Shad Conservation in England and Wales

R&D Technical Report W110

Cyngor Cefn Gwlad Cymru
Countryside Council for Wales

ENGLISH NATURE

Shad Conservation in England and Wales

R&D Technical Report W110

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with some illustrations by Peter Stebbing

Research Contractor:

Environment Agency, North West Region

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Statement of use
This report should be used to increase the knowledge and awareness of the ecology and status of shad populations of England and Wales and the distribution of shad in the UK. It contains the analysis of population data collected in 1979. There are guidelines for the planning of monitoring programmes and it is a useful reference document for planning.

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EXECUTIVE SUMMARY

This document reports on research which was carried out as part of a larger programme on Species Management in Aquatic Habitats (Gulson, 1994). The Environment Agency, English Nature and the Countryside Council for Wales jointly funded the project.

Alosa alosa (allis shad) and *Alosa fallax* (twaite shad) are classified as rare and listed in Appendix III the Bern Convention and Annexes II and V of the EC Habitats Directive. Annex II requires that Special Areas of Conservation are designated for shad and that Member States should ensure the appropriate management of these and other sites where they are known to occur so that the favourable conservation status of the species can be secured. In addition, allis shad is protected under Schedule 5 of the Wildlife and Countryside Act (1981) and both species are now included in Section 9(4)(a) of the Act, which makes it an offence to intentionally obstruct access to spawning areas, or to damage or destroy gravels used for spawning.

Assessments were made of

- the distribution and status of *Alosa* in Britain;
- population trends;
- the influence of water temperature and flow on year class strength of twaite shad from the River Severn;
- variation in the age at first spawning;
- ongoing and other possible methods of monitoring shad populations (estimates of manpower and equipment requirements are presented).

The principal findings were that

- allis shad have been recorded in 26 UK and 10 Southern Irish waters, with one known historical spawning population in the River Severn;
- twaite shad have been recorded in 37 UK and 15 Southern Irish waters, four of which are known to support spawning populations (rivers Wye, Usk, Severn and Tywi) and one known historical spawning population in the River Thames;
- 25 spawning sites are known to exist in the River Wye, eight of which have been confirmed;
- five spawning sites are known to exist in the River Usk, four of which have been confirmed;
- two spawning sites are known to exist in the River Severn, both of which have been confirmed;
- seven spawning sites are known to exist in the River Tywi, although none have yet been confirmed;
- year classes from 1975, 1976, 1982-84, 1989 and 1990 were particularly strong, whilst those from 1977-81 and 1985-88 were particularly poor;
- recuitment since 1990 has been fairly stable;
- the population of twaite shad in the River Severn appears to be relatively healthy and although the total numbers fluctuate, it seems able to withstand up to four years' bad

recruitment in five;

- most twaite shad in the Severn Estuary population matured before they were aged six;
- year class strength of twaite shad in the Severn Estuary was positively correlated with mean monthly temperature and negatively correlated with mean monthly flow;
- July temperature explained most of the variability in year class strength of twaite shad in the Severn Estuary;
- the onset of maturity of twaite shad in the Severn Estuary seems to be related to density-dependent processes, suggesting that immature fish congregate in a fairly restricted area when at sea, which may break down as mature individuals enter the rivers to spawn;

The future prospects are that

- the population of adult shad will increase over the next five years;
- between four and five years' data are required to describe the mean age at maturity for the population of twaite shad in the Severn Estuary;
- tests for significant differences between catches should be between catch records which are separated by at least two years;
- future monitoring for adults should include numerical and biological records from the Lydney putchers by-catch in the short term, to be run concurrently with longer term methods, such as fish counters, at least until these methods have been appraised and assessed;
- future monitoring for juveniles should support the sampling programme at Hinkley Point 'B' Nuclear Power Station and include a pilot study of the feasibility of monitoring 0+ shad by counting eggs and sampling 0+ juveniles in the Wye, Usk and Tywi estuaries.

KEY WORDS

SHAD, *ALOSA ALOSA*, *ALOSA FALLAX*.

1. INTRODUCTION

1.1 Introduction

This study is a component of the generic Environment Agency project on Species Management in Aquatic Habitats (Gulson, 1994). This identified a list of river and wetland species for which the Environment Agency, English Nature and the Countryside Council for Wales required guidance on appropriate management practices. From a provisional list of over 950 rare species, the application of various criteria identified 11 species/groups as being of high priority, with a further 20 of lower priority. The allis and twaite shad (*Alosa alosa* and *Alosa fallax*) are included amongst the list of high priority species.

A.alosa and *A.fallax* are classified as rare, and listed in the Bern Convention and Annex II and V of the EC Habitats Directive, which provides some protection for these species by placing an obligation to assess numbers and exploitation of the population. Under the Habitats Directive there is also an obligation to designate a series of Special Areas of Conservation (SAC) for the shad, and to ensure the appropriate management of these and other sites where they are known to occur, so that the favourable conservation status of the species can be secured. In addition, allis shad is protected under Schedule 5 of the Wildlife and Countryside Act (1981) and both species are now included in Section 9(4)(a) of the Act, which makes it an offence to intentionally obstruct access to spawning areas, or to damage or destroy gravels used for spawning

In order to deliver the requirements of the Habitats Directive to ensure the favourable conservation status of the species, it is necessary to be able to designate and subsequently manage Special Areas Of Conservation for shad. This requires knowledge of those areas utilised by shad during their period of residency in fresh and estuarine waters, and the identification of factors which are important in regulating the size of the population, ideally to quantify their significance. In this way the effect of an impact can be assessed. This information is needed by English Nature and Countryside Council for Wales to meet their duties to conserve these species. It is also required by the Environment Agency to meet its conservation duties and ensure that specific requirements of shad are adequately taken into account in Local Environment Agency Plans and other operational work.

1.2 Overall project objective

To produce a species action plan. To report on the past and present status of *Alosa alosa* and *A.fallax* in England and Wales. To identify and quantify, if possible, those factors important in regulating the size of the population, and outline requirements to ensure the favourable conservation status of the two species of shad.

1.2.1 Specific objectives

1. Undertake a literature review and produce a bibliography.

2. Analyse data collected on *A. fallax* from the Severn Estuary between 1979 and present with specific regard to; the composition and size of the spawning population over the period, variation in year-class strength, variation in age at maturity and the rate of annual mortality.

3. Design and cost various sampling strategies which aim to monitor the current status of the populations.

4. Analyse previously collected samples of *A. alosa* for basic biological information.

5. Identify gaps in current knowledge important for the conservation of the species and how such information might be obtained.

6. By interviewing EA staff, anglers and others, and field visits if necessary, identify sensitive locations (spawning sites, obstructions to migration) that may require additional protection.

7. Prepare a Species Action Plan for *Alosa* sp. in England and Wales taking into account information obtained in 1-6 above, and setting it in the context of the Biodiversity Action Plan and UK SAPs developed by Peter Maitland for DOE. To highlight the role the Environment Agency, EN and CCW have in delivering the objectives of the action plan.

8. Prepare and cost a Project Initiation Document for Phase II.

1.3 Description of *Alosa alosa* and *Alosa fallax.*

1.3.1 Description of the genus *Alosa* Linck, 1790

The diagnostic features of the genus have been described by Whitehead (1985), Hoestlandt (1991), Svetovidov (1952) and Wheeler (1969). The genus consists of moderate to large herring type fish, reaching up to 65 cm fork length. The body is slightly compressed laterally and has a prominent keel of scutes along the ventral surface (Figure 1.1). The upper jaw has a distinct median notch into which the tip of the lower jaw fits (Figure 1.2), and there are no teeth on the vomer. Total gill raker count ranges from 30 to 160 with the upper gill rakers, when numerous, overlapping the lower gill rakers at an angle of the first gill arch. The body is covered by well developed scales which are normal, the hind borders being smooth, and there are no enlarged or fringed scales along the dorsal surface. The pelvic fins have one unbranched fin ray and eight branched finrays (i 8).

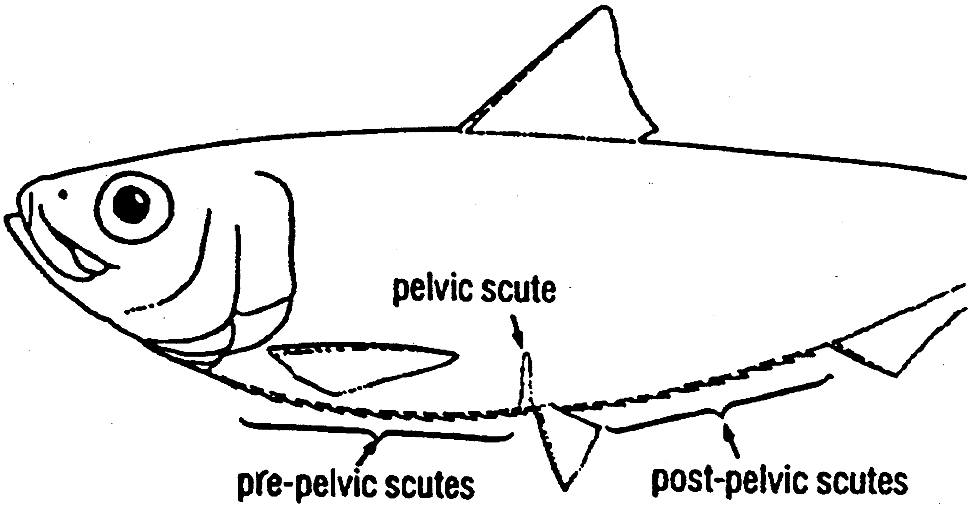

Figure 1.1 Ventral scutes along the ventral carina (Whitehead, 1985)

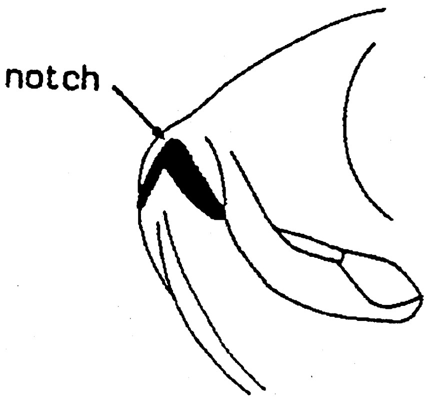

Figure 1.2 Distinct notch into which the symphysis of the lower jaw fits (Whitehead 1985)

1.3.2 *Alosa alosa* (allis shad) and *Alosa fallax* (twaite shad)

The main feature distinguishing the two species is the number of gill rakers on the first gill arch. The number of gill rakers are dependent on the size of the fish (Figure 1.3).

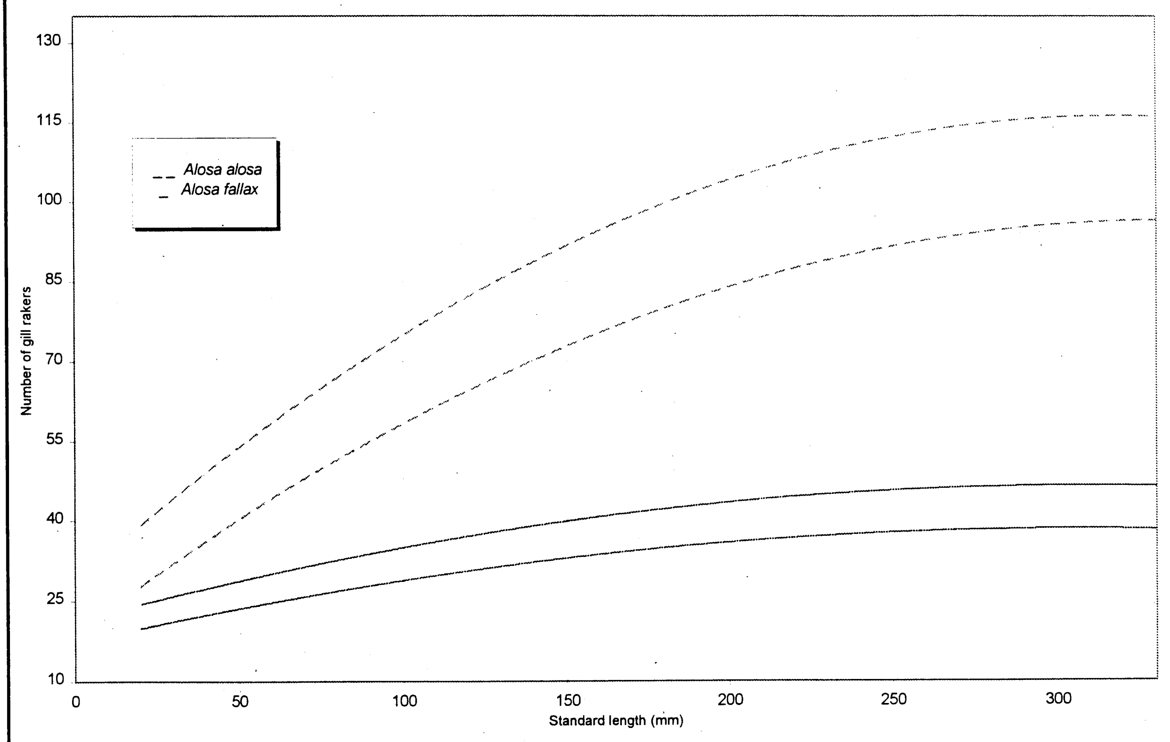

Figure 1.3 Smoothed minimum and maximum number of gill rakers for Alosa alosa and Alosa fallax in relation to standard length (reproduced from Taverny, 1991)

For fish greater than 30 cm fork length; *Alosa alosa* have a total of between 90 - 160 long thin gill rakers, which are longer than the gill filaments while *Alosa fallax* have between 35 - 60 coarse gill rakers approximately the same size as the gill filaments (Figure 1.4). In addition the gill rakers on *A. alosa* have densely packed spines while those on *A. fallax* bear few spines. Specimens with an intermediate number of gill rakers also exist and are considered hybrids.

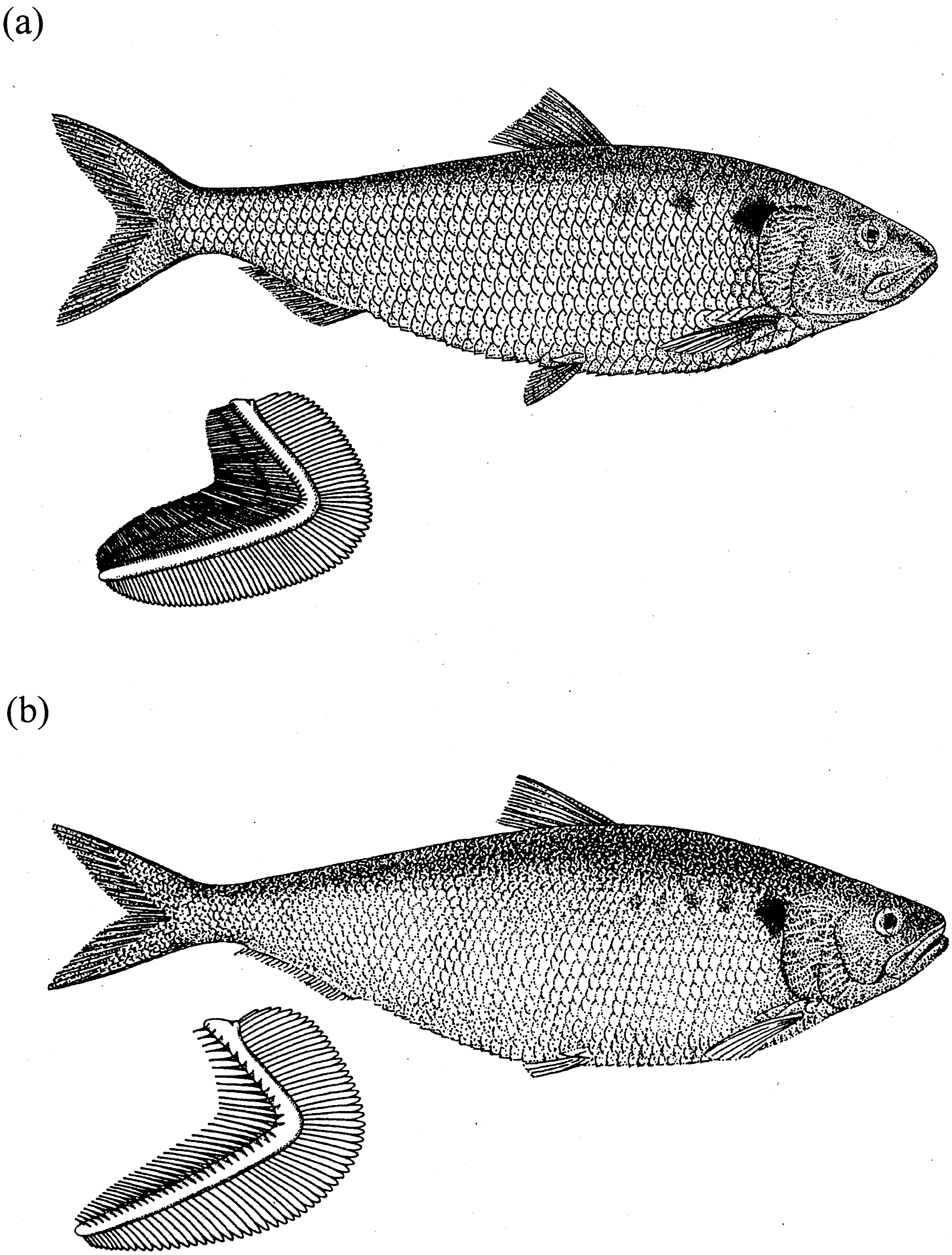

Figure 1.4 ***Alosa alosa*** **(a) and** ***Alosa fallax*** **(b) (Gysin, 1994) with detail of first gill arch (Maitland, 1972).**

1.4 Life history of *Alosa alosa* and *Alosa fallax*

1.4.1 *Alosa alosa* (allis shad)

The life history of *Alosa alosa* is shown diagrammatically in Figure 1.5a. Allis shad mature between 2 - 5 years for males and approximately a year later for females. The majority of populations of allis shad have a semelparous life history, spawning only once. In the Loire, however, a small proportion of the population are repeat spawners (iteroparous) (Menneson - Boisneau and Boisneau, 1990). The mature fish enter the estuary on the freshwater phase of their spawning migration between March and June. Spawning is dependent on temperature and usually occcurs during June and July. The 0+ fish remain in fresh and/or estuarine waters during the summer, migrating into the estuary in the autumn and into the sea the following spring.

1.4.2 *Alosa fallax* (twaite shad)

The life history of *Alosa fallax* is shown diagrammatically in Figure 1.5b. Twaite shad mature when aged between 2 - 5 years. Males mainly mature at ages 3 and 4 years and females mature approximately one year later. Twaite shad have an iteroparous life history. Up to 6 spawning migrations having been recorded. The mature fish enter the estuary on the freshwater phase of their spawning migration between April and June. Spawning occurs, depending on temperature, between May and July after which the adults migrate seaward. The 0+ fish remain in fresh and/or estuarine waters during the summer and migrate to sea in the autumn. A portion of these re-enter the estuary the following spring, migrating to sea once more in late summer/early autumn.

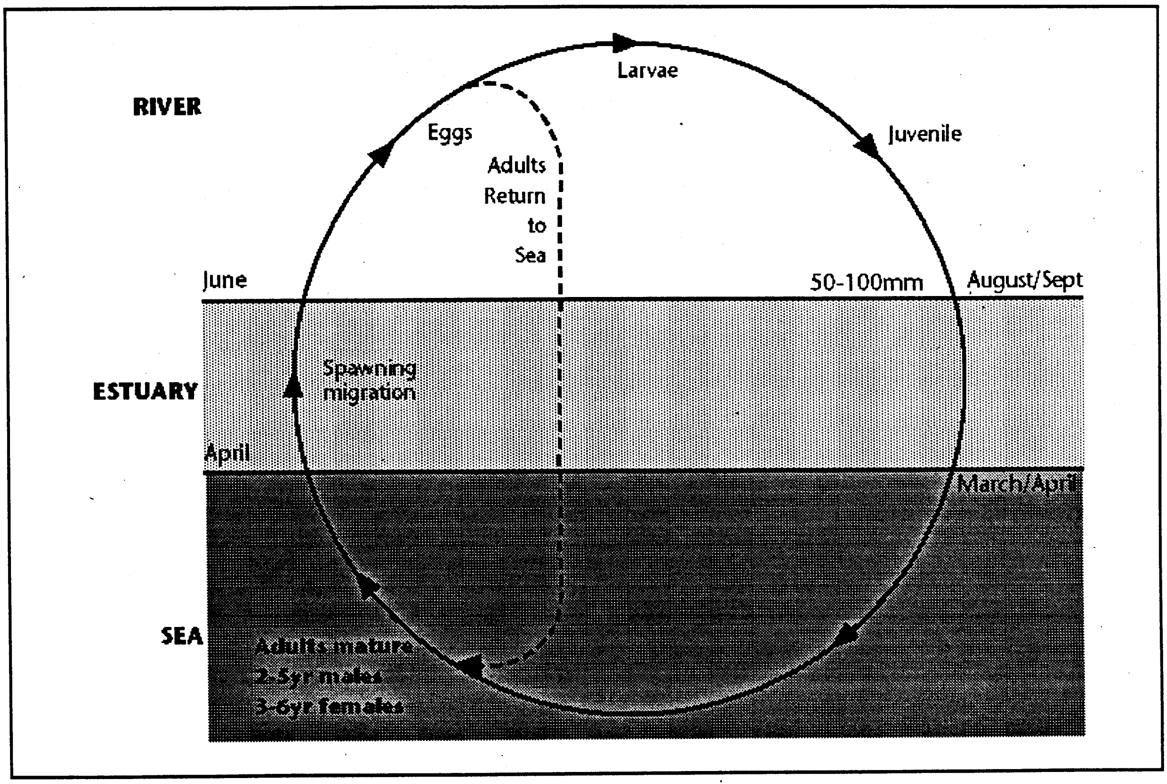

Figure 1.5a **Life cycle of *Alosa alosa* (from Taverny, 1991)**

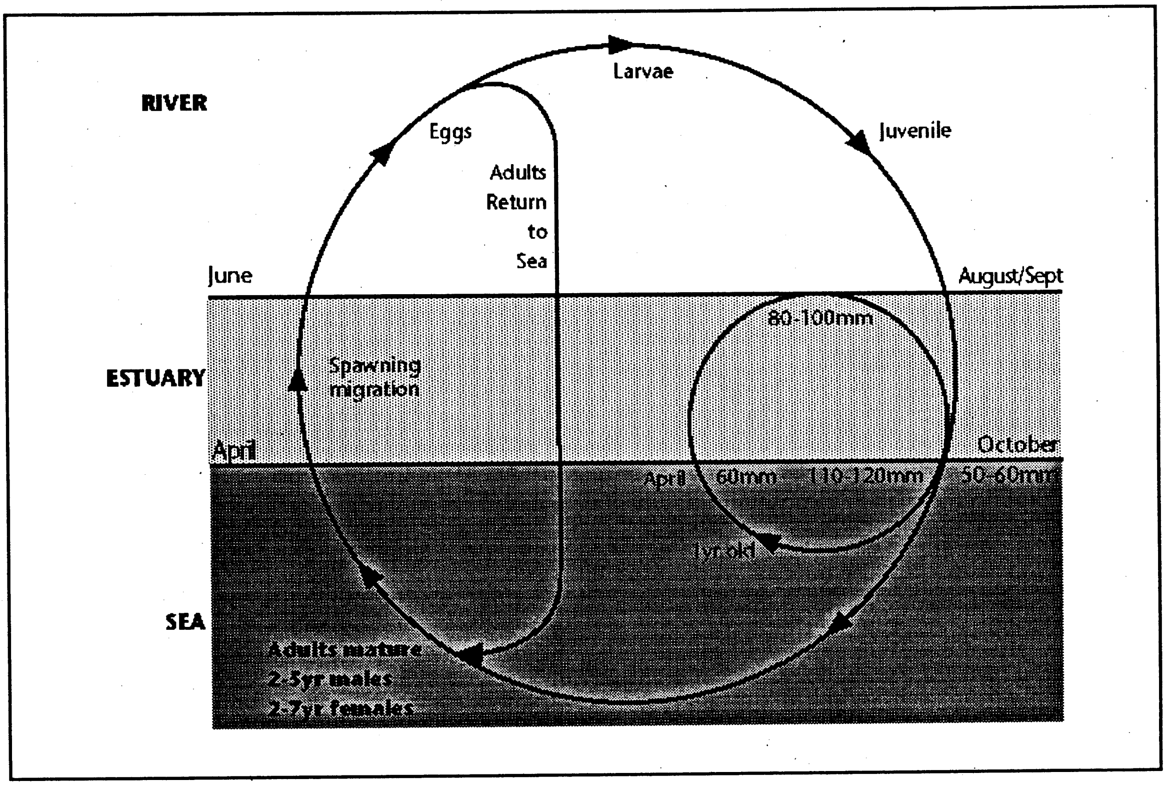

Figure 1.5b **Life cycle of *Alosa fallax***

2. DISTRIBUTION AND STATUS OF *ALOSA* IN BRITAIN

2.1 Introduction

The occurrence of allis and twaite shad, in the rivers and around the coast of the British Isles, has been reported by Aprahamian and Aprahamian (1990), Maitland (1972 & 1979) and by Potts and Swaby (1993). The aim of this section is to report on the past and present distribution of both species of shad and to identify, wherever possible, those river systems which presently support or historically supported a self-sustaining population.

2.2 Distribution of *Alosa alosa* in the British Isles

In the British Isles, the allis shad (*Alosa alosa*) is now considered rare (Aprahamian and Aprahamian, 1990; Maitland and Lyle, 1991, 1992), with no known spawning sites in the British Isles (Maitland and Lyle, 1993). Potts and Swaby (1993) reported on the distribution of *A.alosa* around the coast of the British Isles and found they were particularly concentrated in the Severn Estuary, the south west of England and the east coast of Scotland (Figure 2.1).

2.2.1 Scotland (Figure 2.2)

On the east coast of Scotland, they were seen ascending the River Tay at the turn of the century (Buckland, 1880; Maxwell, 1904) and there have been several catches recorded in the inner Tay estuary (Anon., 1881, 1884-1901, 1901-1918, 1918, 1995a). Parnell (1837) found that allis shad were occasionally caught and mistaken for herring in the Firth of Forth, although more recently they have been reported as present in the area (Maitland, 1980). Further south they were frequently taken at the mouth of the River Tweed (Houghton, 1879). Maxwell (1904) reported them ascending the Tweed and a ripe female has also been reported by Rae and Wilson (1952). More recently Campbell (pers. comm) reported two female allis shad; one caught at the mouth of the Tweed (June 1993) and the other approximately 64 km upstream (June 1985); but no definite spawning areas are known.

On the west coast of Scotland *A. alosa* have been reported as common in June around the mouths of rivers draining into the Solway Firth (Service, 1892); Rae and Wilson (1961) found a specimen in the mouth of the River Dee and Gordon (1921) reported that they ascended the River Cree to spawn. Allis shad have occasionally been caught at Innerwell in the Cree Estuary. Studies carried out between 1989 - 1994 by Maitland and Lyle (1995) reported that around twenty five allis shad a year are caught in the salmon stake nets fished on the north shore of the Solway, mainly between May - July (Table 2.1). Individual allis shad caught in the Solway have been ripe for spawning (Lyle, pers. comm.). This may indicate that there is a spawning site in the area, possibly in the lower reaches of the rivers Bladnoch and Cree (Maitland and Lyle, 1995). Specimens have also been landed at Ayr (Burkel, pers. comm).

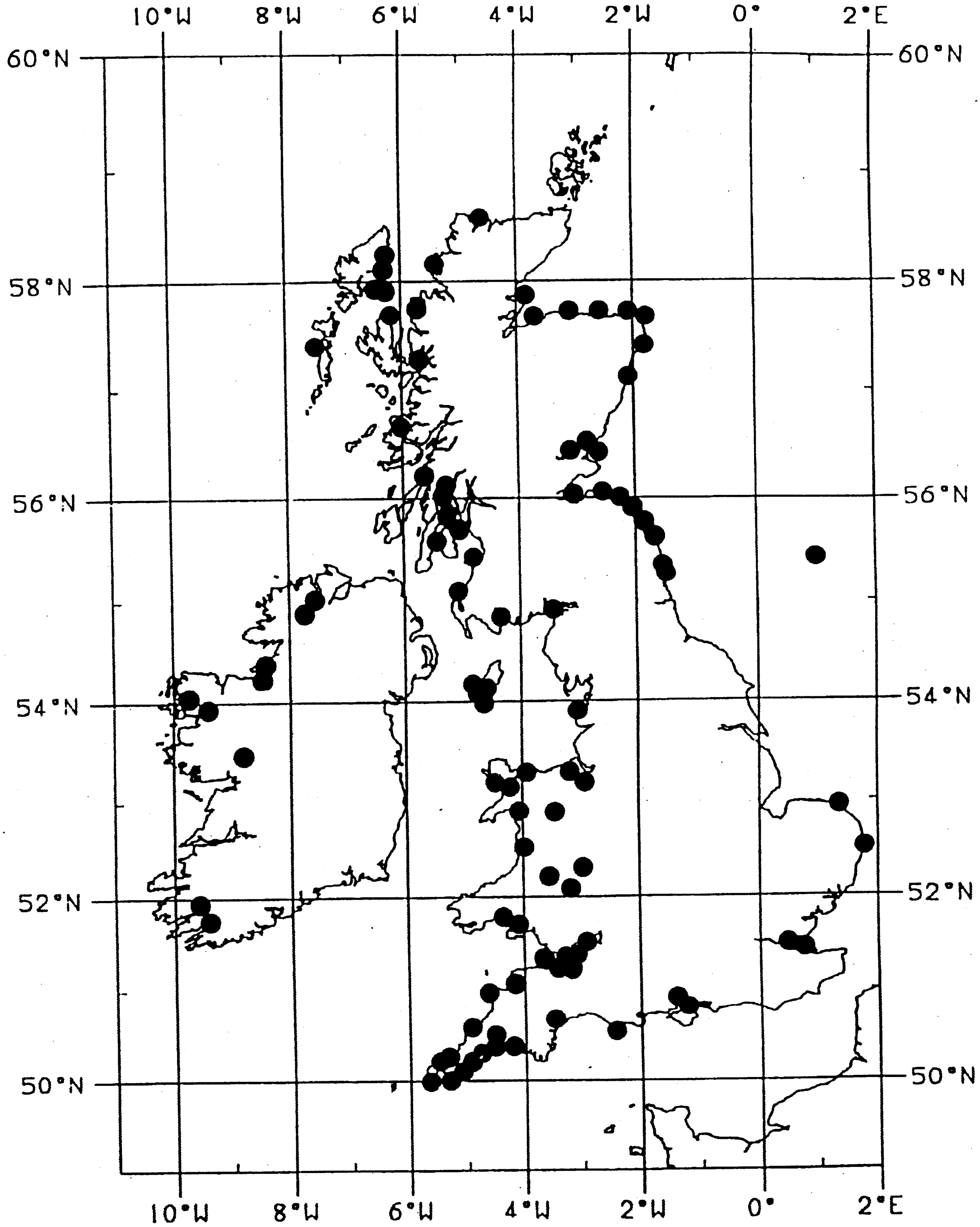

Figure 2.1 Coastal distribution of *Alosa alosa* in the British Isles (from Potts and Swaby, 1993).

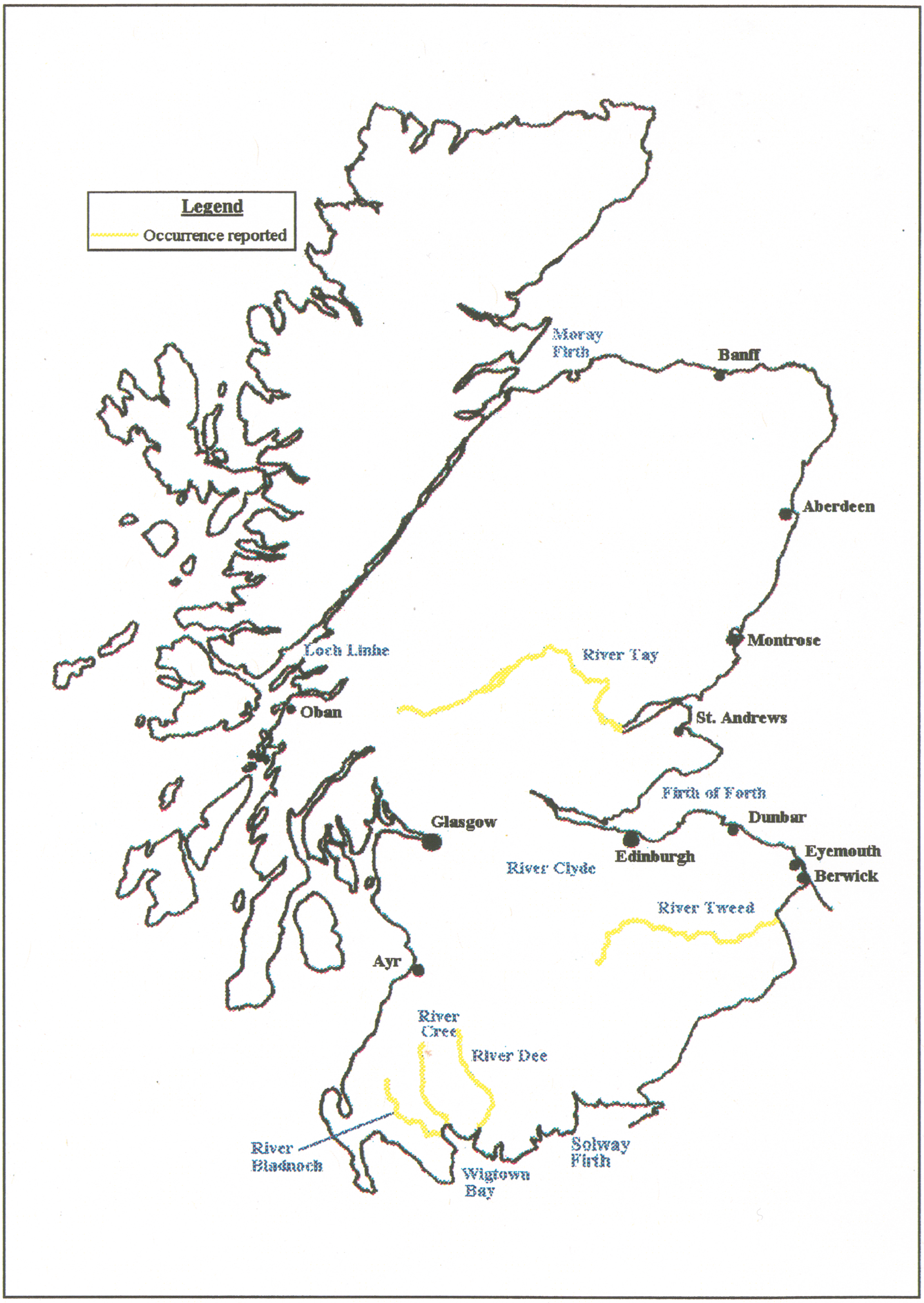

Figure 2.2 Distribution of *Alosa alosa* in Scotland

Table 2.1 The number of allis shad taken in nets along the Solway coast between April and September 1989-1994 (Maitland and Lyle, 1995).

Month	1989	1990	1991	1992	1993	1994
April	0	0	2	0	0	3
May	9	17	6	4	0	5
June	5	6	6	13	4	3
July	12	3	2	10	3	6
August	1	0	3	7	0	2
September	0	0	0	0	0	0

2.2.2 England and Wales (Figure 2.3)

2.2.2.1 Scottish Border - River Trent

In June 1997 an allis shad (406 mm fork length, 952 g) was caught in a J net operating along the coast near Bridlington (Tingley, pers. comm.). Carr (1906) recorded a specimen taken in the River Trent at South Clifton and another near Newark. More recently, in 1995, an allis shad was caught at Carlton on the River Trent (Anon., 1995b) and in 1997 a shad which resembled an allis was caught in the River Wharfe (a tributary of the Ouse) at Tingley, upstream of its confluence with the River Trent (Frear, pers. comm.).

2.2.2.2 River Trent - River Thames

Historically Cunningham (1911) stated that allis shad are not abundant but according to Paget *"are commonly found with herring at Yarmouth"*. Two specimens were recorded by Gurney (in Cunningham, 1911) from Lowestoft in 1840. In 1996, six shad were caught off the north Norfolk Coast in what is currently a small salmon and sea trout fishery (J. Cave, pers. comm.), unfortunately these were not identified to species.

At Sizewell 'A' Power Station, Turnpenny and Utting (1987) caught a total of six allis shad between May 1981 - April 1982 and estimated the total annual catch to be fifty-three allis shad.

Yarrell (1836) mentions an allis shad being taken in the Thames above Putney and in 1833 at Hampton Court Palace. Houghton (1879) reported that allis shad were found only rarely in the Thames and similar reports by Andrews (1977) and Well (1958-1960) suggest little change over the period. Single specimens have been caught at Southend on Sea (Anon., 1994a), West Thurrock Power Station in 1975 and 1976, Blackwell Point in 1976, Richmond in 1977 (Andrews and Wheeler, 1985) and upstream of Teddington Weir, the tidal limit in 1993 (G.Armstrong, pers. comm).

