 1+ and 2+ individuals present and evidence suggests that whiting migrate to deeper waters as soon as they are large enough to do so (Potter et al. 1988). Changes in salinity have been shown to have a marked effect on the abundance of young whiting in the estuary and numbers in samples decline dramatically when the salinity falls below 10‰ for prolonged periods (Potter et al. 1988).

While resident in estuaries, young whiting are active predators consuming brown shrimp (*Crangon*), young shore crabs (*Carcinus*), amphipods and gobies. An analysis of young individuals collected from Oldbury indicated crustaceans contributed 70% of the diet (Hardisty et al. 1974b). Larger whiting consume a higher proportion of fish species, especially sand eels and sprats, but they will also take smaller whiting, poor-cod, Norway pout and flatfish. Other items in the adult diet include various species of crab and polychaete worm, cuttlefish, squid and gastropods (Wheeler 1969).

4.7.2 Bib (Trisopterus luscus)

The bib is extremely common in shallow water, particularly over areas of sand, around the coast of the British Isles. Spawning occurs at depths of 50-70 m mainly between March and April. In the Severn Estuary, 0+ fish appear at Oldbury in August when they are 40-49 mm in length and they grow rapidly to reach 70-79 mm by November/December (Claridge & Potter 1984). Only a few fish >130 mm are caught in the inner estuary but larger fish up to 295 mm are recovered from Hinkley Point. Bib reach sexual maturity in their first year and they commonly reach 310 mm by the time they are four years old.

In estuaries they feed on brown and pink shrimps (*Crangon* and *Pandalus*) and shore crabs (*Carcinus*). The diet of adult bib has not been studied.

4.7.3 Poor-cod (Trisopterus minutus)

Poor-cod are common around British coasts, but they tend to be found further offshore than the related bib. Spawning in the English Channel peaks in March and April at depths of 50-100 m. Females can grow to 230 mm and live for six or more years, but males rarely exceed 170 mm in length or live longer than four years.

According to Wheeler (1969), only first year fish are found close inshore and enter estuaries. This is consistent with the fact that although Claridge and Potter (1984) obtained as many as six year classes in samples from Berkeley, Oldbury and Hinkley Point, most fish greater than two years old came from the seaward end of the estuary at Hinkley Point. Poor cod were particularly abundant at Oldbury between 1972 and 1977 and in some years contributed 90-99% of the number of fish in autumn samples. On average, over a five year period it was the sixth most abundant species. When sampling was repeated in the 1990s however, the abundance of poor cod had declined dramatically (Potter et al. 2001). The reason for this reduction in numbers is not clear.

Larval fish feed on planktonic crustaceans and polychaetes but as they grow, their diet changes to a varied mixture of crustaceans, polychaetes and fish, a diet typical of an unspecialised bottom feeder (Wheeler 1969).

4.7.4 Pollack (Pollachius pollachius)

Spawning in pollack peaks in March, probably at a depth of about 100 m. The eggs and larvae are pelagic and drift into shallow water where they remain for the first two years of life. It is at this time that they may be found in estuaries, but there is only limited information about the biology and ecology of the pollack at this stage in the life-cycle. Claridge and Potter (1984) recorded a unimodal length-frequency for pollack at Oldbury in September of 100-109 mm with a few larger fish >200 mm appearing at Hinkley Point. In their third year, or when they have grown to approximately 260-310 mm, they move offshore into deeper water where they continue to grow until they reach about 520 mm in their fifth year (Wheeler 1969).

A study of a related species (*Pollachius virens*) in Canadian waters concluded that rocky shores are important nurseries for juvenile pollack (Rangeley & Kramer 1995). These authors found that on rising tides, pollack moved from the subtidal zone to the open intertidal zone in large schools before dispersing among available depths and throughout algal habitats in small schools or as solitary fish. On falling tides, pollack schooled in the open habitat in offshore intertidal and subtidal zones.

Adult pollack feed mainly on fish, particularly sand eels, but also sprats, herring and small gadoids. They will also take rock-dwelling fish such as wrasse, blennies and rockling as well as some larger crustaceans (Wheeler 1969).

4.7.5 Northern rockling (Ciliata septentrionalis)

The similarity of the more familiar five-bearded rockling (*Ciliata mustela*) to the Northern rockling (*Ciliata septentrionalis*) suggests that the latter species has probably been under-recorded in the past. It was first identified in the Severn Estuary and Bristol Channel in 1972 (Hardisty & Huggins 1975) and the fact that numbers have been increasing in the estuary since that time implies that this species has been extending its southerly range (Hardisty & Huggins 1975; Claridge & Gardner 1977).

The Northern rockling is an offshore species usually found at depths of 30-90 m and although it also occasionally occurs at shallower depths, it is never found intertidally (Wheeler 1969). Relatively little is known about the biology and ecology of this species but it has been studied in the Plymouth area from samples obtained either by trawling or recovered from cod stomachs. The development of the eggs and larvae have also been described for this population (Dando 1975). With regard to the Severn Estuary and Bristol Channel, samples collected from four power station the between 1972 and 1976 revealed that this species is present in the region between December and March with peak numbers of males occurring earlier than females (Claridge & Gardner 1977). In these samples, the 0+ year class made up approximately 65% of the total catch with 1+ and 2+ groups contributing 32 and 2% respectively. These data also showed that both sexes reach sexual maturity by the end of their first year, and following movement out of the estuary into deeper water, they probably breed between April and early May (Claridge & Gardner 1977).

