The Distribution, Biology and Ecology of Shad in South-West England

R&D Technical Report W1-047/TR

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This report presents the findings from a 2 year collaborative project, between the Environment Agency and English Nature, studying the distribution, biology and ecology of shad *(Alosa sp)* in the Environment Agency's south-west region. Through this study a successful survey methodology for shad has been designed. This has led to changes in our understanding of shad ecology and distribution in the South West region. The conclusions and recommendations provide essential guidance and information for similar projects.

Keywords
Allis shad, Twaite shad, *Alosa alosa, Alosa fallax*

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EXECUTIVE SUMMARY

Allis (*Alosa alosa*) and twaite shad (*Alosa fallax*) occur throughout Europe, but in recent years the population of both species has declined. This has been attributed primarily to;

- poor water quality;
- low water flows;
- habitat destruction or degradation and,
- the construction of large navigation weirs that hinder shad access to spawning grounds.

There is a lack of information about the distribution and spawning status of allis and twaite shad in the United Kingdom, although evidence suggests there may be spawning populations, particularly in south-west England. In the South West shad have been recorded from estuaries and notably, adult allis shad from the River Tamar, highlighting the need to investigate both species in the area. This Research and Development project, concentrating in south-west England, is intended to be used as a template for the investigation of shad in other Environment Agency regions.

The Environment Agency is a lead partner in the Biodiversity Species Action Plan (BAP) for both shad species and has therefore signed up to specific actions. This project aimed to deliver some of the actions attributed to the Environment Agency, in particular to investigate the current population and spawning status of shad and to develop species monitoring and management plans. Specific project tasks included the approach of potential project partners and useful sources of information, and the assembly of information on shad distribution, biology, ecology and similar studies. Allis and twaite shad were studied in the marine phase, mainly through recording commercial by catches of shad in trawls and examining specimens. Studying the shad freshwater migration phase involved liasing with salmon netsmen and river anglers, as well as using video footage from fish counters. Catches were recorded and specimens examined, where available. Assessment of spawning habitat and surveys for shad eggs and juveniles were also undertaken if records (e.g. video counter) indicated shad had moved into freshwater.

A wide range of potential project partners were contacted, including DEFRA and Sea Fisheries Officers, nature conservation organisations, marine zoological research organisations, information and record centres, angling clubs, fishing tackle shops, commercial fishermen, salmon netsmen, fish wholesalers/auctioneers and fishmongers. A poster and recording form were designed and distributed, including project information, to a range of people from the groups listed above. The project was also promoted through the media, in press, by radio and on television. People were encouraged to contact the Agency with records of shad catches, or in the case of commercial fishermen, with specimens of shad caught as a by catch. The sex, stomach contents, parasites and sexual condition of specimens was recorded, and measurements/counts were made of certain biological characters, such as total body length, body weight and number of gill rakers on the first gill arch. Age-class and spawning history was estimated using fish scales.

In the marine phase twaite shad were recorded at approximately twice the frequency of allis shad. Both shad species were distributed all around the South West coast,

particularly along the south coast, although this may reflect a greater fishing effort on the south coast compared to the north. Anecdotal evidence suggests that catches of shad at sea were significantly greater during 2000 than in previous years; occasionally catches of up to one and a half tonnes of shad were made off the coast of south-west England. Allis and twaite shad were usually caught in trawls and were most abundant during the winter months offshore of Lands End, Looe and Plymouth (South-east Cornwall), Torbay (South Devon) and Lyme Bay (South Dorset). Significant numbers of records also came from fishermen using inshore bass and gill nets.

Although twaite shad were the commoner species at sea, allis shad were recorded far more frequently than twaite from estuaries in the South West. Most records of shad caught during their freshwater phase came from salmon netsmen. Adults of both species were recorded from the Exe and Torridge estuaries in Devon. Adult allis shad were also recorded from the Tamar and Fowey estuaries in Cornwall, with anecdotal reports describing catches in the estuaries of the Camel, Fal/Helford and Lynher, Cornwall, and the Dart Estuary, Devon. Immature allis shad were recorded from the Camel, Fal/Helford and Fowey estuaries in Cornwall, and from the Dart and Kingsbridge estuaries in Devon.

Shad were observed migrating upstream on video footage taken at Gunnislake Fish Pass on the River Tamar. Gunnislake Weir forms an artificial boundary between fresh and salt water, previously considered to be impassable to shad. Anglers caught adult allis shad in spawning condition as far as fifteen miles above the tidal limit in the River Tamar. Additionally, salmon netsmen in the Tamar, Fowey and Torridge estuaries caught adult allis shad in spawning condition and in June 2001, two spent males were caught in the Tamar Estuary. Although twaite shad were caught from the Torridge and Exe estuaries, fish in spawning condition were only caught from coastal waters. Seine netting was carried out in the Camel, Tamar, Helford and Fal estuaries from May until September 2000 (No juvenile shad were found; sample methods, sites and conditions were designed to catch juvenile bass). A one-day survey of the Tamar Estuary at Holes Hole (National Grid Reference SX 428653), in August 2001, also failed to detect juvenile shad.

River Habitat Survey (RHS) methodology was used to determine likely spawning habitat on the River Tamar. Surveys for shad eggs were carried out in the River Tamar and upper Tamar Estuary from June until August 2000, using kick-sampling methods. Shad eggs were found at one site immediately below Gunnislake weir (National Grid Reference SX 436712). This site was similar to descriptions of shad spawning sites on rivers with known populations. The eggs were identified as alosid by staff at the Agency Fish Hatchery, and strongly suspected to be those of allis shad, although this was not conclusively proven. Attempts were made to hatch and rear the eggs; in 2000 and 2001 under laboratory conditions and in 2002 at Calverton Fish Hatchery. Upon hatching, the development and behaviour of the larvae confirmed that the eggs were alosids. The larvae were very similar to descriptions and diagrams of allis and twaite shad larvae in literature, although the larvae did not survive long enough to permit conclusive identification of shad species.

Shad eggs were present below Gunnislake weir from mid-June until early August 2000, and from mid-May until mid-June 2001 (In 2002, eggs were present in mid-June although the exact period of egg presence was not monitored). This corresponded with periods in which shad were observed migrating upstream at the Gunnislake Fish Pass and catches were made by anglers in freshwater. Gonadosomatic indices (gonad weight in proportion to body weight) calculated for allis shad in the Tamar were greatest in May and June. In 2000, most observations of shad migrating upstream at Gunnislake Fish Pass were in June, whereas in 2001, upstream shad migration was in May. These observations suggest that spawning may occur slightly later in the Tamar than in other allis shad populations; one author described peak spawning in the Loire as occurring in April/May. Males were caught by estuary netsmen earlier in the year than females which suggests, as reported in other studies, that male allis shad migrate first followed by females later.

The timing of spawning and upstream migration of allis shad in the River Tamar was dependent on low flows and high water temperatures. At Gunnislake, the mean flow at times of shad migration in 2000 and 2001 was 5.8-6.3 m^3/ s, calculated using hourly flow data when shad were observed migrating upstream. The mean water temperature at times of upstream shad migration on the River Tamar was 16.7 ^oC.

Environmental conditions described in literature as suitable for initiating shad spawning migrations, spawning activity and the successful development of eggs and larvae, occurred later in the season on the River Tamar, than in other rivers with allis shad populations. In 2000, water temperatures necessary to initiate the spawning migration (13-17 ^oC) did not occur in conjunction with low flows until June, whereas in 2001 suitable water temperatures and low flows prevailed from early May and continued throughout the summer. This is considered to explain the earlier migration in 2001 on the Tamar. Temperatures described in literature as necessary for the survival and development of eggs and larvae (> 16 ^oC) occurred intermittently on the River Tamar between May and August in both years, although it is possible that the water temperature did not remain high enough for long enough, to allow egg development, even during the hottest part of the summer. This suggests that allis shad are near the northern limit of their range in the River Tamar.

Although conclusive spawning evidence in terms of juveniles was not found, it can be deduced that allis shad are attempting to spawn in the River Tamar, on the basis that there is no other reason for adult fish in spawning condition to migrate upstream into freshwater. It is unclear at this stage if the upstream migration of allis shad is hindered by artificial obstructions such as the weir at Gunnislake.

In both shad species, counts of gill rakers on the first gill arch, dorsal fin rays and anal fin rays were similar to their respective populations in northern and western France. In terms of biological characteristics, twaite shad were more similar to French and Irish populations than to populations from the Severn, Wye or Tywi.

Growth rate (in terms of length at age) was similar in allis shad to other populations but body size (in terms of weight at age and at length) was smaller than in French populations. Conversely, twaite shad caught from south-west England appeared to have a faster growth rate (greater length and weight at age) than populations in France, Ireland or the UK. Observations tend to suggest that twaite shad from south-west England are more similar to French populations than to UK populations.

Fish scale analysis revealed evidence of repeat spawning in adult allis shad caught from the Tamar Estuary, although the proportion of repeat-spawners was not determined. The age of first spawning among allis shad was 4-5 years in males and 5-6 years in females, which is typical of reports from most other populations. Most twaite shad caught from around the coast of south-west England were found to have spawned either once or twice before. Most female twaite shad first spawned in their fourth year, as described in other populations; insufficient males were aged to include in the analysis.