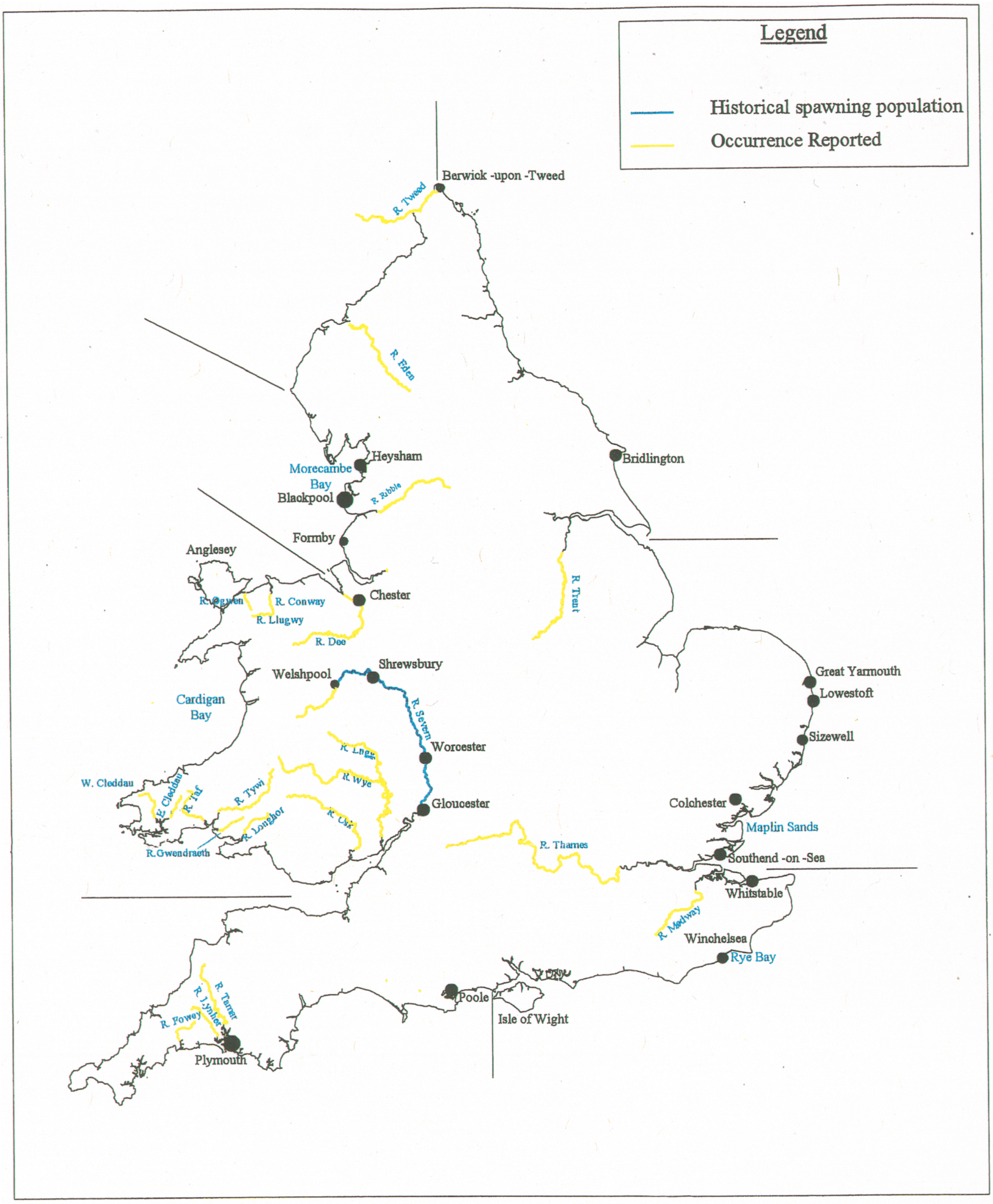

Figure 2.3 Distribution of *Alosa alosa* in England and Wales

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2.2.2.3 River Thames - River Avon

On the River Medway, Van den Broek (1979) reported catches of allis shad at Kings North Power Station and five adult shad were netted in July 1996 at Allington weir, the upper tidal limit. It is probable that these were allis shad (D.Scranney, pers. comm.). Later that year a single allis shad was obtained together with two twaite (Anon., 1996).

The catch of fish in the keddle nets on Winchelsea beach, Rye Bay was monitored between 6 June - 5 September 1996, a total of fifty tides being sampled. The percentage of occasions on which shad were caught are shown in Table 2.2, some of which were thought to be allis shad (D.Scranney, pers. comm.).

Table 2.2 The occurrence of shad in the keddle nets in Rye Bay between 6 June - 5 September 1996.

Month	Number of tides surveyed	Percentage of tides on which shad were caught
June	18	11.1
July	20	15.0
August	11	54.5
September	1	100

2.2.2.4 River Avon - River Severn

In 1893, twelve allis shad were taken in Plymouth Sound and up to six hundred fish at a time were taken in mackerel seines off Mevagissey (Cunningham, 1906 in Potts and Swaby, 1996). [Cunningham, 1896 #1017] also reported eight allis shad from Plymouth Sound. Single specimens have also been reported from the River Tamar (Marine Biological Association, 1957). At Gunnislake weir one shad was caught in 1990, although not identified to species (Reay, pers. comm.) and more recently allis shad have been caught below the weir (Potts and Swaby, 1996). Also in 1993 two allis shad were recorded from the Fowey estuary (Potts and Swaby, 1996).

In the River Severn a population of *Alosa alosa* was known to exist up to the middle of the nineteenth century (Day, 1890). Gmelin (1800) stated that "*the Severn produces the shad in higher perfection than any other British river*". Allis shad and to a lesser degree twaite shad were of considerable economic importance to the fishermen of the Severn. It was common for shad to make up as much as one third of their income from a fishery and in some instances when there had not been a good run of salmon they would have brought in a lot more (Salmon Fisheries Commission, 1861). The decline of the fishery has been attributed to navigation weirs constructed around 1842 (Houghton, 1879; Day, 1890). The weir at Worcester is the most likely to have prevented the allis shad reaching their spawning grounds, which extended as far as Welshpool (Salmon Fisheries Commission, 1861) and the River Vyrnwy nearby (Pennant, 1810). Whitchell and Strugnall (1892) commented that the decline in the fishery meant that allis shad had to be imported to Stroud from as far away as Norway. Forrest (1908) also makes mention of the fisheries on the Severn, situated between north of Shrewsbury and south of Bridgnorth, having declined as a result of the construction of navigation weirs.

More recently only a few allis shad have been reported from the River Severn and its estuary (Claridge *et al.*, 1986; Jones, 1992; Maitland, 1972, 1979) and may be regarded as rare; only two specimens were caught between 1974 and 1976 by Claridge and Gardner (1978) and one specimen by Hardisty and Huggins (1975). An unusual catch of a spent allis shad was made in eel-nets at Gloucester in November 1995 (A. Bewick, pers comm). Allis shad are occasionally caught by netsmen in the Severn Estuary.

2.2.2.5 River Severn - River Dee

Symonds (1908) recorded allis shad as *"frequenting the Wye and Lugg but are not common: they are numerous near Ross and the Rev Trumper has taken them at Clifford"*.

Allis shad have been reported in the River Wye this century (Edwards, 1982; Ellison, 1935; Maitland, 1972, 1979; Mann, 1989; Anon., 1994b) but again it must be considered rare (Mann 1989). The implications from Ellison (1935) are that a breeding population of allis shad exists in the Wye, however, none were recorded during an extensive survey in 1980 (Aprahamian and Aprahamian, 1990). It is also interesting to note that in the minutes of evidence taken before the Commissioners appointed to enquire into the salmon fisheries in England and Wales, allis shad did not appear to contribute significantly to the value of the fishery, and the evidence would seem to indicate that relatively few were caught (Salmon Fisheries Commission, 1861).

Alosa alosa have also been reported in the rivers Ogwen (Herdman and Dawson, 1902), Conway (Forrest 1907), Severn and Dee (Anon., 1994b), Usk, Loughor and Tywi in Wales (Maitland 1972, 1979; Anon., 1994b). A spawning shad, believed to be an allis was spotted on the River Tywi in 1990, around the Penlan Cystanog area (A.G.Thomas, pers comm) and viable populations of allis shad are considered to exist in the Gwendraeth and Taf (Potts and Swaby, 1995). A dead shad approximately 60cm long was recovered by a fisherman from the Tywi at Nantgaredig in August or September 1997 (P. Clabburn, pers. comm.). Its size and a photograph which was taken of the fish suggest that it was a spent allis, although this was not confirmed. Between May and July 1997, at least fifteen shad (several of which were identified as twaite) were caught in the Tywi estuary seine net fishery, which was lower than in previous years (Roberts, pers. comm.). In the same year, several shad were caught in the River Tywi by anglers, mainly during increased river flows (Roberts, pers. comm.).

Reports of recent catches of allis shad have been made by commercial netsmen in the Eastern and Western Cleddau (Morrell pers. comm.).

During the late sixteenth and early seventeenth century *"Shadde"* were described as occurring around the Pembrokeshire coast in great plenty (Owen, 1892). This probably refers to allis shad.

2.2.2.6 River Dee - Scottish Border

In 1995 a shad was recovered from the River Dee at Chester, although the species was not known. A single shad has been recovered from the Ribble Estuary, although the species was not known. MacPherson (1901) recorded allis shad as occasional summer visitors to inshore waters such as the mouth of the River Eden in June.

2.2.3 Ireland (Figure 2.4)

The allis shad is considered to be an indigenous species in Ireland, but there is no direct evidence to confirm it has ever spawned in Irish waters (Quigley and Flannery, 1996) and it has been classified as rare (Wheeler, 1969) and endangered (Quigley, 1996). However, records of its occurrence in fresh water include the River Ilen near Skibbereen (Gibson, 1956; Brennan 1963), Lough Leane (Maitland, 1979; Went, 1953; Went and Kennedy, 1969) and the rivers Foyle (Bracken and Kennedy 1967; Maitland, 1972), Moy (Maitland, 1972) and Slaney (Fahy, 1982). Viney (1996) has reported its occurrence in the rivers Corrib and Foyle.

Allis shad have been reported in the River Shannon (Jenkins, 1942; Twomey, 1967; Maitland, 1979; Went, 1953) but Bracken and Kennedy (1967) state that records of allis spawning in the Shannon are incorrect. They say that only one authentic record can be traced; a fish taken at Killaloe in the nineteenth century (Mayne, 1861).

Several specimens have been recorded in coastal waters and estuaries (Bracken and Kennedy 1967; Twomey, 1967; Maitland, 1972; O'Riordan, 1965; Went, 1974; Went and Kennedy, 1976). In Dingle Bay, Bracken and Kennedy (1967) reported that trawlers caught numerous specimens between February and April, numbers caught declined during the months of May and June only to increase again in July and August suggesting that spawning may take place in one or more of the rivers draining into Dingle Bay. Around the coast of Northern Ireland, Vickers (1959) reported specimens from the Foyle Estuary and Portballintrae, Co. Antrim.

2.3 The distribution of *Alosa fallax fallax* in the British Isles

In the British Isles the past and present distribution of self-sustaining populations of twaite shad (*Alosa fallax*) were reviewed by Aprahamian and Aprahamian (1990). Their occurrence around the British Isles has been reported by Aprahamian (1981), Maitland (1972 ; 1979) and by Potts and Swaby (1993). Potts and Swaby (1993) reported on the distribution of *A.fallax* around the coast of the British Isles and found they were particularly concentrated along the east coast of Scotland and the south and west coast of England and Wales up to the area of the Dee estuary (Figure 2.5).

2.3.1 Scotland (Figure 2.6)

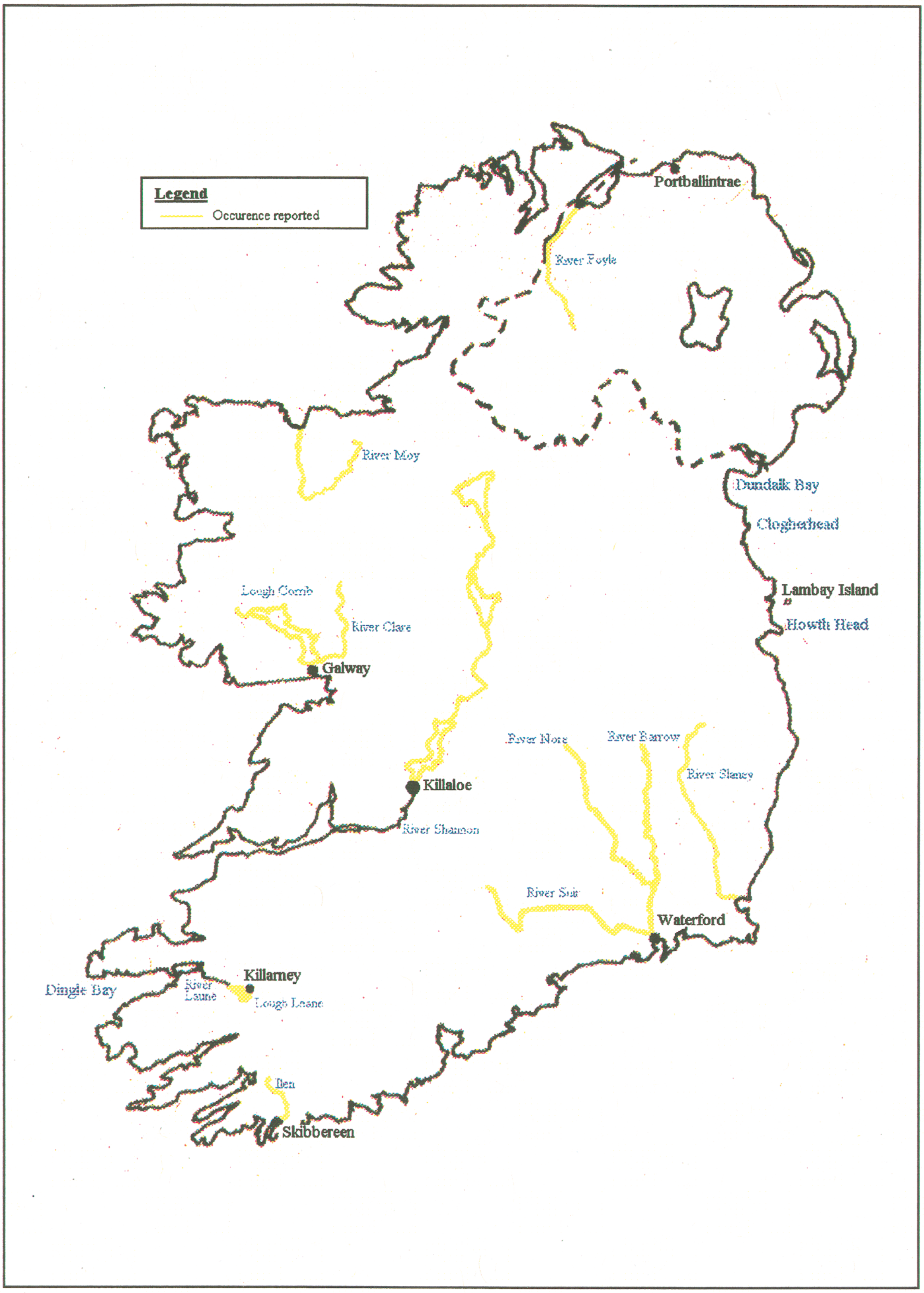


Figure 2.4 Distribution of *Alosa alosa* in Ireland

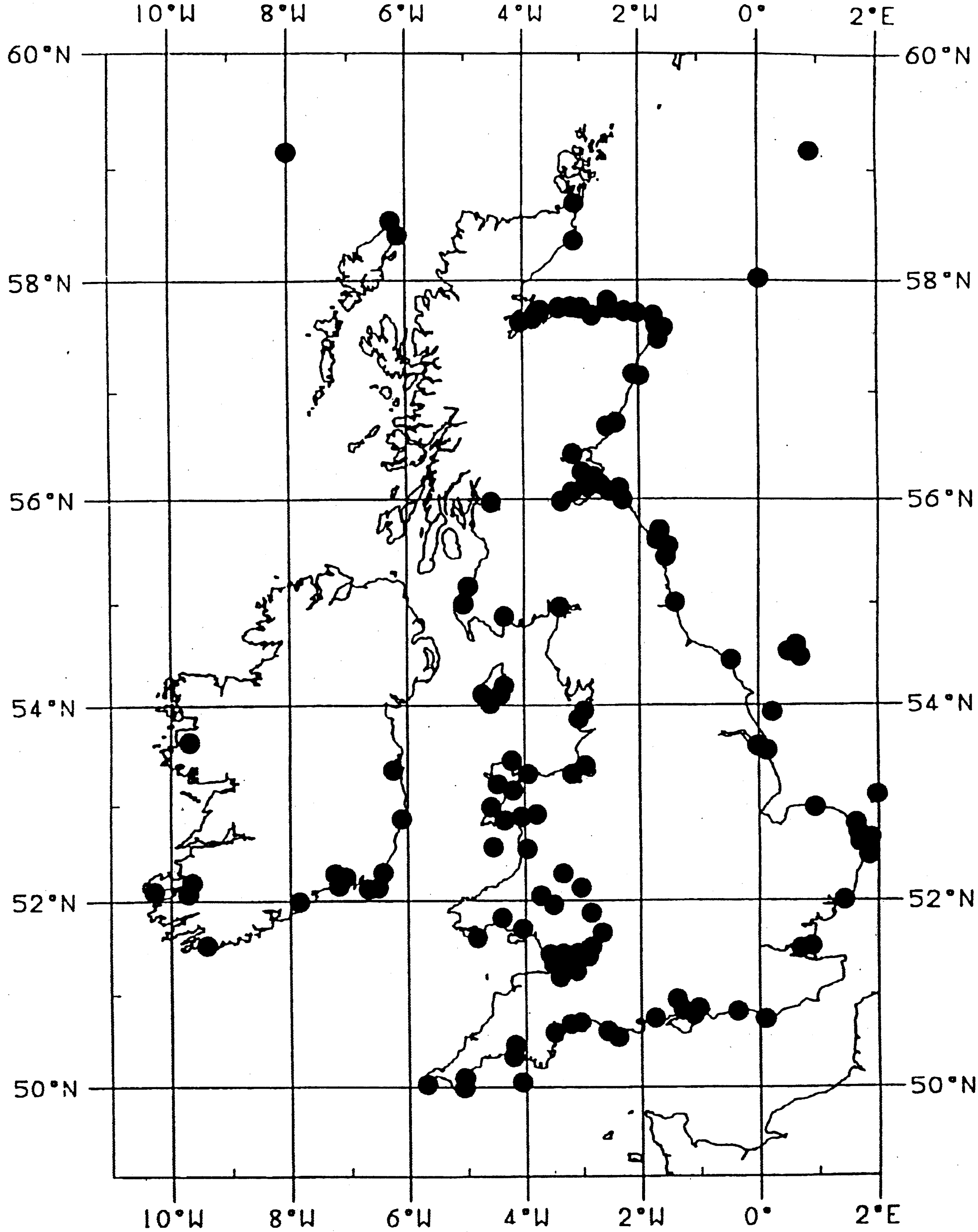


Figure 2.5 Coastal distribution of *Alosa fallax* in the British Isles (from Potts and Swaby, 1993).

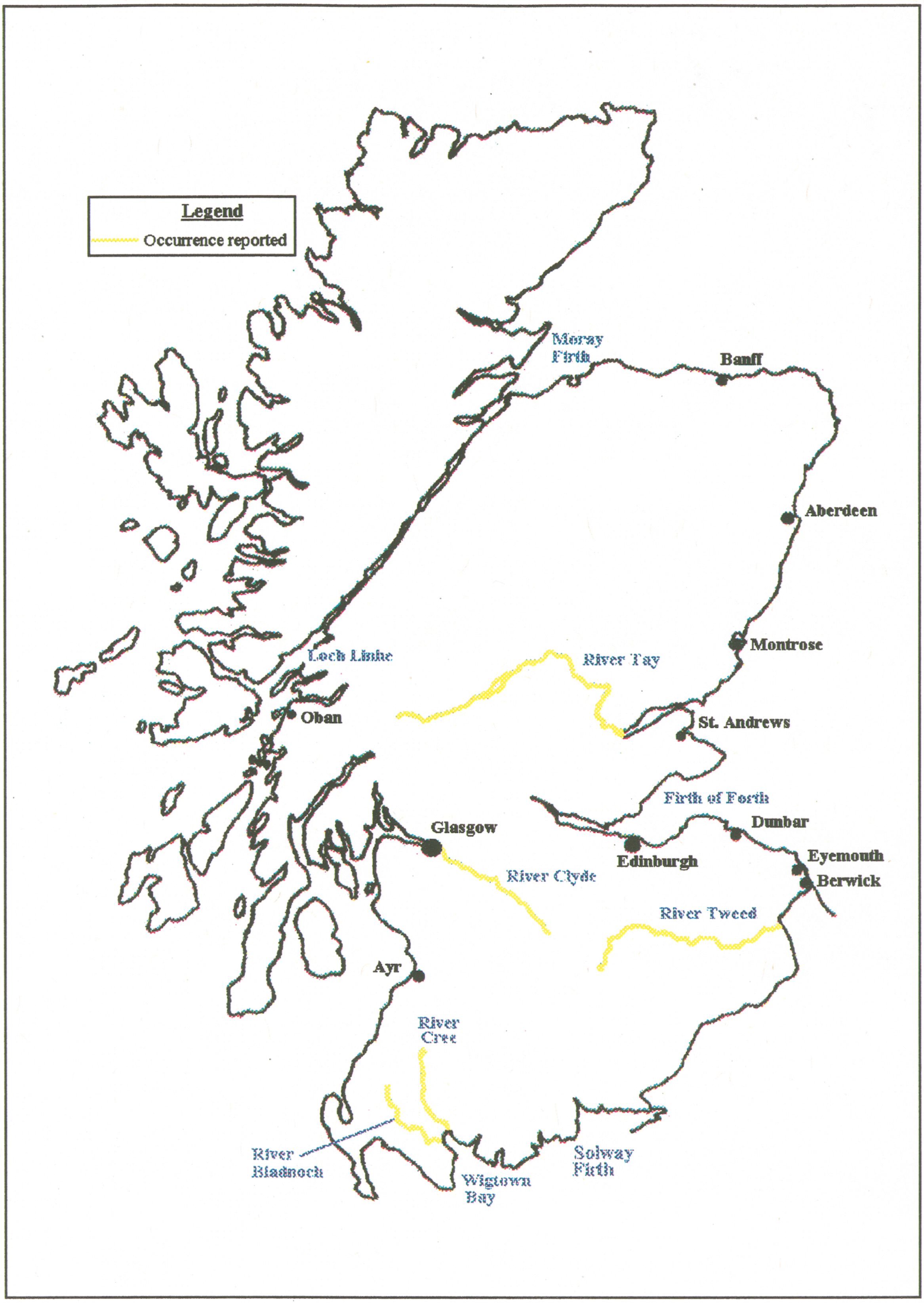


Figure 2.6 **Distribution of *Alosa fallax* in Scotland**

Houghton (1879) reports catches off the north east coast at Berwick, the Tweed, Firth of Forth, the Dunbar coast and the River Tay. Buckland (1880) recorded their occurrence in the River Tay as does Day (1880-1884) together with Banff, St. Andrews, Firth of Forth and Berwickshire.

Sim (1903) reported their occasional presence on the east coast of Scotland at sites including the Firth of Forth, between Aberdeen and Montrose and between Banff and the Moray Firth. Parnell (1837) observed twaite shad entering the Firth of Forth in tolerable abundance towards the end of July, and then disappearing after August. More recently they have been reported as present in the Forth area (Maitland, 1980). Rae and Lamont (1964) reported that in 1962, a large number were caught off Eyemouth during the winter. Relatively large numbers were also caught in 1956 (Rae and Wilson, 1961) and in 1957 (Rae and Lamont 1961).

Twaite shad were common in Wigtown Bay off the west coast of Scotland (Burkel pers comm.; Gladstone, 1912; Gordon, 1921). In the Solway Firth, around twenty five are caught each year mainly between May and August (Table 2.3) by the commercial salmon nets (Maitland and Lyle, 1995). Gordon (1921) mentions that they spawned in the River Cree, however, Hutchinson (pers. comm.) who carried out extensive netting in the Cree during the early 1980s, found only one specimen. The occurrence of ripe females between April and July followed by spent fish between June-September and the spatial variation in catch within the Cree estuary led Maitland and Lyle (1995) to suggest that the most likely spawning area for twaite shad was in the mouth of the River Bladnoch, or within its lower tidal reaches. Twaite shad have occasionally been caught at Innerwell in the Cree Estuary.

Table 2.3 The number of twaite shad taken in nets along the Solway coast between April and September 1989-1994 (Maitland and Lyle, 1995).

Month	1989	1990	1991	1992	1993	1994
April	0	0	2	1	1	14
May	8	2	6	2	0	15
June	11	8	9	5	5	7
July	3	2	2	3	6	8
August	6	2	1	5	0	11
September	1	0	0	0	1	0

Twaite shad have also been reported from around the River Clyde (Bagenal, 1965). Further north, a single specimen was caught in Loch Linnhe near Oban in 1976 (Gordon, pers comm.)

2.3.2 England and Wales (Figure 2.7)

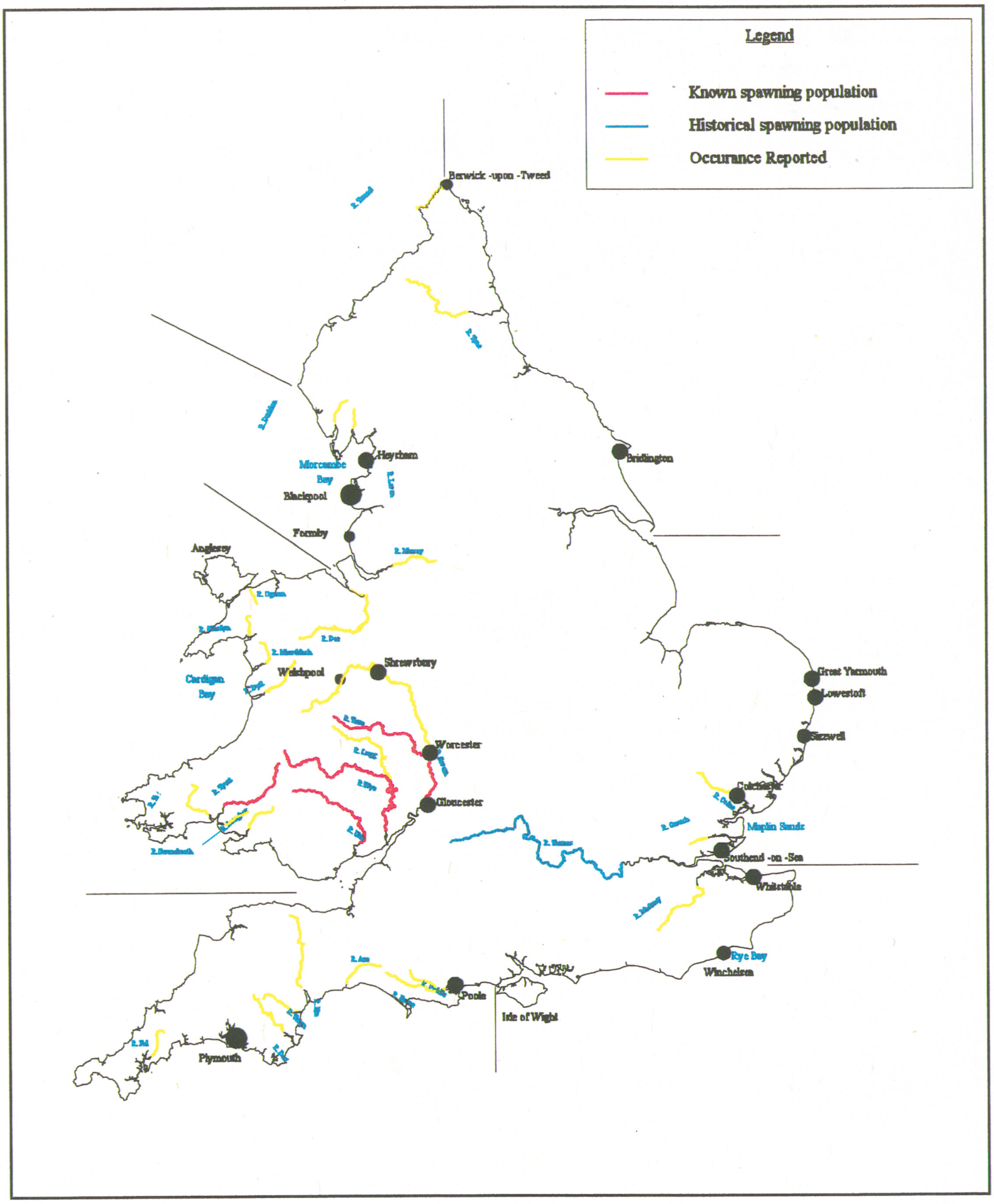


Figure 2.7 **Distribution of *Alosa fallax* in England and Wales**

2.3.2.1 Scottish Border - River Trent

A single specimen was reported from the River Tyne in 1901 (Meek 1916).

2.3.2.2 River Trent - River Thames

In East Anglia, occasional catches were made along the coast to Yarmouth (Day, 1880-1884; Lowe, 1901; Meek, 1916). In 1996, six shad were caught off the north Norfolk Coast in what is currently a small salmon and sea trout fishery (J. Cave, pers. comm.), unfortunately these were not identified to species. In the River Colne *Alosa fallax* were reported to be quite common at the start of the nineteenth century by Dr Laver (Murie, 1903). More recently a trawler man using herring mesh around the Crouch and Blackwater areas in the Thames estuary caught 2-3 fish per day in winter and early spring (R. Barker, pers. comm). There has been a general upward trend in the Essex fisheries, with the fishermen around Maplin Sands regularly making catches of shad between June and August (R. Wright, pers. comm).

In the nineteenth century, the River Thames enjoyed great numbers of *Alosa fallax* at spawning time around the first point of land below Greenwich, opposite the Isle of Dogs (Yarrell, 1836). It is believed that it was a very common fish in the tidal reaches of the Thames, reaching upstream to Teddington, and probably much beyond this before the construction of the weir (Wheeler, 1958). Towards the end of the nineteenth century, the numbers of twaite shad in the Thames had decreased greatly (Buckland and Walpole, 1879; Houghton, 1879). Wheeler (1979) states that by the end of the nineteenth century, shad were not found in the middle reaches of the tidal Thames or upstream, although Boulenger (1902) and Murie (1903) claimed that they were still abundant.

The decline of the population in the Thames is probably the result of a deterioration in water quality and not due to the construction of navigation weirs, as these were mainly built between 1811-1815 before the species started to decline (Aprahamian and Aprahamian, 1990; Day, 1880-84; Houghton, 1879; Yarrell, 1836). This was also suspected by Mr Henry Farnell, secretary to the Thames Angling Preservation Society (HMSO, 1861) who blamed the decline on the increase in the numbers of steamers stirring up great amounts of "... *frightfully offensive stuff...*" (Salmon Fisheries Commission, 1861).

The twaite shad is now classed as extremely rare on this stretch of river (Aprahamian and Aprahamian, 1990; Maitland, 1972, 1979; Wheeler, 1958, 1979). Wheeler (1979) found that there was a strong tendency for twaite shad to occur during the winter months in the estuary of the Thames, but found no evidence of a spawning migration. Similarly Robbins (1962) stated that *Alosa fallax* were abundant in the outer estuary in autumn at Leigh-on-Sea and Wheeler (1958, 1969) reported that they were regularly caught by anglers at Southend. Further into the inner estuary, Andrews (1977) found that *Alosa fallax* had penetrated the Thames to 10 km below London Bridge in 1975-1976 but it is believed that the numbers present were less than ten a year. Eel fishermen operating between Dartford and Erich have caught the occasional specimen of twaite shad (S. Colclough, pers. comm).

2.3.2.3 River Thames - River Avon

Murie (1903) reported that twaite shad frequent the Queensborough Swale, near Whitstable and Newell (1954) reported their occasional occurrence around the Whitstable area. An increase in the occurrence of twaite shad in catches from the Kent fishery, mainly between June and August, has been reported and one fisherman in Whitstable is presently interested in their commercial exploitation (R. Wright, pers. comm.). On the River Medway, samples of *Alosa fallax* were taken at Kings North Power Station by Wharfe, Wilson and Dines (1984). At Chatham in October 1994, as part of a fish rescue, many (hundreds) of shad, including juveniles were caught (D.Scranney, pers. comm), unfortunately these were not identified to species. The fact that juvenile shad (fish of approximately 90mm) were present would seem to indicate that a spawning population may exist in the vicinity. Further upstream two twaite shad were caught during a fish survey at Allington Weir, the tidal limit in the River Medway, in August 1996 (Anon., 1996).

Occasional specimens of twaite shad are captured in the English Channel (Bruce *et al.,* 1963). Both twaite, and some allis have been found in keddle nets on Winchelsea Beach, Rye Bay (Table 2.2) (D. Scranney, pers. comm.), and twaite shad have been recorded around Hampshire and the Isle of Wight (Boulenger, 1900).

2.3.2.4 River Avon - River Severn

Shad (twaite) have been seen in the Wareham Channel, mouth of the rivers Frome and Piddle in 1993/94 (G. Lightfoot, pers. comm.) and caught in Poole harbour (Anon., 1995c).

Twaite shad have been recorded along the south west coast (Marine Biological Association, 1957); around Devon (Cunningham, 1906), in large numbers off the Cornish coast (Couch, 1877) and in the mouth of the River Dart (Yarrell, 1859; Cunningham, 1906). More recent specimens have been reported from south west England by Anglers Mail (Felton, 1972; Anon., 1974a and Anon. 1978) and Angling Times (Anon., 1974b).

They are comparatively rare in the south west rivers (Aprahamian, 1982). Odd numbers are caught by salmon netsmen in the Rivers Axe, Exe, Dart and Teign (Davis, pers. comm.). During the 1960s the net fishermen in the Exe reported reasonable numbers of twaite shad but had noticed a decline during the 1970s (Kennedy, pers. comm.). Similarly Potts and Swaby (1996) reported their occurrence in the Exe and it is thought that they may spawn there (Diver, pers. comm.), although this needs to be confirmed. It is possible that they still visit Carrick Roads in the Fal estuary, but spawning activity in the River Fal or its tributaries has yet to be confirmed (J. Bridger, pers. comm). They have also been reported from the north Cornish coast by Potts and Swaby (1993).

A self-sustaining population of *A. fallax* currently exists in the Severn (Aprahamian, 1981, 1982; Aprahamian and Aprahamian, 1990). In the past twaite shad migrated up the Severn far above Shrewsbury (Day, 1880-84) until the construction of navigation weirs at Worcester and Shrewsbury around 1842 caused a decline in numbers (Day, 1890; Forrest, 1907). Symonds

(1908) found shad in the River Lugg up to Tidnor Mill and in the River Teme below Powick weir. In 1996 a twaite shad was caught in a fish trap on Tewkesbury weir. At present their upstream limit can be taken as Diglis Weir at Worcester on the Severn, though the very occasional specimen has been reported from upstream of the weir, and Powick weir on the River Teme. Studies on the population have been carried out by Andersen and Kennedy (1983), Aprahamian (1981, 1982, 1985,1988, 1989), Claridge and Gardner (1978), Claridge *et al.*, (1986), Hardisty and Huggins (1975) and Kennedy (1981).

At present the population in the Severn would appear to be reasonably stable (see section 3), however, information presented in the Annual reports of the Severn Fishery District (1869-1965) and Severn River Authority (1966-1979) indicate considerable concern that the twaite shad was declining in a similar manner to that already seen for allis. Except for a small improvement in the population during the early 1930s, the inference is that the population was considerably lower than in the past (or at present) and it was not until 1955 that the population increased. Changes which have occurred during this period are uncertain, but it is suspected that they were related to an improvement in water quality.

2.3.2.5 River Severn - River Dee

Kissack (1978) reported that a fishery existed on the Wye as early as the sixteenth century when *"shad were bought at Monmouth to relieve the poor during lent"*. This fishery had declined by the nineteenth century.

A spawning population of *A. fallax* are known to exist in the rivers Wye (Aprahamian, 1982), Usk (Aprahamian and Aprahamian, 1990) and Tywi (Aprahamian and Aprahamian, 1990; Neville-Jones, 1972; M. Todd, pers. comm.). Spawning populations have also been reported in the rivers Taf, Gwendraeth (Neville-Jones, 1972; Potts and Swaby, 1995) and the Loughor (Shaw 1977), although verification is needed, as twaite shad only appear to be caught infrequently in these rivers. Cacutt (1979) reported that twaite shad were fairly common around the south coast of Britain, especially in the Severn and the Wye. Specimens have been recorded in the Taff, Loughor, Dyfi, Dysynni and Glaslyn (Anon., 1994b). Between May and July 1997, at least fifteen shad (several of which were identified as twaite) were caught in the Tywi estuary seine net fishery, which was lower than in previous years (Roberts, pers. comm.). In the same year, several shad were caught in the River Tywi by anglers, mainly during increased river flows (Roberts, pers. comm.).

In north Wales, a spawning population was thought to exist in the River Ogwen in 1902 (Professor White in Herdman and Dawson, 1902), and in the late 1970s a number of adults were found in the Rivers Dyfi and Mawddach, suggesting the possibility of a spawning population here (Lewis pers. comm., Shaw 1977). On the north Welsh coast, Gosling (in Forrest, 1907) found them around Anglesey, and Lister (in Forrest, 1907) found them in Cardigan Bay. In June 1981, ten ripe adults were taken in seine nets from Porthmadog harbour in the Glaslyn estuary (R.A. Brassington, pers. comm). They are occasionally found in the River Dee (Davidson, pers. comm.; Ellison and Chubb, 1962; O'Hara, 1976; Walker in Johnstone; 1906). In 1995 a shad was recovered from the River Dee at Chester, although the species was not known.

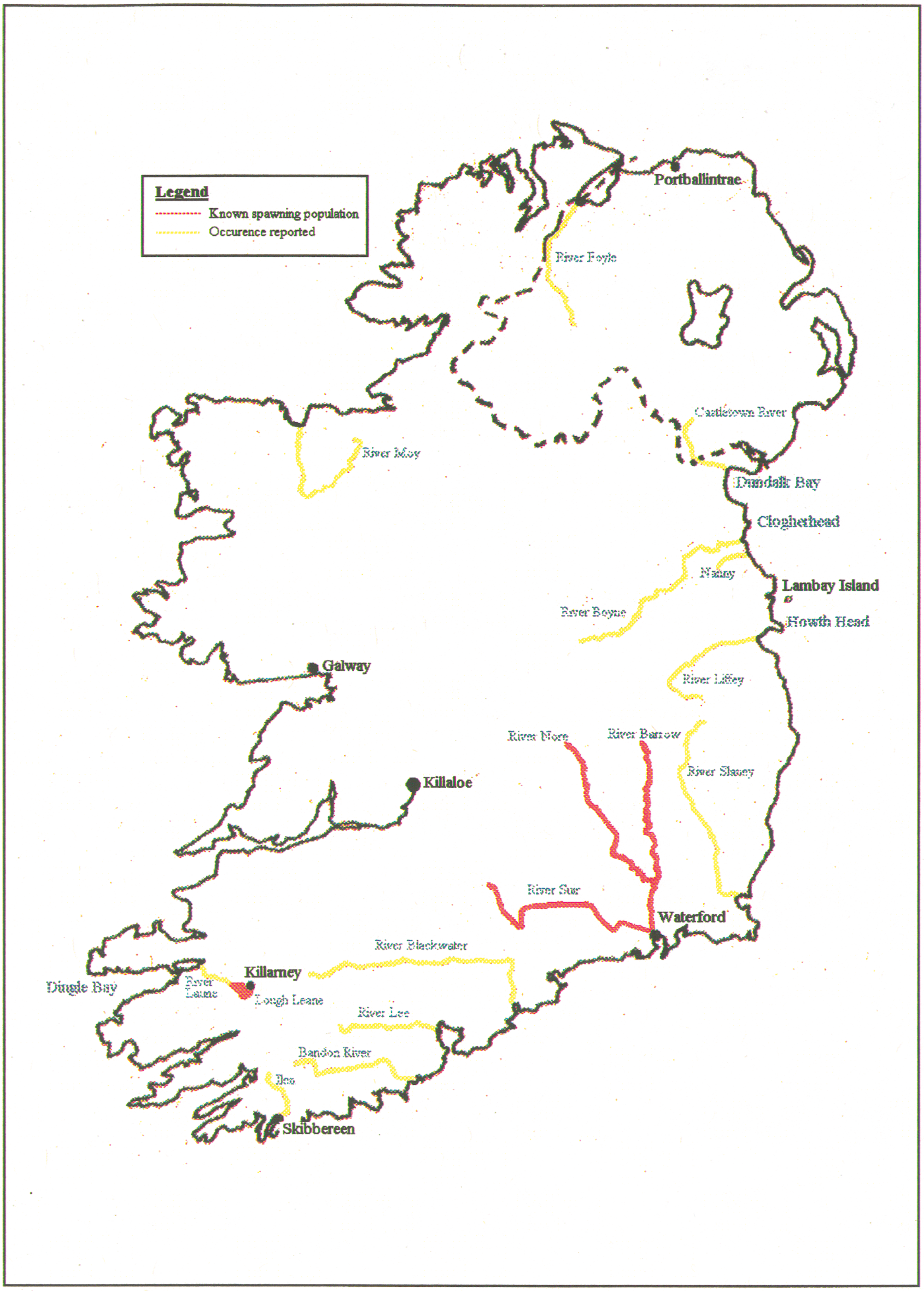


Figure 2.8 Distribution of *Alosa fallax* in Ireland

2.3.2.6 River Dee - Scottish Border

The presence of twaite shad has been recorded around the coast of Lancashire at Formby, Heysham and Blackpool, and from the Mersey (Herdman and Dawson, 1902), as well as the Dee (Herdman and Dawson, 1902; Anon., 1994b). Johnstone (1906) recorded twaite shad around the River Mersey, Formby, Blackpool and Morecambe Bay. A single shad has been recovered from the Ribble Estuary, although the species was not known. MacPherson (1901) recorded them off the Cumbrian coast. Ellison and Chubb (1962) recorded their presence in the English Solway and the River Duddon. Five twaite shad were netted in the Kent Estuary in 1993, and Le Cren (1993) reported a specimen which had been caught in the Leven estuary during the 1940s. In 1997, two twaite shad were caught off the south west coast of the Solway at Siddock by bass netsmen (A. Cruddas, pers. comm.).