Based on a small number of individuals, Wheeler judged the adult diet to consist of demersal invertebrates including decapod crustaceans and polychaete worms (Wheeler 1965). Stomach analysis by Claridge and Gardner (1977) has shown that in the Severn Estuary, amphipods form a major component of the diet with smaller proportions of mysids and polychaetes.

4.7.6 Five-bearded rockling (Ciliata mustela)

Although mainly a littoral species and therefore abundant in intertidal pools on rocky shores, little is known about the biology or ecology of this species (Figure 4.7). Breeding takes place offshore in the winter and spring. The eggs are pelagic and the larvae are known as mackerel-midge because of their greenish/blue dorsal surface and silvery sides and belly. The larvae metamorphose into the dull colour of the adult when they arrive at the shore in the summer. In the estuary, where they occur below the low tide level, five-bearded rockling probably consume brown and pink shrimps, shore crabs, some gammarids and isopods and small fish such as gobies (Wheeler 1969).

Figure 4.7. Five-bearded rockling (*Ciliata mustela*). *Photograph David Bird.*

4.7.7 Conservation issues: Codfish

The gadoids make an extremely important contribution to the fish fauna of the Severn Estuary. A few species depend on estuary as a nursery in the early years of life and this fact is critical to the management of whiting which are an important commercial fish in Europe and one of the principal items of inshore boat fisheries. Bib, poor-cod and pollack are mainly caught in trawls, but are not fished commercially, except for processing into fish meal.

4.8 Bass (Serranidae)

A very successful family of fish which are found in numerous forms in all oceans. They are mostly shallow-water inshore species. Bass are well known to penetrate estuaries often almost into fresh water.

4.8.1 Bass (Dicentrarchus labrax)

An ichthyoplankton survey of the Bristol Channel indicated that bass spawn predominantly offshore during March and April (Jennings & Pawson 1992). However, the fact that ripe and ripening fish are commonly found in estuarine waters suggests that, under appropriate conditions, this species may also spawn in shallower inshore water, perhaps even in estuaries (Wheeler 1969). Post larval fish were recovered in plankton samples from the Bristol Channel by Russell (1980) in June and July and evidence suggests that the larvae drift inshore where they remain in shallow water <50 m deep for approximately 30 days (Jennings & Pawson 1992).

Movement of very young bass into estuaries is believed to be an active process whereby larvae that have reached a particular stage in development actively seek suitable nursery habits (Jennings & Pawson 1992). It is certainly true that young bass a few mm in length are very common in estuarine samples in the autumn and represent 0+ fish that hatched earlier in the year. This view is supported by a study of bass in the Severn Estuary and Bristol Channel in the 1970s (Claridge & Potter 1983). These data show that bass with a mean standard length of 35 mm begin to move into the estuary during late August and September and reach peak abundance between September and early November. The vast majority of individuals recovered from the inner estuary at Oldbury (99%) were 0+ fish, with just a few individuals that were one year older. In the Bristol Channel at Hinkley Point, a few 2+ to 5+ bass were recovered, but even here, the total contribution of all older year classes was <1% of the total.

In the late autumn, the number of bass recovered from power stations begins to fall as fish move back downstream towards the sea. This movement takes place when water temperatures in the estuary declines below approximately 13-14°C (Kennedy 1972). Similarly, the considerable variation in the number of bass that enter the estuary each year has been correlated with inter-annual variations in the water temperature (Claridge & Potter 1983). It is well established that strong year classes of bass can be related to higher than average temperatures at the time of spawning and during the first summer of growth (Kelley 1979; Henderson & Corps 1997).

Strong recruitment in one year tends to increase cannibalism in subsequent years generating an approximate three-year cycle in abundance (Henderson & Corps 1997). The biology and ecology of older fish is poorly understood, but it has been suggested that bass grow rather slowly and may take as long as 20 years to reach a length of 300 mm (Wheeler 1969).

The diet of young bass consists of crustaceans, including amphipods (*Gammarus*), isopods (*Idothea*, *Ligia*) and brown shrimp (*Crangon*) and they also eat young sand eels, herring, sprat and gobies. Larger bass prey on a wider range of fish but appear to have a preference for species that form shoals such as sprat, herring and sand smelts (Wheeler 1969).

4.8.2 Conservation issues: Bass

Bass are only abundant on the southern and western coasts of the British Isles and also the Atlantic coast of France. They rely heavily on estuaries for the early years of their life, and hazards to their survival are considerable and increasing (Kelly 1988). The impact of the *Sea Empress* oil spill on bass recruitment in 1996 was therefore of some concern. It was subsequently shown however, that although the survival of bass larvae and the growth of the 0+ year class may have been adversely affected locally, the overall impact on bass recruitment was probably less than the year-to-year variation that occurs naturally (Lancaster et al. 1998). Bass have always been highly regarded by anglers as sport-fish in U.K. but until relatively recently, the commercial fishery for bass was unpredictable and small (Wheeler 1969). Today, they are heavily exploited using monofilament gill nets, seines, trawls and occasionally long lines (Kelly 1988). Bass of all sizes are attracted to warm water effluents and this may expose them to a higher risk of contamination. Any tendency to congregate near the warm water effluent from power stations could increase mortality if they enter the cooling water intakes.