Allis shad were relatively small in terms of weight at length and at age, compared to other populations- so much so, that twaite shad caught from south-west England were actually heavier at length than allis shad (although the maximum size recorded for allis shad specimens was larger than in twaite shad). Literature reports that allis shad are larger than twaite shad, so there is a good chance that identification of species by the layperson based on size will result in the misidentification of species. Furthermore, the project revealed that the pattern of flank spots in the two species is not as described in current literature. Adult specimens of allis shad had a single, large pre-opercular flank spot and adult twaite shad usually had several flank spots. Most immature allis shad, however, had numerous spots along each flank, but this is not described in current literature. In twaite shad, spots (excluding the first pre-opercular spot) were observed to be typically darker, larger, better defined and fewer in number than in immature allis shad. A count of the gill rakers remains the most conclusive method of distinguishing between the two species.

Mysid shrimps dominated the diet of allis shad, whereas twaite shad were almost entirely piscivorous, feeding mainly on sprats (*Sprattus sprattus*). Three species of parasites were recorded; *Contracaecum aduncum*, *Clavellisa emarginata* and *Mazocreas sp*. Infection parameters were observed to be similar to other European populations.

The age of allis shad caught at sea is strongly skewed in favour of the 3+ age class, whilst that of the spawning population was composed of 4-7 year olds. In the marine environment, twaite shad aged between 3+ and 6+ predominated in catches. The age difference in allis and twaite shad caught at sea probably explains the observed differences in modal size group of allis (30-35 cm) and twaite shad (40-45 cm) recorded in marine catches. The sex ratio in allis shad adults was equal, whereas in twaite shad catches appeared to be strongly biased towards females. Most adult allis shad were caught in estuaries, whereas twaite shad were almost exclusively caught at sea; there may be a size-related bias associated with marine trawls, resulting in the over-representation of females in the catch. Alternatively, the apparently female-biased sex ratio may be an effect of smaller fish being harder to sex, of which males will comprise the majority.

This project has gone some way to satisfying the BAP targets for allis and twaite shad. In south-west England the estuaries with a significant shad presence have been identified enabling follow-up surveys to be undertaken. The River Tamar in particular appears to be important for allis shad, and in the future attempts should be made to clarify the spawning status of allis shad in the Tamar. English Nature have been informed of the discovery of shad eggs at Gunnislake; evidence suggests this could be the only known spawning site for allis shad in the UK and the identification of these eggs is a high priority. As a direct result of the project, allis shad have been added as a designated interest feature to the Tamar Estuary Special Area of Conservation (SAC), affording the species special protection and ensuring that favourable management plans for the Tamar catchment are produced and implemented. Future planning, discharge and abstraction consents and the management of net fisheries in the Tamar catchment, will need to consider the high level of protection afforded to allis shad under the Habitats Directive 1992.

Major advances have been made in the awareness to shad conservation and the recording of shad in the South West. The use of a recording form and database has been very successful, particularly among salmon netsmen. Although a database has been set up during this project to record shad from the South West, a national database for shad records should be created. Project information, particularly the posters, resulted in a very good response to the project by commercial fishermen, fish wholesalers and fishmongers. Many fishermen are now aware of the importance of shad as an endangered species and are now passing on information about shad catches, as well as returning shad caught as a by catch. However, important information about shad catches at sea still goes unreported, yet this could be collated by DEFRA and Fisheries Officers when catch information about commercial fish species is recorded. The project strongly recommends that shad are recorded in a similar way to 'Total Allowable Catch' (TAC) species at fish ports by DEFRA, identified as a key partner in the Shad SAP Process.

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GLOSSARY

Alosid	Subfamily Alosinae
Anadromous	Migrating from the sea into freshwater
Chromatophore	A pigment-containing cell
Clupeomorphs	Superorder Clupeomorpha; Herring-like fishes
Cumec	Cubic metre of water per second
Gill rakers	Horny processes fringing the inner edges of the gill arches
Gonadosomatic Index	Gonad weight as a proportion of total body weight
Interoparous	Spawning more than once
Meristic	Relating to countable serial features, such as fin rays, gill rakers etc.
Morphometric	Relating to measurable characters, such as body weight, length etc.
Pyloric caeca	Blind tubes at the start of the intestine in teleosts
Resistivity Fish Counter	Equipment that detects upstream or downstream fish movements as changes in electrical resistance
Semelparous	Spawning once only

1 INTRODUCTION

1.1 Introduction to Species

Allis shad (*Alosa alosa*) and twaite shad (*Alosa fallax*) are anadromous (i.e. they reproduce in fresh water and mature in the sea) members of the herring family. Shad have been reported from as far north as Iceland (Saemundsson 1949), at the northern most limit of their range, to Morocco in the south (Furnestin 1952, Blanc *et al* 1976, Matallanas 1981, Sabatie 1993) and as far east as Scandinavia (Pethon 1979) and the Baltic Sea (Manyukas 1989). Allis shad have been reported only from the western part of the Mediterranean (Sostoa *et al* 1979, Douchement 1981), while twaite shad are encountered throughout the Mediterranean (Aprahamian *et al*, in prep.).

The population of allis shad has declined significantly throughout Europe (e.g. Day 1890, de Groot 1989, Sabatie 1993, Alexandrino 1996). There is no conclusive evidence of UK spawning stocks at present, although spawning has been recorded in the River Tamar, England (Hillman, pers. obs.) and may also spawn in the Solway Firth, Scotland (Maitland *et al* 1995). Twaite shad populations have also declined in many parts of Europe (e.g. Le Clerc 1941, Poll 1947, Philippart and Vranken 1981, 1982, de Groot 1989, Aprahamian *et al* 1990, Alexandrino 1996, Mileriene 1997). In the UK it is now absent in several rivers where it previously spawned, such as the Thames (Aprahamian *et al* 1990). Spawning populations of twaite shad now exist in the rivers Severn, Wye, Usk and Tywi (UK) and in the Barrow, Nore and Suir in Ireland (Aprahamian *et al* 1990).

Several factors are thought to have caused the decline. Poor water quality is believed to be the main reason for the decline in the population of twaite shad from the River Thames and other rivers (Aprahamian *et al* 1990). Physical barriers to the movement of shad have also been responsible for the decline in certain populations throughout their range (e.g. Day 1890, LeClerc 1941, Sabatie 1993, Alexandrino 1996, Mileriene 1997). Habitat destruction and over exploitation are also recognised as potential causes of population decline, as occurred in the River Rhine (de Groot 1989).

Allis and twaite shad are listed on Annexes II and V of the Habitats Directive. Allis shad is listed on Appendix II and twaite shad on Appendix III of the Bern Convention. Allis shad is also protected under Schedule 5 of the Wildlife and Countryside Act (WCA) 1981.

1.2 Project Background

The Environment Agency, in partnership with English Nature (EN), funded a student project in Cornwall researching shad populations in 1998. The main focus of this project was to collect information on shad, particularly in the Tamar complex, and to test a number of survey methodologies. The project identified that records exist for shad within Cornish estuaries and along the coast of Cornwall. A significant number of additional records were gained through the 1998 project, which suggested that shad were under-recorded in the area. As a result of specimens obtained from the salmon netsmen in the Tamar Estuary, the project revealed evidence to suggest that allis shad may spawn in the Tamar. Limited surveys for juveniles and eggs were unsuccessful in the 1998 project.

The 1998 project showed that information on the marine adult phase of the shad lifecycle could be collected from fishing ports, particularly from DEFRA staff, as adult shad were often landed as a bycatch of commercial fishing operations. The 1998 project also showed that by liaising with salmon netsmen, the main users of the estuary that encounter shad, many records and much useful information could be gained.

A report produced in 1998 for the Environment Agency outlined the current knowledge of shad in the Tamar Complex (Reay 1998). The report included several records of allis shad and unidentified shad in the Tamar complex but no freshwater records or evidence of a spawning run.

1.3 Project Objectives

The overall objective was to investigate the spawning distribution and status of shad in south-west England, with particular emphasis on clarifying the status of shad in the River Tamar. The project sought to address many of the proposed actions in the Biodiversity Species Action Plans for allis and twaite shad, which are as follows;

Allis shad

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

Twaite shad

- Encourage anglers and commercial fishermen to record and release the shad they catch.
- Identify all spawning rivers and migration routes and provide them with protection, where appropriate.

Both species

- Seek to secure favourable actions in management plans covering any confirmed spawning sites within one year of discovery.
- Consider establishment of a monitoring scheme to record incidental catches by anglers and commercial fisheries.
- Support a pan-European study of shad to determine the status, genetics, biology and conservation needs of the shad across Europe.
- Pass information gathered during survey and monitoring of this species to Joint Nature Conservation Committee (JNCC) or British Record Centre (BRC) in order that it can be incorporated in a national database and contribute to the maintenance of an up-to-date Red List.
- Prepare and distribute guidance to all coastal fishermen and angling centres in appropriate areas explaining the threat to shad in the UK, reminding them of the legal protection afforded to shad and, if a monitoring scheme is established, explaining the need to record all catches and notify the appropriate body.

The approaches used during this project to investigate shad distribution and identify shad spawning rivers, will serve as guidance to projects investigating shad distribution and status in other parts of the UK. The effectiveness of the recording scheme used during this project and the methodologies used to detect shad will influence approaches to recording shad at a national level.