2.3.3 Ireland (Figure 2.8)

The distribution of twaite shad in Ireland has been reported by O'Maoileidigh *et al.* (1988) where it has been classified as vulnerable (Quigley and Flannery, 1996; Quigley, 1996). Day (1880-1884) stated that small numbers of twaite shad were taken in all major estuaries along the south coast of Ireland. These included the rivers Barrow, Nore, Suir, the Munster Blackwater and the Laune. Cacutt (1979) also reported that twaite shad enter rivers in the south east and south west of Ireland. In the twentieth century spawning populations of *Alosa fallax* have been recorded in the rivers Barrow, Nore, Suir and Blackwater (Brennan, 1963; Bracken and Kennedy, 1967; Gibson, 1956; Maitland and Lyle, 1991; Twomey, 1967; Went, 1946, 1953; Went and Kennedy, 1976; Whelan, 1989). Specimens have also occurred in the rivers Ilen, Bandon and Lee (Went, 1963), the Castletown river, the rivers Boyne, Nanny and Liffey, the estuary of the Slaney (Bracken and Kennedy, 1967) and in the Foyle Estuary (Johnson, pers. comm.).

Around the Irish coast, occasional specimens have been recorded (Maitland, 1972; Potts and Swaby, 1993; Went, 1953). A single fish was found on the east coast at Clogherhead (Minchin and Molloy, 1978), others at Howth (O'Riordan, 1965), Dundalk Bay and east of Lambay Island (Bracken and Kennedy 1967) and the Slaney and Ilen Estuaries (Bracken and Kennedy, 1967). In fact, in the Slaney Estuary, Fahy (1982) reported that a small fishery for twaite shad existed between 1965 - 1976, with annual catches ranging from 22-860 kg with a mean of 400 kg.

In the Irish Sea occasional specimens are caught in trawls (Bracken and Kennedy, 1967; Bruce *et al.* 1963; Jenkins, 1942; Marine Biological Association, Plymouth, 1957). Minchin (1977) reports them in the southern Irish Sea.

A landlocked population of twaite shad, known locally as the goureen, exists in Lough Leane, south west Ireland (Gibson, 1956; Trewavas, 1938; Twomey, 1958; Went, 1946; Went and Kennedy, 1976; Wheeler, 1977). They had become distinct from their migratory relatives and were subsequently named *Alosa fallax killarnensis* by Regan (1916). Wheeler (1977) states that the population was "*presumably isolated by isostatic or tectonic changes of a local nature*". The form is unique to Killarney and does not occur in any other region of the British Isles. Studies on the population have been carried out by O'Maoileidigh (1990), Trewavas (1938) and Twomey (1958).

2.4 Spawning distribution within the rivers Wye, Usk, Severn and Tywi.

Maps are based on the 1992 Ordnance Survey 1:50,000 scale map with the permission of the Controller of Her Majesty's stationary Office © Copyright.

2.4.1 Known spawning areas of shad in the River Wye

2.4.1.1 General catchment description and migration route

The River Wye is internationally renowned for its salmon fishery, which has played a large part in the development and management of the catchment as a whole. The catchment is predominantly rural with scattered urban development along the length of the river. It has a natural meandering course for the most part, although the flow regime has been altered in places to improve the salmon fisheries interest.

The upstream migration route for shad is mostly free from obstructions, enabling access to spawning sites throughout the system. The upstream limit of the spawning migration in the River Wye has been found to be Builth Wells (Welsh Water Authority Annual Reports, for the Wye, 1962-1981) although adult shad have been reported as far upstream as Newbridge on Wye (Ellison, 1935).

There is a hydroacoustic counter at Redbrook which was installed in 1995 to count migrating salmonids (see Figure 2.9). It is possible that this may also be used to count shad in the future (see Section 6.3.1.2).

2.4.1.2 Location of reported spawning grounds within the Wye catchment

Large shoals are seen at Builth Wells and in the lower Irfon, where it is believed they spawn (Peter Gough, pers. comm.). The shoals of shad in the lower Irfon were those featured on an angling programme 'Screaming Reels'.

Various other locations along the River Wye have been reported as spawning grounds by the fisheries Ghillies, fishermen, Environment Agency staff and local people. These are detailed in Table 2.4 and their locations shown within the catchment are shown in Figures 2.9, 2.10, 2.11 and 2.12.

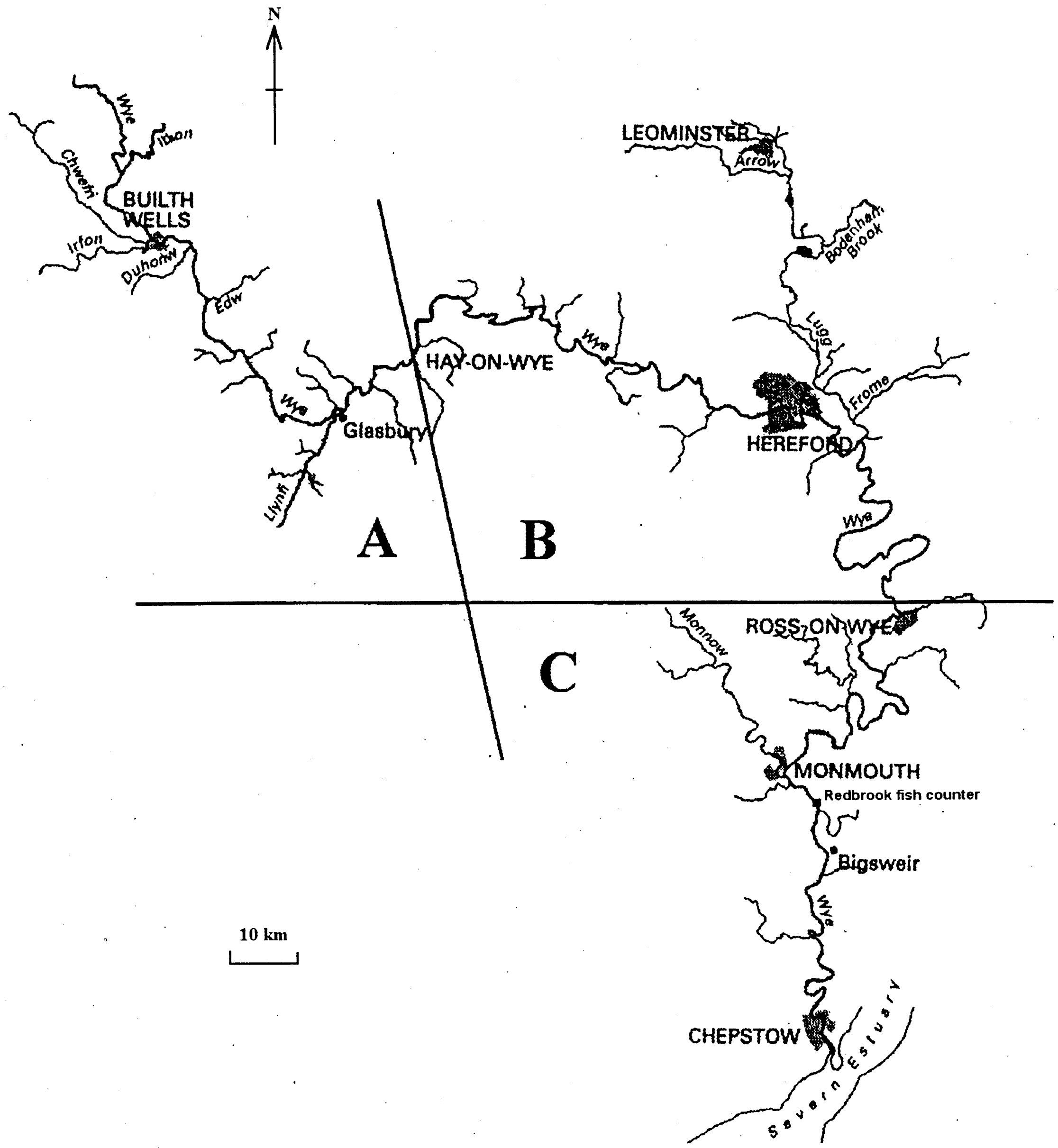


Figure 2.9 **The River Wye, showing the divisions for spawning site distribution sections A, B and C.**

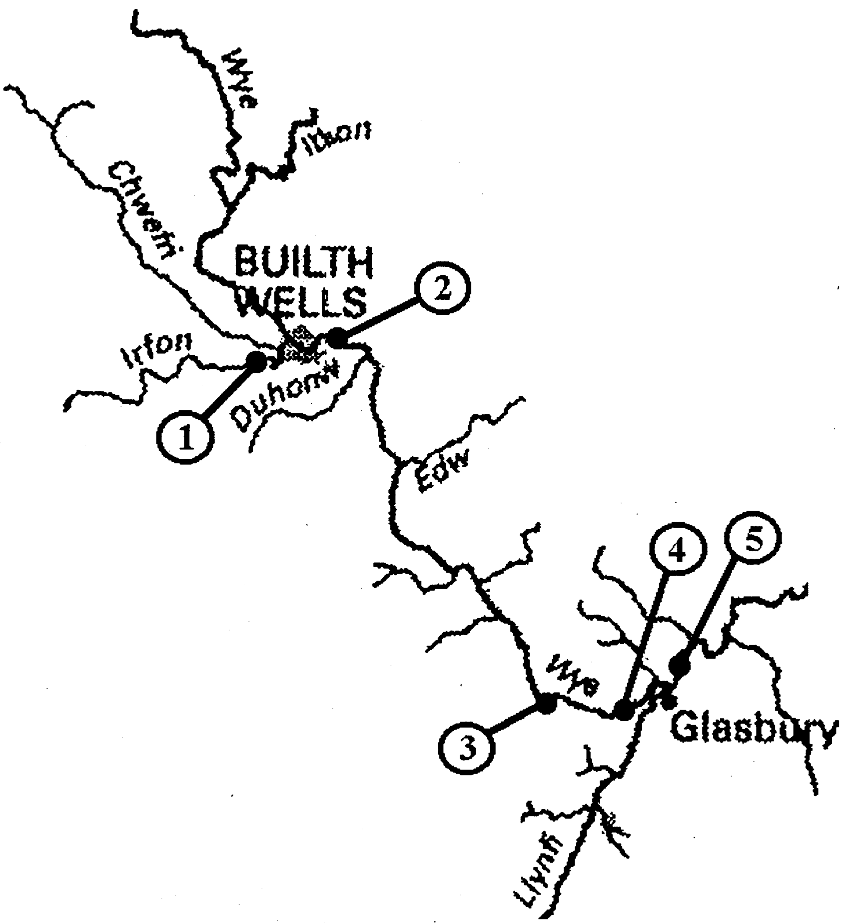


Figure 2.10 **Section A - Location of known spawning sites within the Wye catchment between Llanwrthwl and Hay-on-Wye (see Table 2.4 for site details).**

Table 2.4 Spawning locations reported to be used by shad along the River Wye (* indicates sites where eggs were found)

Ref. no.	Site name and grid reference	Description & source of information
Table 2.4 Section A - Llanwrthwl to Hay-on-Wye (see Figure 2.10)		
Tributary		
1	Lower Irfon SO.030.505 - SO.035.516	Lower kilometre of the Irfon, upstream of the bridge is used for spawning. (Source - Peter Gough, Environment Agency)
Main River Wye		
2	Builth Wells SO.043.512 - SO.044.514	Shallow site, mostly bed rock and fairly large boulders with small amounts of gravel on the river bed. Shallow shelving banks with a few shrubs and trees, surrounding land used for grazing. The area 200 metres downstream of Builth road bridge is used for spawning. (Source - Peter Gough, Environment Agency; Aprahamian (1982); Maitland and Lyle (1995))
3	Boughrood SO.130.383	(Source - Phil Jordan, Ghillie)
4*	Pipton SO.163.382	Areas of bed rock show through the gravel shoals at this site. There is a deep pool under one bank. Overhanging trees and shrubs on both banks backed by cultivated farm land. (Source - Aprahamian (1982)) *eggs found in 1980
5	Glasbury SO.181.394	A very shallow gravel run with large areas exposed under low flow conditions. One bank is very heavily undercut, producing a deep pool. Surrounding land is used for grazing. (Source - Aprahamian (1982))

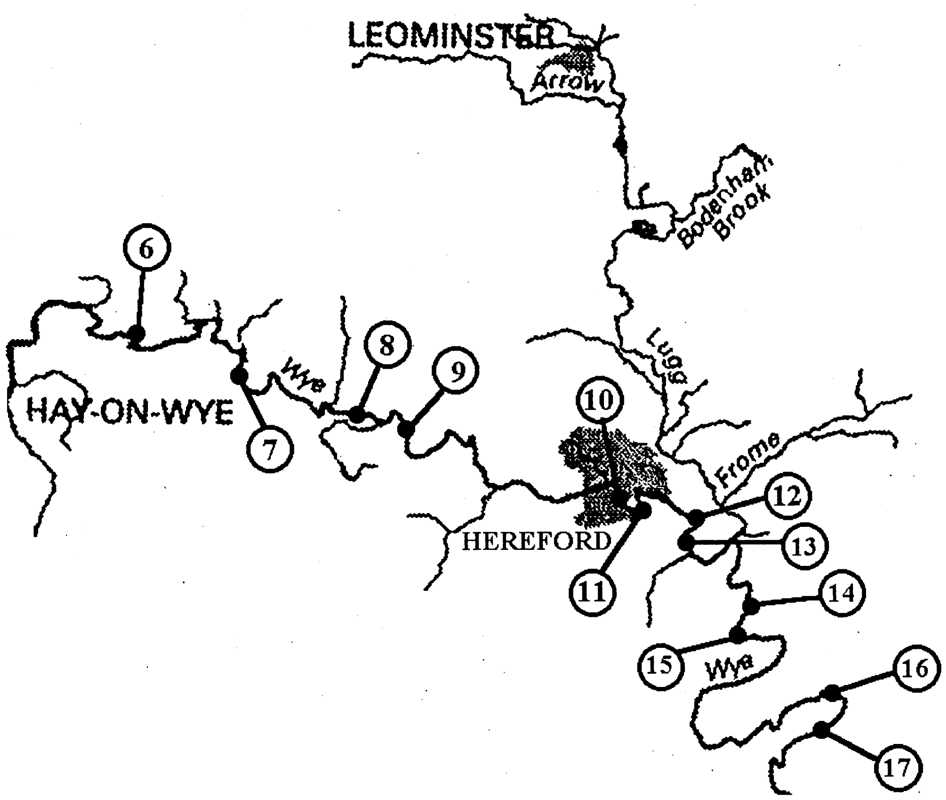


Figure 2.11 **Section B - Location of known spawning sites within the Wye catchment between Hay-on-Wye and Ross-on-Wye (see Table 2.4 for site details).**

Table 2.4 continued		Section B - Hay-on-Wye to Ross-on-Wye (see Figure 2.11)
6*	Winforton SO.291.463	A loop on the river consisting of two gravel fords with a deep pool of slack water in between. Banks steep and topped with grazing land. (Source - Fisheries Owner via Sarah Davis, English Nature; Aprahamian (1982)) * eggs found in May 1980
7	Bredwardine SO.336.446	(Source - Phil Jordan, Ghillie)
8	Byford SO.399.426	Very long shallow gravel ford averaging 0.5 metre or less deep. Both banks shallow and overhung with trees. (Source - Aprahamian (1982))
9	Bridge Sollers SO.412.424	Shallow, fast flowing water downstream of the bridge. (Source - Phil Jordan, Ghillie)
10	Bartonsham SO.513.392	Shallow, fast flowing water. (Source - Mike Beech, Hereford Anglers)
11	'Sewer Stream', Hereford SO.522.389	Shallow, fast flowing water over gravel. (Source - Mike Beech, Hereford Anglers)
12*	'The Byfields', Hampton Bishop SO.548.382	The spawning area (where eggs were found) is approximately 75 metres long and almost half of the river width (10 metres). Most of the site is riffle, with deeper water upstream and a very deep pool on a sharp bend downstream. The channel bed is mainly consolidated gravel and sand with some cobbles. Some trees on both banks. Not many boughs overhang the channel but lots of in-stream vegetation (mainly *Ranunculus*) providing some cover. Steep banks (left bank has set back embankments), topped with flatter improved/semi-improved grazing and scrub land. (Source - Bill Griffiths, Ghillie) * eggs found in 1997
13	'Upper Red Bank', Hampton Bishop SO.543.373	Shallow area of fast flowing water over gravel shallows. (Source - Bill Griffiths, Ghillie)
14	Fownhope SO.574.339	Shallow, fast flowing water over gravel shallows. (Source - Glen Kedwood, Ghillie)

15*	Ballingham SO.566.328	Similar to 'Green Stream', Courtfield, with a large gravel shoal extending half way across the river. The bank where the main channel runs is very steep. Surrounding land is used for grazing. (Source - Glen Kedwood, Ghillie; Aprahamian (1982)) * eggs found in 1980
16	'Gilberts Run', Foy SO.614.300	Approximately two thirds of the river bed shallow, fast flowing water. Deep pool downstream. (Source - Lyn Cobley, Ghillie)
17*	'Hole-in-the-Wall', Foy SO.609.287	Site has been managed so that most of the flow is towards the right bank, with shallower areas towards the left bank and a series of islands. Large spawning area lies towards the downstream end of the islands, although eggs were found throughout the site in the shallow, gravelly areas. Altogether the site is approximately 170 metres long and 55 metres wide, of which the spawning area covers approximately half, towards the right bank. Here the water is deep and flows very fast compared to the left side of the channel, where it is shallow and riffley over consolidated cobble/gravel and sand. Left bank and islands provide some shading of the spawning area and there is also a lot of in-stream vegetation (mainly *Ranunculus*). Both banks are fairly steep, the right one being re-enforced at the toe for most of the site. Right bank is mainly farm land, left bank has rough pasture and is used for water sports and activities by a children's holiday camp, PGL. (Source - Lyn Cobley, Ghillie)

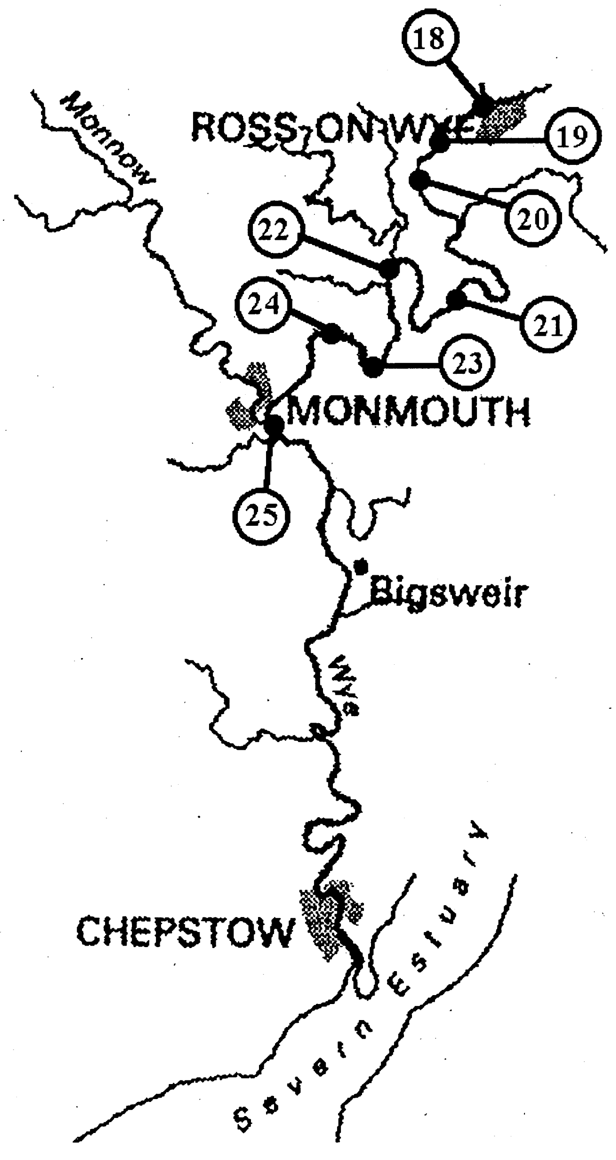


Figure 2.12 **Section C - Location of known spawning sites within the Wye catchment between Ross-on-Wye and Chepstow (see Table 2.4 for site details).**

Table 2.4 continued		Section C - Ross-on-Wye to Chepstow (see Figure 2.12)
18*	Wilton island SO.589.241	The spawning area where eggs were found is approximately 90 x 20 metres, around and downstream of a mature island which is situated towards the left bank, approximately 200 metres downstream of Wilton road bridge. Flow pattern is mainly fast, deep water with shallower riffley areas around the island, where eggs were found. Substrate is mainly consolidated gravel and sand with some larger cobbles in deeper areas. Vegetation around the island and on the right bank provides some channel shading, as well as the in-stream cover from *Ranunculus*. Both banks are steep with bankside paths and improved grassland. (Source - Colin Gittins, Ghillie) * eggs found in 1997
19	'Hom Stream', Hom Green SO.573.224	Fast flowing shallow water over a gravel bed. (Source - Colin Gittins, Ghillie)
20	'The Windmill & The Maddox', Pencraig SO.566.218 - SO.568.214	Situated on a bend in the river with steep banks on either side, one heavily wooded, agricultural land on the other. There are a series of gravel shoals culminating in a deep pool and back eddy. (Source - Colin Gittins, Ghillie; Aprahamian (1982))
21*	'Green Stream', Courtfield SO.584.173	A large gravel shoal extending two thirds across the river bed is a main site feature. The bank where the main channel runs is steep and heavily wooded, with overhanging trees. The gravel shoal is backed by a shallower bank, lightly shrubbed and topped by cultivated fields. (Source - George Woodward, Ghillie; Aprahamian (1982)) * eggs found in 1980 and 1997
22	Old Forge SO.558.181	(Source - Colin Gittins, Ghillie)
23	The Biblins SO.549.144	(Source - George Woodward, Ghillie)
24	'Martins Pool', Little Doward SO.539.155	Shallow water surrounding mid-channel island towards right bank used for spawning. Channel is very full of weed during the summer months. (Source - Colin Gittins, Ghillie)

25*	Monmouth SO.514.121	Main feature in the channel is a crib or croy made of concrete with a deep pool resulting downstream. There is a slight current apparent during summer flow. The rest of the river is a series of runs and pools with a large gravel shoal on the opposite bank. The surrounding land is river meadows and a dense wood on the cribside. (Source - Aprahamian (1982)) * eggs found in 1980

2.4.2 Known spawning areas of shad in the River Usk

2.4.2.1 General catchment description and migration route

It is possible that the weir at Trostrey could be a barrier to the migration of shad, although adults have been filmed migrating over it and recorded further upstream at Abergavenny. The concrete lip at Usk Town Bridge may also impede the migration of shad in low flows, as could the water intake weir at Rhadyr in high flows (Jenkins, pers. comm.).

2.4.2.2 Location of reported spawning grounds within the Usk

The most upstream site where eggs have been found is Llanellen, just downstream from Abergavenny. Various locations along the River Usk have been reported as spawning grounds by Environment Agency Staff and local people (see Table 2.5 and Figure 2.13).

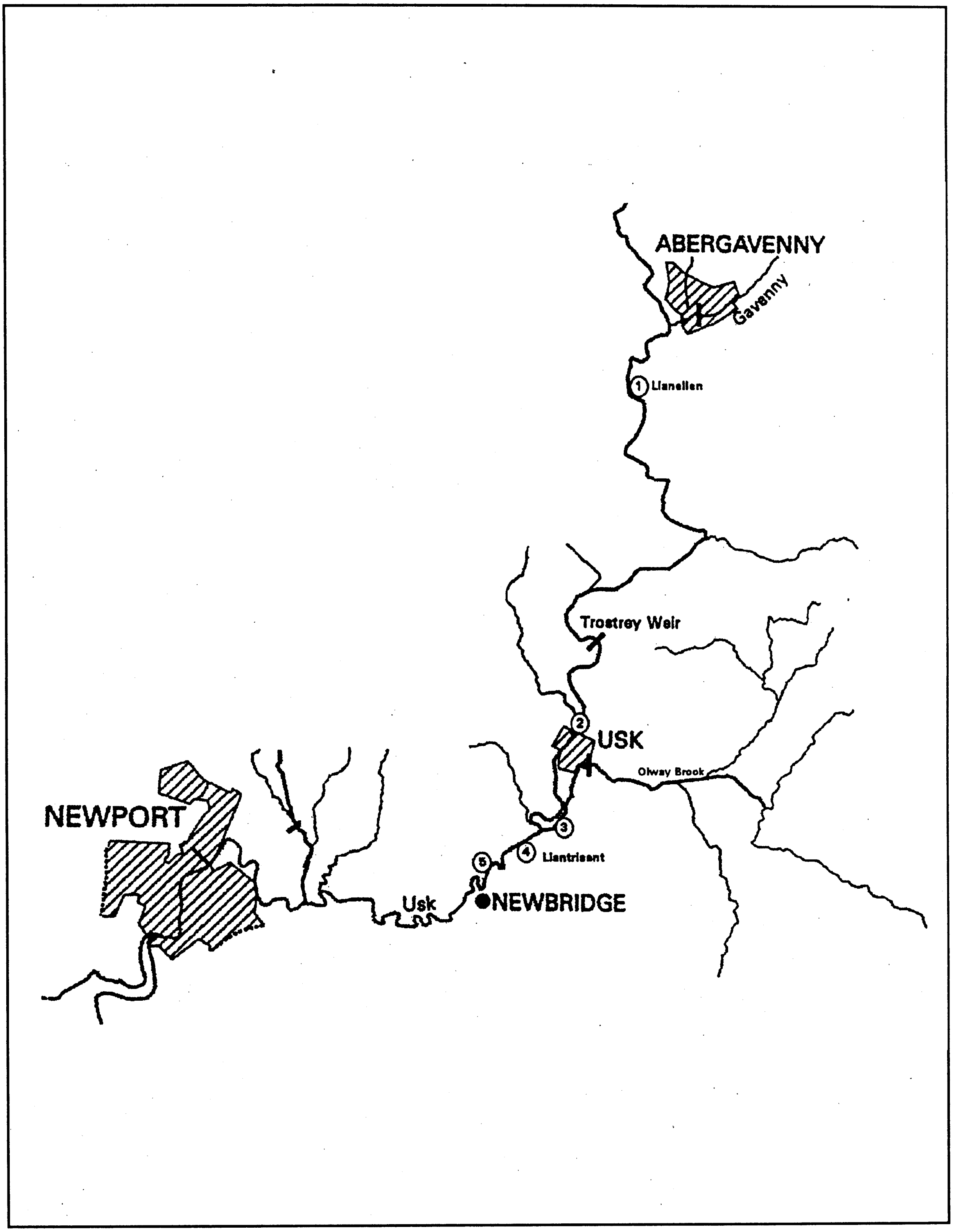


Figure 2.13 Location of known spawning sites within the Usk catchment (see Table 2.5 for site details).

Table 2.5 Spawning locations reported to be used by shad along the River Usk (* indicates sites where eggs were found)

Ref. no.	Site name and grid reference	Description & source of information
1*	Llanellen SO.307.109	Shallow, fast flowing site with a predominantly gravel substrate. (Source - Miran Aprahamian, Environment Agency) * eggs found in 1990
2*	Usk Town Bridge (A472) SO.374.007	A heavily engineered channel which is embanked and steep on both sides, downstream of the main road bridge in Usk. The channel is approximately 30 metres wide, most of which is shallow and riffley with deeper, fast flowing water towards both banks. The habitat is similar upstream of the bridge and down stream for approximately 2.5 km. It is possible that shad may use the whole of this area to spawn. The bed is loose, comprising mainly cobbles with some gravel and coarse sand. The spawning area (where eggs were found) covers most of the central channel and is not shaded, although there is some in-stream vegetation to provide a little cover. (Source - Keith Jenkins, Environment Agency; Maitland and Lyle, 1995) (* eggs found downstream in 1997; eggs collected at Llanbadoc in 1994)
3	Llanllowel - confluence of Olway Brook ST.385.983 - ST.388.980	From Llanlowell and ends near the confluence with Olway Brook. The river has carved a new channel across the corner of the old channel. The new channel is shallow and has created good spawning areas for shad. (Source - Keith Jenkins, Environment Agency)
4*	Llantrisant Pumping Station ST.385.970	The site is downstream of the Olway Brook confluence where it is shallow and gravelly. (Source - Miran Aprahamian, Environment Agency) * eggs found in 1990
5*	Lower Llangybi - Newbridge-on-Usk ST.385.960 - ST.388.963	Eggs were found in gravel shallows. (Source - Keith Jenkins, Environment Agency; Maitland and Lyle (1995)) * eggs found at 'The Daltons', Llangybi in 1997; eggs collected at Llanbadoc in 1994

2.4.3 Known spawning areas of shad in the River Severn

2.4.3.1 General catchment description and migration route

The Severn is the longest river in England and Wales, which has historical importance for various reasons. It originates in the Welsh uplands and threads its way through several counties in England and Wales before reaching the estuary, which is also one of the largest in the UK. Its position and use for navigation has contributed to the management of the catchment, so that several weirs exist which impede the migration of shad. It is thought that impassable weirs which were built within the system have had a deleterious effect on the spawning population within the system. Eggs have been found below the weir at Powick on the River Teme, which is probably a barrier to further migration in low flows as is Diglis weir on the Severn at Worcester.

2.4.3.2 Location of reported spawning grounds within the Severn

Eggs have been found on several occasions at Powick Weir as well as in a macroinvertebrate drift net left in the flow downstream of Haw Bridge in 1980 (see Table 2.6 and Figure 2.14). However, drift nets which were deployed downstream of Haw Bridge and Lower Lode on the River Severn for four hours on 2nd. June 1997 did not catch any eggs.

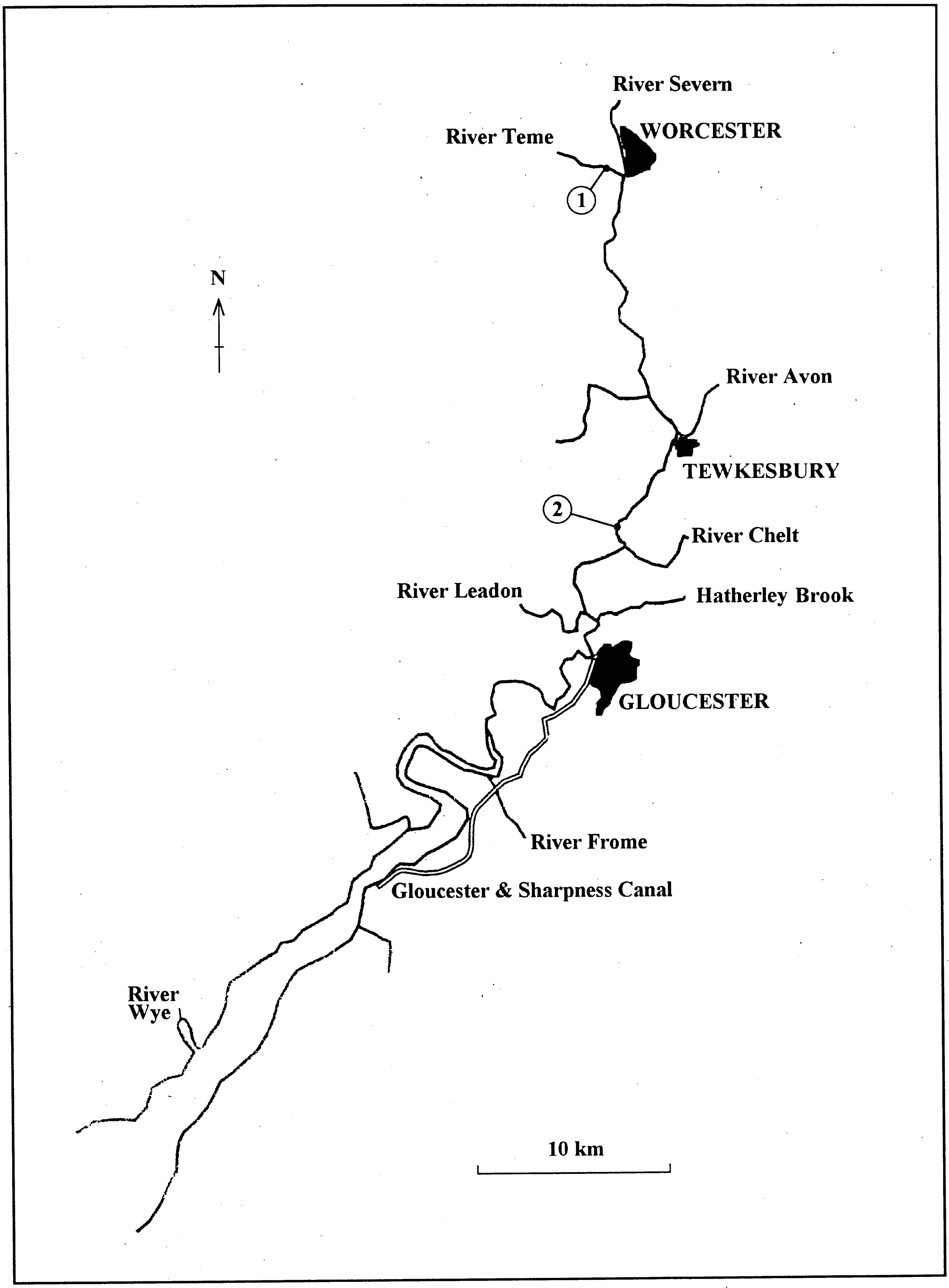


Figure 2.14 Location of known spawning sites within the Severn catchment (see Table 2.6 for site details).

Table 2.6 Spawning locations reported to be used by shad along the River Severn (* indicates sites where eggs were found)

Ref. no.	Site name and grid reference	Description & source of information
Tributary		
1*	Teme, d/s Powick Weir SO.833.524	Downstream of the weir the flow pattern becomes less turbulent, leading to a smoother flowing area where the eggs were found. There is some marginal shading, although most of the site is open. The channel is approximately 15 metres wide, within which the spawning area lies towards the right bank and is approximately 10 metres wide x 50 metres long. The substrate is consolidated with gravels with some larger cobbles and silt. Banks are moderately steep with surrounding farm land and a new bypass road, currently under construction. It was noted that this could have been the cause of increased siltation of the gravels in 1996 since the site was last seen, in 1980. (Source - Aprahamian (1982)) *eggs found in 1979, 1980 and 1997
Main River Severn		
2*	Severn, d/s Haw Bridge SO.845.277	The river here is navigable and dredged regularly, making it very deep and wide. The site is downstream of a road bridge situated on a large bend in the channel, making the flow pattern smooth. Vegetation overhangs the channel from both banks. Eggs have been found drifting within the water column towards the right bank, although shad have not been seen spawning in the area. It is possible that the eggs found may have originated from a spawning site further upstream. (Source - Aprahamian (1982)) *eggs caught using drift nets in 1980

2.4.4 Known spawning areas of shad in the River Tywi

2.4.4.1 General catchment description and migration route

Through natural development within its valley, the River Tywi has developed an interesting series of meanders, eroding banks away to leave very deep pools and depositing its substratum to create shallow shingle banks and islands. When in spate, which it often is, the water is generally very fast and deep, although the reservoir at Llyn Brianne has reduced the effect of rain on the catchment as a whole. The sea trout (sewin) fishery is internationally renowned and the salmon fishery is also very successful.

It is thought that Nantgaredig weir is most probably a barrier to migration to shad, although specimens have been caught upstream of this on occasion; two were caught in May 1997 on a local club stretch approximately 200 m upstream of the Nantgaredig Bridge and one was caught at Llangadog in the late 1970's (Source - Mike Todd, Environment Agency). Migration to Llangadog requires traversing the weir at Llandeilo, which is possibly an obstacle at low flows.

Shad are regularly seen and caught by fishermen in the Tywi and some of its tributaries, notably the Gwili and Cothi. At the time of writing, four spawning sites had been confirmed on the River Tywi. The furthest upstream confirmed site is at Llandeilo, approximately 30 km upstream of the freshwater limit. The other confirmed sites are at Llanegwad, Nantgaredig and White Mill (upstream and downstream of the footbridge).

2.4.4.2 Location of reported spawning grounds within the Tywi

The main spawning areas are considered to be between the top of the tidal reaches (u/s Carmarthen) and Llanegwad (see Figure 2.15). Spawning has also been observed just downstream of Llangadog, at Manordeilo. In 1988, many shad from a particularly large run spawned in the White Mill / Cystynog areas (Mike Todd, pers. comm.). It is thought that shad also spawn between Manordeilo and Llanegwad in some years (Mike Todd, pers. comm.).

Various locations along the River Tywi have been reported as spawning grounds by staff from the Environment Agency and Countryside Council for Wales as well as anglers and local people (see Table 2.7 and Figure 2.15).