4.9 Gobies (Gobiidae)

This is a highly successful family with a wide geographical distribution that has diversified to occupy many different habitats. In the Severn Estuary, eight species have been identified, but only three are especially abundant in the estuary – the common goby and two closely related species of sand goby.

4.9.1 Common goby (Pomatoschistus microps)

This is the most common goby found in intertidal areas, on sandy and muddy shores and in estuaries. It is able to tolerate low salinities and penetrates far upstream almost into fresh water. Common gobies have an extended spawning period that lasts from April to September during which several broods are produced. The eggs are laid on the underside of empty bivalve shells and are guarded by the male. Although young fish are only 3-4 mm when they hatch, they grow rapidly during the summer months and reach maturity by the end of the first year. They have a short life span and most adults die in the second year. Goby populations show marked seasonal fluctuations, with numbers increasing rapidly during the summer months before crashing to much lower levels when temperatures fall in the autumn.

4.9.2 Sand goby (Pomatoschistus minutus & Pomatoschistus lozanoi)

The genus *Pomatoschistus* contains three closely related species whose taxonomy has been the subject of considerable debate (Webb 1980). For practical convenience, the two species that occur in the region are often referred to as the *P. minutus* / *P. lozanoi* complex. These sand gobies are abundant in inshore waters over sandy and muddy bottoms and both species enter estuaries, but do not penetrate as far upstream into fresh water as the common goby. In other aspects however, their life-cycle is very similar to that of the common goby. Thus, spawning begins in March and extends throughout the summer to September. The young hatch at 2-3 mm and are planktonic until they reach 12 mm, when they take up a benthic existence. They grow rapidly during the summer and reach about 50 mm by the end of their first year of life when they become sexually mature. Most individuals die after spawning in their second year (Wheeler 1969).

In most years at Oldbury, they are the most abundant species present, often contributing >80% of the total fish abundance and this emphasises the importance of habitats provided by the shallows of the inner estuary (Claridge et al. 1985). While both species reach maximum abundance in January, *P. minutus* numbers decline sharply from February to April and are not present in May and June. By contrast, numbers of *P. lozanoi* are present throughout the year (Claridge et al. 1985).

The feeding habits of the common goby or of either species of sand goby have not been studied in the Severn Estuary. There is however, information on the diet of gobies from the Mondego estuary in Portugal. This study showed that polychaetes, molluscs and amphipods were the most important items in the diet of *P. microps*, while for *P. minutus* the dominant prey items were polychaetes, mysids and decapods (Leitao et al. 2006).

4.9.3 Black goby (Gobius niger)

The black goby is the largest of the Northern European gobies and is one of very few species that can complete their entire life-cycle within the estuary. It also occurs in sheltered bays with sandy or muddy bottoms and is common amongst eel-grass beds (*Zostera spp.*). The spawning habits are very similar to those of other gobies. Eggs are laid between May and August and the young are 2.8-4.0 mm long on hatching, pelagic at first and then moving to the bottom when approximately 10-12 mm. Sexual maturity occurs in the second year for most individuals, but is sometimes delayed until the third year. They can reach 90-100 mm by the time they are four or five years old. Their diet has been studied in Danish waters where it is known to consume a variety of crustaceans including small crabs, isopods, gammarids, mysids and amphipods (especially *Corophium*). It also consumes small molluscs, polychaete worms and a number of small fish including other species of goby and recently metamorphosed flatfish (Wheeler 1969).

Where it is abundant, it competes for food with other species, particularly flatfish. It is itself consumed by many other benthic species such as eels.

4.9.4 Conservation issues: Gobies

Common gobies are a keystone species in the trophic structure of the estuary. They form a critical pathway of energy flow through the estuarine food web and are an important component of the diet of many species of estuarine fish and wading birds. Sand gobies are widely preyed on by bottom-living fish, flatfish, in fact, they are probably eaten by virtually all fish species with a big enough mouth. The eel grass beds of *Zostera* near the second Severn crossing is ideal habitat for the black goby and is likely to be of conservation value for this and other species that are associated with eel grass beds.

4.10 Mullets (Mugilidae)

Three species of grey mullet (Mugilidae) are known to occur in north-western European waters (Wheeler 1969). The golden mullet (*Liza aurata*) has been recorded from Milford Haven but not elsewhere in the region. The thick-lipped grey mullet (*Chelon labrosus*) is a widespread and common marine species, but rarely occurs in the estuary and can be regarded a marine straggler. The thin-lipped grey mullet (*Liza ramada*) however, is relatively abundant throughout the Severn Estuary and Bristol Channel (Claridge & Potter 1985).

4.10.1 Thin-lipped grey mullet (Liza ramada)

This species depends on estuarine conditions for at least part of its life. It is tolerant of low salinity and is believed to actively migrate into estuaries where it can often be observed feeding in shoals at the surface (De Silva 1980). Adult thin-lipped mullet probably do not feed during the winter months which are spent offshore in deeper water before they move back into shallower water in the spring and summer to feed.