1.4 Collection of Information

This project began on 17 January 2000 and finished on the 28 February 2002. During the period 17 January 2000 until 14 November 2001 records on shad distribution were collected and information from specimens contributed to data sets (Tables 35-40, Appendix). Information on biology and ecology was collected in an opportunistic way during the project, depending on the availability of specimens/information. As such, it was not always possible to collect data sets sufficiently large as to reach firm conclusions about aspects of the biology or ecology of shad in south-west England.

Fieldwork was carried out in spring and summer 2000 and 2001 (see Section 2 for details). Limited resources were available during the project and wherever possible fieldwork was carried out within an existing programme (e.g. estuarine bass surveys). Cost-effective fieldwork methods were usually selected in preference of more expensive surveys.

In June 2002, as a follow-up exercise to the project, shad eggs were collected from the River Tamar for hatching and rearing.

1.5 Project Outputs

This report is the main project output (i.e. the technical report), which is summarised in the Technical Summary. This report contains the technical methods, results, discussion, conclusions and recommendations from the project, including advances in the knowledge of shad distribution and spawning status in south-west England. The technical report also contains information about investigations into the spawning status of allis shad in the Tamar complex. A Project Record was also produced; this contains information about how the project was carried out and who was involved. The project record also contains a literature review of allis and twaite shad, which was carried out at the beginning of the project.

2 METHODS

2.1 Distribution

The existing distribution of allis and twaite shad is presented in the Literature Review, within the Project Record. This report presents records collected or collated during the project. This includes records of actual fish, anecdotal records of catch frequencies or estimated abundance based on an individuals' knowledge of catches, and historical records that were collated during the project. Because of the variable nature of records an abundance index was devised in order to create maps of relative abundance.

Records of shad were only attributed to species if identification had been made. As such, the distribution of unidentified/unconfirmed shad records are presented separately. Inshore, estuarine and freshwater records could be attributed accurately to a national grid reference (NGR). Offshore catch locations are less reliable and were often approximated by the reporter. Due to the opportunistic nature in which records were collected, the difficulties associated with accurately relating offshore records to fishing effort and the brief nature of the project, it was not possible to produce a map of relative abundance, relating catch distribution to fishing effort.

Details on who was approached and the response from different groups, the information sent and the recording scheme used during the project are contained within the Project Record.

2.2 Abundance Index

It became apparent during the project that most of the commercial fishermen approached had at some point caught shad. However, the records rarely described precise numbers of shad caught on specific dates. Catch information usually involved verbal estimates of catch frequency. As the quality of information varied, so too did the type of record. Records described either the catch of a single fish, multiple fish or an estimate of catch frequency. These records were either recent or historic. The record referred either to a specific date or in some cases a large time period spanning several years.

In view of the great variability of both type and quality of record, it was necessary to create an abundance index that took into account the number of fish caught, the number of occasions on which fish were caught and the total number of records from a particular location. This index was used to create distribution and relative abundance maps for each species (Figures 7 and 8). Due to the limitations in obtaining accurate information about where commercial fishermen operate and the relative fishing effort in different areas, it was not possible to correct the number of records received from each area for relative fishing effort. Neither were attempts made to correct the number of records received against the method of capture, since it was not known, a) which methods would generate the most records and b) what proportion of the true number of catches by each method would be reported.

Four categories were created to describe the abundance of shad at a particular location on distribution maps (Table 1). In order to consider number of fish and occasions on which fish were caught at a particular location, Equation 1 was used to assign an abundance category to a particular catch location:

Equation 1 (Number of records) x (Total number of fish) = Abundance Index Value

Table 1: Calculation of abundance category

Abundance Index Value	Abundance Category
1	1
2-10	2
11-50	3
> 50	4

There is no limit to the age of a record when calculating the abundance category, although Figures 7 and 8 feature recent catch records only that have not been published (post-1970).

The decision to consider both the number of fish caught and the number of occasions on which they were caught, reflects the need to alleviate bias from differences in fishing methods at different locations, particularly when considering freshwater and estuarine catches.

In estuaries and freshwater, fishing methods include relatively small seine nets and rods which account for small numbers of fish per catch. At sea, much larger nets are used over much greater areas (particularly trawls), so large catches of shad on relatively few occasions were considered only as important as multiple catches of single fish in estuaries/freshwater when calculating abundance category.

Where phrases were used to indicate the abundance of shad at a particular location, it was necessary to assign an abundance category to each phrase. Despite the different choice of words by individuals to describe a catch frequency, by exercising caution and by underestimating abundance, the inclusion of this type of record is considered to be justified.

The phrases encountered and the corresponding abundance category ascribed to them are listed in Table 2.

Wherever possible the recorder was asked to express the catch frequency in numeric terms, but where records were received second-hand this was not possible. If a combination of numeric records and verbal catch frequency records existed for a particular location, the verbal estimation was considered first. The lowest abundance index value (Table 1) in the category corresponding to a verbal phrase (Table 2) was assigned first (e.g. 'Twaite shad are *occasionally* caught' corresponds to Abundance Category Number One). This number is then treated as a numeric record and an abundance index value is calculated, using other numeric records.

Table 2: Conversion of worded catch-frequency estimation to abundance category of shad at a particular location

Phrase	Abundance category
Very occasional	1
Occasional	1
Rare / Rarely caught	1
Scarce	1
A few	2
Several	2
Numerous	2
Frequent / Frequently	3
Plenty / Plentiful	3
Common	3
Many	3
'x' per haul / net / draft	Variable
'x' per day	Variable
'x' kg per day	Variable
'x' per season	Variable
'x' per year	Variable

Example

Three records exist for a particular location (Table 3)

Table 3: Example in calculating abundance category

Record No.	Record	Total 'number' of fish
1	" Several shad are caught per season"	2
2	4 shad caught on 31/03/1999	4
3	1 shad caught on 01/02/1999	1
Totals	3	7

(i) Using Equation 1: (Number of records, A) x (Total number of fish, B) = (Abundance Index Value, C)

(ii) A(=3) x B(= 7) = C
C – 21

Referring to Table 3, an Abundance Index Value of 21 falls in **Abundance Category 3**.

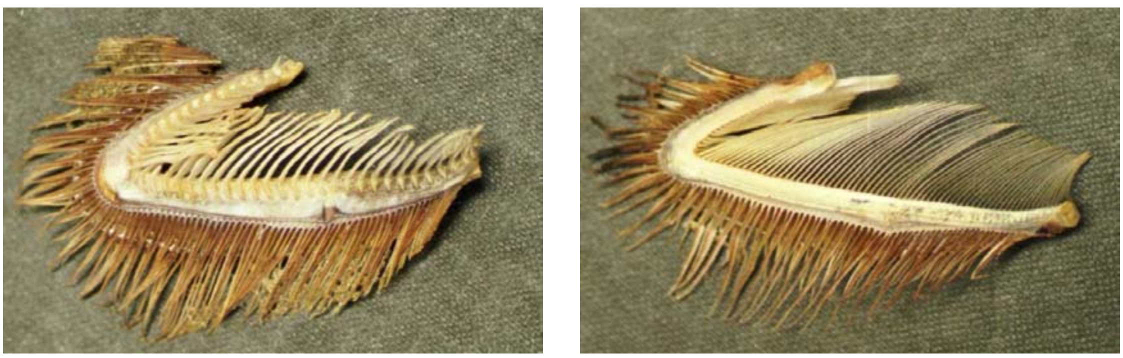
2.3 Catch Information

Ideally, records of shad catches included species, length, weight, a National Grid Reference, date, catch size and additional details such as water depth, catch method and the other species present in the catch. Records for each species (using records since 1970) were separated by catch method and by time of year to examine the spatial distribution of catches and the relative importance of different fishing methods.

2.4 Biology

Where specimens were available for analysis, the number of gill rakers on the first gill arch and the number of anal and dorsal fin rays were counted to, 1) compare shad from south-west England to populations elsewhere, 2) investigate differences between the two species and 3) (in the case of gill rakers) identify hybrids (Figures 1 and 2). The number of dark spots along each flank were also counted to investigate the external differences between allis and twaite shad. The number of flank spots was often an ambiguous feature. Some specimens had lost all or most of their scales, revealing spots that would otherwise have remained hidden. Furthermore, spots were often very faint/small, which made recording subjective. On the basis that (a) most specimens that were examined had suffered substantial scale loss and (b) the extent of scale loss upon capture appeared to be similar for both species, all discernible flank spots were recorded and data from all specimens was included in the analysis.

For analytical purposes adult allis shad were considered separately to immature fish. Based on data from several population studies contained in Aprahamian *et al* (in prep.), an adult was arbitrarily defined (for the purposes of investigating meristic and morphological characteristics) as having a total length greater than or equal to 40.0 cm. Twaite shad specimens smaller than 31.0 cm were not encountered during this project. According to data contained in Aprahamian *et al* (in prep.) this is approximately the size at which twaite shad mature, so no attempt was made to separate the data into adult and immature fish for the purposes of investigating meristic and morphological characteristics.