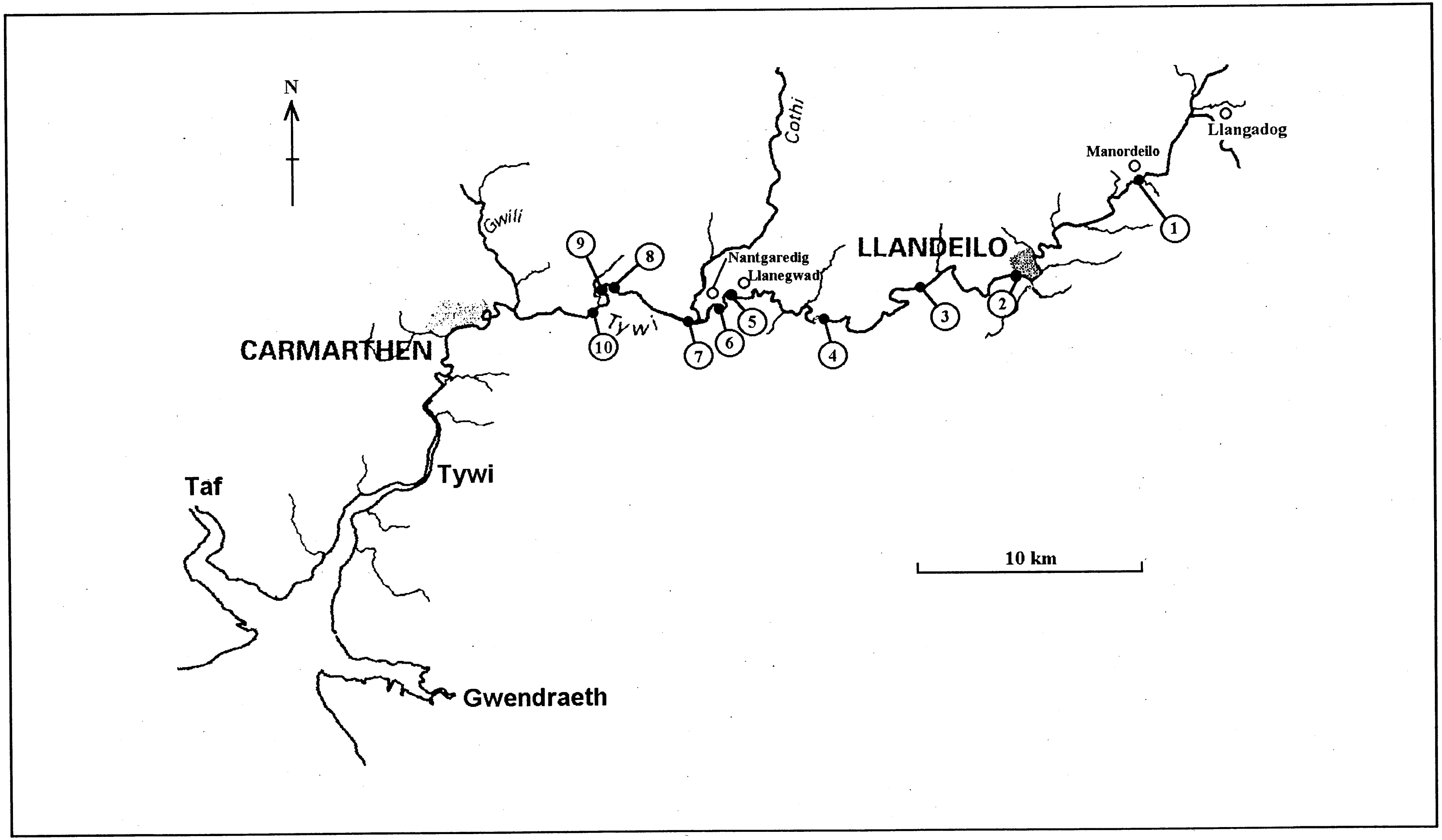


Figure 2.15 Location of known spawning sites within the Tywi catchment (see Table 2.7 for site details).

Table 2.7 Spawning locations reported to be used by shad along the River Tywi (* indicates sites where eggs were found)

Ref. no.	Site name and grid reference	Description & source of information
1	Manordeilo SN.677.257	(Source - Mike Todd, Environment Agency)
2*	D/S Llandeilo Bridge SN.627.220	Shallower water on right hand bank downstream of weir *eggs found in 1998
3	U/S Cilsan Bridge SN.589.214	Moderately shallow, fast-moving water precedes an area of deeper, slow-moving water upstream of the bridge. (Source - Mike Todd, Environment Agency)
4	D/S Dryslwyn Castle Bridge SN.553.202	Shallow, fast moving water on left of channel downstream of deeper water below bridge. (Source - Mike Todd, Environment Agency)
5*	Llanegwad SN.515.212	Fast-flowing, shallower water on right of channel downstream of a deep pool. *eggs found in 1998
6	Bremenda SN.517.209	Shad seen swimming spirally, 'chasing their tails' in May and June 1997 over flat gravel stretch where the water was shallow, suggesting that they were spawning. (Source - Steve Ellery, Environment Agency)
7	D/S Nantgaredig Bridge SN.493.203	Turbulent water around mid-channel islands upstream of bridge lead to shallows on side bar towards right bank and deeper, fast moving water towards left bank. (Source - Mike Todd, Environment Agency)
8*	U/S White Mill Bridge SN.468.215	Fast flowing water over gravel area (possibly used as a ford) in between deep water. (Source - Rees --, Countryside Council for Wales) *eggs found in 1998
9*	D/S White Mill Bridge SN.468.215	Fast, shallow water surrounding mid-channel island, deeper water towards right bank, where eggs found. (Source - Mike Todd, Environment Agency) *eggs found in 1998
10	Cystanog SN.462.203	Spawning shad, which were believed to be allis, were seen between 29th - 31st April 1990 in the area (Source - A. Gwynne Thomas, pers. comm.).

3. POPULATION TRENDS

3.1 Introduction

Detection of a change in the size of a population can be obtained either through comparison with historic data or from estimates predicted from a model, which in many instances require a time series of data to develop. Long term data sets can provide an estimate of the natural variability in population size and are important when trying to understand the factors which affect abundance. These are vital pieces of information required by managers when evaluating the status of stocks and trying to decide whether action is required. For example, whether a significant decline in the population is the result of natural factors or whether some other cause, which can be influenced, is responsible.

The aim of this section is to report on the trends in the population of *Alosa* species within the British Isles and from other river systems within Europe.

3.2 Data sources

3.2.1 Severn Estuary

The population entering the Severn Estuary at the start of the freshwater phase of their spawning migration has been sampled between 1979 - 1996 by Aprahamian (pers. comm.). Counts of shad caught were obtained from the putcher net fishermen operating near Lydney on the Severn Estuary (NGR ST611991). The putcher rank consists of 650 conical shaped baskets. Since 1979 the size and configuration of the baskets has changed and the estimated effect on fishing effort is shown in Table 3.1. For the years 1982 - 1984 no estimates of fishing effort were available. In addition, over the period 1982 - 1984 the construction material of the putchers was altered from mild to stainless steel; it was not possible to estimate the impact of this on the catch.

Table 3.1 Change in the effective fishing effort of the putcher rank over the period 1979 - 1996, together with the raising factors used to enable between-year comparisons in catches.

Year	Effective fishing effort (arbitrary units)	Raising factor
1979	293	2.35
1980	384	1.79
1981	475	1.45
1985-1986	585	1.18
1987	586	1.17
1988-1996	689	1.00

The proportion of tides on which counts of shad were taken, between April 15th (start of the salmon net season) and June 19th, is shown in Table 3.2. No counts were made in 1982 and only a limited number, less than 10% of the 127 tides available, were counts made in 1979, 1983 and 1984.

Table 3.2 Proportion of tides where the catch was counted between 15th April - 19th June (1979 - 1997).

Year	% of tides inspected	Year	% of tides inspected
1979	6	1989	46
1980	67	1990	63
1981	19	1991	45
1982	0	1992	46
1983	5	1993	34
1984	10	1994	17
1985	26	1995	23
1986	18	1996	61
1987	11	1997	61
1988	29		

The migration period was divided up into nine periods and the best five were used to calculate an abundance index (mean catch per tide in the best five periods), as the timing of the migration through the estuary differed between years. In addition to the counts, samples of shad were taken at intervals throughout the migration period to partition the run according to sex, age and spawning history. Sample size ranged from zero in 1982 to 617 in 1990 with a mean of approximately 340 (Figure 3.1). The CPUE index was calculated separately for males and females as follows:

$$\text{CPUE Index} = \sum_{i=3}^{12} \sum_{j=0}^{6} \sum_{k=1}^{5} \bar{x}_{ijk} / 5$$

Where:

$\bar{x}$ = mean catch of shad per tide of fish age i, spawning group j in period k,

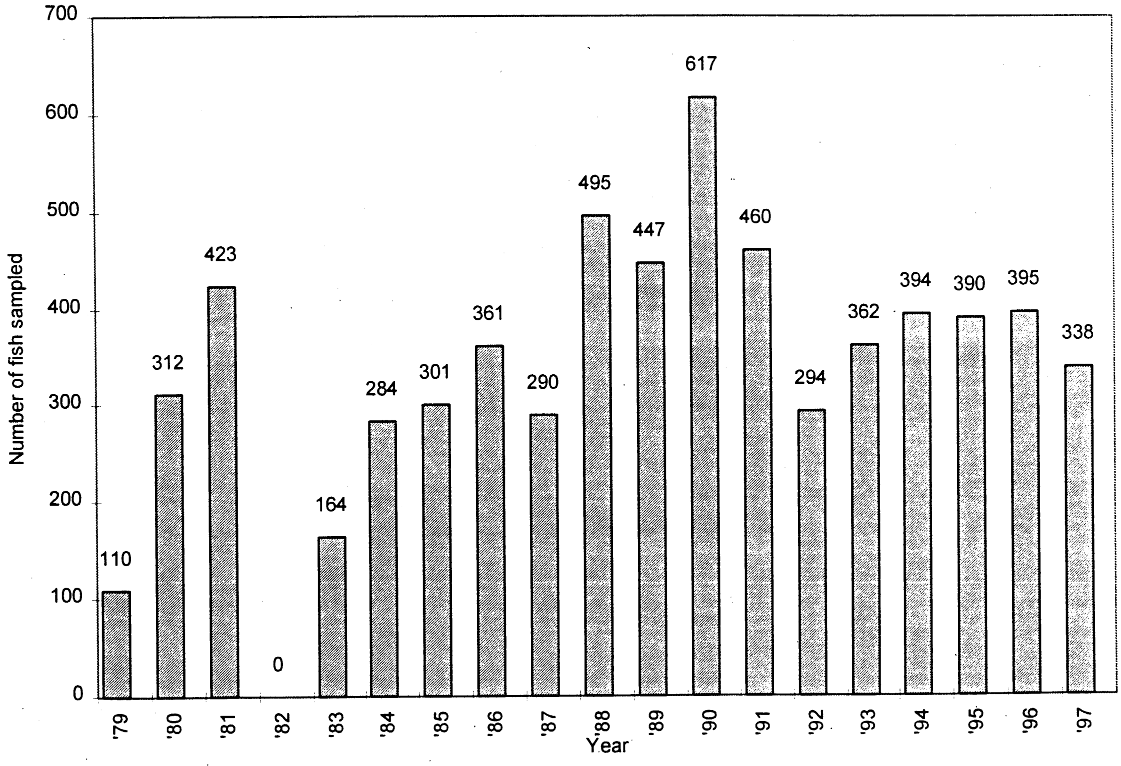


Figure 3.1 Number of shad sampled each year showing mean sample size using data from all periods (1979 - 1997)

As the number of tides sampled in 1979 and between 1982 - 1984 were low (Table 3.2), the index for these years was estimated using mortality data calculated as follows:

$$Z = \text{Ln}\,(CPUE_{(t)}) - \text{Ln}\,(CPUE_{(t+1)})$$

where :
Z = Instantaneous rate of mortality
CPUE = the mean catch per tide, for the best five periods, of fish of a particular age and spawning group in year t

The 1979 index was back calculated using the 1980 CPUE index and mortality data from the years 1980/1981. For the period 1982 - 1984 the CPUE of the older age classes in the years 1982-1984 were estimated from the 1981 catch using mortality data from 1980/1981; while the younger age classes were back calculated from the 1985 catch using the mean annual mortality rate for the years 1980 - 1981 and between 1985 - 1996. This was done to make allowance for the change in construction material of the putcher rank and because it provided the closest approximation to the age structure recorded in 1979, 1983 and 1984. Only those age and spawning groups where the number of samples taken was ≥5 were used in the estimate of mortality rates.

3.2.2 Bristol Channel

Quantitative monthly sampling of fish and crustaceans at Hinkley Point 'B' Nuclear Power Station has been carried out by P. Henderson (pers. comm.) since October 1980 (except during 1986 when sampling was not monthly). Sampling dates were chosen to work tides of intermediate range in the spring-neap cycle. On each visit six consecutive one hour samples were collected in plastic baskets of 6 mm mesh size, positioned to collect all the debris washed from two of the four drum screens. The debris was sorted, the fish and crustaceans identified to species and the number captured per hour recorded. The standard length of the fish was measured. The method is selective towards juvenile fish with the majority of the shad caught being of age 0+ (Holmes and Henderson, 1990).

3.2.3 Other data sources

Other sources of data on trends in the size of population over recent years were obtained from Thiel *et al.* (1996), Travade *et al.* (1996), Dartiguelongue (1996), Larinier (pers. comm) and from the FAO Catch Statistics (Anon., 1993).

3.2.3.1 *Alosa fallax* from the Elbe estuary, Germany.

Thiel *et al.* (1996) reported monthly estimates of abundance and biomass of *A.fallax* from the Elbe estuary, between 1984 - 1986 and 1989 - 1994. Sampling between March 1989 - May 1994 was carried out at monthly intervals at 11 sites. The adult and juvenile stages were sampled using a stow net (opening 90m^2, mesh size 8 mm knot to knot in the cod end) and the eggs and larvae were sampled using a ring net (opening 90m^2, mesh size 0.5-2mm). The data for the period November 1984 - December 1986 was from Möller (1988).

3.2.3.2 *Alosa Alosa* from the rivers Garonne and Dordogne, France.

The number of upstream migrating *Alosa alosa* recoded at Golfech and Bazacle on the River Garonne and at Tuiliere on the River Dordogne for the period 1987 - 1995 has been reported by Travade *et al.* (1996) and at Mauzac on the River Dordogne for the years 1987, 1989 - 1995 by Dartiguelongue (1996). The 1996 data for all four sites were obtained from Larinier (pers. comm.).

At all sites fish pass installations have been installed; a fish lift at Golfech, a single vertical slot pool type pass at Bazacle; a combination fish elevator and pool type passes at Tuiliere and Mauzac. The passage of fish was recorded using an image analyzer coupled to a camera and the data recorded for later analysis (Travade, 1990).

3.2.3.3 *Alosa alosa* and *Alosa fallax* in the Northeast Atlantic and Mediterranean.

The FAO Catch Statistics report the combined catch of *Alosa alosa* and *Alosa fallax* in the Northeast Atlantic and Mediterranean.

3.3 Trends in population size

All the census data mention in section 3.2, with the exception of that for *Alosa alosa* from the rivers Garonne and Dordogne, consisted of catch data and it is assumed in this section that catch represents stock. It is acknowledged that this may not be the case, certainly because of gear selectivity, and because there may be large between year variation in the level of exploitation.

However, with specific regard to twaite shad in the Severn a significant correlation ($P<0.005$) existed between the number of juvenile twaite shad caught at Hinkley Point 'B' Nuclear Power Station in year n and the number of six year old female twaite shad caught in the putcher rank in year n+6 (Figure 3.2). This would certainly seem to suggest that the catch of juveniles at Hinkley reflects the adult stock.

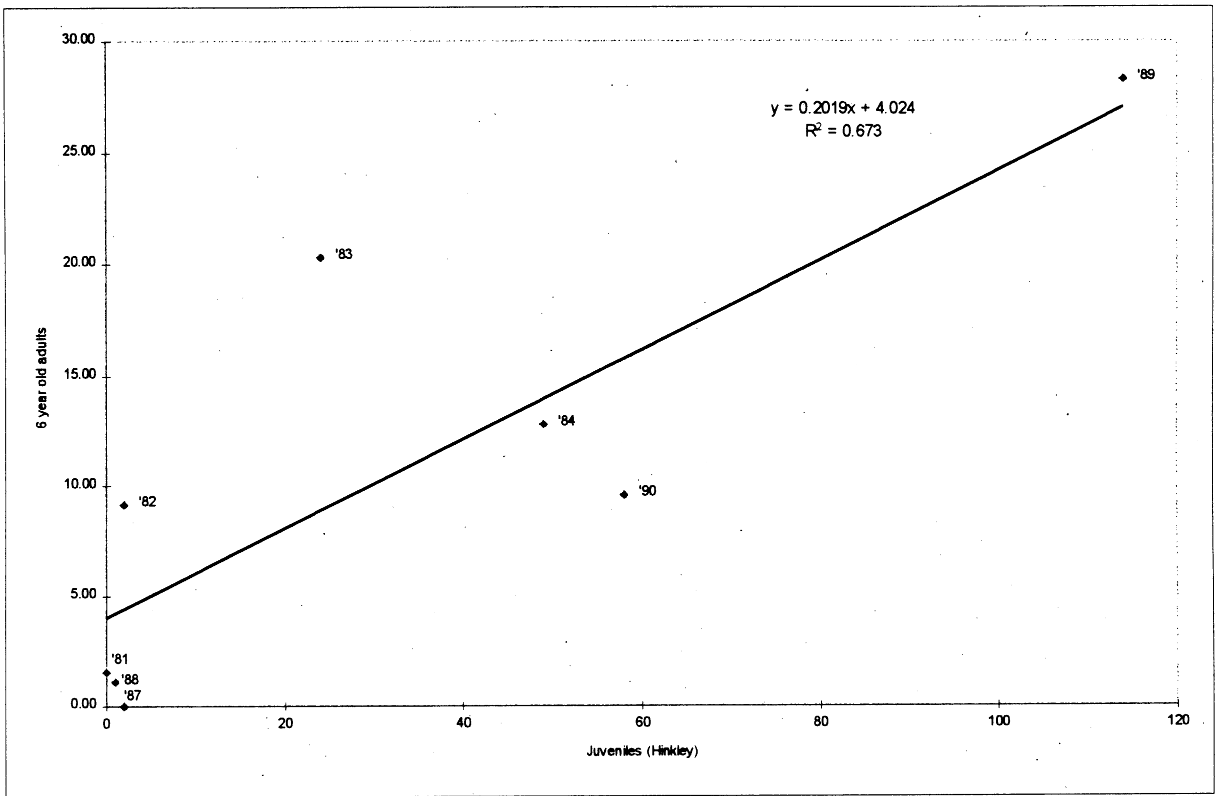


Figure 3.2 The relationship between the number of six year olds caught in the putchers at Lydney and the juvenile catch at Hinkley Point 'B' Nuclear Power Station for year classes from 1981 to 1990.

3.3.1 Severn Estuary

The abundance of female twaite shad caught in the putcher rank near Lydney in the Severn Estuary between 1979 - 1996 is shown in Figure 3.3. The catch reached a peak in 1982 followed by a decline to a minimum in 1985. The number caught then increased steadily attaining another peak in 1994, after which the catch declined slightly.

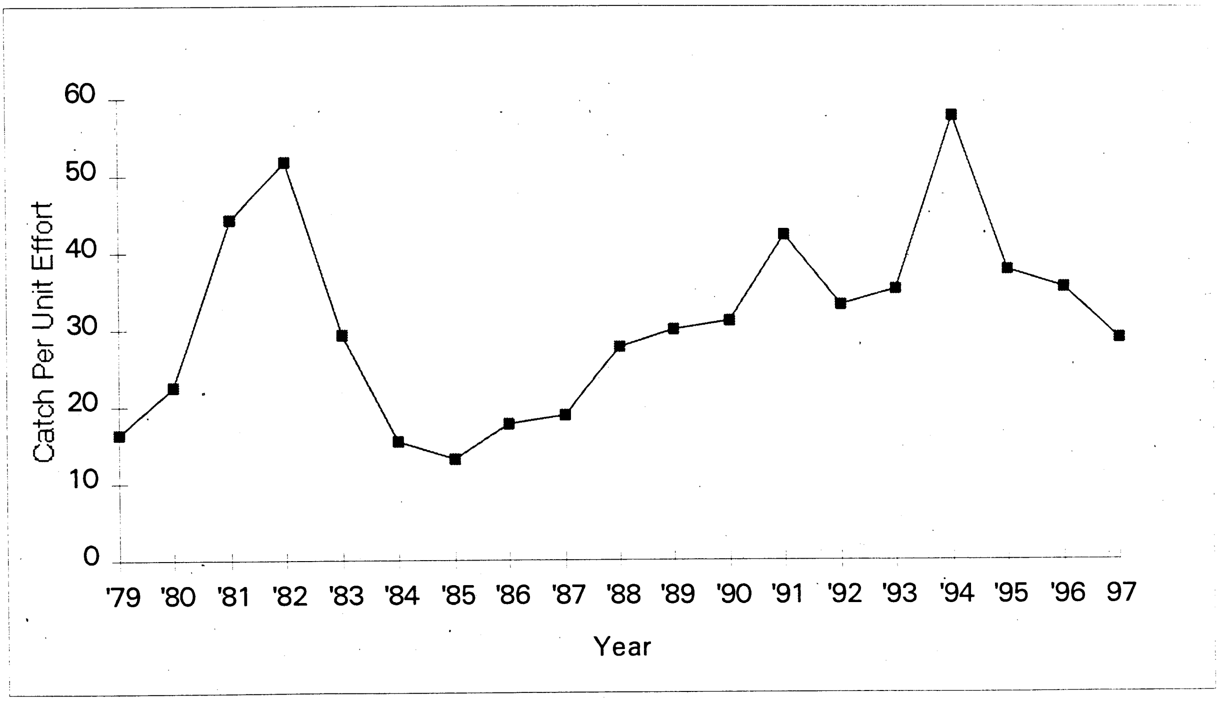


Figure 3.3 Average annual catch per unit effort of shad in the putcher rank (1979 - 1997)

The decline in catch between 1982 - 1985 was a consequence of poor recruitment into the adult population from the 1977 - 1981 year-classes (Figure 3.4). The steady build up in the population from 1986 was a consequence of the 1983 and 1984 year-classes moving through the population. The catch in 1993 would have significantly declined had it had not been for the entrance of the 1989 year-class to the spawning stock. The 1989 year-class has subsequently come to dominate the population in recent years (Figure 3.4).

3.3.2 Bristol Channel

The abundance of twaite shad caught at Hinkley Point 'B' Nuclear Power Station between June 1 of year n and May 31 of year n+1, from 1982 - 1996 is shown in Figure 3.5 (1985 and 1986 are excluded as samples were not taken monthly). The vast majority of the fish caught were age 0+. Over the period the number of twaite shad caught has fluctuated widely with good recruitment in 1989 and 1990 and particularly poor recruitment in 1982, 1985 - 1988 and in 1993. The reasons for this are discussed in section 4.

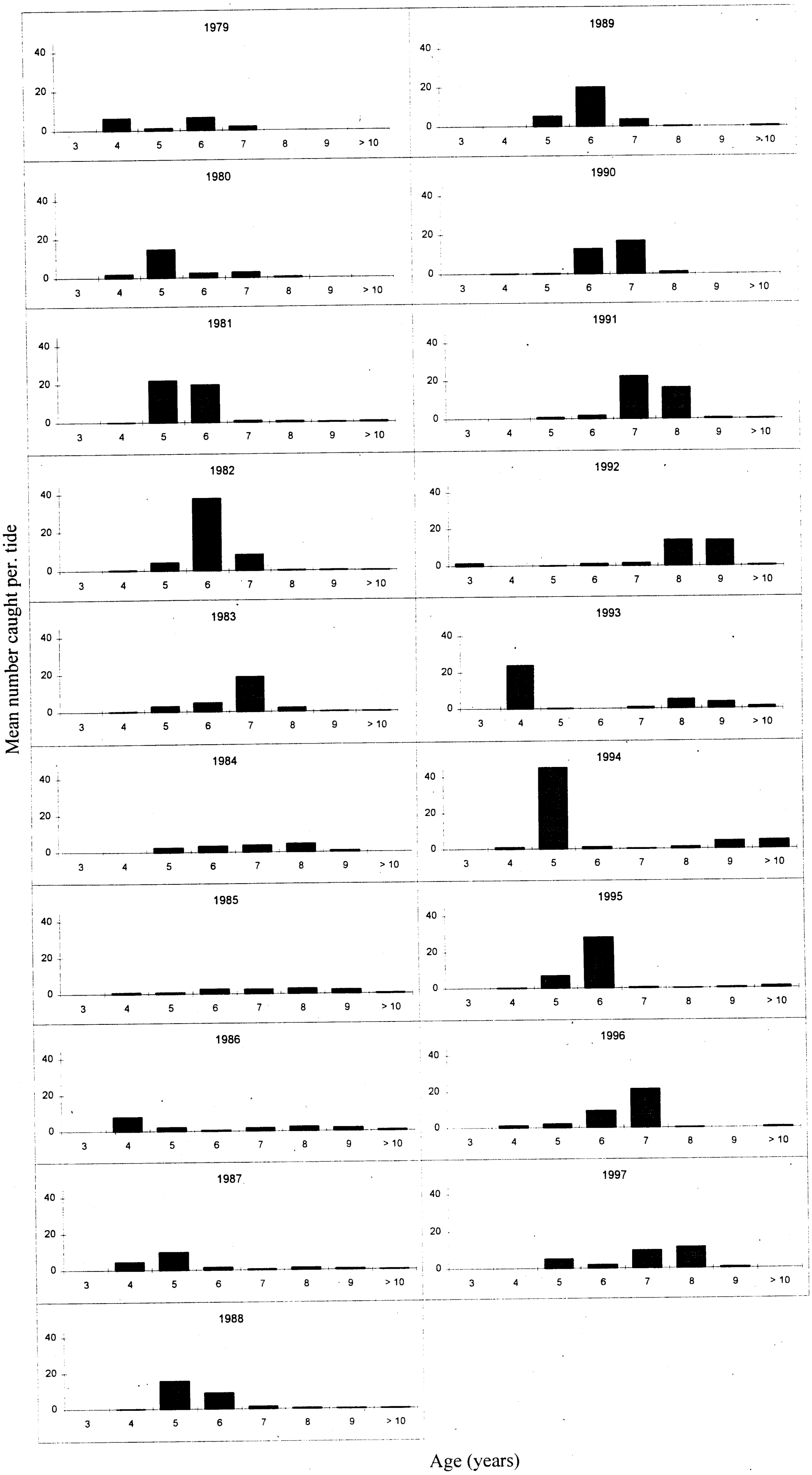


Figure 3.4 **The mean number of female twaite shad caught per. tide of different age groups for the period 1979 - 1997.**

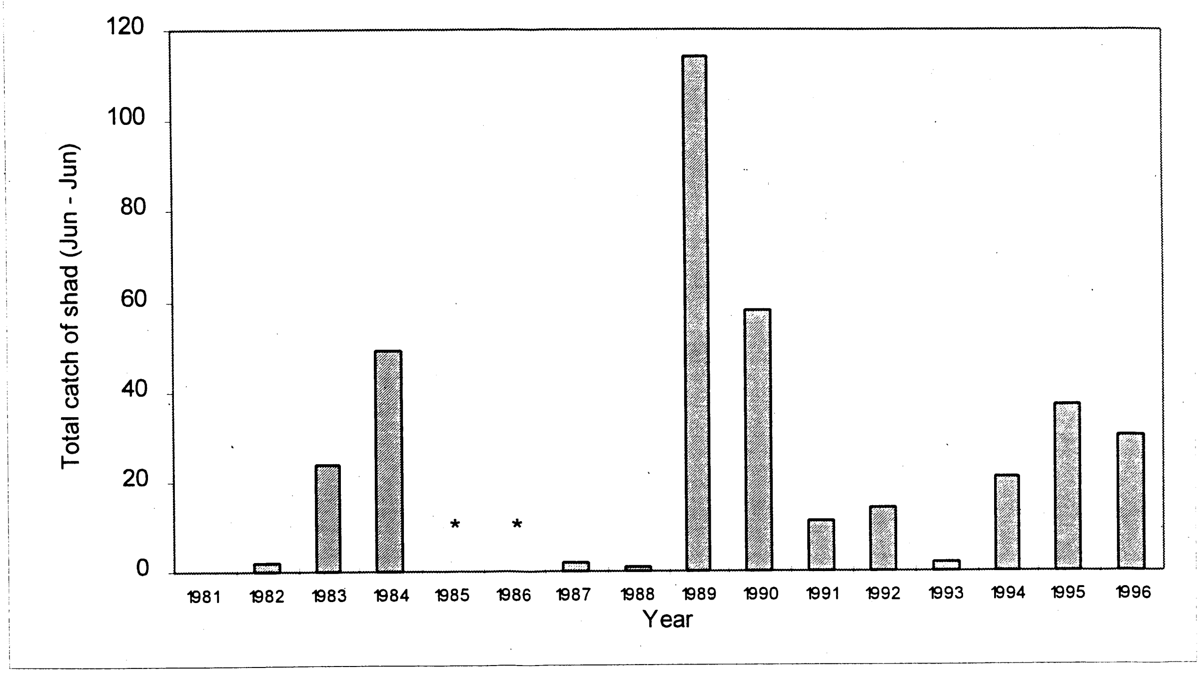


Figure 3.5 **Number of twaite shad caught at Hinkley Point 'B' Nuclear Power Station between June 1 of year n and May 31 of year n+1, from 1981 - 1996, Henderson pers. comm. (* counts excluded as data in 1986 were not recorded monthly).**

Since there was a correlation between the number of 0+ twaite shad caught at Hinkley in year n and the number of 6 year old twaite shad in the adult population in year n+6 (Figure 3.2) it would be expected that the strength of a particular year-class, measured during the first year of life, will subsequently be reflected in the adult population. As such, the size of the adult population is dependent on the strength of the various year-classes mature at that time. The data from Hinkley would therefore suggest that the adult population size in the Severn fluctuates, but to a lesser extent than that suggested by the Hinkley data. This is because twaite shad are repeat spawners and a year-class can dominate the spawning population for a number of years, as shown in Figure 3.4.

3.3.3 River Elbe

Between 1985 - 1994 the size of the spawning stock remained relatively stable both in terms of numbers and biomass (Figure 3.6). However, the mean abundance of the 0+ age group between 1989-1990 was significantly higher than between 1991-1994, though this was not the case for the 1+ age group which showed that peak abundance occurred in 1993 (Figure 3.7).

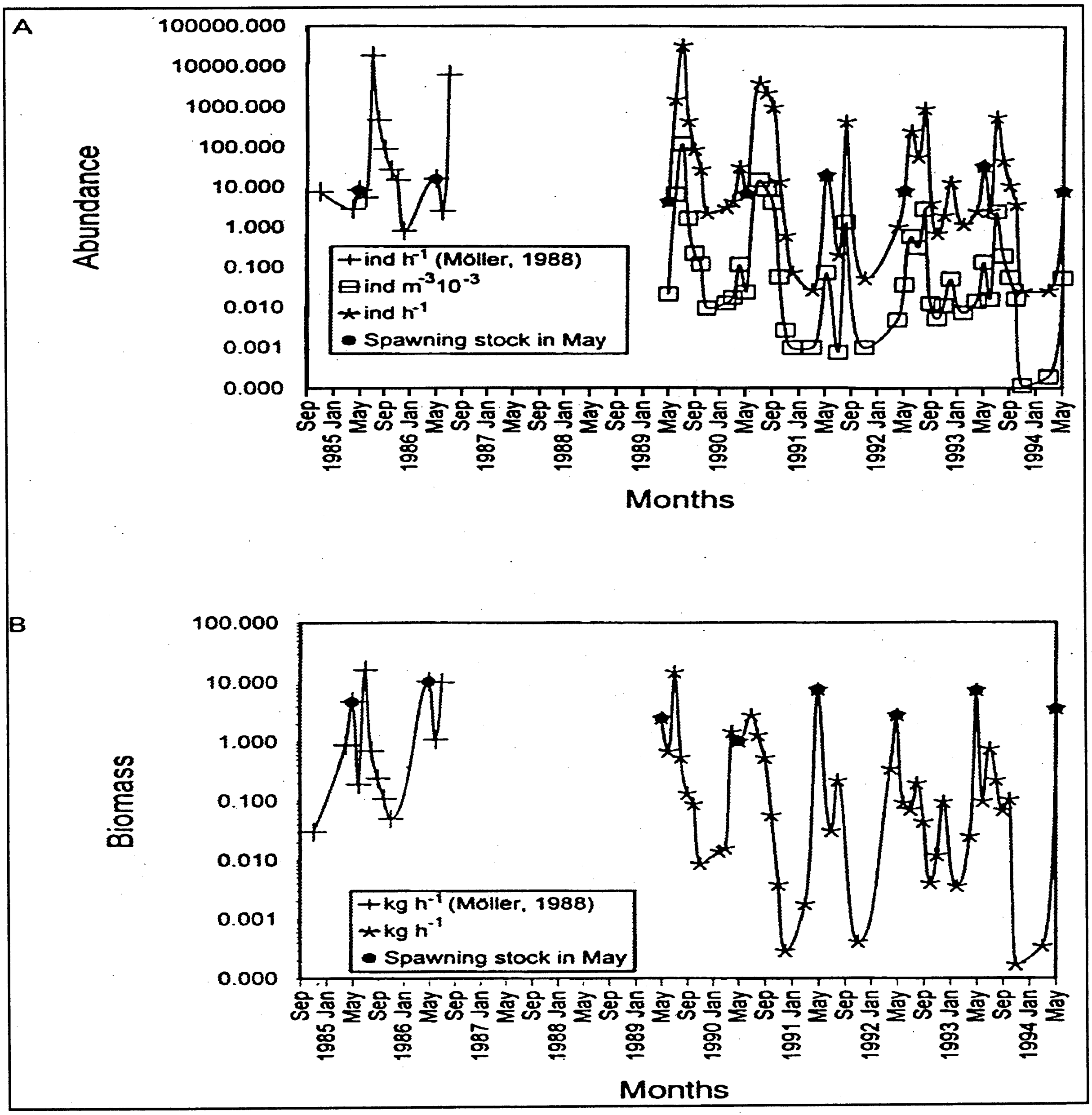


Figure 3.6 **Monthly estimates of abundance (A) and biomass (B) of twaite shad between 1984 and 1994, including the data provided by Möller (1988) covering November 1984 to December 1986 (from Thiel *et al.*, 1996).**

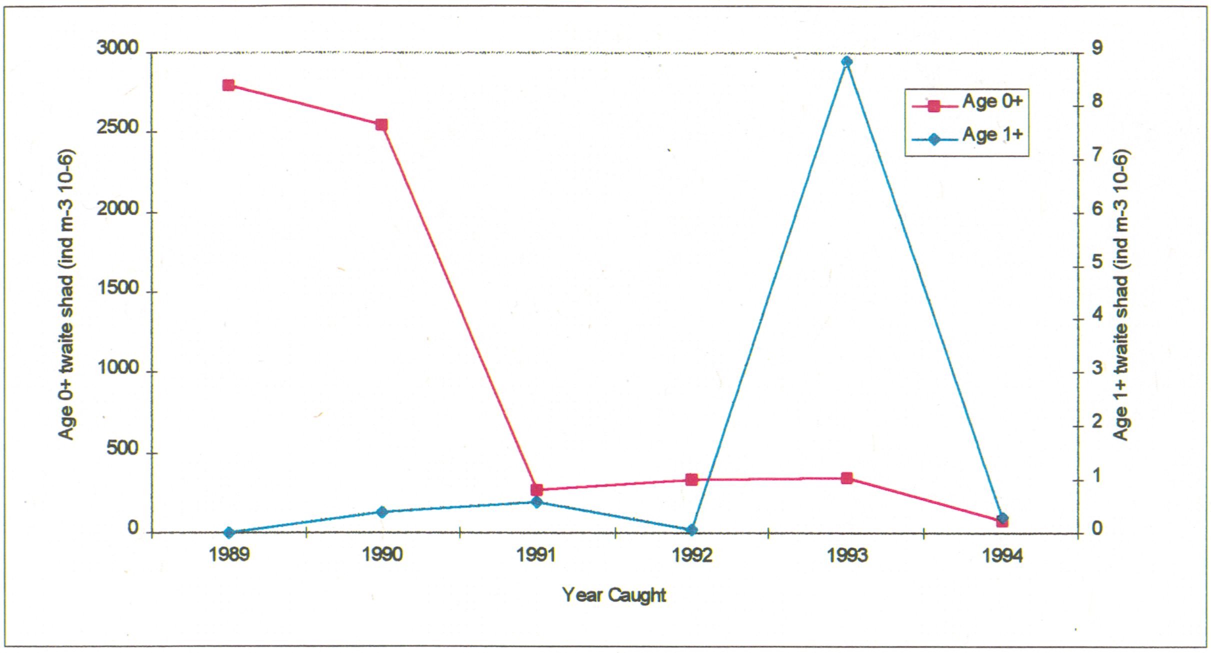


Figure 3.7 **The abundance of 0+ and 1+ twaite shad from the Elbe estuary between 1989 - 1994 (Thiel *et al.*, 1996).**

Figure 3.8 shows the relationship between the mean abundance of the 0+ age group in year n and that of the 1+ age group in year n+1. The absence of a correlation ($r^2 = 0.13$; $P>0.05$) would appear to suggest that in the Elbe, the population is regulated mainly through density dependent processes.

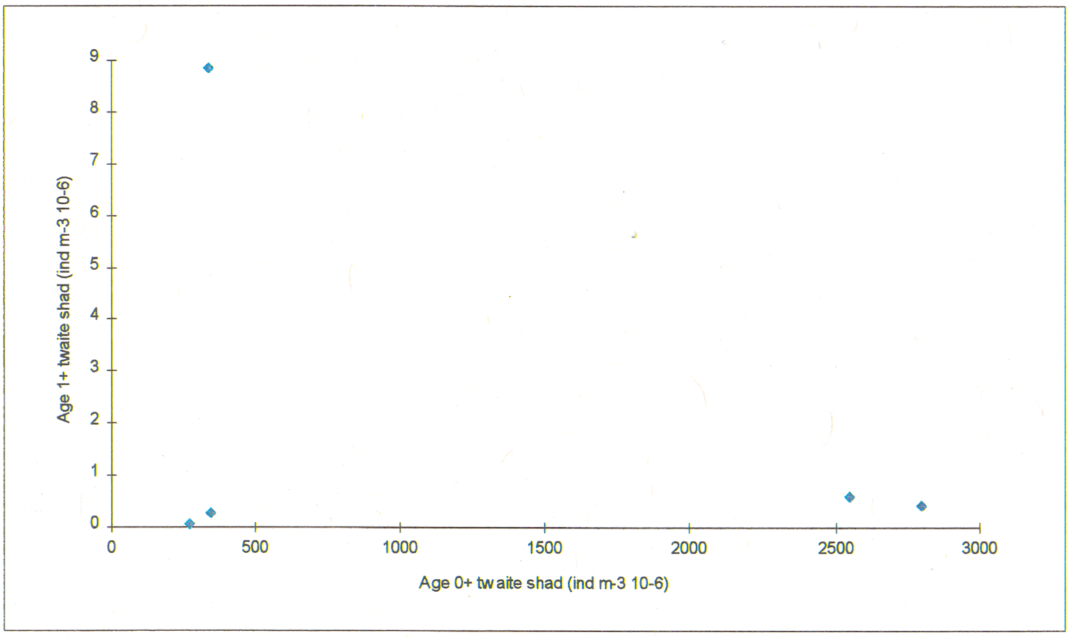


Figure 3.8 **The relationship between the number of age 1+ and 0+ twaite shad from the Elbe estuary (Thiel *et al.*, 1996).**

3.3.4 River Garonne and Dordogne, France

The number of *Alosa alosa* recorded at the four monitoring sites; Golfech and Bazacle on the River Garonne and at Tuiliere and Mauzax on the River Dordogne, is presented in Figure 3.9.