Claridge & Potter (1985) estimated the spawning time for thin-lipped mullet in the region to be between April and June. In 1976, the young 0+ mullet first appearing in samples at Oldbury had a mean length of 23 mm in August increasing to 53 mm by December. In the same year, peak abundance occurred at Oldbury in October and November and numbers then fell from May onwards. Mullet measuring 100-110 mm were occasionally recorded in these samples and identified as 1+ fish, but they were never present in large numbers and very few fish were caught that exceeded a length of 140 mm at this site (Claridge & Potter 1985). Samples from power stations elsewhere in the system with deeper water often contained fish >200 mm and this implies that thin-lipped mullet move away from shores and into deeper water as they increase in age and size (Claridge & Potter 1985).

Thin-lipped mullet are primarily detritivores and consume diatoms and epiphytic algae. They also ingest larval gastropods and crustaceans, perhaps incidentally with plant material.

4.10.2 Conservation issues: Mullet

As a consequence of their detritivorous diet, mullet play a significant role in the trophic structure of the estuary, but there are presently no concerns about their abundance or conservation.

4.11 Silversides & Sand-smelts (Antherinidae)

Sand-smelts belong to a large family of small fishes that are widely distributed in tropical and warm temperate seas world-wide (Wheeler 1969). The Antherinidae are represented by a single genus in Europe and of the two species known from northern European waters *Atherina boyeri* is less common than *Atherina presbyter* but the former species is dependent on estuarine conditions.

4.11.1 Big-scale sand-smelt (Atherina boyeri)

The big-scale sand-smelt was first reported on the Cornish coast in 1846 (Couch 1849) and was not found again until the mid-1950s when it was caught in warm water marine docks at Swansea and at Cavendish Dock, Barrow-in-Furness (Markowski 1966). It has subsequently only been observed in samples from the Severn Estuary and Bristol Channel (Creech 1992). *A. boyeri* is an estuarine species that appears to be attracted to low salinity, although it also occurs in the sea and fresh water. A study of a population in Aberthaw Lagoon in the Bristol Channel has shown that it reaches maturity in its first year and has a life span of two years. Spawning occurs between April and June and adults grow to a maximum length of 93 mm. (Creech 1992). The diet of sand-smelts in the Severn Estuary has not been studied, but based on information from other populations in Europe, it is likely to feed principally on small crustaceans with occasional worms and molluscs (Wheeler 1969).

4.11.2 Conservation issues: Silversides

Outside of the Mediterranean basin, populations of *A. boyeri* appear to be restricted to isolated localities and in the Severn Estuary probably represents the northern limit of its distribution. The fact that populations are relatively isolated implies that there may be significant genetic differences between populations and this could have implications for their conservation (Henderson & Bamber 1987; Henderson et al. 1988).

4.12 Sea Snails (Liparidae)

Members of this family tend to be small fish, with many representatives associated with cold and/or deep sea. All sea snails have a conspicuous suction disc under the head which is used very effectively to anchor them to the substratum.

4.12.1 Sea snail (Liparis liparis)

Sea snails are small, plump fish that first appear in the estuary in late July and August. The main influx begins in October and maximum abundance occurs in December and early January (Badsha & Sainsbury 1978). The sea snail population in the Severn Estuary and Bristol Channel is at the extreme southern limit of its range so it is not surprising that their appearance in the estuary is inversely correlated with water temperature (Henderson & Seaby 1999). They were consistently the fifth most abundant species of fish at Oldbury in the 1970s and 1990s (Potter et al. 2001) and on average, the sixth most abundant at Hinkley Point between 1981 and 1998 (Henderson & Seaby 1999).

The males move out of the estuary to the spawning grounds in January and are followed by the females a few weeks later and breeding takes place over a short period in the spring. The eggs are laid amongst hydroids on rough ground in shallow water and the larvae are planktonic. Sea snails have a life span of just one year they and grow to a maximum length of about 100 mm.

The diet of the sea snail population in the estuary has been studied by Badsha and Sainsbury (1978). In terms of frequency, amphipods (*Gammarus*) were the most important dietary item recorded in the stomach, but in terms of weight, the brown shrimp (*Crangon*) was more significant. They also consume small fish such as gobies, young crabs, amphipods and polychaete worms (Wheeler 1969).

4.12.2 Conservation issues: Sea Snails

Despite their rather gelatinous and fragile appearance, sea snails have one of the more stable populations of fish species in the estuary (Henderson & Seaby 1999). Although their benthic habits make them vulnerable to heavy metal contamination (Badsha & Sainsbury 1978), there are no specific environmental or conservation concerns for this species.

4.13 Sticklebacks (Gasterosteidae)

Sticklebacks have a very wide distribution. They are extremely adaptable and capable of tolerating a wide range of environmental conditions. Three species have been recorded in the Severn Estuary and Bristol Channel. The ten-spined stickleback (*Pungitius pungitius*) is primarily a freshwater species and the fifteen-spined stickleback (*Spinachia spinachia*) mainly marine. Only the familiar three-spined stickleback (*Gasterosteus aculeatus*) is common in the estuary but unlike its more spiny relatives, this species is probably capable of completing its life-cycle in fresh or brackish water.