(a) *A.fallax* (less than 60 rakers) (b) *A. alosa* (more than 90 rakers)

Figure 1: First gill arch appearance and approximate number of gill rakers for (a) *A. fallax* and (b) *A. alosa*

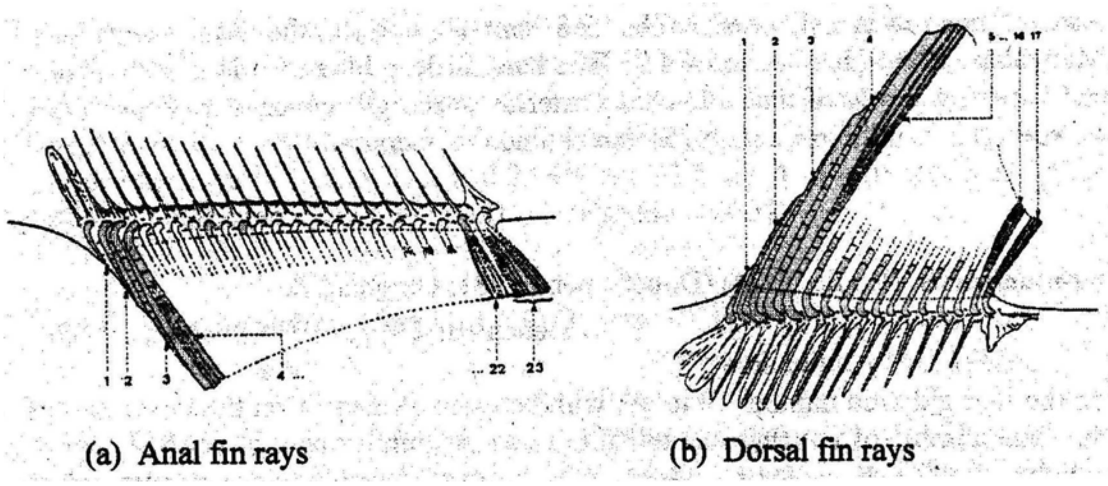


Figure 2: Fin rays of *A. alosa*: anal (a), and dorsal (b). (from Douchement 1981)

2.5 Ecology and Life History

2.5.1 Reproduction

Shad were sexed by the appearance of the gonads; in males, the testes appear relatively smooth compared to the ovaries of females, in which the oocytes give the gonads a granular appearance. A gonadosomatic index (GSI) was obtained for each specimen by removing and weighing the gonads and expressing the gonad weight as a percentage of the total body weight.

Spent fish were defined as having recent spawning marks on their scales and a very low GSI (<1.0) upon examination during or immediately after the spawning period.

2.5.2 Spawning

2.5.2.1 Determination of fish age and spawning history

Scales were used to estimate the age of fish and to determine spawning history; otoliths were not used in this study. Mennesson-Boisneau and Boisneau (1990) compared estimates of age from both scales and otoliths and found for both allis and twaite shad that the level of agreement between both methods was greater than 90 %. Scales were usually taken from dead specimens of shad obtained opportunistically from netsmen, anglers or commercial fishermen. Scales were occasionally taken from live specimens by salmon netsmen and passed to the Project Officer.

2.5.2.1.1 Scale sample, preparation and presentation

Scales were taken from a standard area above the mid-line and in line with the dorsal fin. In this zone the scales are more symmetrical, there is a lower percentage of replacement scales and the scales are generally more readable (growth rings are clearer and there is less chance of annuli being obscured by spawning marks) (Bagliniere *et al* 2001). Where possible a sample of twenty scales was taken and at least five scales were used to age a fish; if this sample did not provide a clear indication of age/spawning history a further five scales were examined, and so on. Scales were cleaned by rubbing between two fingers, in a very dilute solution of liquid soap and warm water. Scales were examined using a microfiche machine that magnified scales by sixty.

2.5.2.1.2 Definitions

2.5.2.1.2.1 Annulus or winter ring

The annulus corresponds to a structural discontinuity surrounding the scale, more often appearing as a crease, cut or fusion of the circuli (very thin narrow striations) An annulus may be described as a white/clear line running parallel to the border of the scale, showing concentric thin striae which widen from the centre outwards. The line is generally visible all around the scale, particularly the lateral and anterior fields. The clarity of the annuli ranges from a white line only apparent because of a distortion and/or a difference in width, or a waviness but no break of the thin striae, to strongly marked, very wide bands with or without distortion of the thin striae (Bagliniere *et al* 2001).

2.5.2.1.2.2 Spawning marks

Spawning marks are formed during the pre-reproductive period by lateral absorption and/or erosion of the scale followed by rapid regenerative scale growth. The spawning or reproduction mark appears as a continuous concentric line more or less opaque, variable in width and overlapping the thin striae. Between the spawning mark and the edge of the scale two types of thin striae can be observed. The two types reflect different levels of distortion (erosion/absorption) of the scale; 1) those which run parallel to the spawning mark, corresponding to a minor distortion and 2) island-like aggregations of striae, impregnated with large white swirls corresponding to major structural disorganisation (Bagliniere *et al* 2001).

2.5.2.1.2.3 Anniversary or birth date

Bagliniere *et al* (2001) state that the anniversary date for allis and twaite shad should correspond to the median reproduction date as opposed to the start date of the freshwater phase of their spawning migration, and they suggest that if the median date is not known the date from a geographically close population of the same species be used. The median date for allis shad in France is 1 July (Cassou-Leins and Cassou-Leins 1981; Dautrey and Lartigue 1983, Mennesson-Boisneau *et al* 1986, Taverny 1991). Aprahamian (1982) reported the median date for twaite shad from the Severn as 1 June. These two dates were used to represent the respective anniversary dates of allis and twaite shad caught from south-west England.

2.5.2.1.2.4 Age notation and determination of spawning history

Methods used were as described in Bagliniere *et al* (2001). The total age was determined by adding the total number of annuli and spawning marks on the scales. For fish at the start of the freshwater phase of their spawning migration the edge of the scale was considered as an annulus, even if the annulus was not visible. Thus the total age is the sum of the number of annuli plus one for the scale's edge. In cases where fish have marked "plus" growth on their scales and are not close to their anniversary date, a "+" has been assigned to their age, as it is not possible to consider these fish to be one year older.

The number of previous spawnings and the age at first spawning was determined by counting the number of spawning marks on the scale. Fish caught during their freshwater migration phase were judged to have spawned or been yet to spawn on the basis of a) the reproductive state of the gonads and b) the presence of a spawning mark at the edge of the scale.

2.5.2.2 Survey of the River Tamar for spawning activity

On 23 May 2000 a survey was conducted along the River Tamar from Greystone Bridge (SX 368804) to Woodtown Farm (SX 376786) and back. This search was carried out by two people and took place from 1945 until 0045, based on observations relating to time of spawning by Cassou-Leins and Cassou-Leins (1981). High power torches were used to search for signs of spawning activity at the riffle sections along the river.

2.5.2.3 Kick sampling for shad eggs

2.5.2.3.1 Spawning site characteristics

To aid the identification of shad eggs, sampling was carried out during the period 7-9 June 2000, on the Rivers Wye and Irfon, Wales, with an experienced shad biologist. This provided valuable experience of identifying eggs, locating spawning sites by knowledge of site characteristics, and locating eggs on the spawning sites. A River Habitat Survey training course was completed prior to commencing kick sampling; this permitted the recognition of key river characteristics associated with shad spawning sites.

Glides were the predominat flow feature in a spawning area, with smaller areas of runs and riffles; substrate was gravel/pebble; and shallow areas were present (<0.8m depth) (Caswell and Aprahamian 2000). Caswell (unpublished) found that even at sites dominated by a substrate other than gravel or pebbles, eggs would be found in gravel/pebble pockets. Water depth at which eggs were found was typically less than 1.0 metre, and usually between 0.2 and 0.3 m.

Caswell (unpublished) noted that improved/semi-improved grass was the most common land use category at spawning sites, where cattle were the predominant grazers. Vertical or steep banks were present at all sites and extensive (i.e. greater or equal than 33 %) at 45 % of sites; Caswell (unpublished) suggests that this may be a significant factor in reducing livestock access to the channel, thus reducing bank erosion and siltation, which would be detrimental to egg survival.