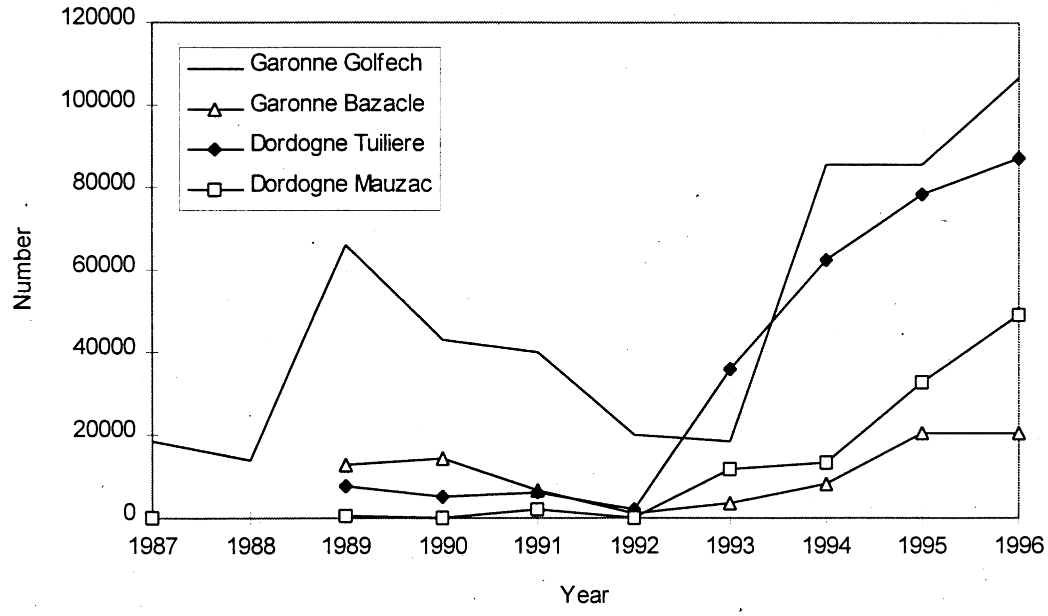


Figure 3.9 The number of upstream migrating *Alosa alosa* recorded at four locations on the rivers Garonne and Dordogne (Dartiguelongue, 1996; Larinier, in press; Travade *et al.*, in press).

The numbers have fluctuated over the period, however on each river system there is a trend towards an increase in numbers over the last 4 - 5 years. The fluctuation in numbers is considered to reflect not only variation in recruitment but also variation in environmental conditions, particularly temperature and discharge, during the estuarine and fresh water phase of their spawning migration (Travade *et al.*, 1996).

3.3.5 Northeast Atlantic and Mediterranean

The combined catch of *Alosa alosa* and *A.fallax* from those countries bordering the Northeast Atlantic and those in the Mediterranean between 1982 - 1991 is shown in Figure 3.10. Over the period the catch has remained relatively stable, fluctuating between approximately 400 - 600 tons. It is obviously difficult to interpret any trend, as the graph reflects the combined catch of the two species and does not allow for the differences in the selectivity of the gear operated in the various countries.

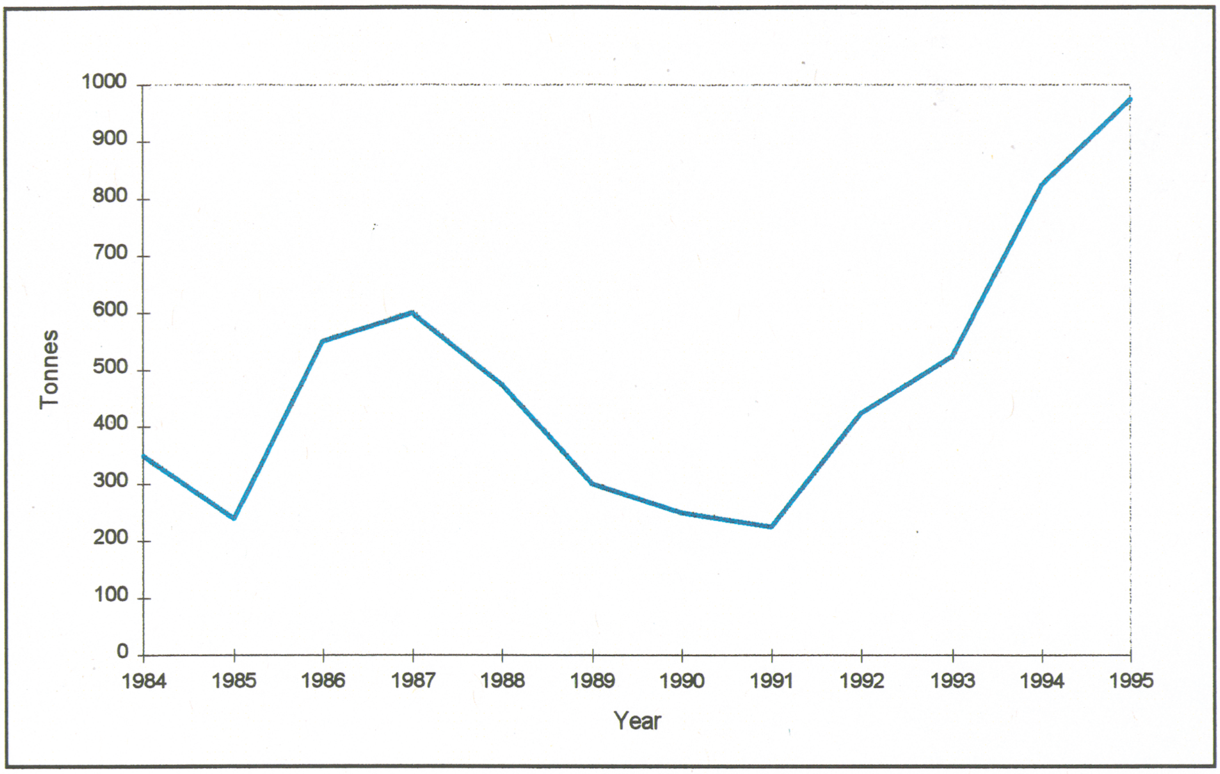


Figure 3.10 Combined catch of *Alosa alosa* and *A. fallax* in the Northeast Atlantic and Mediterranean Sea, taken from FAO catch statistics (Anon., 1993, from Bagliniere (1995)).

3.3.6 Comparison between systems

A comparison between the abundance of age 0+ twaite shad collected from Hinkley Point 'B' Power Station in the Bristol Channel (Henderson pers. comm.), and that from the Elbe estuary (Thiel *et al*., 1996) is shown in Figure 3.11, for the period 1989 - 1994. Both sets of data show good recruitment in 1989 and 1990 compared with the period 1991 - 1994. This may indicate that environmental factors, operating over a wide geographic area, are largely responsible for the similarity in the data sets.

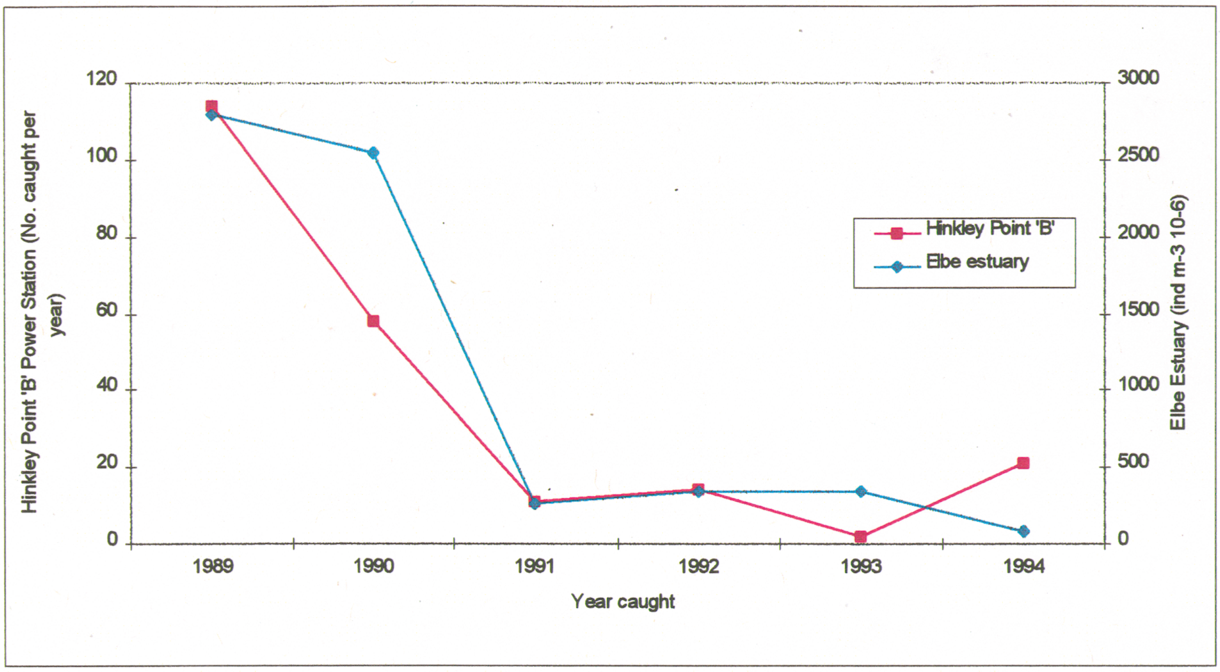


Figure 3.11 A comparison between abundance estimates for twaite shad age 0+ from Hinkley Point 'B' Power Station in the Bristol Channel (Henderson pers. comm.) and from the Elbe estuary (Thiel *et al.*, 1996).

3.4 Conclusion

The current status of the twaite shad population in the British Isles, as indicated from the Severn Estuary and Bristol Channel data, would appear to be relatively healthy. This assumes that these two studies accurately reflect the status of stocks in other systems, which may well be the case if large scale environmental factors control population size as the correlation between the Bristol Channel and Elbe data sets suggested.

As with most species there is a tendency for the population to fluctuate. From the data analysed, it would appear that the twaite shad population in the Severn can withstand a number of consecutive years of poor recruitment; at the most four poor years in five. The effect of environmental factors on recruitment will be discussed in section 4.

The future prospects for the population, as predicted from the catch of 0+ twaite shad at Hinkley Point 'B' Nuclear Power Station, is for an increase in the adult population over the next five years as the 1994 - 1996 year-classes mature and enter the adult population.

No information was available on the trend in the population of allis shad around the British Isles.

4. THE INFLUENCE OF WATER TEMPERATURE AND FLOW ON YEAR CLASS STRENGTH OF *ALOSA FALLAX* FROM THE RIVER SEVERN

4.1 Introduction

Recruitment in *Alosa fallax* populations has been found to vary between years with good recruitment associated with warm years (Holmes and Henderson, 1990; see also section 3.3.2). An ability to predict trends in recruitment and in abundance of the population has significant management implications, in particular it assists with the decision making process. Also an understanding of the mechanism by which factors operate on a population may lead to measures which mitigate against their impacts, therefore improving the management of the resource and avoiding inappropriate management action being taken.

Year class strength (YCS) of *Alosa sapidissima* has been shown to be mainly under the control of abiotic factors, in particular flow and temperature (Marcy, 1976; Leggett, 1977; Crecco and Savoy, 1984), and secondary related to the size of the spawning stock (Crecco, Savoy and Whitworth, 1986). Similarly Henderson and Brown (1985) found that YCS for a landlocked population of *Alosa pseudoharengus* was determined mainly by water temperature.

Though the direct mechanism has not been determined it was postulated by Crecco and Savoy (1987) that regulation was through advection of the larvae away from their food supply, into areas of higher predation pressure and/or into environments into which they are not physiologically adapted.

The aim of this section was to investigate whether similar hydrological and climatic factors were controlling the population of twaite shad in the River Severn.

4.2 Materials and Methods

Year class strength (YCS) was determined from the number of six year old female shad caught in the putcher net fishery which operates near Lydney on the Severn Estuary (NGR ST611991), see section 3.2.1. Of those fish which were caught at Lydney and aged, >99% of virgin fish matured at or before they were age 6. Therefore the number of six year olds was chosen to represent YCS. For the 1974 and 1975 year classes and those between 1979-1990, YCS was determined directly from catch data; for 1973 and 1976-1978 YCS was estimated as described in section 3.2.1. The 1972 YCS was estimated from the relationship between the number of fish aged six caught in year n and the number of fish caught in year n+1 (Figure 4.1) using the number of seven year olds caught in 1979.

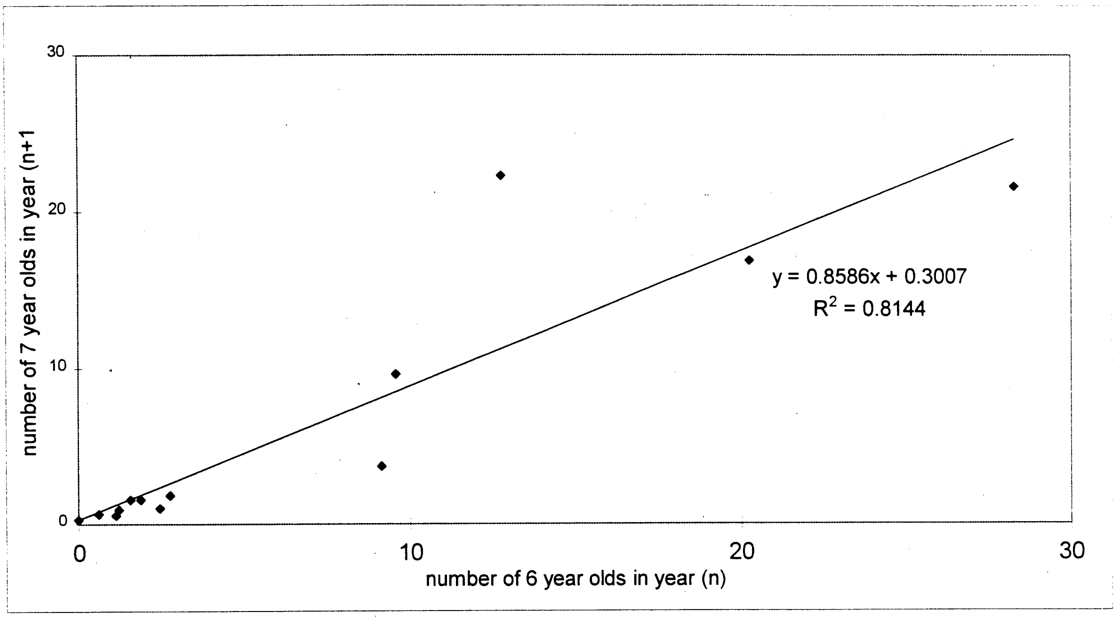


Figure 4.1 **Relationship between the number of fish aged seven caught in year (n+1) and the number of six year old fish caught the preceding year n.**

For the years 1991-1996 YCS was estimated from the relationship between the number of juvenile twaite shad caught at Hinkley Point 'B' Nuclear Power Station (see section 3.2.2) between June 1 year n - May 31 year n+1, and the number of six year old female shad caught in the net fishery in year n+6 (Figure 4.2).

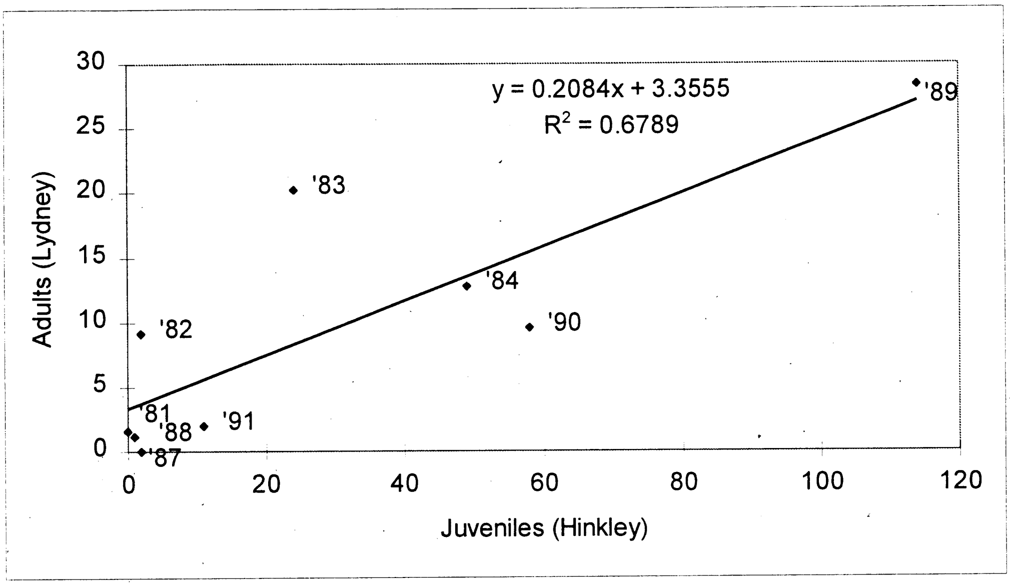


Figure 4.2 **The relationship between the number of six year olds caught in the putchers at Lydney and the catches of juveniles at Hinkley Point 'B' Nuclear Power Station of the same year class (Henderson, pers. comm.) for the period 1981 - 1991.**

YCS was transformed using natural logarithms as this gave the best approximation to a normal distribution. Mean daily flow for the period 1972-1996 and mean daily temperature from 1989-1996 was obtained from Saxon's Lode on the River Severn (NGR SO863390). Daily temperature (0900 hr) in the Severn Estuary between 1972-1996 was obtained from Oldbury Nuclear Power Station (NGR ST603947). A significant correlation existed between the temperature recorded in the river and that in the estuary for the months May-October 1989-1996 (Table 4.1). Therefore the Oldbury data was used to represent the temperature conditions in both environments. The best approximation to a normal distribution was obtained using Log_e flow and untransformed temperature data.

Table 4.1 Correlation between the mean monthly temperature measured at Saxon's Lode in fresh water and that at Oldbury Nuclear Power Station in the estuary, for the months May-October 1989-1996.

Month	Correlation Coefficient (r)	Significance
May	0.927	P<0.005
June	0.863	P<0.020
July	0.833	P=0.020
August	0.970	P<0.001
September	0.942	P<0.002
October	0.973	P<0.001

4.3 Results

YCS varied over the period 1972-1996, with extremely good spawning success in 1976 and 1989 and particularly poor recruitment in the periods 1977-1981 and 1985-1988 (Figure 4.3). Since 1990 recruitment has remained relatively stable.

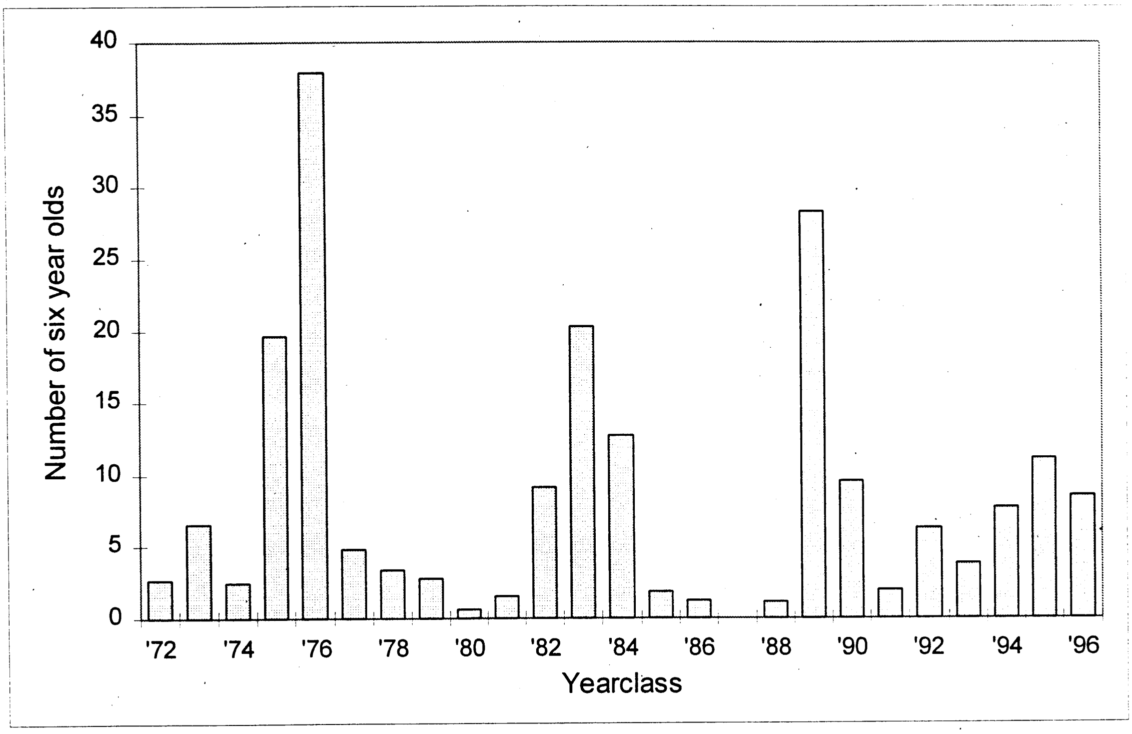


Figure 4.3 **Number of six year old fish caught at Lydney (1972, 1992 - 1996 year classes rebuilt using relationship between fish aged 6 and 7)**

The relationship between Log_e YCS, water temperature and Log_e flow for the months May-October in their first year are shown in Figures 4.4 a & b.

Water temperature had a positive influence on YCS with mean July temperature explaining the greatest proportion of the variance in YCS, followed by August, June and October; May and September did not significantly explain the variation in YCS (Table 4.2).

Flows in the months June - August were significantly inversely correlated with YCS, with the greatest proportion of the variability explained by August flows, followed by flows in July and June (Table 4.2). Flows in May, September and October were not significantly correlated with YCS. August flow in 1987 was considered to be an outlier in the relationship between YCS and August flow (Figure 4.4b). Excluding the 1987 data point improved the proportion of variability explained from 42.3% to 53.9%. However for June and July there was no significant improvement in the proportion of variance explained.

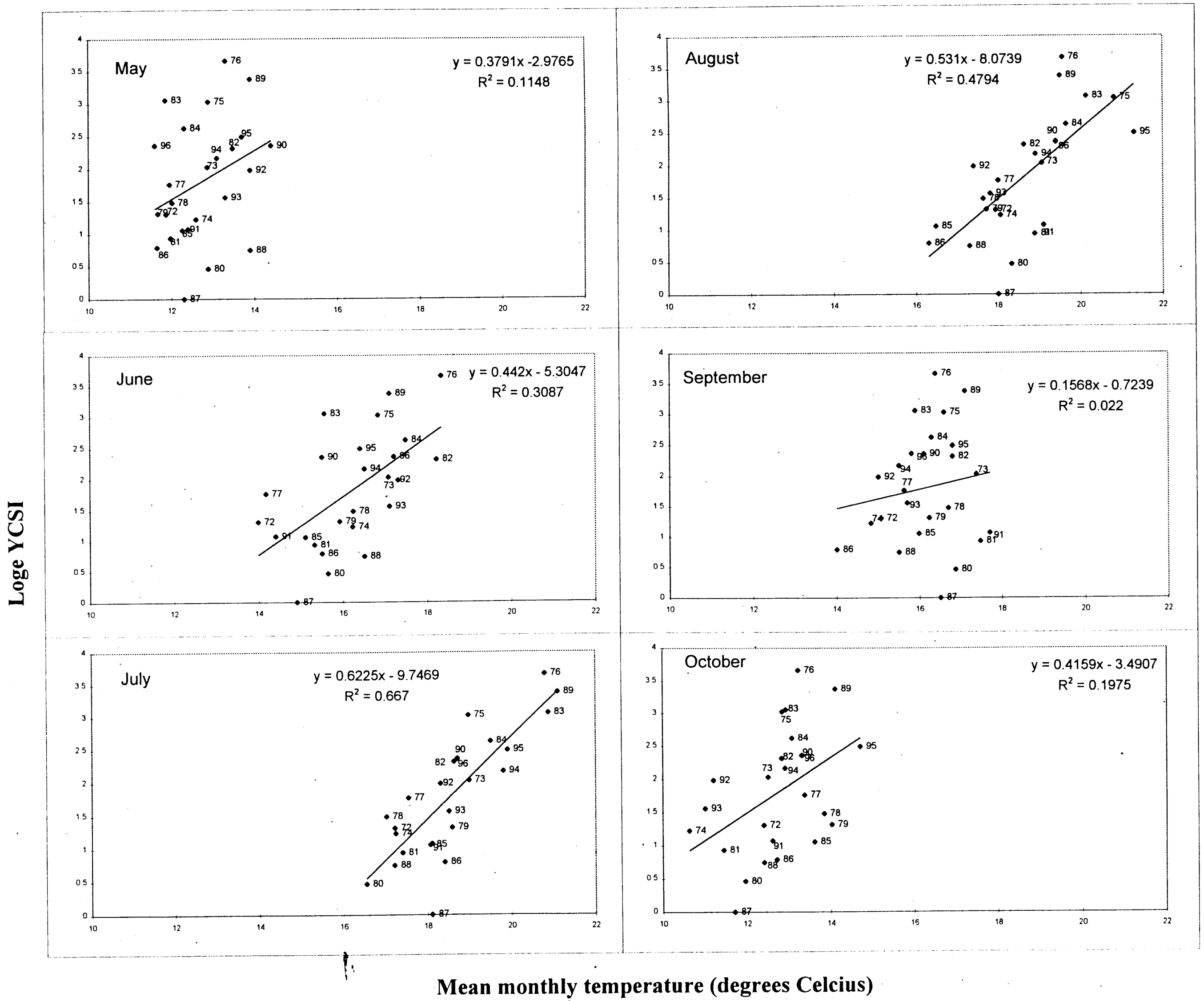


Figure 4.4a **Relationship between year class strength of shad caught at Lydney and mean monthly temperature at Oldbury Power Station (1972 - 1996).**

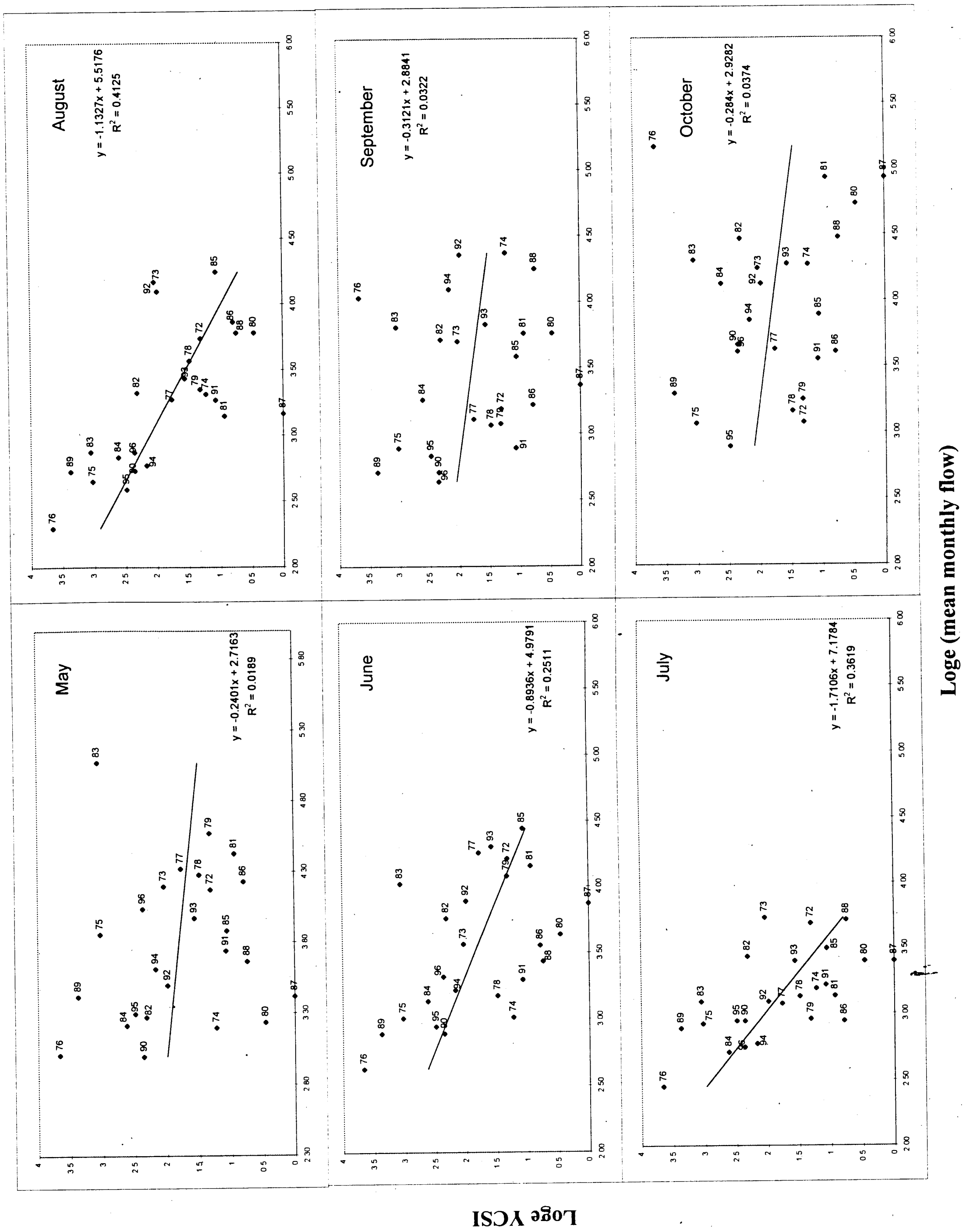


Figure 4.4b Relationship between year class strength of shad caught at Lydney and mean monthly flow at Saxon's Lode (1972 - 1996).

Table 4.2 Coefficient of determination (r^2) for the relationship between Log_e YCS v temperature and YCS v Log_e Flow for the period May-October (NS = p>0.05, *significant at P<0.05, ** P<0.01, *** P<0.001).

Month	Coefficient of determination (r^2) Log_e YCS v Temp.	Coefficient of determination (r^2) Log_e YCS v Log_e Flow
May	0.115 NS	0.023 NS
June	0.309**	0.277**
July	0.671***	0.368**
August	0.509***	0.423***
September	0.049 NS	0.042 NS
October	0.187*	0.043 NS

There was significant collinearity between monthly temperatures and flows and between the two environmental variables (Table 4.3 a-c). In five out of the six cases the temperature in one month was significantly positively correlated with that in the following month (Table 4.3a). Similarly with flow, the flow in one month was directly related to that in the preceding month in all cases except August - September (Table 4.3b). In addition, the flow in June was correlated with that in August. In all months, except September, water temperature was negatively correlated with flow and in a number of cases there was also a significant inverse correlation between temperature and flow in different months (Table 4.3c).

Table 4.3a Correlation between mean monthly temperature (*significant at P<0.05, ** P<0.01, *** P<0.001).

Month	May	June	July	August	September
June	0.465*				
July	0.262	0.478*			
August	0.253	0.293	0.601**		
September	0.139	0.095	0.148	0.412*	
October	-0.017	0.042	0.447*	0.331	0.259

Table 4.3b **Correlation between mean monthly flows (*significant at P<0.05, ** P<0.01, *** P<0.001).**

	May	June	July	August	September
June	0.594**				
July	0.187	0.553**			
August	0.272	0.594**	0.744***		
September	-0.102	0.203	0.270	0.332	
October	-0.227	0.143	0.141	0.066	0.690***

Table 4.3c **Correlation between mean monthly temperature and $\log_e$ flow (*significant at P<0.05, ** P<0.01, *** P<0.001).**

Temp/Flow	May	June	July	August	September	October
May	-0.68***	-0.39	-0.09	-0.19	-0.08	0.07
June	-0.43*	-0.46*	-0.40*	-0.54**	-0.17	-0.29
July	0.01	-0.34	-0.58**	-0.44	0.04	-0.38
August	-0.17	-0.27	-0.63***	-0.78***	-0.25	-0.35
September	0.20	0.26	-0.14	-0.34	-0.30	-0.65***
October	0.11	0.23	-0.06	-0.15	0.09	-0.58**

4.4 Discussion

The importance of environmental factors in regulating the size of anadromous *Alosa* populations has also been reported by Crecco and Savoy (1984), Leggett (1977) and Marcy (1976). Crecco and Savoy (1984) found that June temperature, river flow and precipitation explained 40.2%, 46.2% and 50.4% of the variability in YCS for *A.sapidissima* and correlation coefficients for all other months were generally <0.3 (P>0.05). YCS was positively correlated with temperature and inversely related to flow and rainfall. Marcy (1976) reported that 46% of the total variation in the production of juvenile *A.sapidissima* could be explained by river discharge during June, though this was not significant at the 5% level of probability. However, a multiple regression relating juvenile abundance to both density independent and dependent factors which explained 86% of the total variation, showed river discharge to be the most important, followed by temperature with a smaller influence from the number of adults available to spawn. However, Leggett (1977) reported that of these three variables, river discharge was the least important explaining between 0.7%-3.0% of the variation in juvenile abundance (this difference was found to be the result of miscalculation of the data by Marcy (1976) (Leggett, pers. comm.). Shoubridge and Leggett (1978) found that 58% of the variation in YCS for *A.sapidissima* could be predicted from water temperature during and shortly after spawning, indicating that the egg and larval stages represent the critical period.

Although the influence of temperature has been highlighted as significant for a number of *Alosa* populations, the mechanism(s) of its effect have not been determined. Mann (1991) suggested that an increase in temperature may result in faster growth, so that the 0+ fish pass more rapidly through the stage at which they are vulnerable to predation from aquatic invertebrates. He suggested that it may also affect the availability of food to the young life stages. The negative effect of river flow on YCS could act in a number of ways; (1) an increase in unfavourable feeding conditions (increased turbidity), (2) the transport of the juvenile stages and their food to areas of low food density, (3) the transport of juveniles to areas where they are physiologically unsuited and (4) the transport of juveniles to areas of higher predation. Crecco and Savoy (1987) certainly found a significant positive correlation between YCS and zooplankton density and between YCS and the percentage of larval shad (<13 mm) with food in their guts.

Although climatic factors have been found to act as the major regulatory influence in *Alosa* populations, Crecco and Savoy (1987) found that density dependent factors accounted for 10-25% of the variability in recruitment. The development of stock recruitment models incorporating a combination of environmental factors (June flow, May flow, May & June rainfall) for *A. sapidissima* in the Connecticut River were found to explain between 80-90% of the variability in recruitment (Crecco, Savoy and Whitworth, 1986; Crecco and Savoy, 1987).

5. VARIATION IN THE AGE AT FIRST SPAWNING

5.1 Introduction

The age at which an organism becomes sexually mature may be regarded as an adaption for optimizing their reproductive potential, and is likely to depend on the rate of juvenile to adult survival, the rate at which fecundity increases with age and the energetic cost of reproduction (Bell, 1976, 1980). There have been a number of studies which have shown that the age at maturity has differed between populations of *Alosa sapidissima* (Leggett, 1969; Carscadden and Leggett, 1975; Leggett and Carscadden, 1978; Shoubridge and Leggett, 1978; Sabatié *et al.*, 1996), but none have examined inter-annual differences. The aim of this section is to examine whether the age at first spawning was under the control of density dependent factors.

5.2 Materials and Methods

The mean age at which female twaite shad from a particular year-class spawn for the first time was determined from six year old fish caught in the putcher net fishery operating near Lydney on the Severn Estuary (NGR ST611991), see section 3.2.1. The age at first spawning was determined from scales as *Alosa* spp. produce a characteristic scar (spawning mark) once spawning has been completed and the fish resume feeding. Six year old fish were chosen as most of the fish have matured by this age, very few fish have been recorded maturing at age seven (<1%).

An index of stock size was calculated from year-class strength and assuming a constant annual mortality rate. Year-class strength was determined as described in section 4.2 and mortality rate was taken from the relationship between the number of 6 year old female shad caught in year n and the number of 7 year olds caught in year n+1 (Figure 5.1). An index of total biomass was estimated using mean weight at age (Table 5.1) and assuming a 50:50 sex ratio.

Table 5.1 Mean weight of male and female *Alosa fallax* at age.

Source of material	sex	Rates of Growth in Total Weight (W in g)									Reference
		1	2	3	4	5	6	7	8	9	
R.Severn	M	4.8	50.0	176.8	321.6	399.9	461.0	530.8	529.8	569.6	Aprahamian (1982)
	F	6.1	63.3	220.2	430.4	593.6	713.3	770.7	839.5	950.2	

The age at first spawning and the biomass index were transformed to give the best approximation to a normal distribution, as follows; $1/\sqrt{\text{age at first spawning}}$ and Log_e biomass.

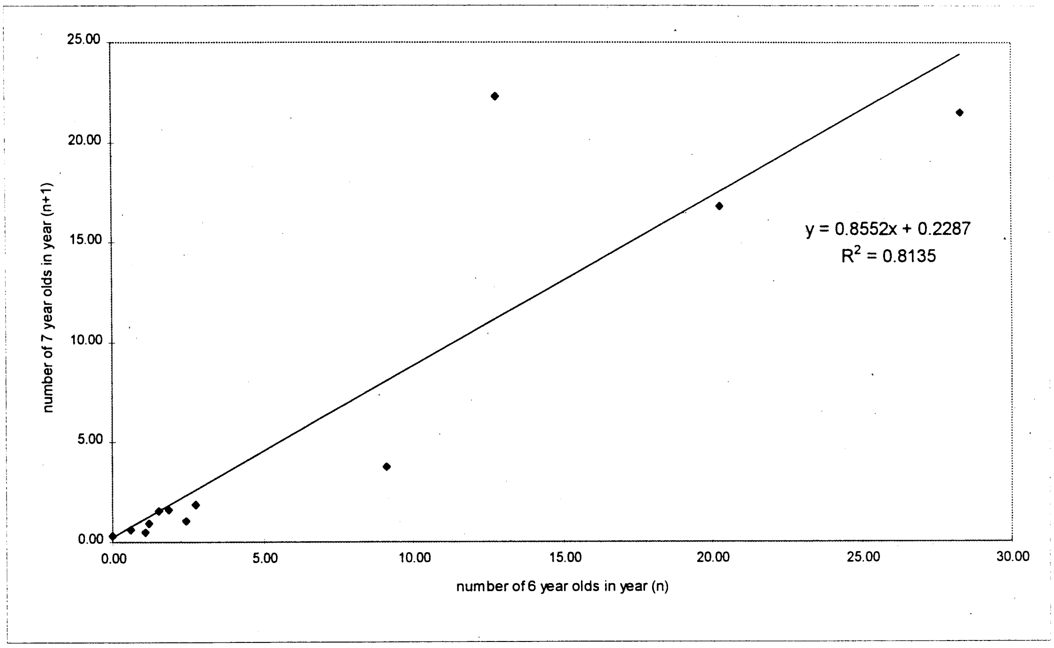


Figure 5.1 Relationship between the number of seven year old fish caught in year (n+1) and the number of fish aged six caught in year n.

5.3 Results

The percentage of fish spawning for the first time at ages 3-6 years for the 1973-1990 year classes is shown in Table 5.2. The mean age at first spawning has ranged from 4.41 years (1981) to 5.40 years (1986), however, for some year-class, in particular 1980, 1987 & 1988, the number of fished aged was small (<10). Of the 16 year-classes where a reasonable number of fish were aged, the majority (8) of the age classes matured at age 5 (50%), four at age 4 (25%), one at age 6 (6.25%) and three where approximately equal numbers matured at 4 and 5 (18.75%) and one at 5 and 6 (6.25%).