4.13.1 Three-spined stickleback (Gasterosteus aculeatus)

Although three-spined sticklebacks are one of the most abundant and widespread freshwater species of fish in northern Europe, they are also very common in estuaries and can even tolerate full-strength sea water (Figure 4.8). Spawning occurs mainly in April and May at a water temperature of between 14-18ºC. The males build a nest on the bottom from plant material in which female lay her eggs. The male defends the nest and aerates the eggs by fanning with his pectoral fins. The young grow rapidly at first to reach 21-50 mm by the end of the first year, but then grow more slowly reaching 30-52 mm in the second year and 45-70 mm by the end of the third year. Most sticklebacks mature in their first year and rarely live longer than 3.5 years. In estuarine conditions, small sticklebacks feed on copepods and larval molluscs and as they grow, switch to larger crustaceans including gammarids, amphipods (*Corophium*) and isopods (*Idothea* and *Jaera*) (Wheeler 1969).

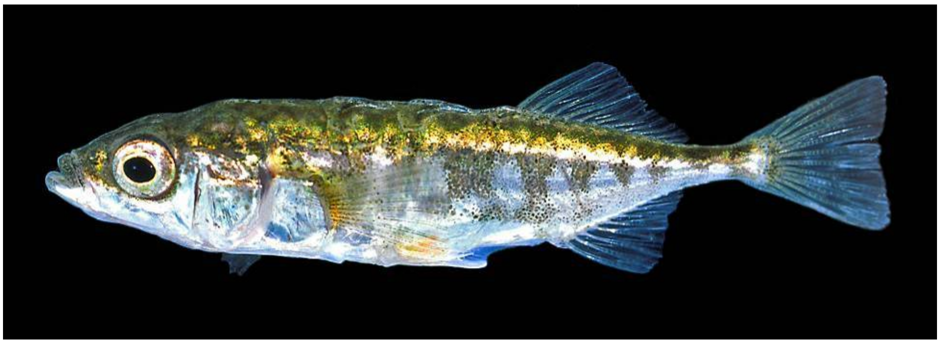

Figure 4.8. The three-spined stickleback (*Gasterosteus aculeatus*). A highly adaptable species tolerant of a wide range of salinity. *Photograph David Bird.*

4.13.2 Conservation issues: Sticklebacks

This species is widespread and abundant. The reproductive biology of three-spined stickleback has been extensively studied. Consequently, this species may be suitable for monitoring the effects of endocrine disruption.

4.14 Plaice, Dabs, Halibut, Flounders (Pleuronectidae)

This family of flatfish contains a number of familiar food fishes including plaice and halibut. Although all species normally have their eyes on the right side of the body, reversed individuals are relatively common in flounder.

4.14.1 Flounder (Pleuronectes flesus)

The founder is the only European flatfish to penetrate well into estuaries and to even live in fresh water for short periods (Figure 4.9). Although primarily an estuarine species, flounders migrate offshore mainly in March and April to spawn in deeper water (27-54 m). The eggs are small (0.95-1.02 mm) and float near the surface, gradually sinking as they develop. When newly hatched, the young are 2.5-3.0 mm long and they grow to 15-30 mm before metamorphosing into the adult form and taking up life on the bottom. These young fish can be found close to the shore line and enter estuaries where they grow rapidly. At the end of their first year they average 80 mm, at their second 140 mm, at their third 190 mm and at their fourth 240 mm. Males mature at a length of about 110 mm and females at 170 mm.

In terms of mean annual numbers, flounders were third most abundant species in samples obtained at Oldbury between 1972 and 1977 and the seventh most abundant species between 1996 and 1998 (Potter et al. 2001). They achieved a similar ranking in samples at Hinkley Point between 1981 and 1998 (Henderson & Seaby 1999). They are the only flatfish for which adults are regularly caught and larger individuals have an important role as predators. Their relative abundance, benthic habits and trophic position has made them a species of choice for environmental monitoring (Henderson & Holmes 1991; Henderson & Seaby 1994; Allen et al. 1999; Rotchell et al. 1999; Kirby et al. 2000; Rotchell et al. 2001; Kleinkauf et al. 2004).

The diet of flounders in the Severn Estuary has been studied in some detail (Hardisty et al. 1974b; Moore & Moore 1976). Flounders feed most actively during the warmer months and in the coldest months of year, feeding may cease altogether so that 80-95% of flounder stomachs are empty during the winter. The diet of young fish, <60 mm in length, consists mainly of the mysid *Neomysis integer.* Those between 60-350 mm feed heavily on the polychaete *Hediste diversicolor* in February and on the amphipod *Gammarus salinus* between February and April. Later in the year, these species are replaced by *N. integer* and the decapod *Crangon vulgaris* (Moore & Moore 1976). Other reports suggest that shore crabs and small molluscs, including the baltic telling, *Macoma balthica*, may be taken by larger individuals (Wheeler 1969; Hampel et al. 2005).