2.5.2.3.2 Selection of kick-sampling sites on the River Tamar

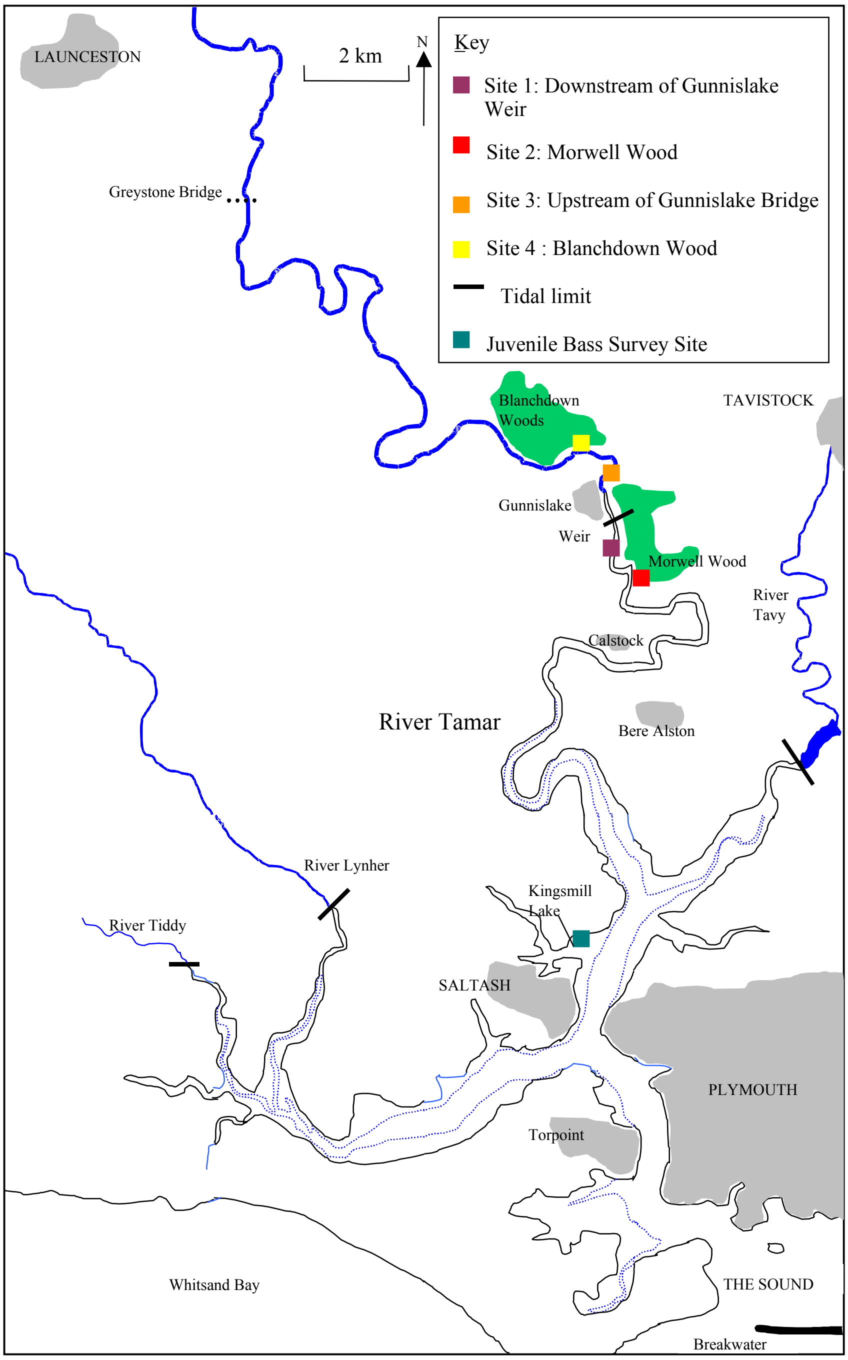


Figure 3: The location of kick-sampling sites and juvenile bass survey sites on the River Tamar

Video footage from the Gunnislake fish counter (SX 436711) and numerous catches of shad by anglers and estuary netsmen warranted an investigation of the River Tamar, with respect to the spawning status of shad. The highest density of records for shad on the Tamar is at Gunnislake. Based on this observation, sampling for eggs began below the first riffle section below Gunnislake Weir. A total of four different sites on the Tamar were sampled during 2000 (Sites 1-4; Downstream of Gunnislake Weir [SX 436712], Morwell Wood [SX 440704], Upstream of Gunnislake Bridge [SX 435726], Blanchdown Wood [SX 431728]) and one (Site 1) during 2001 (Figure 3). Due to the restrictions during the 2001 Foot and Mouth Epidemic, plans to survey other sites on the River Tamar and sites on the River Fowey were abandoned.

2.5.2.3.3 Methodology

Kick sampling was carried out at each site with the aim of finding eggs. A standard macro invertebrate hand net (250 µm aperture) was used to collect material dislodged by kicking upstream of the net for 15 - 30 seconds. The net was checked for eggs after each kicking interval and any detritus or channel substrate removed before kicking resumed. Shallow gravels were targeted together with adjacent macro-habitat. If no eggs were found the survey was terminated (a comprehensive assessment of the habitat was judged by Caswell (2000) to comprise approximately 25 kicks, or 30 - 40 minutes). If eggs were present, the extent of the spawning area was determined by progressively kick sampling (c. 10m) upstream and downstream. To confirm the limit of a spawning area, sampling was continued for at least another kick-sample after the last egg was recorded.

During the 2001 kick-sampling surveys the catch per unit effort was calculated for each sample occasion, to establish the relationship between egg abundance and environmental conditions (namely water temperature).

2.5.2.3.4 Timing of kick sampling surveys

In 2000, kick sampling commenced on the 12 June and was carried out periodically until 28 August. In 2001, surveys were carried out from 4 May until 25 June. In 2000, high flows prevented kick sampling until 12 June. Water temperature was monitored regularly in 2001; when water temperature reached 12 ^{o}C kick-sampling surveys commenced.

2.5.3 Ontogeny

2.5.3.1 Hatching and rearing alosid-type larvae at Launceston

On 4 July 2000, approximately 30 eggs (thought to be those of allis shad) were collected and placed in an aerated flask containing rainwater at 18.0 ^{o}C. Upon hatching, larvae were transferred to a 24" x 12" x 15" (61 cm x 30.5 cm x 38.1 cm) Clearseal aquarium tank containing rainwater. The water was aerated using a Nimrod 4 pump and airstone.

The water was kept clean by partial replacements every 2-3 days. Tap water was left in a container for 24 hours to allow chlorine to evaporate. Tetra Aquasafe was added to neutralise other chemicals in the water. Sea salt was also added in low concentration (c. 10 g per 5 litres). Detritus was removed daily by siphoning through a piece of rubber tubing.

The larvae were fed 'Interpet Liquifry No.1 for egg layers' and newly hatched brine shrimp (*Artemia sp*.). Larvae were killed and preserved in 50 % Industrial Methylated

Spirit (IMS) at 6, 12 and 15 days old. These were then examined using a Leica MZ APO light microscope (magnification range 8 - 80) and photographed using a Leica Wild MPS 52 microscope camera (Figures 54-60, Appendix).

On 4 August a second batch of approximately 25 eggs were collected from the spawning site at Gunnislake and placed in an aerated flask containing dechlorinated tap water (treated with Tetra Aquasafe).

2.5.3.2 Hatching and rearing alosid-type larvae at Calverton Hatchery

In 2001, attempts were made to collect eggs to be sent to a fish hatchery for hatching and rearing to fry, where conditions might offer a better chance of survival. Due to low egg densities during 2001, this exercise was abandoned. In 2002, approximately 200 eggs were successfully collected and sent to the Agency Fish Hatchery at Calverton.

The eggs were examined using a light microscope under 30-70 times magnification (Figure 63, Appendix). Dead and unfertilised eggs were removed, along with any detritus. The eggs were placed in 45 cm square rearing trays containing bore-hole water at 16-18 ^{o}C. There was a constant flow of water through the rearing trays; the bore-hole water was naturally oxygen rich, as it was pumped up at 10 ^{o}C. No further aeration was used. The eggs were split into two batches as a precaution against a mass mortality due to fungal infection.

Upon hatching, larvae were examined and dead ones removed and preserved in 70 % ethanol on an oportunistic basis. Due to the rapid decomposition of larvae few samples were obtained at this stage. After the yolk sac had been absorbed larvae were fed on newly hatched brine shrimp. Larvae were kept at 16-18 ^{o}C. Notes were made on the development and behaviour of the larvae as long as they were alive. Opportunistic sampling and preserving of larvae continued throughout the rearing process.

2.5.4 Demography

Shad that were available for examination were measured, weighed, sexed and aged. Total body length and fork length were measured using a one metre measuring board; total body length is used in subsequent analyses. Body weight was measured using one of two sets of scales; small fish were weighed using a pair of Pesola 1 kg scales, larger fish using Salter 10 kg scales. Fish were weighed in a net and the weight of the net was then subtracted from the total. Fish were sexed by the appearance of the gonads as described in Section 2.5.1. The sex of immature fish or fish not in spawning condition could not always be determined in which case sex was recorded as unknown. Age was estimated from scales as described in Section 2.5.2.1. Fish caught in trawls were often susceptible to complete scale loss, which precluded the ageing of fish from scales.

2.5.4.1 Marine catches

The frequency of occurrence of body length categories of each species in marine catches was investigated. Variation in body length within catches was also investigated. Where possible fish were aged and sexed.

2.5.4.2 Estuarine and freshwater catches

The body length, weight, sex and age of adults caught from estuaries (and freshwater), particularly the Tamar, was recorded.

2.5.5 Growth

Relative size was investigated by plotting body weight against total body length for fish of each species (Methods for weighing and measuring fish are described in Section 2.5.4). The methods used for ageing and sexing fish are described in Sections 2.5.2.1 and 2.5.1. The small number of fish that were aged and sexed prevented detailed analysis of growth rate for each species. The small size of the data set precluded backcalculation of body length at age.

The majority of fish encountered during this study were from the sea, rather than spawning populations in specific rivers (particularly in the case of twaite shad). This should be born in mind when making comparisons between the growth rate/relative size of shad from south-west England and populations elsewhere. Data on fish weights and lengths was collected opportunistically throughout the year and for a relatively short time period (~two years). Consequently body weights can be expected to fluctuate with the time of year due to changes in reproductive condition.

Age-length data of allis shad from south-west England was compared to data from studies of populations in the Loire (Douchement 1981, Mennesson-Boisneau and Boisneau 1990), Gironde-Garonne-Dordogne (CTGREF 1979, Cassou-Leins and Cassou-Leins 1981, Douchement 1981, Dautrey and Lartigue 1983, Taverny 1991) and Adour (Douchement 1981, Prouzet *et al* 1994). In the case of twaite shad, studies of populations in the Severn, Wye, Tywi (Aprahamian, in prep.), Barrow (Bracken and Kennedy 1967, O'Maoileidigh 1990), Seine (Roule 1922), Loire (Mennesson-Boisneau and Boisneau 1990, Douchement 1981), Gironde-Garonne-Dordogne (CTGREF 1979, Douchement 1981, Taverny 1991) and Adour (Douchement 1981) were used.