Table 5.2 **The mean age and the percentage of female twaite shad spawning for the first time at various ages for the 1973-1990 year-classes.**

Year-class	No. aged	Percentage of fish spawning for the first time 3	4	5	6	Mean Age (yr)
1973	32	0.00	59.37	37.50	3.13	4.44
1974	29	0.00	48.27	27.59	24.14	4.72
1975	145	2.76	42.06	46.21	8.97	4.61
1976	65	0.00	13.84	43.08	43.08	5.29
1977	36	2.78	22.22	50.00	25.00	4.97
1978	28	0.00	3.57	78.57	17.86	5.14
1979	47	0.00	21.28	57.44	21.28	5.00
1980	9	0.00	0.00	88.89	11.11	5.11
1981	17	0.00	58.82	41.18	0.00	4.41
1982	135	0.74	60.74	33.33	5.19	4.43
1983	252	0.79	14.29	53.17	31.75	5.16
1984	214	0.00	6.07	58.42	35.51	5.29
1985	16	0.00	18.75	68.75	12.50	4.94
1986	10	0.00	10.00	40.00	50.00	5.40
1987	1	0.00	0.00	100.00	0.00	5.00
1988	5	0.00	20.00	60.00	10.00	5.00
1989	232	7.33	41.81	42.24	8.62	4.52
1990	87	1.15	27.59	62.06	9.20	4.79

The relationship between the reciprocal root of the mean age at first spawning and the $\log_e$ index of biomass for the 0+ age group through to the combined biomass of age groups 0-6, is shown in Figure 5.2.

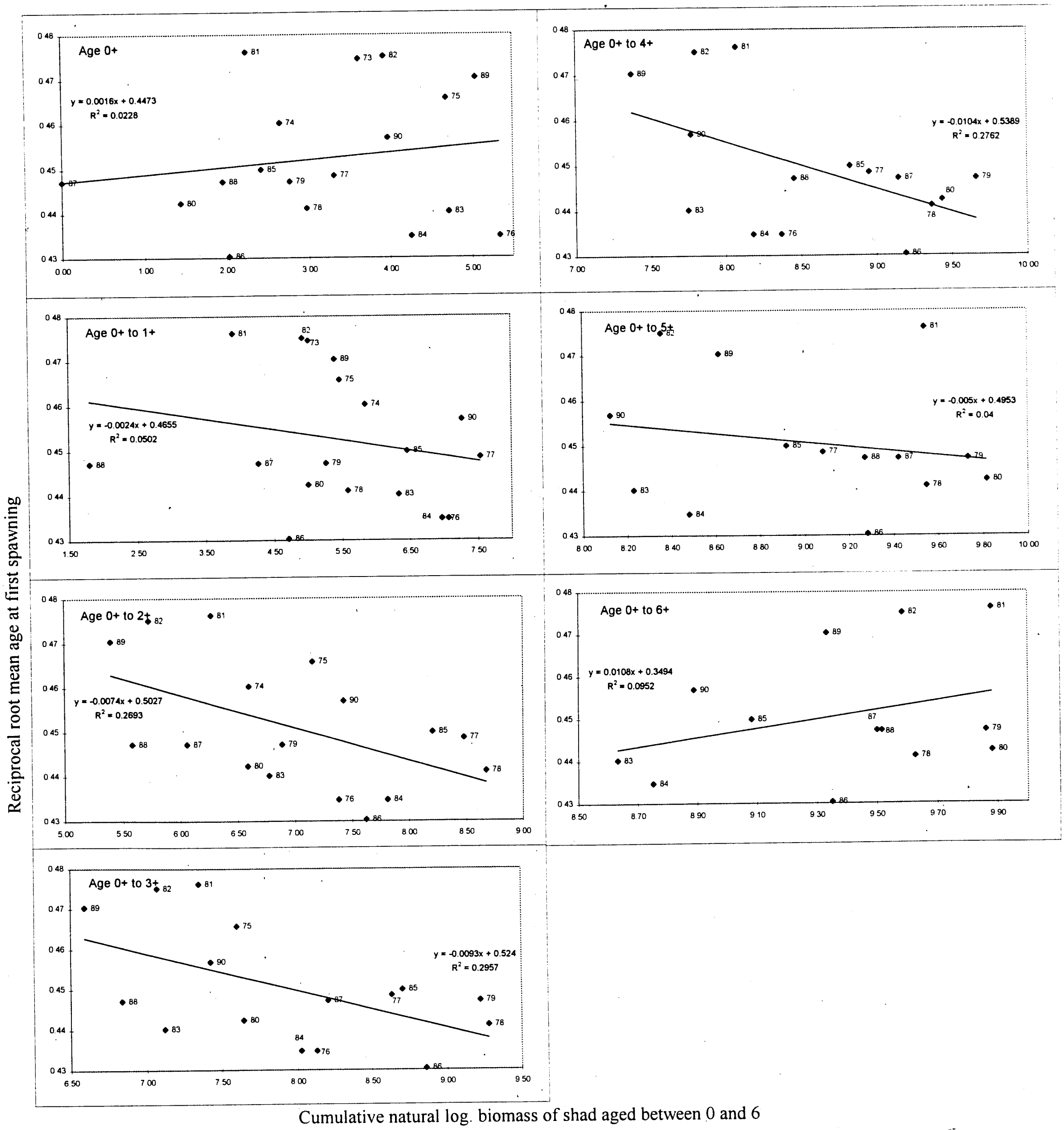


Figure 5.2 **The relationship between the age of first spawning and the biomass index of shad in the Severn Estuary.**

A significant relationship existed between the reciprocal root of the mean age at first spawning and the combined $\log_e$ biomass of the 0-2, 0-3 and 0-4 age groups ($P<0.05$). If those year-classes where <10 fish were sampled were omitted, the proportion of the variance explained increased from 26.9% to 46.0% for the 0-2 age groups and from 29.6% to 39.6% for the 0-3 age groups. There was no significant improvement for the 0-4 age groups.

Between year variation in the age at first spawning was evident from Table 5.2. Therefore to assess the number of years of data that need to be collected in order to describe the mean age at maturity for the population, the mean age at first spawning was computed using data for a varying number of years (Figure 5.3).

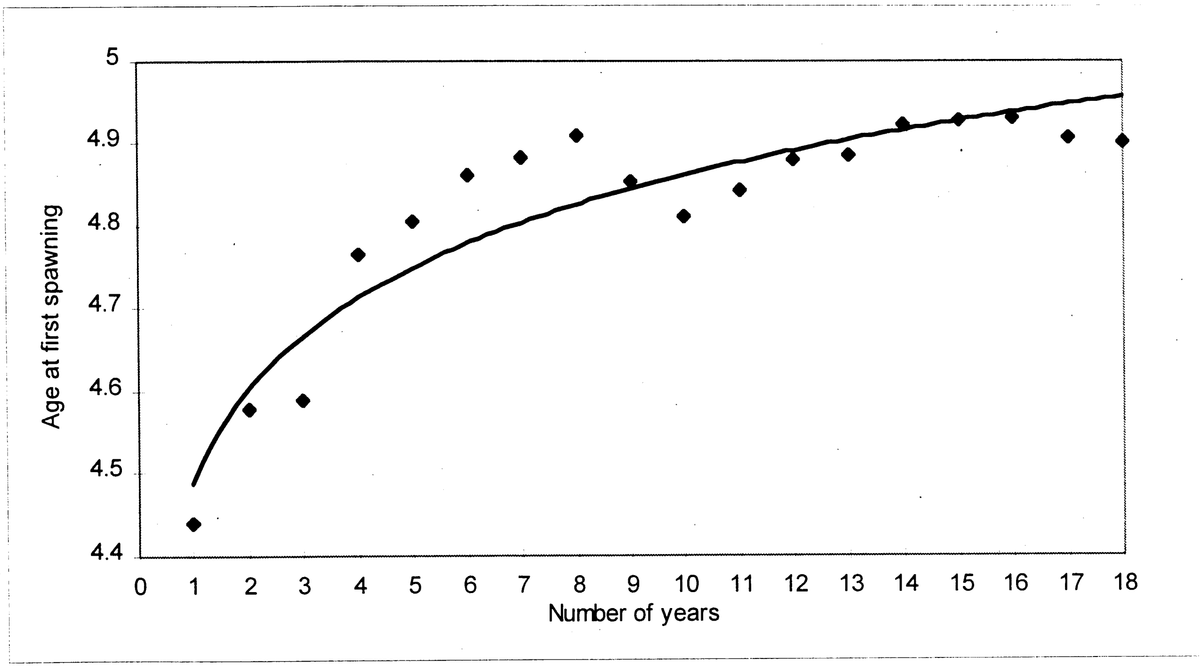


Figure 5.3 The mean age at first spawning for female twaite shad using data for a varying number of years.

The relationship indicated that between 4-5 years of data are required before the relationship reaches a plateau, the estimate should then be within 0.2-0.1 year of the long term mean of 4.9 years.

5.4 Discussion

The relationship between age at first spawning and biomass indicates that the onset of maturity is related to density dependent processes, probably intra specific competition for food affecting growth. If twaite shad must reach a minimum size before maturing then in those years when the rate of growth is slow, a delay in the onset of maturation would be expected. For female twaite shad from the River Severn, Aprahamian (1982) suggested that they must reach a critical size of approximately 330 mm (fork length) before they would enter the adult population. An analysis of the growth rate of the 1975 and 1976 year-classes showed that at age 4 the females entering fresh water on their spawning migration were 328.8 mm (1975 year-class) compared with a fork length of 305.9 and 298.5 mm (1975 and 1976 year-classes, respectively) for those which remained at sea and did not mature until the following year (Aprahamian, 1982).

The findings also suggest that the immature fish, when at sea, must congregate in a fairly restricted area if the older year-classes are to impact on the younger ones. In addition, the fact that the relationship breaks down after the age of four may relate to the onset of maturity, as the mature portion of the population separate off and enter the rivers to spawn and are effectively isolated from the main population.

Of the data used to examine whether the age at first spawning was regulated by density dependent processes, the greatest uncertainty related to the estimate of mortality, as this was derived from mature fish and may not relate to the immature portion of the population. To test the sensitivity of the conclusions the analysis was run using various levels of mortality. The findings indicated that though different estimates of stock size were significantly related to the age at first spawning, the overall conclusion that it was regulated by density dependent factors remained.

Although there have been a number of studies showing that variation in the age at first spawning, as well as other reproductive traits, exist between river systems (Leggett, 1969; Carscadden and Leggett, 1975; Leggett and Carscadden, 1978; Shoubridge and Leggett, 1978; Sabatié *et al.*, 1996), these are mainly based on data collected at the same time. In many instances this may not be practical, and to enable the comparison of reproductive traits between different river systems collected at different times, it is suggested that such comparisons should be based on data collected over 4-5 years. This is to ensure that there is a relatively high level of precision and that true population parameters are compared so that the risk of reaching the wrong conclusion is reduced.

6. MONITORING

6.1 Introduction

The Biodiversity Steering Group Report (1995) states that *"An essential part of the conservation action for species is to measure the changes in their conservation status against targets in the plans. The plans are written on the assumption that existing schemes for monitoring species' distribution, abundance and population trends are continued and refined as necessary, and that where required, new schemes are established to inform future action."* The aim of this section is to outline the current method(s) used to monitor the status of the shad population in England and Wales and to suggest other possibilities.

6.2 Current monitoring

Monitoring of the status of shad stocks is presently undertaken in the Severn Estuary (Aprahamian, pers. comm.), in the Bristol Channel by Dr. P. Henderson (Oxford University) at Hinkley Point 'B' Nuclear Power Station, and by Dr. D. Bird (University of West of England) at Oldbury and Hinkley Point 'B' Nuclear Power stations.

6.2.1 Monitoring in the Severn Estuary

The population entering the Severn Estuary at the start of the freshwater phase of their spawning migration has been sampled between 1979-1996 (Figure 6.1) by Aprahamian (pers. comm.). Counts of shad caught were obtained from the putcher net fishermen, from April 15 (start of the salmon net season) for various periods, until the middle of June. Samples of shad were taken at intervals throughout the migration period in order to partition the run according to sex, age and spawning history (see section 3.2.1).

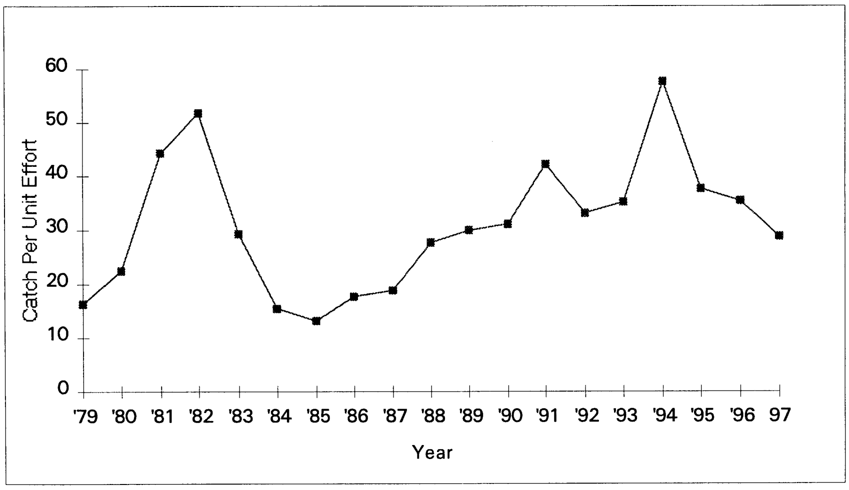


Figure 6.1 Catch per unit effort of female *Alosa fallax fallax* in the Severn Estuary (1979-1997).

In the past sampling has also been carried out using drift and seine nets with a mesh size of 5.05 cm (knot to knot). These nets were designed for catching salmon and as shad are smaller than salmon the effect was to sample the larger and thus older proportion of the spawning run.

One of the possible disadvantages of using catch data is the uncertainty of the relationship between catch and stock. However, the fact that the catch of six year old fish in the putcher rank was significantly correlated to the catch of 0+ fish at Hinkley Point Power Station (section 3.3) does suggest that catch is reflecting stock.

6.2.2 Monitoring in the Bristol Channel

Quantitative, monthly sampling of fish and crustaceans at Hinkley Point 'B' Nuclear Power Station has been carried out by P. Henderson (pers. comm.) since October 1980 (Figure 6.2). Sampling dates were chosen to work tides of intermediate range in the spring-neap cycle. On each visit six consecutive one hour samples were collected in plastic baskets of 6 mm mesh size, positioned to collect all the debris washed from two of the four drum screens. The debris was sorted, the fish and crustaceans identified to species and the number captured per hour recorded. The standard length of the fish was also measured. The method is selective towards juvenile shad with majority of the catch consisting of the 0+ age group (Holmes and Henderson, 1990).

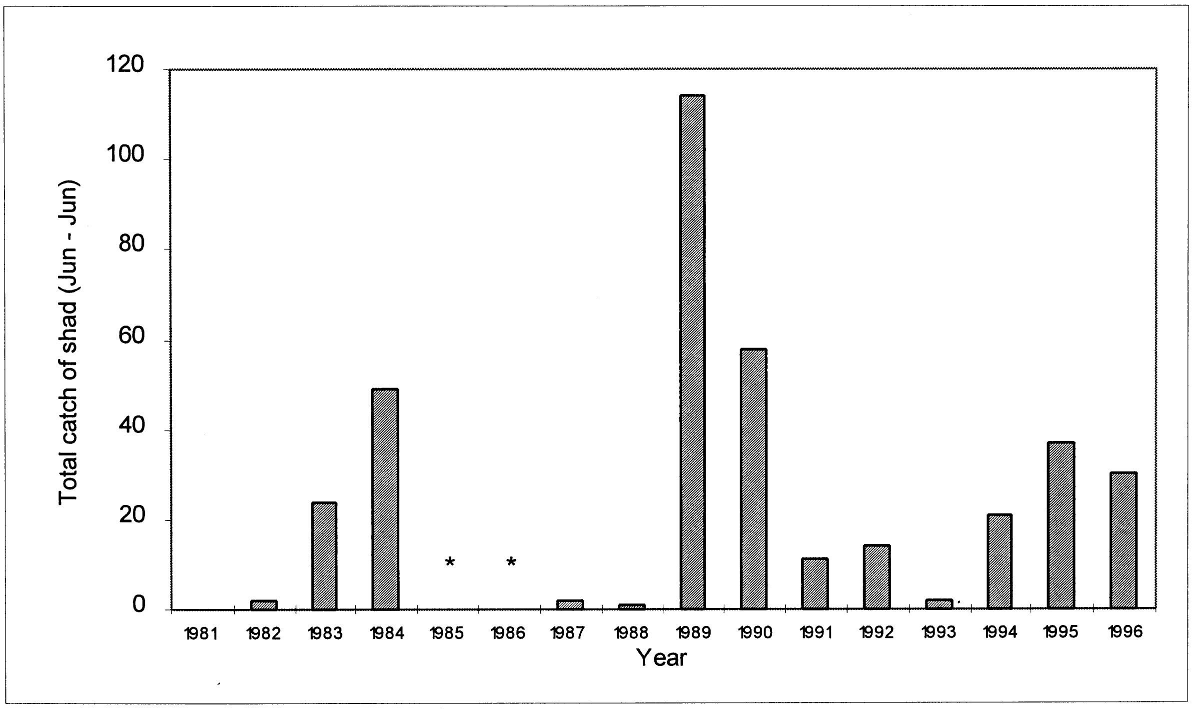


Figure 6.2 **Number of twaite shad caught at Hinkley Point 'B' Nuclear Power Station between June 1 of year n and May 31 of year n+1, from 1981 - 1996, Henderson pers. comm. (* counts excluded as data in 1986 were not recorded monthly).**

Quantitative sampling is also being undertaken by the University of the West of England at

Oldbury Nuclear Power Station at two weekly intervals, and at Hinkley Point 'B' Nuclear Power Station once per month. Sampling started in January 1996 and is programmed to carry on until December 1998. Samples of fish and debris are collected over a 24 hour period. Depending on the amount of trash either the entire sample or a subsample is taken. The numbers of fish caught are adjusted to take into account any differences in effort (quantity of water pumped) between sampling periods.

6.3 Other potential sources of census data.

6.3.1 Adults - Environment Agency facilities.

Of the four rivers known to support spawning populations of twaite shad (rivers Severn, Wye, Usk and Tywi), monitoring facilities owned and operated by the Environment Agency exist on all except the Tywi. The facilities are as follows:

6.3.1.1 Trap and counter - @ Tewkesbury, R. Severn

A trap and resistivity fish counter (Aquantic Logie 2100a) were installed on the right bank at Upper Lode Weir (Tewkesbury) on the River Severn in 1996. The resistivity fish counter has still to be commissioned and certain problems were encountered when operating the trap. The problems have since been addressed and the effectiveness of these facilities for monitoring shad as well as other fish will be assessed by the Environment Agency (Midlands Region).

6.3.1.2 Counter - @ Redbrook, R. Wye

A hydroacoustic counter (HTI System 243) was installed at Redbrook on the River Wye in 1995. A study validating the technique has been carried out as part of the Environment Agency's Research and Development programme (Gregory *et al.*, in prep.). The study, though concentrating on salmon, has shown that there is a strong likelihood that data describing the status of the population could be attained if the frequency was changed from 200 KHz to 400 KHz with a second transducer. A second transducer is required to ensure that the upper part of the water column is analysed as shad have a tendency to swim higher in the water column than salmon (Figure 6.3).

The Environment Agency (Welsh Region) are continuing their validation studies during 1997, however there are no plans, at present, to change the operating frequency nor deploy a second transducer.

6.3.1.3 Counter - @ Trostrey, R. Usk

A resistivity fish counter (Aquantic Logie 2100a) has been installed at Trostrey weir on the River Usk since 1988. Validation has been carried out by G. Jones (pers. comm.) who has shown that it is sensitive enough to count shad, but its counting efficiency has not yet been determined. In addition, as the target species is salmon, the threshold for the counter is set at a level to count fish >50cm in length. From studies carried out elsewhere it should be possible using a Logie counter, with electrodes spaced 41cm apart, to count fish down to 25 cm in length with a reasonable level with a reasonable level of accuracy (Aprahamian *et al.*,1996) which seems suitable for counting shad.

The Environment Agency (Welsh Region) is carrying out a programme of validation studies, aiming to determine the accuracy and the precision of the counter at counting fish of various size groups.

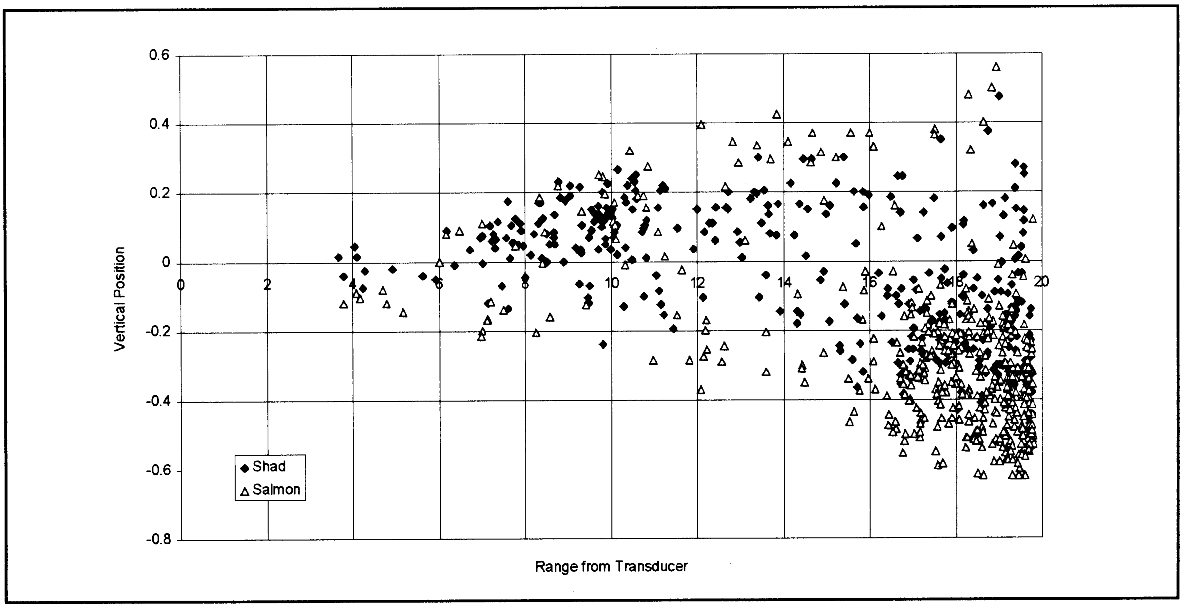


Figure 6.3 Vertical position of salmon and shad within the water column from a hydroacoustic counter at Redbrook on the River Wye (Gregory and Gough, pers. comm.).

6.3.2 Adult - Catch Data

6.3.2.1 Net Fisheries

Catch data from the net fishery in the Severn Estuary has been used to monitor trends in shad abundance (see section 3.2.1). Net fisheries similarly operate in the Tywi estuary (8 seine nets and 12 coracle nets) and it may be possible to obtain similar data on catch and effort from one

or more of these fisheries.

6.3.2.2 Rod Fisheries

Shad can be caught regularly using rod and line. However for stock assessment purposes angling is only successful as a method if the species of interest (shad) is the main target species and is actively pursued by the angler. In most instances this is not the case. Shad are mainly an incidental catch to fishermen who are targeting salmon. Although shad can provide some sport when salmon are not abundant or during the coarse fish close season this is not a regular enough activity to make it a viable monitoring method. It is therefore suggested that unless a particular person or fishery regularly goes fishing for shad, then collection of catch and effort data from

However, angling data may provide some useful information on distribution and areas of importance for shad within the catchment.

6.3.3 Juvenile life stages.

6.3.3.1 Egg stage

The egg stage can be sampled using FBA invertebrate nets (250 mm wide & 1 mm mesh). This method has been used to quantify between year changes in egg deposition at a particular spawning ground by Aprahamian (1982). Although this may reflect differences in the size of the spawning stock spawning at a particular site, this may be more related to discharge levels affecting access (Aprahamian, 1982) than to differences in the size of the total spawning stock. For the egg stage to provide a robust method of monitoring the status of the spawning population, a systematic approach of sampling throughout the spawning range of shad would be required. The effectiveness of this method is dependent on flow conditions, being more successful at low flows. As such, in those years with a wet June, it may not be possible to collect any worthwhile data.

As this method has not been tried on other alosid populations, it is suggested that a pilot study be set up to assess its usefulness in quantifying changes in the status of the spawning stock.

6.3.3.2 Larval and juvenile stages.

At present there is little information about the ecology of the juvenile stages in fresh water, and as such it is not possible to suggest a monitoring programme for these life stages. Studies carried out elsewhere involved the use of plankton nets, small mesh seines and trawls to sample the juvenile stages (Crecco and Savoy, 1984; Hass, 1968; Marcy, 1976). It may be possible to use similar methodologies on UK rivers to quantify variation in recruitment. However, in the first instance, it is suggested that a pilot study be carried out in order to assess the feasibility and cost of the approach.

Sampling of the 0+ age group using seine nets between July and September in the Severn Estuary proved successful in showing differences in year-class strength (Aprahamian, 1982). It may be possible to monitor the 0+ population in the estuaries of other rivers using similar techniques.

6.4 Sampling Strategy

6.4.1 Sampling the migrating population - adult and/or juvenile stages

Sampling should be carried out in a systematic manner over the migration period so that they are equally spaced throughout the period with a frequency which is dependent on the level of precision required. The equations for determining the estimates and associated variance, standard deviation, standard error and confidence limits for unequal-sized sampling units, sampled without replacement are shown in Table 6.1 (Caughley and Sinclair, 1994).

Table 6.1 The estimates and associated variance, standard deviation, standard error and confidence limits for unequal-sized sampling units, sampled without replacement.

	Density (D)	Total Numbers (C)
Estimate	$(\sum c/\sum a)$	$A(\sum c/\sum a)$
Variance	$((n/\sum a)^2)((\sum c^2 + D^2\sum a^2 - 2D\sum ac) / (n-1))(1-(\sum a/A))$	$(An/\sum a)^2((\sum c^2 + D^2\sum a^2 - 2D\sum ac) / (n-1))((1-(\sum a/A))$
Standard Deviation	$\surd$(Variance) $\surd((n/\sum a)^2)((\sum c^2 + D^2\sum a^2 - 2D\sum ac) / (n-1))(1-(\sum a/A))$	$\surd$(Variance) $\surd(An/\sum a)^2((\sum c^2 + D^2\sum a^2 - 2D\sum ac) / (n-1))(1-(\sum a/A))$
Standard Error	Standard Deviation / $\surd n$ $\surd((n/\sum a)^2)((\sum c^2 + D^2\sum a^2 - 2D\sum ac) / n(n-1))(1-(\sum a/A))$	Standard Deviation / $\surd n$ $\surd(An/\sum a)^2((\sum c^2 + D^2\sum a^2 - 2D\sum ac) / n(n-1))(1-(\sum a/A))$
Confidence Limits	Standard error . $t_{\alpha/2}$ $\surd((n/\sum a)^2)((\sum c^2 + D^2\sum a^2 - 2D\sum ac) / n(n-1))(1-(\sum a/A))t_{\alpha/2}$	Standard error . $t_{\alpha/2}$ $\surd(An/\sum a)^2((\sum c^2 + D^2\sum a^2 - 2D\sum ac) / n(n-1))(1-(\sum a/A))t_{\alpha/2}$

Where:

C = the estimate of the total number of fish caught in the period
c = the number of fish caught per sampling unit (hour / tide or day)
a = the size of a given sampling unit (hour / tide or day)
A = the total number of hours, tides or days in the migration period
n = the number of units sampled
D = the estimate of mean density (number of fish caught per sampling unit) $(\sum c/\sum a)$.
$t_{\alpha/2}$ = the upper $100(1-\alpha/2)$ value of 'students' t for the $100(1-\alpha)$% level of confidence (Table 6.2).

Table 6.2 Values of t for different levels of probability.

Level of Confidence	Probability (α)	$t_{\alpha/2}$
99%	0.01	2.576
95%	0.05	1.960
90%	0.10	1.645
80%	0.20	1.282
70%	0.30	1.036

6.4.2 Precision

The precision of the estimate is dependent on the number of samples taken and should be defined at the outset together with the level of confidence. For example the programme might aim to estimate the total catch of shad so that the estimate must be within ±50% of the true estimate with a confidence of 95%, ie there is a 1 in 20 chance that the estimate will be outside this range. An estimate of the number of sampling units (n) can be determined using the following formula:

$$n \geq Var(D) / ((d / (t_{\alpha/2}))^2 + Var(D)/A)$$

Where:

Var (D) = variance of estimate of catch
d = width of the confidence interval
$t_{\alpha/2}$ = the upper 100(1- $_{\alpha/2}$) value of 'students' t for the 100(1- α)% level of confidence

An estimate of the number of samples that need to be taken to ensure that a certain level of precision is achieved at a particular level of confidence can be determined for both juvenile and adult shad.

6.4.2.1 Juvenile shad.

A guide to the number of samples that need to be taken for different levels of precision and confidence can be obtained using data from Claridge & Gardner (1978). Samples were obtained from Oldbury Nuclear Power Station over a 24 hour period, at weekly intervals, between July and November 1975 and 1976. In 1975 the mean catch (D) of shad during the main migration period, August to October inclusive (92 days in total) was 91.58 day^{-1}, and the variance (Var(D))was 7480.23 $fish^2$. The number of samples (days) required to meet various levels of precision and confidence is shown in Table 6.3.

Table 6.3 The number of samples required to ensure that the confidence limits are within a specified proportion of the estimate at different levels of confidence.

Confidence limits (proportion of mean catch)	90% Confidence	95% Confidence	99%Confidence
± 0.25 mean catch	27	34	47
± 0.50 mean catch	9	12	19

6.4.2.2 Adult shad

Using catch data from the putcher rank operating near Lydney in the Severn Estuary between

April 15 and June 18 1996, the mean catch (D) per sampling unit was 35.73 fish, the variance (Var(D)) of the estimate was 429.7 $fish^2$ and the mean size of each sampling unit (a) was 1.34 tides. The number of tides (na) which should be sampled to ensure that the confidence limits are within a specified proportion of the estimate at different levels of confidence are presented in Table 6.4.

Table 6.4 The number of tides (na) require sampling to ensure that the confidence limits are within a specified proportion of the estimate at different levels of confidence.

Confidence limits (proportion of mean catch)	90% Confidence	95% Confidence	99%Confidence
± 0.25 mean catch	13	18	28
± 0.50 mean catch	4	5	8

6.4.2.3 Between year differences

In many instances it is important to determine whether there has been a significant change in the population between years. The number of samples which are required to assess whether there has been a significant change in the catch should take into account the smallest difference that the sampling programme is designed to detect, and the probability of committing Type I and Type II errors.

To ensure a low probability of committing a Type I error (ie falsely rejecting H_0: $D_1 = D_2$) a low α is required (eg setting $\alpha = 0.05$ means there is a 5% chance of rejecting H_0 (the sample means are not equal) when in fact they were equal). A Type II error is committed when H_0 is accepted when the alternative hypothesis (H_a) is in fact true. This probability is donated by the value β (eg setting $\beta = 0.10$ means there is a 10% chance of accepting H_0 (the sample means are equal) when if fact they were different and the probability of accepting H_a when H_a is true is therefore 1- β (0.90) and termed power.

The two types of error are inversely related. A decrease in a Type I error will increase the probability of a Type II error, for any given sample size. The only way of reducing both sets of error is by increasing sample size. The ideal statistical test is one which has a small probability of rejecting H_0 when it is true and a large probability of rejecting H_0 when it is false. The number of sampling units (n) which should be sampled to detect a specific difference in, for example, mean catch (D) at a particular level of confidence and power, can be determined using the following equation:

$n = (2\mathrm{Var}\,(D)/\delta^2)(t_{\alpha/2} + t_\beta)^2$ (adapted from Wyatt and Lacey, 1994)

Where:

Var (D)	=	the variance of the estimate of mean catch
δ	=	minimum detectable difference between means
$t_{\alpha/2}$	=	the upper 100(1- α/2) value of 'students' t for the 100(1- α)% level of confidence.
t_β	=	the upper 100(1- β) value of 'students' t for the 100(1- β)% level of power.

Using the 1996 catch data the mean catch (D) per sampling unit was 35.73 fish, the variance (Var (D)) of the estimate was 429.7 fish^2 and the mean size of the sampling unit (a) was 1.34 tides. If the sampling programme was being designed to detect a minimum difference of half of the catch (δ = 17.87 fish), then the number of tides (na) which would require sampling are shown in Table 6.5.

Table 6.5 Sample size (number of tides) required to estimate a change in mean catch by a factor of 0.5 for different levels of power and confidence; 'students' t values for α and β are in brackets.

Power/Confidence	α = 0.01 (2.576)	α = 0.05 (1.960)	α = 0.10 (1.645)
1-β = 0.95 (1.645)	64	47	39
1-β = 0.90 (1.282)	54	38	31
1-β = 0.80 (0.842)	42	28	23

As presented in Figure 6.1, the data showed significant autocorrelation since the catch in $year_n$ was directly related to the catch in $year_{n+1}$ (r^2 = 0.23). Tests for significant differences between catches should therefore be carried out between catches which are separated by at least two years.

6.4.2.4 Relative change (R)

In a number of instances, there is a requirement to calculate the confidence intervals of the relative change in the population between two occasions; time a and time a+b, for example in the determination of survival rates.

The confidence intervals of R, where R represents the ratio of the change in mean density over b years, *i.e.*

$$R = D_{a+b}/D_a$$

are given by

$$\frac{B \pm (B^2 - AC)}{A} \quad \text{(Wyatt and Lacey, 1994)}$$

Where:

$$A = (D_{a+b})^2 - (t_{\alpha/2})^2.(Var(D_{a+b}))$$
$$B = (D_a)^2.\ (D_{a+b})^2$$

$C = (D_a)^2 - (t_{\alpha/2})^2.(Var(D_a))$.

6.4.3 Age data

Interpretation of changes in catch is difficult without additional age structure data or an idea of the relative abundance of year-classes before they enter the adult population. This is because changes in catch may reflect the combined effect of a number of relatively poor or good year-classes passing through the population. Such a situation could arise for example if there were a number of wet summers, as in the late 1980's (1985 - 1988 inclusive), producing a succession of poor year-classes and a decline in the population from purely natural factors.

6.4.2.1 Sample size to estimate a proportion.

To estimate the proportion of a particular age group in the population to a given level of precision with C% confidence, the number of fish required for ageing can be calculated using the following formula:

$N = u^2 0.5(1-0.5)/\delta^2$

where:

N = number of fish to be aged
u = Standard Normal deviate corresponding to a cumulative probability of (100-C)/2
δ = desired precision

The sample sizes needed to estimate a proportion at various levels of precision are presented, for three levels of confidence in Table 6.6. For example, a sample size of 166 fish is required to ensure the estimated proportion will be within ±0.10 of the true estimate with 99% confidence.

Table 6.6 Sample size required to meet various levels of precision and confidence (value of u in brackets) assuming a proportion (p) of 0.5.

Confidence level	**90% (u = 1.645)**	**95% (u = 1.960)**	**99% (u = 2.576)**
Precision			
0.01	6765	9604	16590
0.05	271	384	664
0.10	67	96	166
0.20	17	24	42

As males mature approximately one year earlier than females the age structure of the population should be determined separately for each gender.

6.5 Equipment and manpower costs

At present an estimate of cost can only be made for sampling of the adult stages on their spawning migrations and of the juvenile stages whilst in the estuary.

6.5.1 Adults

The cheapest option is to obtain the data directly from the salmon net fishermen, but requires close liaison and cooperation with the fishermen. If this is not possible then samples can be obtained directly using seine nets. In the past the nets used had a mesh of size of 5.05 cm (knot to knot) which proved to be too large to effectively sample those fish < 30 cm in length (Aprahamian, 1982). It is therefore suggested that a smaller mesh net should be used.

Equipment cost

Seine net: 120m long, 2m deep, 37mm mesh (knot - knot) with a 30m bunt of 25mm mesh, floats & weights = £900.

Manpower cost

A minimum of three persons are required to operate a seine net. A day should be allocated for each sampling occasion to enable at least three samples to be taken and to cover travel time etc.. The total man power requirements per sampling occasion is therefore three man days.

Assuming that the aim of the study was for the 95% confidence limits of the estimate to be within ±50% of the true estimate then a total of seven samples (Table 6.4) would be needed between mid-April and mid-June, giving a manpower requirement of 21 days.

6.5.2 Juveniles

It is possible to provide some estimates of the cost of monitoring the juvenile (age 0+) population in the river and estuary using seine nets and from power station sampling.

6.5.2.1 River and Estuary

Juvenile samples have been obtained from the Severn Estuary using a micromesh seine net (mesh 3 mm).

Equipment cost

Seine net: 20m long, 3m deep, micromesh, floats & weights = £350.

Manpower cost

Sampling requires a minimum of two people and is generally carried out at low water. It is possible to sample two or three sites depending on the time available during any tidal cycle.

Thus the man power requirement per sampling occasion is between 1 - 0.6 man days per site.

Assuming that the aim of the study was for the 90% confidence limits of the estimate to be within ±50% of the true estimate then a total of nine samples occasions (Table 6.3) would be required, giving a manpower requirement of 18 days. On each sampling occasion, it is suggested that between 2 - 3 sites are sampled per occasion over a four month period (July - October).

6.5.2.2 Power station

Equipment cost

Two approaches have been used; either all the trash is collected over a 24 hour period and sorted the next day (in which case the equipment costs are negligible), or small mesh nets are placed in the outflow channels from the screens. The cost of these nets (conical micromesh nets 30cm in diameter and 3m in length with a polythene hoop at the front) is £17 each.

Manpower

Power station sampling requires a minimum of 2 people and 6 hours to process all the sample giving a manpower requirement of 2 man days per sampling occasion. Assuming nine sampling occasions over a three month period (the particular months dependent on the location of the power station; at Oldbury and Hinkley power stations, the main months would be August to October), the total manpower requirement is 18 man days.

6.5.3 Age composition of the adult population

As these data are mainly used to interpret trends in year-class strength, it is suggested that age determination be carried out on only one of the sexes, otherwise larger samples sizes are required to maintain the same level of precision. It is suggested that six samples of 50 fish (total 300 fish) be taken at regular intervals during the upstream migration period between mid-April and mid-June. To process (clean, prepare and read) 300 sets of scales is estimated to take 6 man days.

6.6. Recommendations

6.6.1 Adult population

In the short term it is suggested that the monitoring of the shad by-catch in the putcher net fishery in the Severn Estuary should continue. However, as there is no guarantee that this particular fishery will remain in operation in perpetuity, it is recommended that other forms of monitoring the adult population should be investigated. These are;

a) the trap and resistivity counter at Upper Lode Weir @ Tewkesbury on the River Severn,
b) the acoustic counter at Redbrook on the River Wye
c) the resistivity counter at Trostrey on the River Usk.

Programmes to evaluate the performance of the counters are planned for the future. Although the investigations are principally concerned with evaluating the performance of the counters with regard to salmon, they also include shad.