4.14.2 Conservation issues: Flounder

In some parts of Europe, flounder are an important food fish, but in the U.K. they are not as highly regarded as plaice (*Pleuronectes platessa*) and they are mostly caught incidentally as a by-catch while fishing for other species, or by anglers for sport. Flounders are a hardy species, but they can be susceptible to environmental contamination and there is increasing evidence that they may be affected by endocrine disruption (Kime et al. 1999; Matthiessen 2003; Kleinkauf et al. 2004).

Figure 4.9. The flounder (*Pleuronectes flesus*) is the dominant flatfish species in the Severn Estuary. *Photograph David Bird.*

4.15 Soles (Soleidae)

Members of sole family are typically warm-water species that are at the northern limit of their range in British waters. Only one species occurs in any numbers in the estuary.

4.15.1 Dover sole (Solea solea)

Dover sole are the most common members of the Soleidae and are a highly adaptable species. They occur offshore in water as deep as 185 m but are also common in estuaries where they can be found in water only a few metres deep.

Between October and December, both juvenile and adult sole migrate offshore to deeper water. Spawning occurs during April, May and June and the eggs and newly hatched larvae (3.0-3.7 mm) are pelagic. Young fish first appear in plankton trawls in the Bristol Channel in April and May (Russell 1980). They metamorphose into the adult form when they are about 15-18 mm long, at which time they adopt a benthic life and move to nursery areas in inshore waters and in estuaries.

Claridge and Potter (1987) have studied the size and abundance of juvenile sole in the Severn Estuary. The 0+ year class first appeared at Oldbury in July at lengths as small as 23 mm. They had reached a mean length of 84 mm by September and 93 mm by the following April when they were entering their second year of life. By the following August the modal length class of these 1+ fish was 140-159 mm. Most of the sole at Oldbury were <240 mm, but much larger specimens up to 400 mm (546 g) were occasionally caught (Claridge & Potter 1987). Using data from Hinkley Point, Henderson's group have shown that the abundance of juvenile sole in Bridgwater Bay is positively correlated with the seawater temperature in April and May, the time when young fish are migrating back inshore (Henderson & Holmes 1991; Henderson & Seaby 1994). Mature fish however, first undergo a migration to specific spawning grounds in order to breed before moving back inshore in the late spring and early summer.

Whereas larval fish feed predominantly on copepods, larger fish feed entirely on benthic organisms especially amphipod crustaceans, marine annelids and small bivalve molluscs.

4.15.2 Conservation issues: Sole

Sole are a highly valued food fish and are mainly caught by trawling at night when they are most active. In recent years the number of juvenile sole entrained at Hinkley Point has increased almost exponentially (see Figure 3.2) and this has been shown to be highly correlated with increased seawater temperatures during the early part of the season. It has been suggested that this marked increase is a consequence of changes in the North Atlantic Oscillation (Henderson & Seaby 2005b). The abundance and growth of sole in nursery areas has been used as an indicator of environmental and habitat quality (Le Pape et al. 2003; Gilliers et al. 2006; Le Pape et al. 2007) and this approach could be applied to monitor the health of the flatfish assemblage in the Severn Estuary.

5 OTHER FACTORS & ISSUES

5.1 Migratory behaviour

Until relatively recently, the migratory behaviour of fish has mainly been studied through mark-release-recapture techniques involving tags, marker dyes or fin clips (Breteler et al. 2007). The application of Passive Integrative Transponders (PIT) technology (CastroSantos et al. 1996; Boubee & Williams 2006), radio telemetry (Almeida et al. 2002; Andrade et al. 2007; Jansen et al. 2007) or acoustic tracking (Acolas et al. 2004) has enabled the movements of individual fish to be monitored in much greater detail. These studies generally agree on the major factors that affect migratory behaviour.

An increase in water discharge has been shown to stimulate upstream migration by sea lampreys but in years when flow rates are low, they have difficulty negotiating weirs and other obstacles (Andrade et al. 2007). Sea lampreys are mainly active at night (Almeida et al. 2002) although light detection does not appear to be mediated through the eyes but via dermal photoreceptors in the tail (Binder & McDonald 2007). These authors suggests that refuge sites are sought out before sunrise using tactile and possibly hydraulic cues and any activity during the day occurs when the sites chosen at night do not provide adequate concealment after sunrise.

Water temperature and discharge have been identified as the important abiotic factors in the upstream migration of allis shad in the L'Aulne, a small river in Brittany (Acolas et al. 2006) and in brown trout (Jonsson 2002) and Atlantic salmon in Norway (Jonsson et al. 2007). In the case of Atlantic salmon, maximum ascent per day occurred at a flow rate of 12.5-15.0 m^3 sec^{1-} and at a water temperature of 10.0-12.5°C (Jonsson et al. 2007).

In view of concern over the marked decline in European eels, their migratory behaviour has received some attention. In the laboratory, juvenile glass eels have been shown to initiate rhythmic swimming activity in response to water current reversals and this implies that they are sensitive to the ebb and flow of the tide in estuaries (Bolliet et al. 2007). The response to currents has important implications for the design of migratory barriers since it appears that glass eels show a preference for simple siphons over fish ladders when negotiating weirs and similar obstacles (Bult & Dekker 2007). Glass eels activity is also correlated with water temperature and higher temperatures are required before glass eels will attempt to negotiate vertical obstacles (Linton et al. 2007). In the case of downstream migrating silver eels, implanted Nedap-transponders have proved useful for studying their migratory behaviour. When navigating a hydroelectric dam, the majority of silver eels passed downstream during the first five hours of the night (Winter et al. 2006).