2.5.6 Diet

The frequency of occurrence of food items in the diet of allis and twaite shad, was recorded by stomach content analysis. In each fish stomach the presence of food items was recorded. Separate analyses were carried out for the marine and estuarine diet of the two species.

Where possible, dietary items were identified to species level. Identification of stomach contents was carried out either by the Project Officer or staff from the Cornwall Area Biology Team. If fish bones or skin were found in the stomach the dietary item was recorded as unidentified fish. Man-made materials such as plastic, nylon or rubber were recorded as 'synthetics'.

In a sub-sample of twaite shad, the length of sprats (*Sprattus sprattus*) found in the gut was plotted against the size of the predating fish to investigate the relationship between the relative size of the two species.

2.5.6.1 Dietary Diversity

The Shannon-Wiener Function was calculated for each species to provide a measure of dietary diversity. The Shannon-Wiener measure (H') increases with the number of species in the diet; Krebs (1999) observed that in practice, for biological communities H' does not seem to exceed 5.0.

Shannon-Wiener Function

$$H' = \sum_{i=1}^{s} (p_i)(\log_2 p_i)$$

where H'= Index of species (dietary) diversity
s = Number of species
p_i = Proportion of total sample belonging to the ith species

2.5.7 Parasitology

57 allis shad and 88 twaite shad were examined for the presence and prevalence of parasites in the alimentary tract, of which 43 allis shad and 52 twaite shad were also examined for parasites in the branchial chamber. Samples of parasites were collected, preserved in 50 % diluted IMS and sent to the Environment Agency National Fisheries Laboratory, Huntingdon, for identification.

For parasites of the gut cavity, parasite load was recorded as either 'none', 'low' (fewer than 10 parasites counted in 60 seconds) or 'high' (greater or equal than 10 parasites counted in 60 seconds). Parasites of the branchial cavity were fewer in number and were simply counted.

2.5.8 Migration

2.5.8.1 Adult spawning migration

Salmon and sea trout netsmen and to a lesser extent anglers were approached and asked to retain shad specimens caught in estuaries/freshwater for analysis. All netsmen licensed to fish during 2000 and 2001 in estuaries of the South West were approached. The Project Officer attended netting operations with netsmen from the Fowey, Tamar and Torridge during the 2000 season.

Fish caught in estuaries and in freshwater were kept and examined with respect to their reproductive condition; calculation of gonadosomatic indices (GSI) is described in Section 2.5.1. The GSI of adult fish caught at different times of the year was investigated to provide an indication of the timing of peak spawning condition.

2.5.8.1.1 River Tamar Observations

During 2000 and 2001 thirteen shad (including one from 1999) were observed migrating upstream on video footage taken at Gunnislake Fish Counter, River Tamar. Shad were recognised primarily by the presence of a deeply forked tail, but also by a laterally compressed body, the position of fins and the presence of a dark spot behind the operculum. The body lengths of shad observed on video footage were calculated by converting screen lengths, as observed by viewing video footage from the overhead cameras on a monitor, to actual lengths using the measured distances between three electrodes on the fish pass. The calculated sizes of fish, observed migrating upstream at the fish pass, are consistent with the documented range in size of adult allis shad (42.46-66.19 cm; mean = 53.74 cm). The absence of twaite shad records in the catchment, compared to plentiful records of allis shad further indicated that the species observed at Gunnislake Fish Pass was allis shad.

In 2000, routine video footage was collected by Cornwall Area Fisheries Science Team using an overhead camera and a surface-skimming camera in the fish pass. This provided a downward and a left/right view of fish in the pass. Video footage from May until August (inclusive) was watched and the time and date of migrating shad were recorded. In 2001, the surface-skimming camera was not operational and video footage was taken using the overhead camera only. Time constraints restricted the viewing of video footage to May only.

2.5.8.1.1.1 Water temperature

Water temperature at times when shad were a) observed migrating upstream at Gunnislake Fish Pass and b) caught by anglers in freshwater was compared to hourly temperature recordings from a 'Tinytag Plus' data logger in the fish pass.

2.5.8.1.1.2 Water flow

Water flow (measured in cumecs) was compared to hourly flow data recorded at Gunnislake Gauging Station (SX 435725), approximately 1.5 km upstream of Gunnislake Fish Pass, at times when shad were a) observed migrating upstream at Gunnislake Fish Pass and b) caught by anglers in freshwater. Flow at the times of observed shad migrations was compared to data from the period May to August, May 1956-June 2002. Q values for this period were calculated, i.e. daily mean flow values exceeded for a given percentage of time.

2.5.8.1.1.3 Tidal state

Tidal height and state (springs or neaps) was noted at times when shad were observed migrating upstream at Gunnislake Fish Pass.

2.5.8.1.1.4 Diurnal variation in migration

The time of day was noted at times when shad were observed migrating upstream at Gunnislake Fish Pass.

2.5.8.1.1.5 Detection of shad via Gunnislake Resistivity Counter

The size of the energy deflection created when shad swim over the electrodes in the fish pass was compared to those of twenty-six salmonids within the same size range (i.e. 42.5-66.2cm), which were randomly selected from video counter data collected on days when shad were observed migrating upstream. This was done to investigate potential differences in the resistivity deflection created by alosids and salmonids, as they pass over the electrodes in the fish pass.

2.5.8.2 Juvenile seaward migration

2.5.8.2.1 Seine netting for juvenile shad

On 22 August 2000, the Project Officer assisted with a sampling program for juvenile twaite shad at two sites on the Severn Estuary; this provided valuable skills for the identification of juvenile shad.

With the exception of one day of survey work in the Tamar Estuary, in August 2001, resources did not permit a sampling program that specifically targeted juvenile shad. However, various researchers conducting ongoing juvenile bass surveys in estuaries of south-west England carried out a netting programme during the summer months. The Helford Voluntary Marine Conservation Association (HVMCA) conducted surveys at a number of locations in the Helford and Fal estuaries. Mr Donovan Kelly, a bass researcher, conducted surveys at selected locations on the Camel and Tamar estuaries.

2.5.8.2.1.1 Helford and Fal Estuary Bass Surveys

In 2000, netting commenced on 15 May and continued until 11 September. The HVMCA samplers used an 18.3 m x 1.8 m seine net with mesh size 5 mm knot to knot. The net was deployed from a dinghy and pulled in using hauling lines. Most of the bass sampling sites on the Fal and Helford were sampled at high tide. In 2001, netting in the Helford and Fal estuaries commenced on 11 May and continued until 18 June.

Figures 4 and 5 show the location of bass sampling sites on the Fal and Helford estuaries; Tables 4 and 5 show the sampling conditions at each site.

Table 4: Fal and Helford Estuary juvenile bass survey sites, sampled in 2000

Date	Site Name	Grid Reference	Tide state	Depth (m)
15 May	Polwheveral Creek (Helford)	SW 738284	High	1.0
6 June	Ruan Creek (Fal)	SW 855407	Low	<1.0
12 June	Bonallack Creek (Helford)	SW 713263	Low	<1.0
12 June	Groyne Point (Helford)	SW 741262	High	3.0
29 August	Lamorran (Fal)	SW 878420	High	>1.0
11 Sept.	Groyne Point (Helford)	SW 741262	Low	>1.0