Following an assessment of the feasibility of using the various counters and trap to monitoring the shad population, it is recommended that the method(s) which provides a reasonable level of accuracy and precision be adopted as the main method for monitoring trends in the adult population. It is suggested that the preferred method of monitoring the adult population is run concurrently with the catch data from the Severn Estuary so that the trend can be hind cast back to 1979. This assumes that catch in the Severn Estuary is related to stock in the rivers Severn, Wye and/or Usk.

6.6.2 Juvenile population

It is recommended that continued support be given to the sampling programme being carried out at Hinkley Point 'B' Nuclear Power Station by Dr. P. Henderson and Dr. Richard Seaby of PISCES Conservation Ltd.. At present the Environment Agency are developing a renewable contract with PISCES to contribute £5, 000 $year^{-1}$ along with other interested parties towards the cost of continuing the monitoring with the intention that it may continue for at least the life of the power station (approximately ten years).

To obtain river specific data on trends in the abundance of 0+ group shad it is recommended that a pilot study to assess the feasibility of monitoring the 0+ age group in the Wye, Usk and Tywi estuaries be undertaken.

6.6.3 Auxiliary information

It is recommended that biological details (age, sex, size, spawning history) be collected from the adult population in order to be able to better interpret the catch (or counter) data and to assist in predicting trends in the population.

7. ASSESSMENT OF THE HABITAT REQUIREMENTS OF JUVENILE SHAD

7.1 Methodology

7.1.1 Selection of sampling sites

Local knowledge depicted the location of sampling. Contact with bailiffs, fisheries officers, ghillies, anglers and angling clubs revealed areas which were considered to be frequently used for spawning. Often these individuals described the characteristic habitat very accurately and suggested other areas which might be worth sampling.

7.1.2 Techniques applied

Several techniques were used to characterise the spawning sites (see following sub-headings). In addition, each site was described in appearance, photographed and sketched. Kick sampling was used to determine the presence / absence of eggs or larvae. In the first instance, 4 sites where eggs were found (confirmed spawning sites) have been quantified. The area where eggs were found within the spawning area was drawn as accurately as possible on the sketches. NB Eggs may have drifted into the gravel interstices from spawning activity upstream of their location.

Kick sampling

A standard macrovinvertebrate handnet (250 μm aperture) was used to sample material dislodged when kick sampling approximately 0.5 m upstream. At one site on the River Tywi, four additional plankton nets (250 μm aperture) were anchored in the current downstream of the kick sampling activity.

Gravel areas were targeted for kick sampling, especially those which appeared to have been recently disturbed, suggesting spawning activity. In addition, adjacent micro habitats were sampled, for completeness (where possible). During sampling, the net was checked intermittently for eggs, larvae and factors which may have affected the sampling efficiency, e.g. excess detritus which may have an effect on collection efficiency. After kick sampling for up to 3 minutes, the contents of the net were re-examined for the presence of eggs and/or larvae before kick sampling again. This sequence was repeated until it was felt that most of the substrate in the area considered to be suitable for spawning was sampled.

RHS (River Habitat Survey)

RHS is a technique which has been developed by The Environment Agency to assess the physical structure of freshwater streams and rivers based on a standard 500 m sample unit (Environment Agency, 1997). The assessment consists of ten 'spot-checks' at equal (50 m) distances along the 500 m and a 'sweep up' of all features along the length, including those which are not represented in the spot-checks. Each spot-check comprises an assessment of flow types, physical features, vegetation structure, land use and vegetation types. Physical features are assessed from a 1 m wide 'transect' across the channel, while vegetation structure, land use and channel vegetation types are assessed within a 10 m wide transect across the river. In the sweep up the extent of each feature is assessed over the 500 m stretch.

HABSCORE

HABSCORE is a system for measuring and evaluating stream salmonid habitat features (Barnard and Wyatt, 1995). Its use relies on the completion of a series of forms covering site habitat (HABform), catchment features (MAPform) and fishery survey results for the site (FISHform). Only the HABform was completed when quantifying the spawning habitat for shad. On the HABform, measurements are recorded every ten metres. Measurements taken include channel length, width and boundary depth profile, substrate composition, flow, sources of cover for >10 cm brown trout and an estimate of the percentage of deep water within the area surveyed.

Flow measurement

A calibrated Valeport BFM-002 current meter was used to measure the average flow speed and depth at various locations over the spawning area (at ⅔ of the total depth). The presence/absence of eggs at each position was simultaneously recorded.

7.2 Results

7.2.1 Sites where eggs and/or larvae were recovered

In June 1997, shad eggs were collected from seven sites on the rivers Wye, Usk and Severn. As well as those of shad, eggs containing pigment were also found at some of the sites. These were distinguished from shad eggs found using the identification notes in Appendix 1. A total of fourteen sites have been confirmed as used by shad for spawning on these rivers to date (see Table 7.1).

Table 7.1 Spawning sites identified and confirmed on the rivers in England and Wales to date

River	No. spawning sites identified to date	No spawning sites confirmed, *(*confirmed in 1997, #quantified in 1997)*
Wye	25	8 *(*4, #3)*
Usk	5	4 *(*2, #1)*
Severn	2	2 *(*1)*
Tywi	7	0

General character of the sites

Eggs were usually found in fast-flowing water over shallow gravel areas, lodged between the interstices of gravel and on occasion between the leaves of submerged plants.

Depth of water

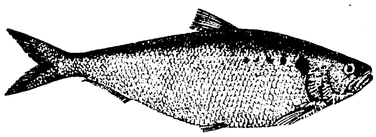
Eggs were recovered in June 1997 from water between 15 - 50 cm deep, but most frequently at a depth of approximately 37 cm.

Flow

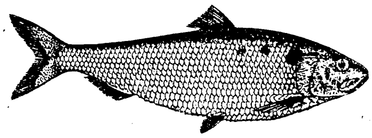
Eggs were recovered in June 1997 from water flowing between 0.03 - 1.21 metres/second, but most frequently at a rate of 0.70 metres/second.

8. SPECIES ACTION PLAN

TWAITE SHAD (*ALOSA FALLAX*)
(Bony Horseman, Chad, Goureen, Herring Shad, Killarney Shad, May Fish, Queen of the Herring, Shad)



ALLIS SHAD (*ALOSA ALOSA*)
(Ale Wife, Bony Horseman, Chad, King of the Herring, May Fish, Shad)



The Rio Biodiversity Convention, signed by the British Government in 1992, required the development of national programmes for the conservation of biological diversity. The Environment Agency and Ministry of Agriculture, Fisheries and Food are the joint lead partners on allis and twaite shad under the UK Biodiversity Strategy. This Species Action Plan has been amalgamated and developed from the separate plans presented in the Biodiversity Steering Group Report (1995) and through consultation with English Nature, Countryside Council for Wales, Scottish Natural Heritage, Department of the Environment Northern Ireland, National Wildlife Trusts and several research bodies and Institutions. It is intended that this action plan will implement the requirements of the EC Habitats Directive in the United Kingdom.

8.1. GENERAL INTRODUCTION AND CURRENT STATUS

8.1.1 Ecology and life cycle

Twaite shad, *Alosa fallax fallax* and allis shad (*Alosa alosa*) are anadromous (i.e. they reproduce in fresh water and grow in the sea) members of the herring family. Adult twaite shad from the Severn Estuary range between 23 - 45 cm and average approximately 32 cm. Allis shad average approximately 40 cm. On occasion, accurate identification requires the sacrifice of the fish so that the number of gill rakers on the first gill arch can be counted; twaite shad have between 40-60, allis shad between 90-130 (see Figure 8.1). Hybrids with intermediate numbers of rakers do occur.

The species are also characterised by an adipose membrane partially covering each eye and large, circular, weakly attached scales which appear serrated under the belly.

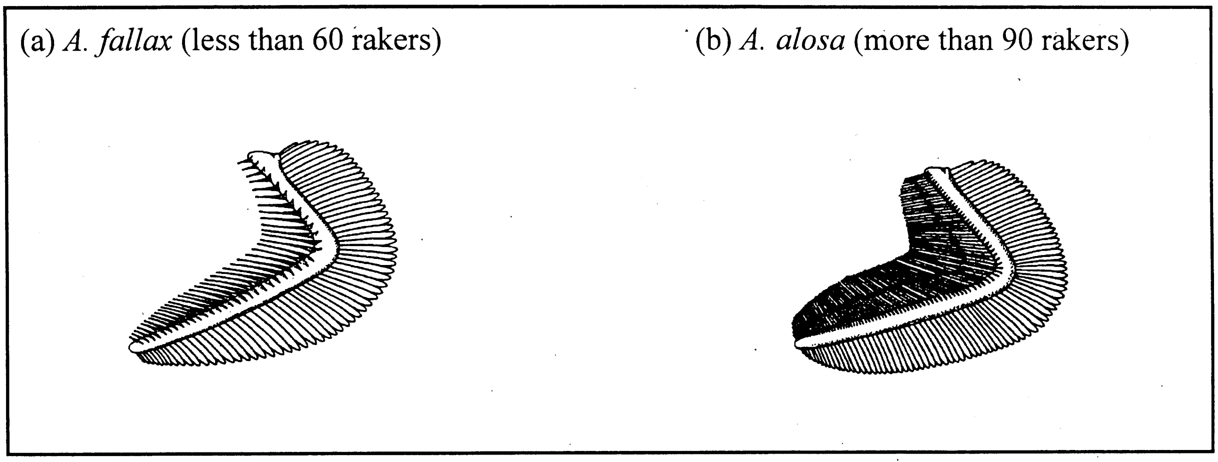
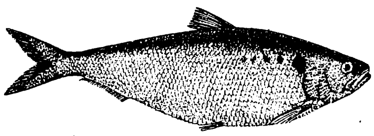
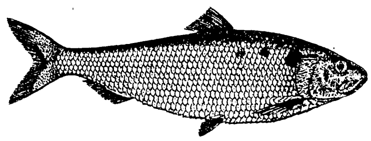


Figure 8.1 First gill arch appearance and approximate number of gill rakers for *Alosa fallax* (a) and *Alosa alosa* (b).

Although little is known about the preferred habitat of shad whilst at sea, both species are recorded in coastal waters and estuaries around the UK throughout the year. Before commencing the freshwater breeding phase of their spawning migration (between April - June), maturing fish form large schools in or near the estuaries. They enter large rivers to spawn, ascending up to 150 km. There is some evidence that shad detect odour and return to their parent river.

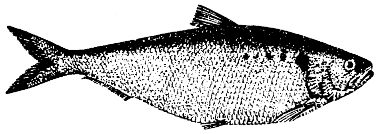


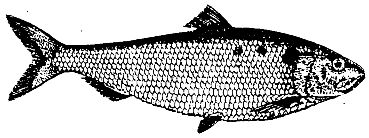


8.1.2 Reproduction and biology

Information from studies on UK populations showed that male twaite shad mature between age 3-4 years, approximately one year before females. The oldest female recorded from the River Severn was estimated at twelve and was making its eighth spawning migration. During the migration period, the sex composition of the run changes. Males make up the largest portion of the run at first, after which the females are dominant. Spawning takes place between mid May and mid June and appears to be dependent on temperature. On the Rivers Wye and Usk, twaite shad are known to spawn in water less than one metre deep, which is usually near deeper pools

Currently there are no known spawning populations of allis shad in the UK and therefore little information on their biology here. From French studies it is known that mature fish run from estuaries into rivers in late spring. Shoals of fish accumulate and spawn at night over gravel substrates in water 1.5 to 2.0 m deep flowing at about 1 ms^{-1}. Water temperature at spawning is generally about 18°C. Afterwards the spent adults drop back downstream to the sea, many of them to die there. The clear eggs remain in crevices in the substrate until they hatch some 4-8 days later. The fry are about 10 mm on hatching but rapidly grow to 8-14 cm after one year. By this time many of





where the fish congregate beforehand. The eggs (2 - 3 mm in diameter) are released into the water column, a proportion of which are deposited on the gravel. The rest drift downstream in the current, developing as they go. Larvae (6 - 8 mm) emerge approximately six days later. The surviving adults return to the estuary after spawning, where a proportion remain until the autumn before migrating seaward. Twaite shad are iteroparous in that they are repeat spawners with the maximum number of spawning migrations recorded being seven. The 0+ fish remain in fresh and/or estuarine waters during the summer, migrating to sea in the autumn. A portion of these re-enter the estuary the following spring, migrating to sea once again in late summer and early autumn. In freshwater juveniles feed mainly on chironomids and simuliidae, and on copepods, cladocerans and mysids in the estuary. While in the estuary and at sea, the adults feed mainly on marine invertebrates and small fish.

them will have descended to the sea and the remainder follow during their second year. The adults mature after 3-4 years at about 30-40 cm when they start their spawning migration. The food of the young fish is mainly bottom living invertebrates, especially midge larvae and crustaceans. The adults, feeding in salt water, predominantly rely on zooplankton but also to a minor extent on small fish.

The population decline of both species in many parts of Europe has been attributed to the effects of pollution, river obstructions and overfishing. It is therefore vital to recognise the importance of any rivers which still have spawning stocks.

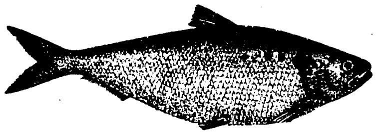
8.1.3 European distribution

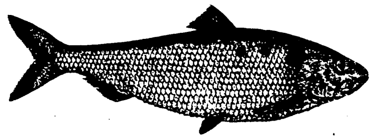
Twaite shad occur along the west coast of Europe, from southern Norway to Morocco and along the eastern Mediterranean (see Figure 8.2).

Twaite shad are native to 14 of the 15

Allis shad occur along the west coast of Europe, from southern Norway to Morocco (see Figure 8.2), and in the Mediterranean eastwards to northern Italy.

Allis shad is native to 12 of the 15 countries





countries of the EU. The species is regarded as Extinct in four, Critically Endangered in one, Endangered in two, Vulnerable in six and Not Evaluated in one (see Appendix 8.1).

of the EU. It is regarded as Extinct in three, Critically Endangered in one, Endangered in six, Vulnerable in one and Not Evaluated in one (see Appendix 8.1).

Most of the rivers used for spawning by *Alosa alosa* and *Alosa fallax fallax* are on the western coast of Europe (see Figure 8.2).

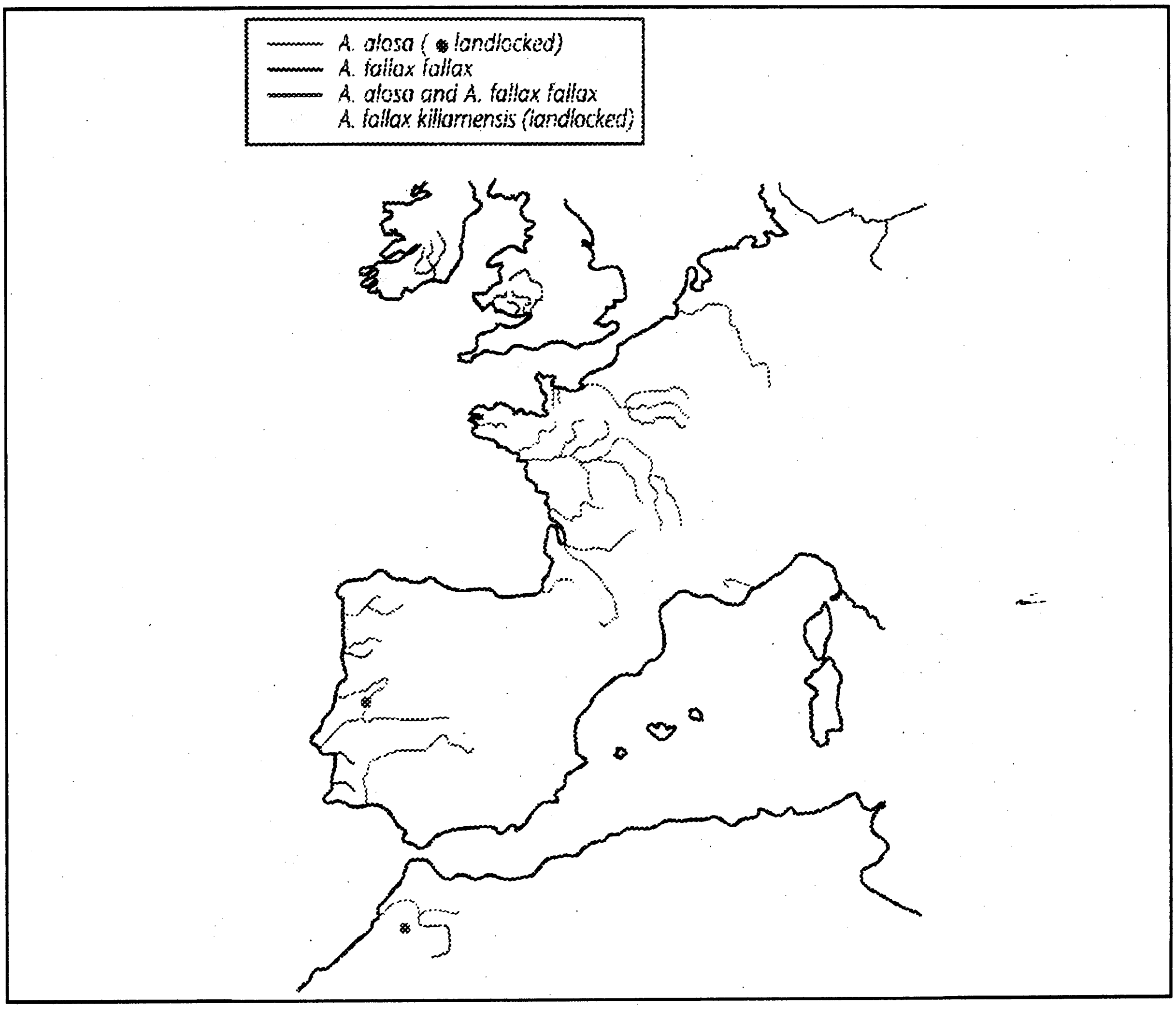
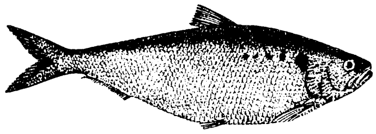


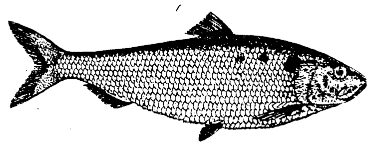
Figure 8.2 Reported spawning distribution of *Alosa alosa* and *Alosa fallax fallax* in Europe.



Several land-locked spawning populations of sub-species which are closely related to twaite shad exist in Ireland, Albania, Italy, Sardinia and Yugoslavia. These sub-species tend to be smaller than the anadromous *Alosa fallax fallax*.

8.1.4 The only rivers in the UK known to have spawning stocks are the Wye, Usk, Severn and Tywi. Recent research strongly suggests the presence of twaite shad spawning grounds in the vicinity of Wigtown Bay in SW Scotland. There is evidence that a spawning population previously existed in the Thames. Recent fisheries survey work in the River Medway found twaite shad downstream of the tidal limit, Allington Lock, which is an impassable barrier to migration.

Information on population size exists only for the Severn since 1979 (see Figure 8.3). These fluctuations possibly reflect the effects of environmental factors, particularly temperature and flow, on the survival of young life stages, from egg to juvenile. It seems that high summer temperature results in good recruitment.



Land-locked populations of allis shad exist in Portugal and Morocco.

8.1.4 There are records of allis shad being caught in a number of UK rivers (the rivers Wye, Severn, Usk and Tywi) and around the coast . There are no known spawning sites in UK rivers. There are also historical records that a spawning population existed in the River Severn and of individual allis shad from some Scottish rivers, e.g. several miles upriver in the Tay and Tweed. Sexually mature allis shad are currently found at spawning time along the Solway Coast and may spawn in one if the rivers there.

Allis shad have suffered considerably from the combined effects of river obstructions, habitat destruction, pollution and overfishing so that they are now considered rare over most of their range. The only breeding populations thought to be successful are in a few rivers in western France (notably the Loire and the Gironde) and Portugal (notably in the Lima and Mondego).

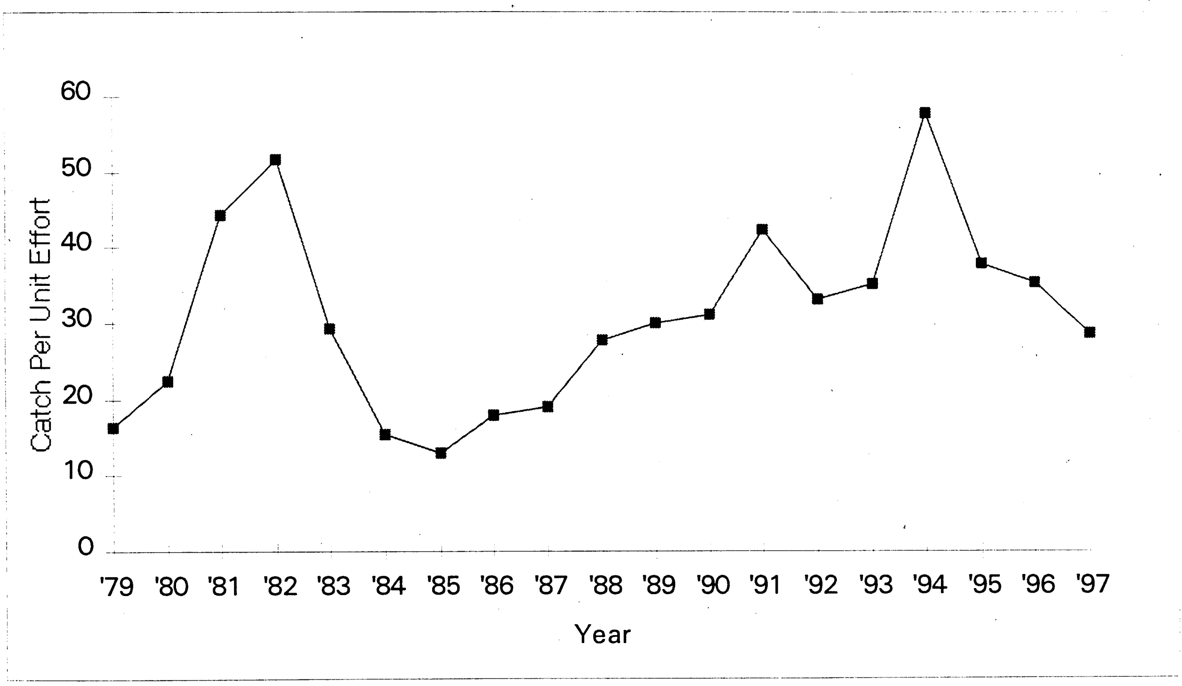


Figure 8.3 **Catch per unit effort of female *Alosa fallax fallax* in the Severn Estuary (1979-1997).**

A survey of coastal netting stations around Scotland showed that low numbers of shad are often taken by netsmen, mostly on the Solway Coast but also in the Moray and Tay Firths and on the Aberdeen and Berwickshire coasts.

8.1.5 The rare and threatened status of twaite and allis shad is reflected in their occurrence on nationally and internationally based protective legislation schedules (see Table 8.1).

Table 8.1 **Summary of legislation relating to *A. alosa* and *A. fallax***

Legislation	***A.fallax***	***A.alosa***
Bern Convention (1979) - Appendix III Member states are required to carry out provisions to ensure the conservation of flora, fauna and their habitats with particular attention to endangered and vulnerable species, including migratory species. Enacted through each member state's legislative system (if there are Regulations which apply).	✓	✓

EC Habitats Directive (EC Directive on the conservation of natural habitats and wild flora (92/43/EEC)) - Annexes II and V EC legislation which was adopted by the UK via the Conservation (Natural Habitats &c.) Regulations, 1994. This places an obligation to assess numbers and exploitation of the population.		✓	✓
Wildlife and Countryside Act (1981)	**Schedule 5** in respect of Section 9(1) intentionally killing, injuring and taking only		✓
	Schedule 9(4)(a) obstructing access to spawning areas, or to damage or destroy gravels used for spawning	✓	✓
UK Biodiversity Action Plan (1994) A framework of proposals to implement the Rio Biodiversity Convention (1992) in the UK which set up Steering Groups to develop a strategy for biodiversity.		✓	✓
EU Red Data Books		see Appendix 1 for designations	

8.2. MAIN THREATS

8.2.1 River and Estuary Barriers. Physical barriers to the movement of shad have been responsible for the decline in certain populations throughout their range. Fish passes designed for salmonids are not altogether suitable for shad as passes are generally characterised by turbulent flow patterns which are not ideal for shad which prefer smooth, laminar flow.

The installation of barriers to migration may also affect the habitat available to shad for spawning both upstream and downstream of the obstruction. The water level increases upstream and decreases downstream, so habitat which was previously suitable for spawning floods or dries out, respectively.

8.2.2 Water Quality (also see Section 2.3 and 2.4). It is believed that poor water quality, in particular low dissolved oxygen associated with pollution from increased urbanisation in the early 19th Century, is the main reason for the decline in the population of shad from the River Thames and other rivers. Other possibilities include increased inert particulate loading (causing bed siltation), temperature changes and ammonia levels.

8.2.3 Water Quantity (also see Section 2.2 and 2.4). Low flows exacerbate poor water quality since the contaminants are diluted less than they are during high flows. In general, water pollution poses most threat during low summer flows when shad migrate to spawn.

When flows are controlled, the needs of juvenile shad and other wildlife should be considered. It appears that high flow levels during late summer affects juvenile mortality, by affecting their food supply and / or by displacing them seaward into the estuary, an environment for which they may not yet be physiologically adapted.

8.2.4 **River Management Works** (also see Section 2.2 & 2.3). The removal of spawning habitat such as gravel shoals, deep pools and other suitable habitat. In-river works resulting in water quality problems e.g. suspended solids re-suspended in the water column, especially during summer months.

8.2.5 **Exploitation**. Incidental catches of adult shad taken by commercial fisheries are considered to be sustainable at present. Some additional juvenile mortality occurs as a result of impingement on power station cooling water intake screens in several estuaries. Further exploitation of shad in the future requires careful consideration.

8.3. CURRENT ACTIVITY

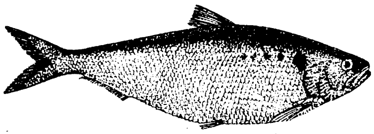
8.3.1 Identification of twaite and allis shad rivers and spawning sites.

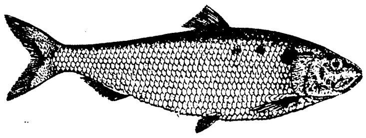
8.3.2 Monitoring of twaite shad migrations involving the collection and analysis of catch data from the River Severn between 1979-1997. Initial work on fish counters on the Rivers Wye and Usk to determine migration and spawning populations.

8.3.3 SNH supports research work in the Solway Firth.

8.3.4 MAFF(CEFAS), SOAEFD and the MBA maintain records of fish caught at sea.

8.4. ACTION PLAN OBJECTIVES AND TARGETS





8.4.1 Seek to ensure the continued survival of twaite shad around the UK.

8.4.2 Confirm the status of the allis shad as a breeding fish in UK waters.

8.4.3 Protect the allis shad in UK waters and seek to ensure the continued survival of stocks.

8.5. PROPOSED ACTIONS WITH PRINCIPAL AGENCIES

8.5.1 Policy and Legislation

8.5.1.1 Modify current legislation (Salmon and Freshwater Fisheries Act, 1975 in England and Wales; The Salmon (Fish Passes and Screens) (Scotland) Regulations 1994 in Scotland) regarding the provision of fish passes suitable for salmonids to include other migratory species such as shad which require different passes and are presently considered with sea fishes in the legislation. (ACTION: Environment Agency, MAFF, SOAEFD, DETR).

8.5.1.2 Prepare guidelines for (local, regional, national) policy makers and legislators on how the species and habitat needs of the shads should be recognised and incorporated into current and future riparian management and development plans. (ACTION: SAP Steering Group).

8.5.2 Site safeguard, land acquisition and management

8.5.2.1 Identify and characterise spawning sites for twaite shad and use this information to identify potential spawning sites for both species of shad. Take into account information from European sites for allis shad. (ACTION: Environment Agency)

8.5.2.2 Seek the protection and positive management of shad habitat (juvenile and adult) and enable the adults to access spawning grounds (particularly where barriers impede access) through the designation of appropriate parts of the catchments where they are found, e.g. as SSSIs or SACs. (ACTION: Environment Agency, EN, CCW, SNH).

8.5.2.3 Seek to secure favourable actions in Local Environment Agency Plans (LEAPs) and other appropriate local plans, e.g. catchment initiatives in Scotland. covering confirmed spawning sites, river migration and juvenile habitat, within one year of discovery. Seek to secure and implement favourable conservation strategies for these rivers by the year 2000. (ACTION: CCW, EN, Environment Agency, BW, SNH, SEPA, SOAEFD).

8.5.2.4 Incorporate the needs of adult and juvenile shad with any activities which could significantly affect river flow levels between May and September, the known migration and spawning season. (ACTION: Environment Agency).

8.5.3 Species management and protection

8.5.3.1 Review quinquennially the distribution and status of shad in the UK. (ACTION: CCW, EN, Environment Agency, SNH).

8.5.3.2 Optimise the range of conditions necessary for the conservation and restoration of shad stocks in the UK. Seek to restore historical populations which may have declined or disappeared and where practicable encourage shad to inhabit their former range by restoring suitable conditions, with a view to extending the breeding distribution in the UK. Consider a translocation project using the nearest suitable stock once appropriate conditions exist at the recipient site. (ACTION: CCW, EN, Environment Agency, SNH).

8.5.3.3 Encourage anglers and net fishermen to record and release the twaite and allis shad they catch, possibly using a shad leaflet to raise awareness. (ACTION: CCW, EN, SNH, SOAEFD, SFCs, Environment Agency, NGO)

8.5.3.4 Twaite and allis shad should be included in a Red Data Book of threatened fish of GB. Information gathered should be incorporated in a national database to contribute to the maintenance of an up-to-date Red List. (ACTION: JNCC, BRC).

8.5.4 Advisory

8.5.4.1 Arrange workshops as necessary for conservation staff, non-Government Organisations (NGOs) and land managers to explain the ecology, distribution and known requirements of shad.

8.5.4.2 Prepare and circulate practical guidelines for riparian landowners and river managers on how to recognise and safeguard the species and habitat needs of shads, particularly with respect to spawning grounds (ACTION: SAP Steering Group).

8.5.5 Future research and monitoring

8.5.5.1 Species Status. Collate information to identify accurately life stages of twaite and allis shad from egg to juvenile, which will help in the identification of possible spawning and rearing areas. Survey current and former sites to establish the current status of both species in the UK. (ACTION: CCW, EN, Environment Agency, SNH, SEPA).

Obtain quantitative information on spawning and nursery sites and relate these to habitat models such as RHS to aid in the prediction of potential spawning areas within catchments. Survey shad catches by coastal and estuarine netting stations to identify possible shad spawning locations. Produce a map to show the distribution of potential sites. (ACTION: CCW, EN, Environment Agency, SNH, SEPA).

8.5.5.2 Spawning and Migration. Obtain information on the behaviour of shad in fresh water (e.g. using radio-telemetry) to identify areas of the river system used during their stay in fresh water. (ACTION: CCW, EN, Environment Agency, SNH).

Assess the impact of environmental factors on the movent of shad in estuarine and fresh waters and the relationship to spawning success. (ACTION: CCW, EN, Environment Agency, SNH).

8.5.5.3 Re-introduction. Investigate the restoration of river migration routes and spawning habitat in rivers formerly occupied by these species to allow translocation of stocks to rivers once suitable conditions are restored. (ACTION: CCW, EN, Environment Agency, SNH).

8.5.5.4 Monitoring Scheme. Establish and maintain a scheme to monitor trends in the status of stocks and enable the regulatory bodies to comply with the Bern Convention and the EU Habitats Directive. Investigate the use of fish counters with shad recognition systems in rivers with known spawning populations as well as incidental catches by anglers and fishermen. (ACTION: CCW, EN, Environment Agency, SNH).

8.5.5.5 Pan-European. Support a study to determine the status, genetics, biology and conservation needs of the shad across Europe to seek to ensure the requirements of the Bern Conservation and the EU Habitats Directive are fulfilled. In particular, test the assumption that UK populations home to their natal rivers, as was found in American tagging studies. (ACTION: CEFAS, SNH, EN, CCW, NGO, Environment Agency).

8.5.6 Communications and publicity

8.5.6.1 Increase public awareness of the presence of shad in local rivers and promote conservation issues. Publicise how the public can help by contributing records to the appropriate body for inclusion in the database, possibly producing a summary poster/leaflet explaining this as well as the identification, distribution, biology and conservation of shad. Develop media opportunities. (ACTION: CCW, EN, Environment Agency, SNH, NGOs).

8.5.7 Steering Group meetings

8.5.7.1 To hold meetings as and when appropriate in order to ensure delivery of the Species Action Plan. (ACTION: CEFAS, CCW, EN, Environment Agency, SNH, NGOs).

Appendix 8.1 Conservation status of twaite and allis shad in European Union countries (Maitland, pers. comm.).

	Alosa alosa	*Alosa fallax*
Extinct 'when there is no reasonable doubt that the last individual has died'	Belgium Luxembourg Sweden	Belgium Luxembourg Netherlands Sweden
Critically Endangered 'when it is facing an extremely high risk of extinction in the wild in the immediate future'	Denmark	Denmark
Endangered 'when it is not Critically Endangered but is facing an extremely high risk of extinction in the wild in the near future'	Germany Ireland Netherlands Portugal Spain UK	Portugal Spain
Vulnerable 'when it is not Critically Endangered or Endangered but is facing a high risk of extinction in the wild in the medium-term future'	France	France Germany Greece Ireland Italy UK
Not Evaluated 'when it has not yet been assessed against the criteria'	Finland	Finland
Absent from red data book or equivalent	Austria Greece Italy	Austria

Appendix 8.22 Key to Abbreviations

BRC	Biological Record Centre (at IFE)
BW	British Waterways
CCW	Countryside Council for Wales
DANI	Department of Agriculture, Northern Ireland
DETR	Department of the Environment Transport and the Regions
DoE(NI)	Department of Environment, Northern Ireland
EN	English Nature
EU	European Union
IFE	Institute of Freshwater Ecology
IUCN	International Union for the Conservation of Nature and Natural Resources
JNCC	Joint Nature Conservation Committee
LEAP	Local Environment Agency Plan
MAFF	Ministry of Agriculture, Fisheries and Food
MBA	Marine Biological Association
NGO	Non-Government Organisation
NRA	National Rivers Authority
RHS	River Habitat Survey
RPBs	River Protection Boards
SAC	Special Area of Conservation
SEPA	Scottish Environmental Protection Agency
SFC's	Sea Fisheries Committees
SNH	Scottish Natural Heritage
SOAEFD	Scottish Office, Agriculture, Environment & Fisheries Department
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
UK	United Kingdom
WCA	Wildlife and Countryside Act
WOAD	Welsh Office Agriculture Department

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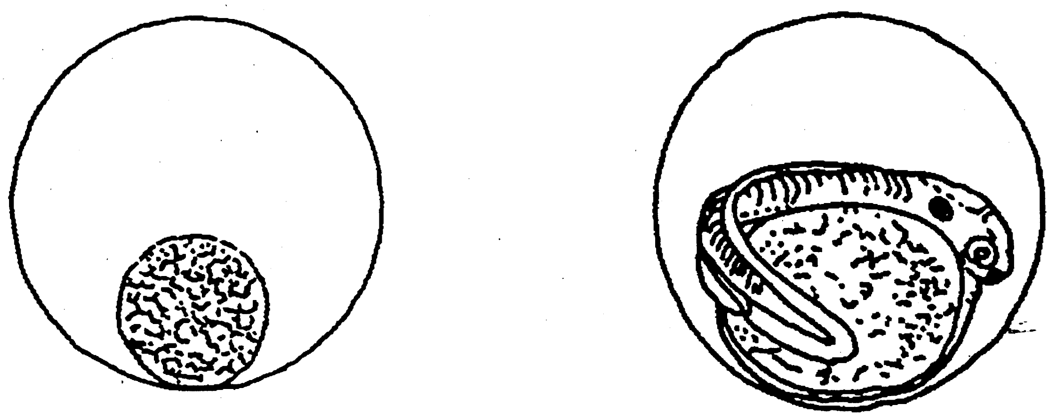
APPENDIX 1 IDENTIFICATION OF THE DIFFERENT LIFE STAGES OF SHAD

1. Eggs

Shad eggs are approximately 2-3 mm in diameter and, before the development of larvae, completely colourless and transparent (see Figure A.1 (a)). The colourless yolk sac distinguishes shad eggs from those of other species, which contain pigment. The granular consistency and absence of colour in the yolk sac of shad eggs resemble clear oil droplets within the eggs. After preservation in 70% methanol, the yolk turns white and opaque, although the rest of the egg remains clear.

It has been reported that shad eggs can successfully develop between 15-25°C. Various authors measuring egg development in several river systems have reported incubation periods of 3-5 days at temperatures between 16.4-19°C. Larvae are apparent to the naked eye within the first days of incubation as a semi-transparent mass within the clear egg. Before hatching, the notochord and eyes are visible (see Figure A.1 (b)) and the larvae move within the eggs, twitching against the outer membrane before hatching. This activity was observed in vitro for up to 12 hours before the larvae ceased to move and were presumed dead.



(a) Egg before development. **(b) Egg during development.**

Figure A.1 Diagram of shad egg (a) before and (b) during the development of larvae (from Erhenbaum, 1894).

2. Pro-larvae, Larvae and Post-larvae

Upon hatching the yolk sac is visible (see Figure A.2).

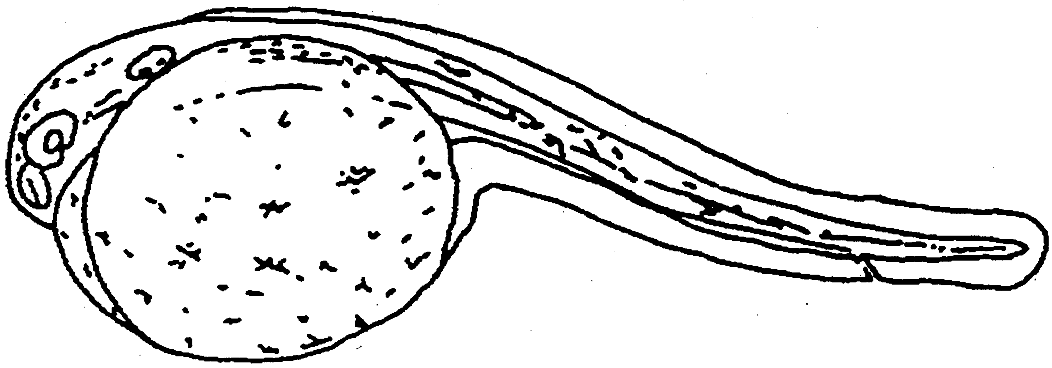


Figure A.2. Newly hatched shad larva (4.25mm long), from Erhenbaum (1894).

Newly hatched from eggs collected in the rivers Wye and Usk in 1997 were approximately 5 mm long. Erhenbaum (1894) and Mohr (1941) recorded newly hatched larvae to be between 5 - 6 mm and 7 - 8 mm long, respectively. Newly hatched larvae taken from the rivers Wye and Usk in 1997 were able to swim to the surface of the collection pots before sinking back to the bottom. Those which hatched did not survive in the sample pots for more than eight hours.