In general, current migratory behaviour along the estuary towards the rivers includes passive tidal drift using flood tides to ascend the estuary and avoiding ebb tides to prevent descent. At some times this mechanism is replaced by targeted and active swimming once freshwater leads have been identified. The precise mechanisms for this are still poorly understood and probably vary seasonally, diurnally and with varying environmental cues, notably freshwater discharge and temperature. The local pathways of migration within the estuary are largely unknown although there is some indication of orientation to the shore. It is probably that most migratory species, perhaps with the exception of lampreys, show fidelity in their homing migration (Sustainable Development Commission 2007a).

5.2 Dietary comparisons

The fact that estuaries in general, and the Severn Estuary in particular, can support such vast numbers of fish is related to the supply of detritus that is mainly washed downstream from rivers (Henderson et al. 1992). This sustains huge numbers of benthic organisms that makes estuaries one of the most productive ecosystems in the world. In Bridgwater Bay, the brown shrimp (*Crangon crangon*) is the single most abundant epibenthic organism and the only crustacean species present throughout the year (Henderson et al. 1992). The 20 km^2 Stolford mudflats were estimated to support between 3×10^6 and 5×10^7 individuals (Henderson & Holmes 1987) which suggests a total adult population in the estuary of 10^8-10^{11} individuals (Bamber & Henderson 1994). The sand goby complex consisting of *Pomatoschistus minutus* and *Pomatoschistus lozanoi*, occupy a similar niche to *C. crangon* but populations are about 100-fold lower. These two species are critically important to the tropic structure and energy flow through the ecosystem (Henderson et al. 1992). The role of other fish species within this broad ecological framework, changes with season and food availability. With the notable exception of pipefish and a few other specialised feeders, most fish show considerable flexibility in their diet and will eat a range of organisms, depending on what is available and abundant at the time. The varied diet of the majority of species is evident from the summary in Table 5.1.

Table 5.1. Summary of the main dietary components of the most abundant species of fish in the Severn Estuary, the life-cycle stage(s) present and their use of the estuary.

Species	**Diet**						**Life-cycle stages**		**Use of estuary**		
	Plankton	Small crustaceans *e.g.* mysids, copepods	Larger crustaceans *e.g. Crangon*, *Carcinus*	Fish *e.g.* Gobies, sand eels	Other invertebrates *e.g.* annelids, molluscs	Detritus	Juvenile	Adult	Nursery	Migratory corridor	Breeding
Sand goby complex		+					+	+	+		+
Whiting		+	+	+	+		+		+		
Flounder		+	+	+	+		+	+	+		
Bass		+	+				+	+	+		?
Sea snail		+					+	+	+		
Poor cod		+					+		+		
Thin-lipped mullet						+	+		+		
Twaite shad							+	+	+	+	
European eel			+	+			+	+		+	
Herring	+	+					+		+		
Sprat	+	+					+		+		+
3-spined stickleback		+					+	+	+		
River lamprey								+		+	
Bib		+					+		+		
Common goby		+					+	+	+		+

5.3 Status & health of the fish assemblage

It is clear from the proceeding sections that the species of fish present in the Severn Estuary form part of a complex ecological community. Some species are dependant on a narrow range environment conditions that regulate all aspect of their life cycle. Others are more flexible in their response to various abiotic influences. Although these life-cycle patterns are predominantly environmentally determined, they can be profoundly affected by anthropogenic activity that, for example, may delay migration or slow growth and in some cases may threaten species survival. Figure 5.2 attempts to collate the most important issues affecting the species of fish that are dependant on the estuary for some part of their life-cycle. By necessity, this table oversimplifies the situation and should only be used as a guide to issues that may be significant. Full details are contained elsewhere in the relevant sections of this report.

Table 5.2. Summary of the main anthropogenic factors that may affect species of fish that rely on the Severn Estuary for some part of their life-cycle. Blank cells indicate a factor is not relevant or is not believed to be an issue for that species. Crosses indicate levels of negative impact or status and ticks positive impact or status. The climate change heading may also include other influences such as improved water quality (Henderson et al. 2007b).