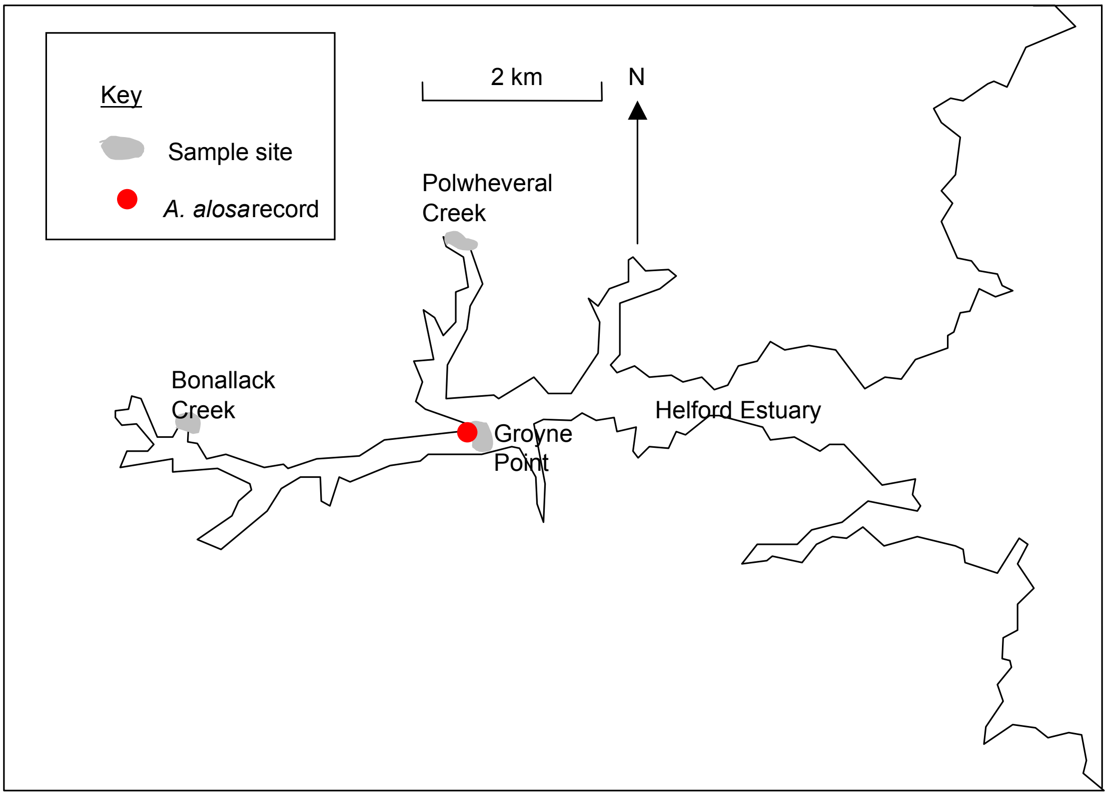


Figure 4: Location of juvenile bass survey sites on the Helford Estuary

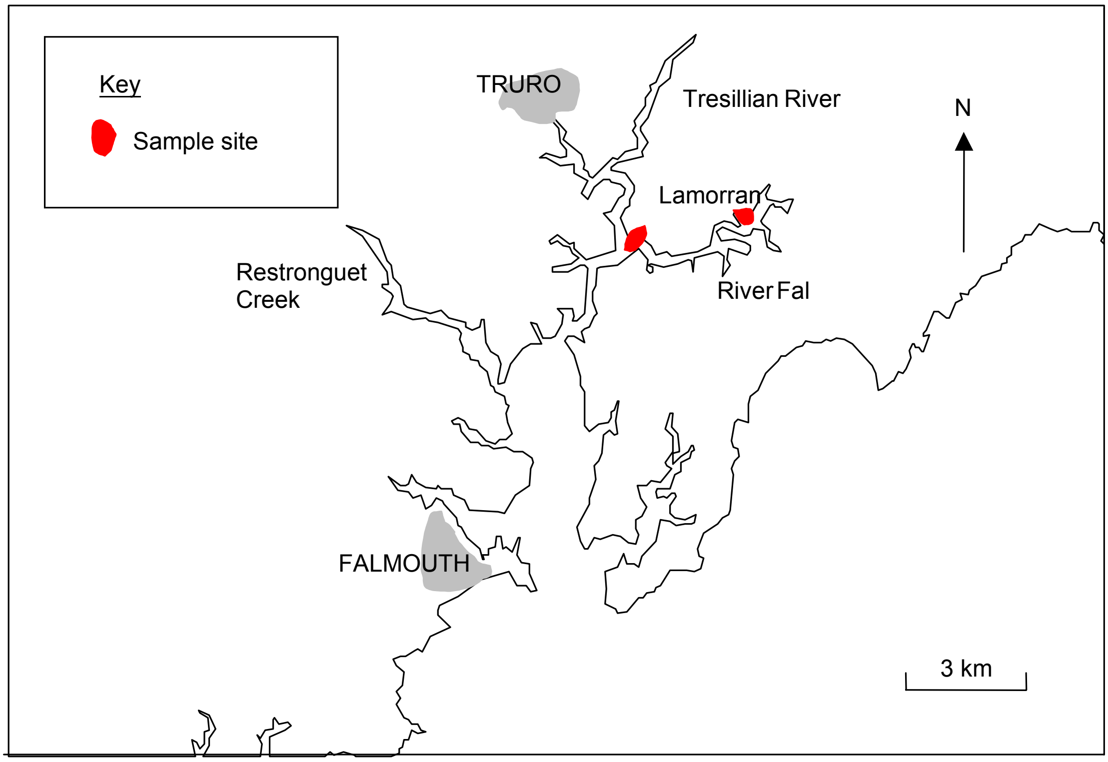


Figure 5: Location of juvenile bass survey sites on the Fal Estuary

Table 5: Fal and Helford Estuary juvenile bass survey sites, sampled in 2001

Date	Site Name	Grid Reference	Tide state	Depth (m)
11 May	Ruan Creek entrance (Fal)	SW 855407	Low	1.0
21 May	Polwheveral Creek (Helford)	SW 739284	High	1.0
24 May	RuanCreek entrance (Fal)	SW 855407	Low	1.0
18 June	Lamorran Eastern Creek (Fal)	SW 878417	High	1.0
18 June	Lamorran (Fal)	SW 878417	High	1.0
29 October	Polwheveral Creek (Helford)	SW 739284	High	0.75

2.5.8.2.1.2 Camel and Tamar Estuary Bass Surveys

Sampling commenced on 29 June 2000 and continued until the 14 August. Mr Kelly selected very specific sampling dates for comparison with previous years results. If the weather was unsuitable on these dates sampling was abandoned. A 13.7 m x 1.8 m sandeel seine net or an 11.0 m x 1.4 m micromesh seine net was used to sample for juvenile bass. The net was set by wading around the mouth of the sample area (usually a small creek) and pulling the net ashore with hauling lines.

Only one site was sampled on the Tamar and Camel estuaries. The sample site on the Tamar Estuary was at Landulph *Spartina* marsh, Kingsmill Lake (SX 431612; Figure 3). This was sampled on the 29 June, 29 July and 14 August. On the Camel Estuary, the sample site was at Trewornan Creek (SW 982738). This site was netted on 12 July, 27 July and 12 August.

2.5.8.2.1.3 Tamar Estuary Juvenile Shad Survey

On 31 August, 2001 a survey was carried out at Holes Hole (SX 428653) in the Tamar Estuary, with the aim of catching juvenile shad. Three members of Serco Denholm (a company contracted by Plymouth Marine Laboratory to undertake boat-orientated fieldwork) assisted the Project Officer with this survey. The survey was carried out by seine netting in the main channel; the net was deployed from a dinghy and pulled into the bank where the catch was landed. The netting took place around low tide (11.18 hrs) from 09.00 until 12.30. The tide was midway between neaps and springs. Initially, a 30m x 3 m x 6 mm net was used but the tidal flow precluded efficient use of this net. A 30m x 2m x 9 mm net was instead used until slack water when it was possible to use the 6 mm mesh net again.

2.5.8.2.1.4 National Marine Monitoring Programme Flounder Trawls

On 20 November 2001 a series of trawls were carried out in the Tamar Estuary at Cargreen (SW 436614- SW 434608). The aim was to collect adult flounder for tissue analysis, as part of an ongoing monitoring programme. The Project Officer attended and monitored the bycatch of these trawls in case shad were caught.

2.5.8.2.1.5 Carnsew Pool and Hayle Estuary Fish Surveys

On 1 and 2 August, 2001, Environment Agency staff carried out a fish species survey in Carnsew Pool, Hayle (SW 553373). A second survey of the main Hayle Estuary (Various sites SW 550380-SW 560378) was undertaken on 1 and 2 October, 2001. A range of nets were used for seine netting, including nets of 8 and 9 mm mesh size, which would have been suitable for catching juvenile shad. Both the surveys were carried out around low tide, which has been described by D. Kelly as the ideal time for catching clupeomorphs.

3 RESULTS AND OBSERVATIONS

3.1 Distribution

Allis and twaite shad were recorded from around the South West coast in considerable numbers during this project; 232 new or unpublished records were collected, involving 648 fish (258 allis [Figure 7], 203 twaite [Figure 8] and 187 unidentified shad [Figure 6]). In addition to actual catches of shad, 85 anecdotal records were collected. Amongst these records were significant catches of up to one and a half tonnes of shad, caught offshore of Lands End.