Larvae with a yolk-sac are referred to as pro-larvae (see Figure A.2 and A.3 (a)). Hass (1969) devised a key to separate yolk-sac lacking larvae of twaite shad from those of smelt, anchovy, herring and sprat (see Table A.1).

Table A.1 Translation of Hass's key for yolk-sac lacking larvae of Clupeiformes from the lower-Elbe.

1	-Body sides above the gut pigmented, sometimes very lightly	2
	-body sides above the gut not pigmented	9
2	-pigments of the body sides above the gut form continuous stripes, which may be discontinuous but do not consist of separated points	6
	-pigments of the body sides above the gut consist of a row of pointed or elongated spots	3

3	-pigments of the body sides above the gut are sharp or indistinguishable but extend beyond the middle of the body	4
	-pigments of the body sides above the gut do not extend beyond the middle of the body	7
4	-from the middle of the body the underside of the gut is pigmented up to the anus, sometimes this is very delicate or completely absent	5
	-the pigmentation of the underside of the gut which starts from the middle of the body is very distinctly developed	6
5	-the distance from the front orbit to the upper fringe of the mouth is significantly smaller than the smallest diameter of the eye	8
	-the distance from the front orbit to the upper fringe of the month is as big as the smallest diameter of the eye	6
6	-eye nearly round, not curviform	II
	-eye obviously higher than wide, curviform	I
7	-pigmentation of the underside of the gut starts at the front part of the body	8
	-pigmentation of the underside of the gut starts in a single or double row near the middle of the body, where there is no more pigment above the gut at the sides of the body. However, pigmentation of the underside of the gut may sometimes be completely absent	9
8	-vertical row of pigment at the base of the pectoral fin often consists of single points	II
	-vertical pigment row at the base of the pectoral fin is absent, not even seen in outlines	I
9	-anus reaches at least the back fringe of the dorsal fin	III
	-anus situated well beyond the back fringe of the dorsal fin	IV

I Smelt
II Twaite shad
III Anchovy
IV Herring & Sprat

More recently Taverny (1991) produced a key for larvae and post-larvae (see Table A.2). This key does not include smelt since they spawn around February which is approximately three months earlier in the year than shad, so that smelt juveniles are well developed and easy to distinguish from other species by size alone when sampling in late summer / autumn.

Table A.2 Translation of Taverny's key for the identification of clupeid larvae and post-larvae of twaite shad, sprat, herring and pilchard.

		Twaite shad (*Alosa fallax*), see Figures A.2 and A.3 (a)	Sprat (*Sprattus sprattus*)	Herring (*Clupea harengus*)	Pilchard (*Sardina pilchardus*)
LARVAE	Newly hatched larvae	4.25mm	3.0 - 3.6mm elongated clupeid form, yolk sac segmented without blood cells containing lipid	5.5 - 5.9mm	3.3 - 4.0mm
	Length after yolk sac absorbed (mm)		5.6 - 6.0mm	8 - 10mm (totally absorbed)	4.0 - 5.5
	Position of the anus	very far back	very far back	very far back	very far back
	Eye pigmentation		pigmented from 5.0 - 6.0 mm	total	
	Body pigmentation		small spots on the head and the line of the back	typically clupeid	small spots scattered from the back of the head to the tail - 1 on the belly near to the tail

		Twaite shad (*Alosa fallax*), see Figure A.3 (b) and (c)	Sprat (*Sprattus sprattus*), see Figure A.5	Herring (*Clupea harengus*), see Figure A.4	Pilchard (*Sardina pilchardus*), see Figure A.6
POST-LARVAE	Importance of the tail	2/3 of body length	less than 1/6 of body length	more than 1/6 of body length	
	Fins	at 20mm all the fins are present	at 18 - 20mm the pelvic fins appear 5.4 muscle units behind the pyloric sphincter muscle (visible in young shad); at 8mm, the dorsal fin starts to develop; at 20mm the dorsal & anal fins are completely developed	at 20 - 40mm the pelvic fins appear 7 to 8 muscle units behind the pyloric sphincter muscle (visible in young shad)	at 18 - 20mm the pelvic fins appear at the same time as the pyloric sphincter muscle; the dorsal fin develops at 7.5mm
	Number of muscle units (on the trunk)	49 - 46 at 20 - 35mm	37 at 10mm 37 - 35 at 10 - 20mm 35 - 31 at 20 - 40mm	47 at 10mm 47 - 46 at 10 - 20mm 46 - 41 at 20 - 40 mm	42 - 41 at 10mm 42 - 41 at 10 - 20mm 41 - 36 at 20 - 40mm
	Anus			very close to base of caudal fin	

	Twaite shad (*Alosa fallax*), see Figure A.3	Sprat (*Sprattus sprattus*), see Figure A.5	Herring (*Clupea harengus*), see Figure A.4	Pilchard (*Sardina pilchardus*), see Figure A.6
Pigmentation	at 20mm one row of spots on ventral side; 1 spot on back & 2 - 3 on mid-lateral side of tail	same as herring	2 rows of spots on the same side. 12 - 14 on the ventral surface and 10 - 12 next to it.	same as herring
Swim bladder development			10mm in winter 15mm in summer	

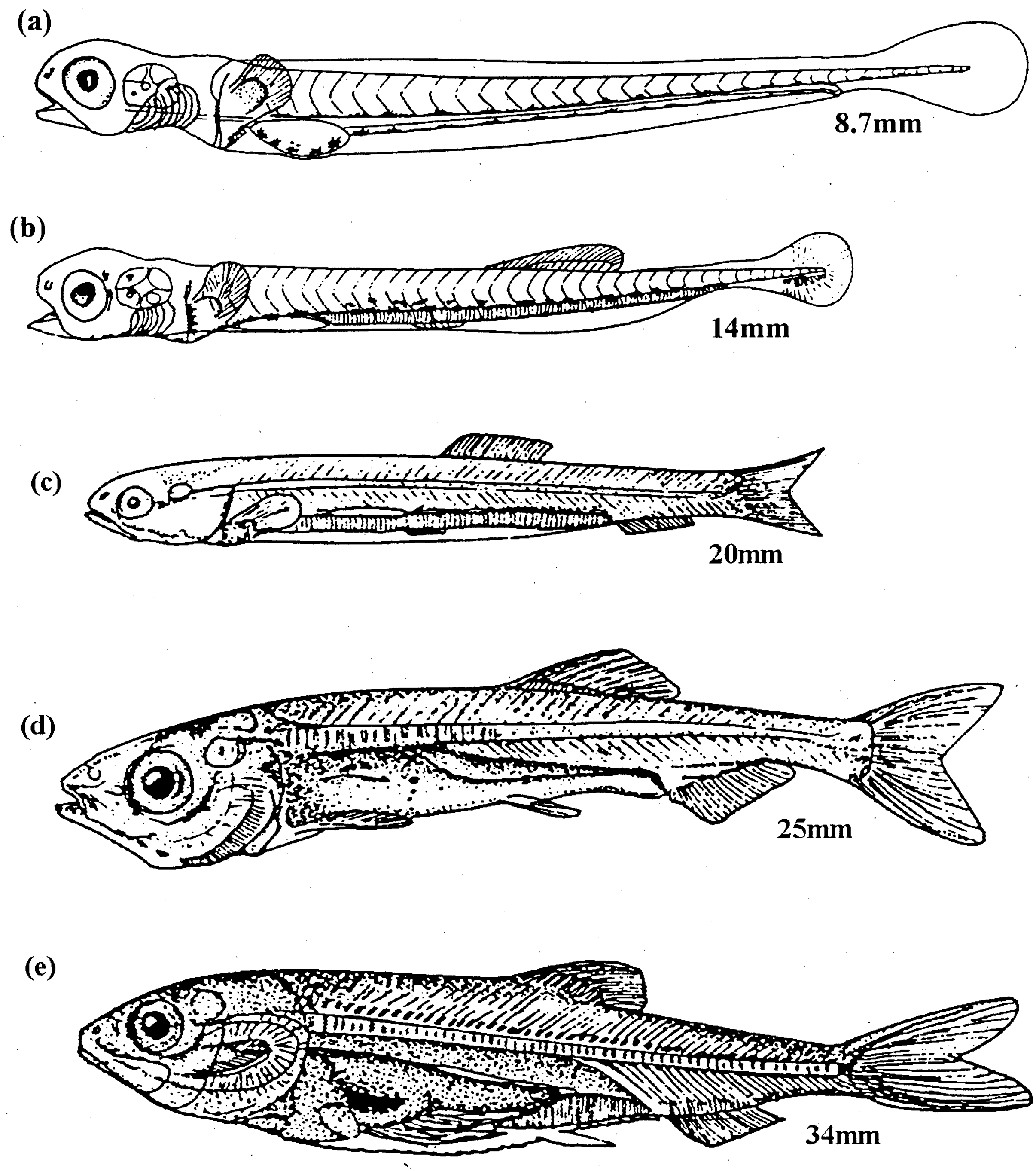


Figure A.3 Diagrams of twaite shad redrawn by Quignard and Douchement (1991) from the figures of Erhenbaum (1894) and Mohr (1941); (a) pro-larva six days after hatching, (b) and (c) post-larvae, (d) transitional larva, (e) juvenile.

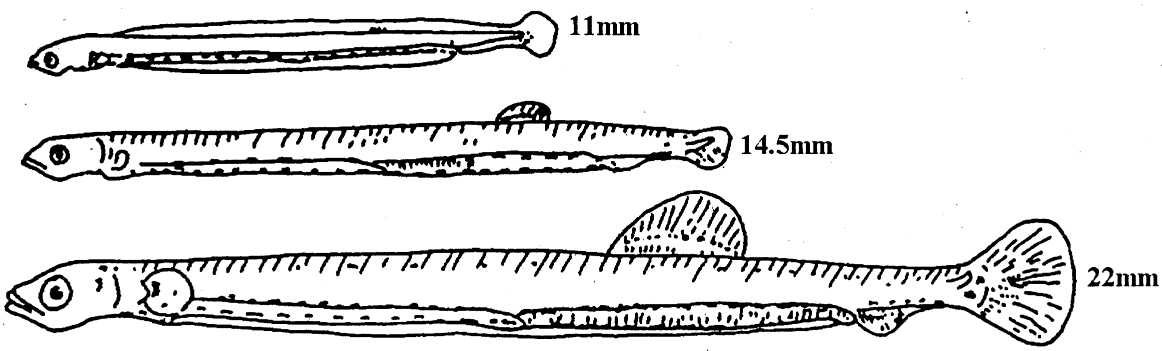


Figure A.4 Herring post-larvae (from Russell, 1976)

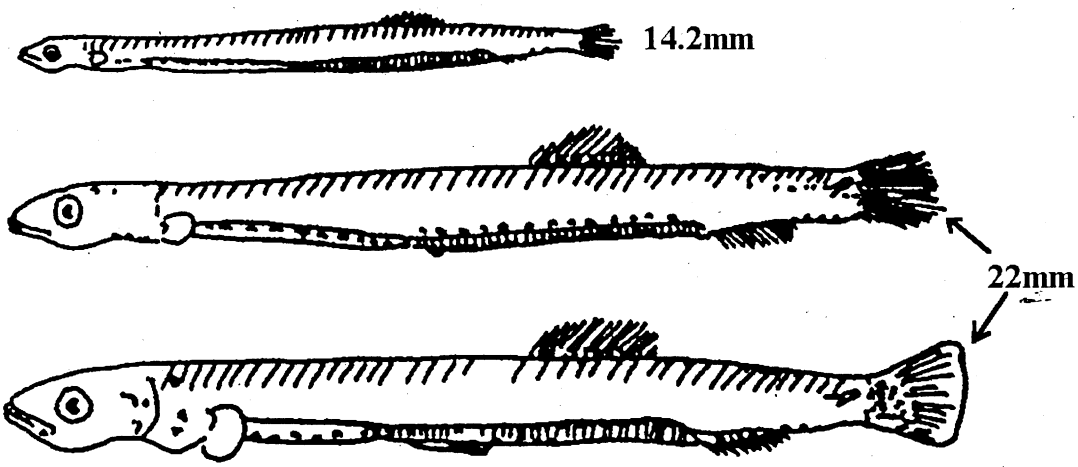


Figure A.5 Sprat post-larvae (from Russell, 1976)

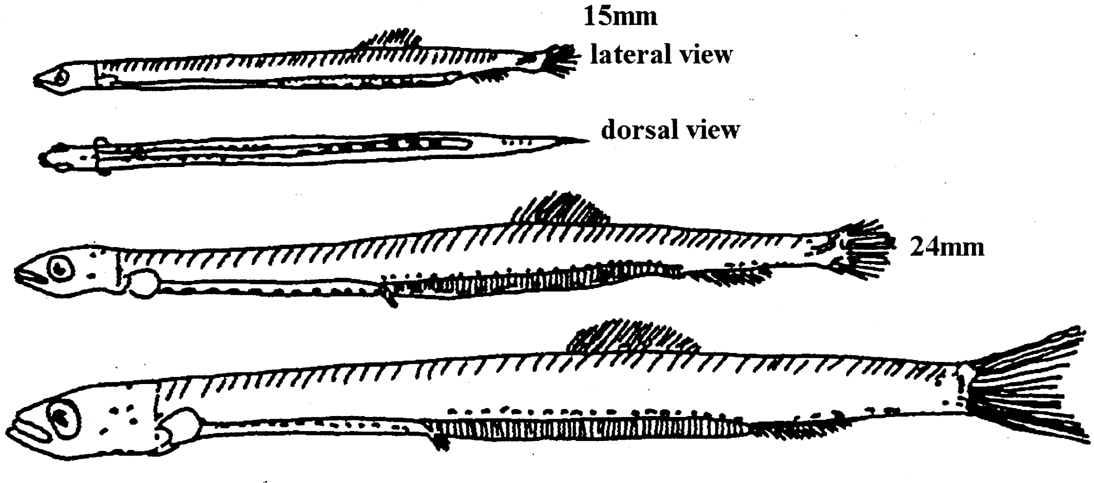


Figure A.6 Pilchard post-larvae (from Russell, 1976)

Measurements of pro-larvae can help in their identification (see Figure A.7 and Table A.3).

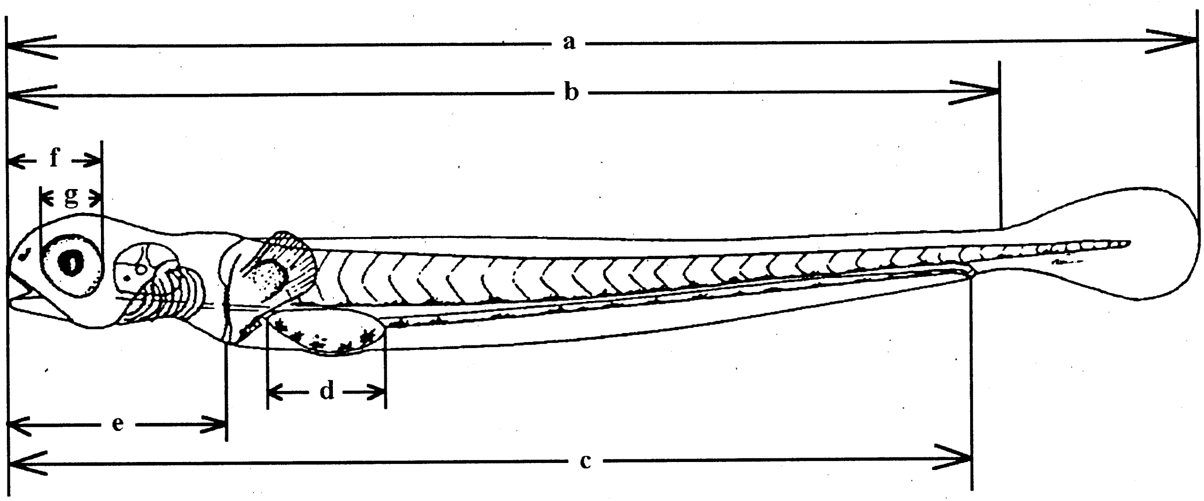


Figure A.7 Description of body measurements of pro-larvae presented in Table A.3 (Quignard and Douchement (1991) from the figures of Erhenbaum (1894) and Mohr (1941)); (a) total length, (b) standard length, (c) length to anus, (d) yolk sac, (e) head length, (f) back of eye to snout, (g) eye diameter.

Table A.3 Body measurements of pro-larvae (mm), from Aprahamian (1982). See Figure A.7 for description of measurements.

Total length	Standard length	Length to anus	Length to anus as % of standard length	Yolk sac	Head length	Head length as % of standard length	Back of eye to snout	Eye diameter
6.205	5.986	4.891	81.71	1.387	0.803	13.41	0.438	0.365
6.497	6.351	5.183	81.61	1.825	0.511	8.05	0.475	0.219
6.497	6.351	5.256	82.76	1.533	0.803	12.64	0.511	0.329
6.789	6.570	5.402	82.22	1.533	0.876	13.33	0.475	0.380
6.862	6.643	5.402	81.32	1.387	0.876	13.19	0.475	0.350
6.862	6.643	5.402	81.32	1.825	0.73	10.99	0.526	0.365
7.154	6.862	5.329	77.66	1.752	0.913	13.30	0.548	0.365
7.373	7.227	5.840	80.81	1.606	0.949	13.13	0.621	0.329
7.592	7.300	5.913	81.0	1.314	0.949	13.00	0.511	0.378
7.592	7.373	6.132	83.17	1.679	0.986	13.37	0.526	0.365
7.665	7.446	6.059	81.37	1.533	1.022	13.73	0.489	0.365
7.665	7.446	6.132	82.35	1.570	1.022	13.73	0.475	0.402
7.738	7.373	6.132	83.17	1.752	1.037	14.06	0.511	0.365
7.738	7.519	6.132	81.55	1.825	0.913	12.14	0.657	0.438
7.811	7.592	6.169	81.26	1.46	1.022	13.46	0.548	0.380
7.811	7.592	6.205	81.73	1.606	0.986	12.98	0.584	0.402
7.884	7.592	6.351	83.65	1.752	1.095	14.42	0.730	0.402
8.03	7.665	6.205	80.95	1.606	1.022	13.33	0.584	0.438
8.249	7.957	6.242	78.45	1.606	1.095	13.76	0.584	0.402
9.198	8.906	7.227	81.15	1.533	1.168	13.11	0.511	0.365

3. Juveniles

When fully formed (at around 35mm) the larvae become juveniles (see Figure A.3 (d) and (e)). The key for the identification of adults may then be used to separate the species (see Section 4 below).

4. Adults

Herring-shaped fish (see Figure A.8).

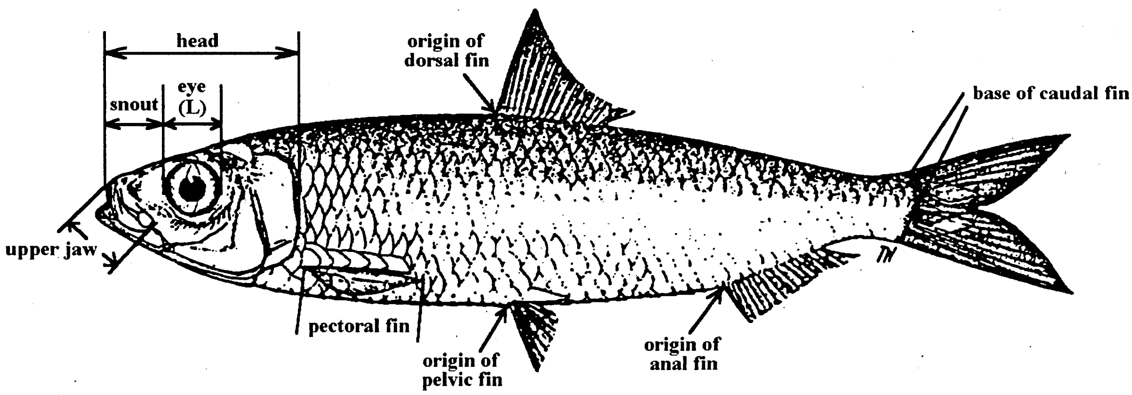
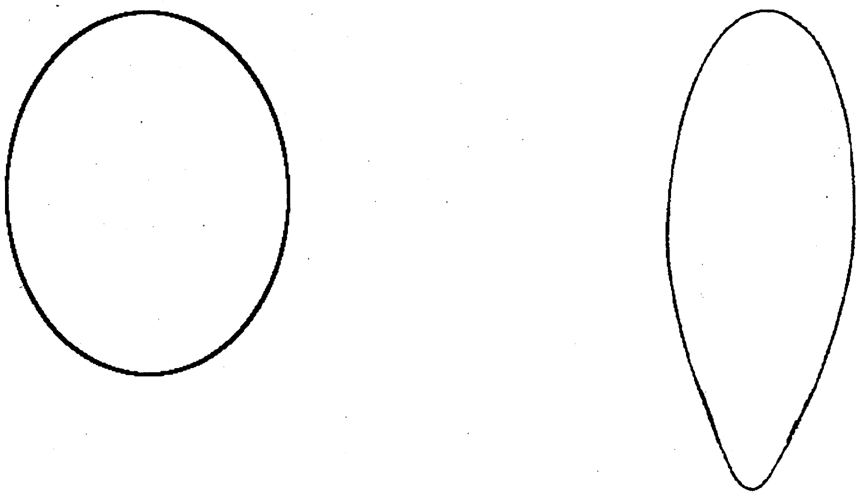


Figure A.8 Morphometric characters and ways of measurement of a typical herring-like fish, according to Whitehead (1985).

1	Slender-bodied fish, laterally rounded (see Figure A.9 (a))	2
-	Deep-bodied fish, laterally compressed (see Figure A.9 (b)). Ventral scales may form a sharp keel of scutes (see Figure A.10)	3



(a) anchovy (b) clupeid

Figure A.9 Lateral shape of families included in the key (adapted from Wheeler, 1978).

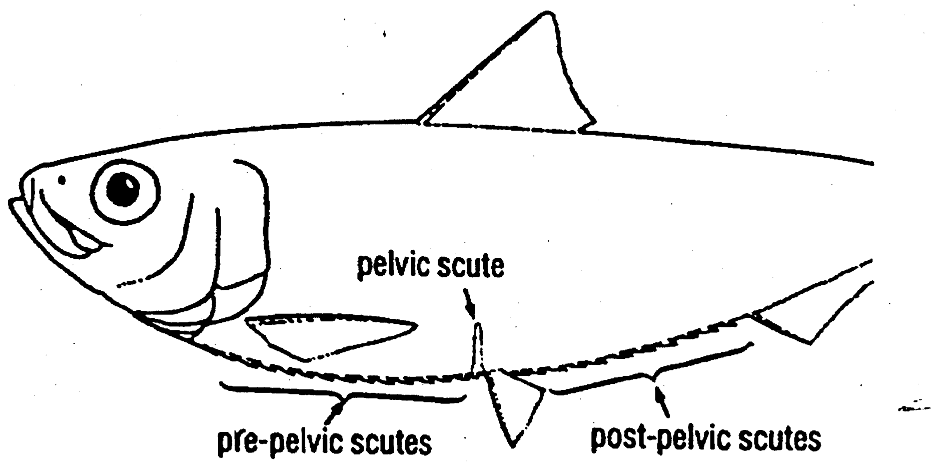


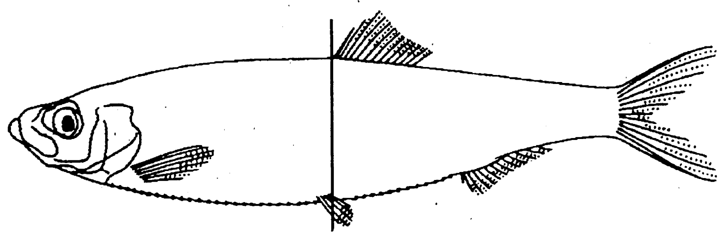
Figure A.10 Ventral scutes formed by scales along the ventral carina (Whitehead, 1985).

2 Ventral scales form a faint ridge, but not sharp scutes. Operculum strongly ridged. Last two anal fin rays elongated. — PILCHARD

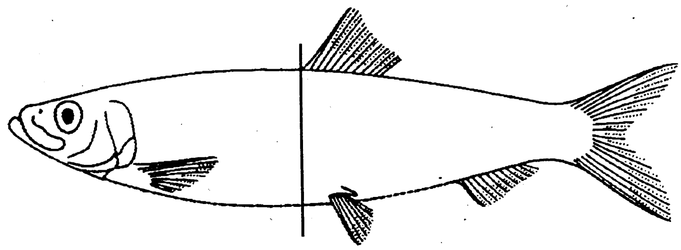
\- No ventral keel. Operculum not ridged. Anal fin rays of equal proportion. — ANCHOVY

3 Dorsal fin originates posterior to pelvic fin. (see Figure A.11 (a)). — SPRAT

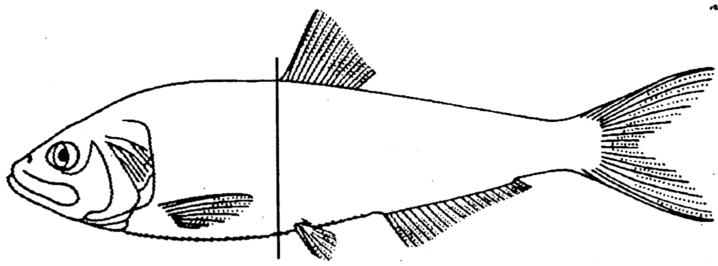
\- Dorsal fin originates in the same position or anterior to pelvic fin (see Figure A.11 (b) and (c)). — 4



(a) Sprat



(b) Herring



(c) Shad

Figure A.11 Respective positions of dorsal and ventral fins of sprat, herring and shad (adapted from Wheeler, 1978)

4 Upper jaw rounded (see Figure A.12 (a*)). Operculum not ridged. Posterior edge of maxillary does not reach beyond posterior edge of eye. Oval eye (wider than long). HERRING

- Upper jaw has distinct notch into which the tip of the lower jaw fits (see Figure A.12 (b*)). Operculum weakly ridged. Posterior edge of maxillary reaches beyond posterior edge of eye. Oval eye (longer than wide). SHAD

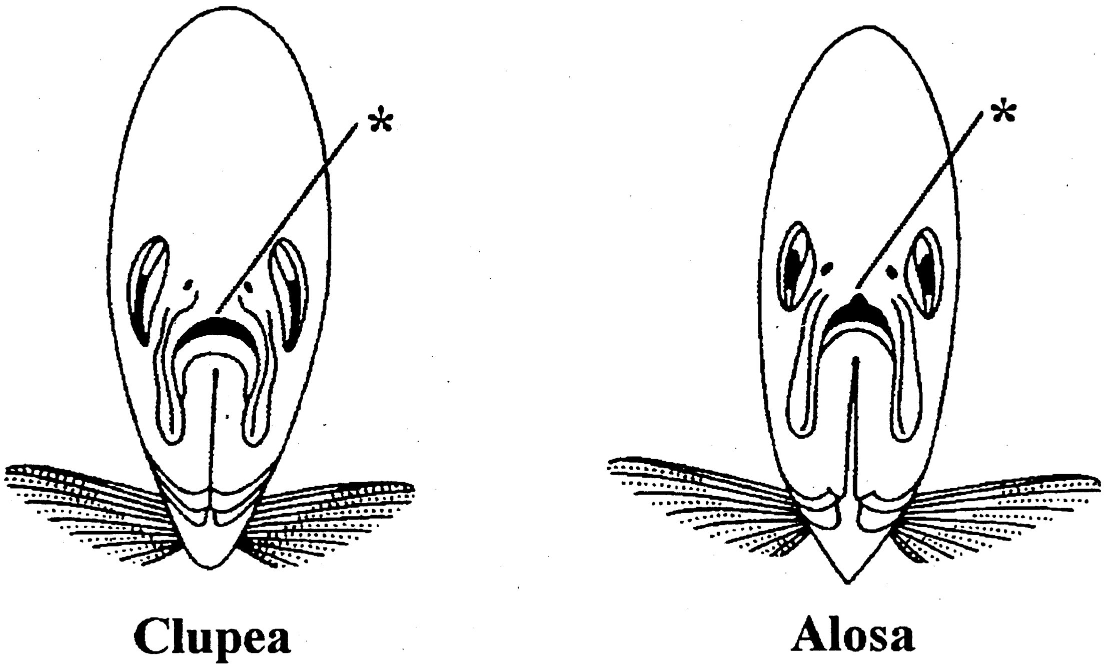


Figure A.12 Heads of herring and shad showing upper jaw* (from Wheeler, 1978)

KEY TO SPECIES

PILCHARD

family CLUPEIDAE
genus SARDINA
One British species, *Sardina pilchardus*

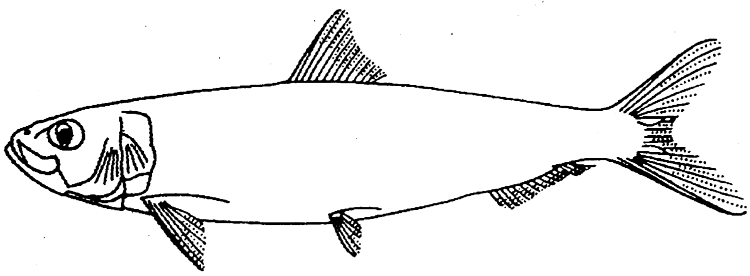


Figure A.13 Diagram of a pilchard (*Sardina pilchardus*) (from Wheeler, 1978)

ANCHOVY

family ENGRAULIDAE
genus ENGRAULIS
One British species, *Engraulis encrasicholus*

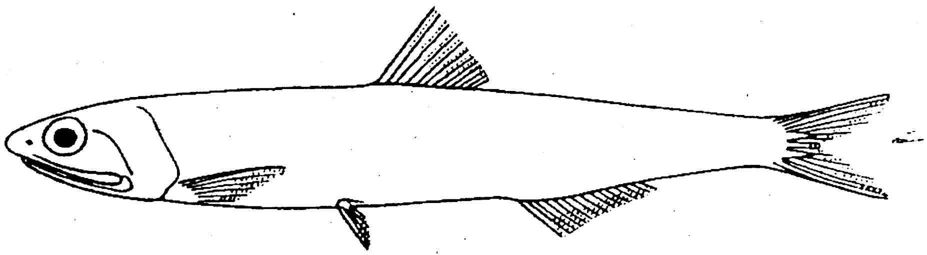


Figure A.14 Diagram of an anchovy (*Engraulis encrasicolus*) (from Wheeler, 1978)

SPRAT

family CLUPEIDAE
genus SPRATTUS
One British species, *Sprattus sprattus*

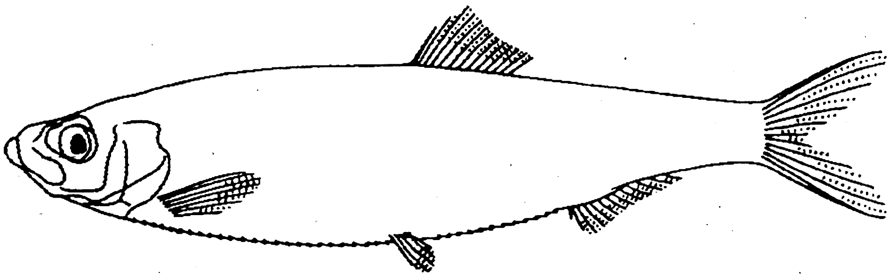


Figure A.15 Diagram of a sprat (*Sprattus sprattus*) (from Wheeler, 1978)

HERRING

family CLUPEIDAE
genus CLUPEA
One British species, *Clupea harengus*

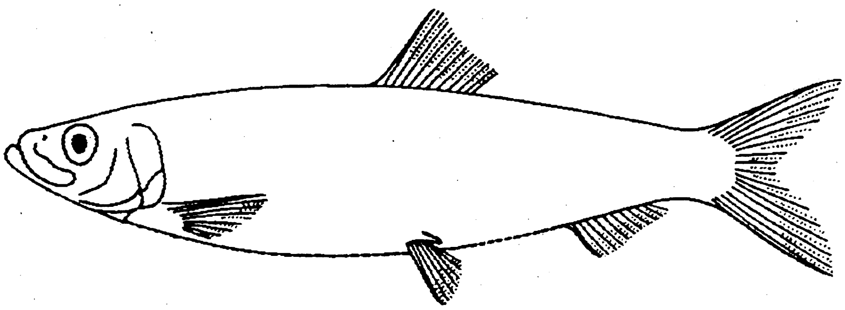


Figure A.16 Diagram of a herring (*Clupea harengus*) (from Wheeler, 1978)

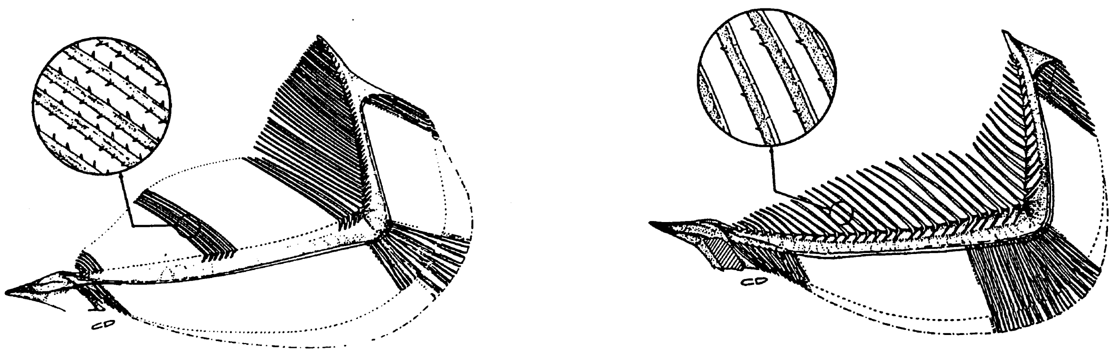
SHAD

family CLUPEIDAE
genus ALOSA

Two British species, *Alosa alosa* and *Alosa fallax*

1 Gill rakers are longer than gill filaments (Figure A.17 (a)) and more numerous, depending on size (Figure A.18). Each gill raker is densely covered with lateral spines (Figure A.17 (a)). Base of caudal fin is covered with many tiny scales with 2 enlarged scales (alae) on either side. Scales are small and arranged in an irregular pattern. — ALLIS SHAD FigureA.19

\- Gill rakers are shorter than gill filaments (Figure A.17 (b)) and less numerous, depending on size (Figure A.18). Each gill raker has few lateral spines (Figure A.17 (b). Base of caudal fin is covered with many tiny scales and 2 enlarged scales (alae) on either side. Scales are large and arranged in a regular pattern. — TWAITE SHAD FigureA.20



(a) allis shad **(b) twaite shad**

Figure A.17 First gill arches of (a) allis shad (*Alosa alosa*) and (b) twaite shad (*Alosa fallax*) showing enlarged individual gill raker structure (from Quignard and Douchement, 1991).

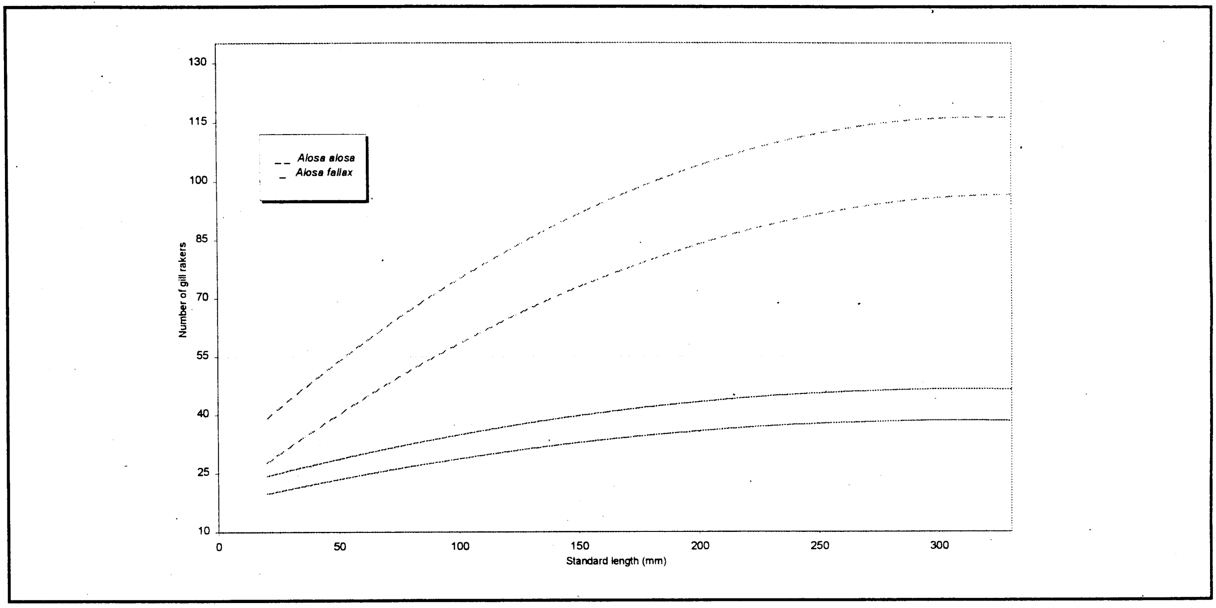


Figure A.18 **Smoothed minimum and maximum number of gill rakers for allis shad (*Alosa alosa*) and (*Alosa fallax*) in relation to standard length (reproduced from Taverny, 1991).**

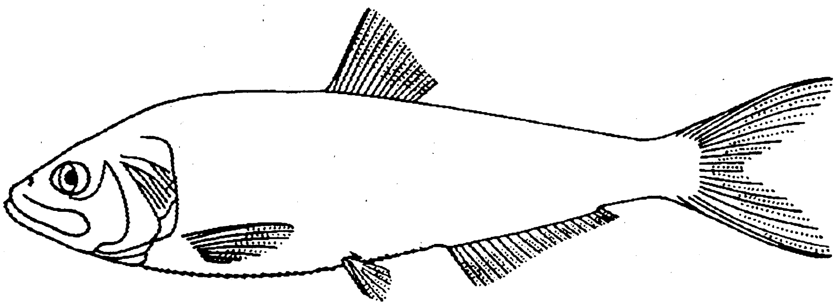


Figure A.19 **Diagram of an allis shad (*Alosa alosa*), from an illustration by P. Stebbing in Wheeler (1978).**

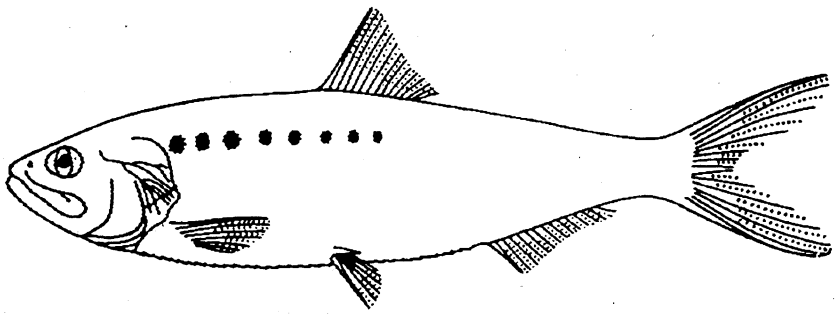


Figure A.20 **Diagram of a twaite shad (*Alosa fallax*), from an illustration by P. Stebbing in Wheeler (1978).**