	Anthropogenic factors affecting life-cycle and/or behaviour						
Species	Spawning sites	Contamination	Climate change	Fishing pressure	Migratory barriers	Turbine-related mortality	**Current overall status**
Sea lamprey	✗		?		✗✗✗	✗✗	✗✗
River lamprey	✗		?	✗	✗✗✗	✗✗	✗✗
Allis shad	✗✗✗	?	?	?	✗✗✗	✗✗✗	✗✗✗
Twaite shad	✗✗✗	?	✗	?	✗✗✗	✗✗✗	✗✗✗
Sprat			✓✓		✗	✗✗	✓✓
Herring			✓✓✓	✗	✗	✗✗	✓
Salmon			?	✗✗	✗✗	✗✗✗	✓
Trout			?	✗	✗✗	✗✗✗	✓
European eel		✗	✗	✗✗✗		✗✗	✗✗
Nilsson’s pipefish			✓✓✓		?	?	✓
Whiting		✗	✓✓	✗	✗	✗	✗
Bib		?	✗	✗	✗	✗	✗
Poor cod		?	✗	✗	✗	✗	✗
Pollack		?	✗	✗	✗	✗	✗
Northern rockling		?	✓✓		?	?	✓
5-bearded rockling		?	✓✓		?	?	✓
Bass	?		✓✓✓	✗✗	?	?	✓✓
Common goby	?	✗	✓✓✓			?	✓✓
Sand goby complex	?	✗	✓✓✓			?	✓✓
Black goby	?	?	?			?	?
Thin-lipped grey mullet		?	✓		?	?	✓
Sand smelt						?	✓
Sea snail			✗		?	?	✓
3-spined stickleback	?	?			?	?	✓
Flounder		✗✗	✓✓✓	✗	✗	?	✓✓
Dover sole		✗	✓✓✓	✗✗	✗	?	✓

6 CONCLUSIONS & RECOMMENDATIONS

The entrainment of fish on the intake-screens of power stations in the Severn Estuary and Bristol Channel has allowed seasonal variations in the abundance of fish in the estuary, as well as inter-annual and longer term trends to be monitored in considerable detail. The 25 year data set available from Hinkley is a remarkable resource and although information from Oldbury is also comprehensive, it covers shorter periods of five years in the 1970s and two years in the 1990s. While regular sampling still continues at Hinkley Point, there is currently no regular assessment of the fish community based on catches at Oldbury.

- The resumption of fish sampling at Oldbury power station would provide the essential information required to continue to monitor the fish assemblage at both the seaward and freshwater limits of the Severn Estuary cSAC.

Despite the potential impact of water intake-screens on fish mortality, the fact remains that, between the 1970s and 1990s, the abundance of many species of fish increased at Oldbury (Potter et al. 2001) and Hinkley Point, and since about 2002, the rate of increase has accelerated by a factor of two to four (Henderson et al. 2007b). The reason for the increase in fish abundance is likely to be multifactorial but there is circumstantial evidence to support a number of possibilities.

- The potential impact of the effects of climate change, particularly temperature, requires careful monitoring. Although some species are already showing exceptional increases in population size that may be the result of increased water temperatures, there are indications that others (*e.g.* European eel, bib, poor cod, pollack & sea snail) are adversely affected.

The fact that even small changes in water temperature can have such profound effects on abundance highlights the sensitive of fish to this environmental cue. The present report contains many examples of species that are known to respond to threshold temperatures that can trigger movement in or out of the estuary or initiate spawning behaviour. Changes in salinity is another important variable that determines fish distribution and abundance. For example, those species less tolerant of reduced salinity may move offshore at particular times of year while others, such as migratory species, may use increased fresh water discharge to trigger the start of their upstream migration. A barrage will profoundly alter the salinity and temperature profiles in the estuary. The overall effect is difficult to predict, but even if the abundance of fish species remain unaffected, their distribution within the estuary will be altered in complex ways. It will certainly involve an increase in the variety and abundance of marine species penetrating the estuary.

- Monitoring the fish assemblage before, during and after a barrage is constructed will be essential if the environmental impact is to be understood and minimised.

The fact that members of the estuarine fish community exhibit remarkably consistent annual cycles in abundance, even when salinity and temperature profiles between years may vary, implies seasonal triggers are important. Thus, the cyclical patterns may not be driven directly by temperature, salinity of freshwater discharge but may be a reflection of sequential immigrations of different species, and particularly those of juvenile marine estuarine-opportunists (Potter et al. 1986; Potter et al. 1997). Tidal cycles are also known to strongly influence fish movement and behaviour on a day-to-day basis and although changing light levels during the monthly lunar cycle could be significant, it is the ambient light level rather than the phase of the moon that is probably important for some species.

- There is a need for more information on the behaviour and responses of fish to environmental triggers. This is especially true for migratory species that are most vulnerable to anthropogenic disruption.

- The exact routes taken by migratory species through the estuary is poorly understood. The application of telemetric techniques now available would help obtain better information about the local migratory patterns within the estuary and would enable a better understanding of their behaviour in the vicinity of barriers and turbines.

The reported decline in the levels of metal contamination in the estuary in sediments and biota (Martin et al. 1997; Duquesne et al. 2006) can only be of benefit to the fish community and it is likely that further improvements in water quality will be reflected in improved growth rates and survival of most species. There is also evidence that contamination by PAHs and other organic compounds is not widespread and confined to a few point sources (Langston et al. 2003). There remains a concern that endocrine disruption may be affecting reproduction in some species, but there is little information available for the Severn Estuary.

- Based on evidence that endocrine distribution has been detected in molluscs from the region (Langston et al. 2007), there is a need to establish whether fish species in the Severn Estuary have also been affected.

The picture that emerges for the fish assemblage in the Severn Estuary and Bristol Channel is one of complex interactions between different species of fish, their predators and prey. The system is characterised by remarkably consistent and robust seasonal cycles in the fish composition, but highly variable inter-annual patterns of abundance that are affected and influenced by a range of environmental variables.

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