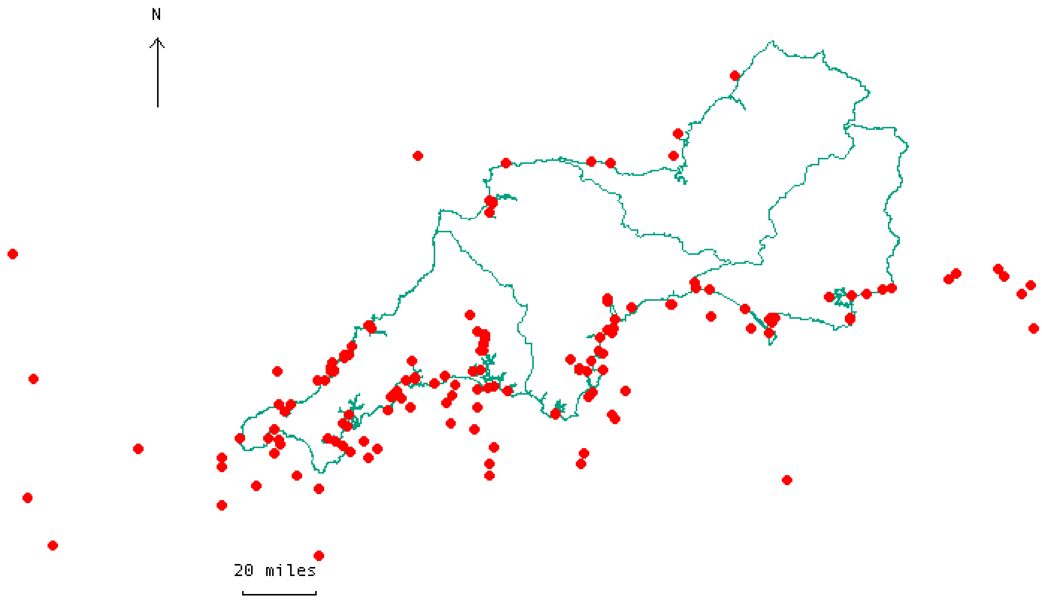


Figure 6: The distribution of shad records in south-west England

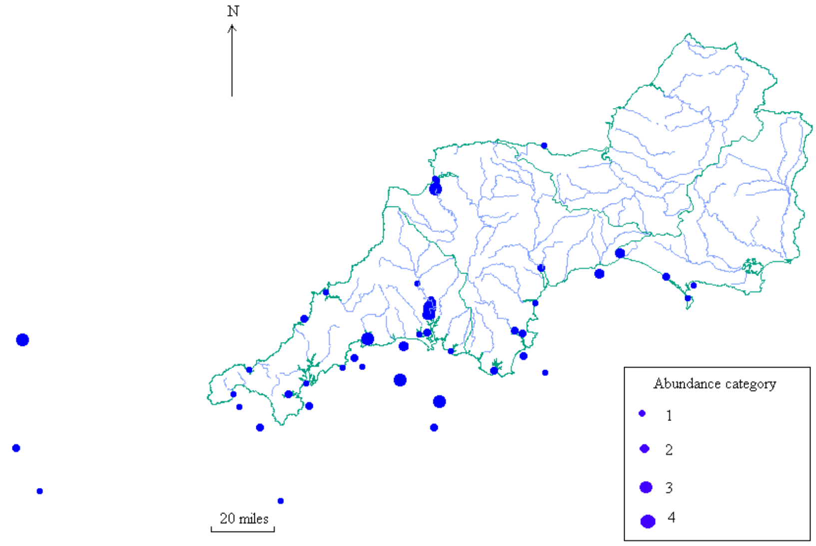


Figure 7: Distribution and relative abundance of *A. alosa* records in south-west England

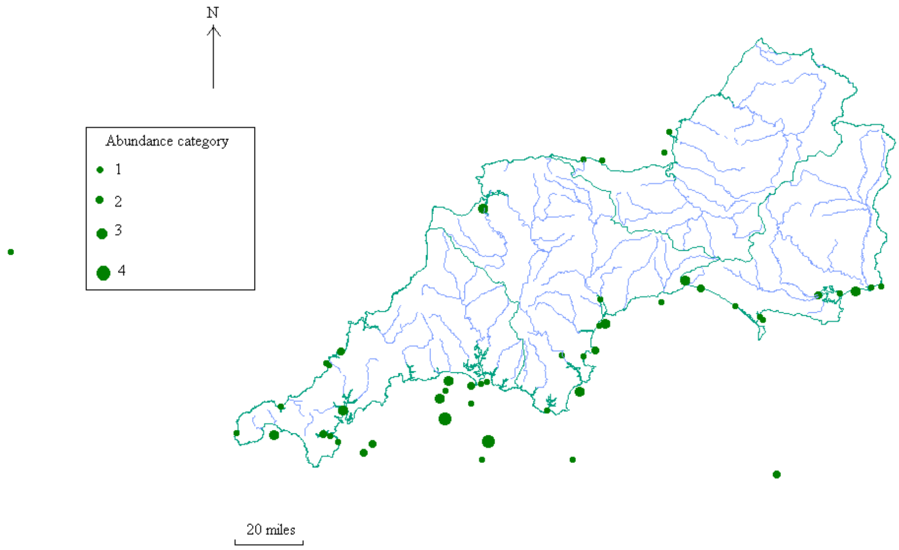


Figure 8: Distribution and relative abundance of *A. fallax* records in south-west England

The distribution of shad records from south-west England is presented using the Environment Agency Area administrative boundaries within South West Region. These are defined, in order of travel around the South West peninsula coast, as;

- South Wessex Area; Walkford Brook, Hampshire (SZ 217932) – River Char, Dorset (SY 365931)
- Devon Area (South Coast); River Char, Dorset (SY 365931) – Battisborough Cove, Devon (SX 600468)
- Cornwall Area (South Coast); Battisborough Cove, Devon (SX 600468) – Lands End (SW 342253)
- Cornwall Area (North Coast); Lands End (SW 342253) – Marsland Water, Devon (SS 212175)
- Devon Area (North Coast); Marsland Water, Devon (SS 212175) – Foreland Point, Devon (SS 755513)
- North Wessex Area; – Foreland Point, Devon (SS 755513) – Little Avon, Gloucestershire (SO 667014)

Distribution records are divided into three sections within each area; allis shad, twaite shad and unidentified shad. The distribution of shad described in the following sections contains records collated during the project as a result of gathering information from previously untapped sources and records of fish that were caught during the project. A summary of the known distribution of shad in south-west England prior to this project is contained within the Project Record (Hillman 2003).

3.1.1 South Wessex Area

3.1.1.1 Allis shad

Allis shad have been caught by anglers fishing from Chesil Beach, Dorset and in Weymouth Bay (S. Taylor, personnal communication). In December 1998, eighteen allis shad were caught in a trawl in western Lyme Bay (Devon Sea Fisheries).

3.1.1.2 Twaite shad

Twaite shad have been caught in the summer salmon fishery and in bass nets during February, at the mouth of Christchurch Harbour (T. Edgell, pers. comm.). Around Christchurch, netsmen refer to shad as ‘summer herring’. From Poole to Hengistbury Head, netsmen have reported catching twaite shad close inshore; “We catch shad from September until around February. After that they tend to disappear” (Keating, pers. comm.). In the early 1980s, several juvenile shad of 7.5-10 cm, believed to be twaite, were netted at the top of Wareham Channel, at the mouths of the rivers Frome and Piddle (D. Jones, pers. comm.).

Four twaite shad of 2-3 lb, were found dead in a lobster pot in Ringstead Bay, Dorset, in the summer of 1999 (S. Taylor, pers. comm.). Fishmongers and DEFRA Officers at Looe and Brixham explained that due to their low commercial value shad are often used by fishermen as pot bait.

Anglers around Weymouth often catch twaite shad; in July 1999 one was caught from Newtons Cove and another from Weymouth Harbour (I. Harrington, pers. comm.).

In December 1998, a twaite shad was caught in an otter trawl off Beer Head, western Lyme Bay (National Marine Aquarium staff, pers. comm.) and at Seatown, Charmouth, a fisherman netted two twaite shad in July 2001 (P. Bale, pers. comm.).

3.1.1.3 Unidentified shad

Fishermen in Poole reported catching shad in bass nets between the entrance to Poole Harbour and Hengistbury Head, about half a mile offshore (J. Davis, pers. comm.); "shad are encountered only occasionally- about one or two every year, usually in the colder months". Most trawler fishermen encounter them but they have very little commercial value and are reportedly often used as bait in crab pots (N. Corner, pers. comm.). J. Bell, a fishmonger in Wimborne, Bournemouth, recalled being offered twenty locally caught shad, each of about 1-1.5 lb; he also reported a catch of two shad from Poole Harbour in September 1999. Mr Bell commented, as have many others, that in 2000 shad were more abundant on the fish market than in previous years.

In August 1999, two shad were caught in the bay adjacent to Swanage Pier (R. Johnson, pers. comm.). One fishermen claimed that he caught approximately six shad each summer during August and September, and that more shad were caught in 2000 than in previous years (R. Johnson, pers. comm.).

In May 2000 and July 2001 anglers caught shad from Weymouth pier (I. Harrington and Edwards, pers. comm.). Another angler reported catching 2-3 shad (approximately 25 cm long) each summer during July and August, whilst feathering for mackerel from Newtons Cove, Weymouth (P. Nash, pers. comm.); he also reported catching shad from Weymouth Pier and over a wreck at the south entrance to Portland Harbour. In 1997 an angler caught a shad whilst wreck fishing offshore of Abbotsbury (I. Harrington, pers. comm.) and in October 2000, a shad was netted just offshore of Weymouth Beach (A. Alcock, pers. comm.).

Shad are relatively common in Lyme Bay, particularly during winter months, and significant numbers are landed at Lyme Regis. J. Parsons (Southern Sea Fisheries Committee) reported catching a daily average of between one and four fish in January 2000, whilst netting between Lulworth and Lyme Regis, Lyme Bay. Fishermen reported catching up to 30-40 kg per day in January and February 2000, although they too commented that shad were more abundant than in previous years (C. Watson, pers. comm.).

3.1.2 Devon Area South Coast

3.1.2.1 Allis shad

D. Clifton (pers. comm.) reported an allis shad caught in November 1998, east of Bundle Head, Teignmouth and in March 2000 a trawler operating within three miles of Start Point netted ten allis shad (I. Todd, pers. comm.). In June 2000, an allis shad of approximately 45 cm in length 'in prime condition', was caught by salmon netsmen at the Topsham end of the Exe Estuary (J. Dell, pers. comm.).

In July 2001, seven shad, of which a representative fish weighed 450 g, were caught at Farmers Quay in the Dart Estuary and in August, a second haul of three shad was made at Duncannon, of which a representative fish weighed 540 g. These two fish were subsequently identified as allis shad.

In November 2001, fishermen netted two allis shad at Rickham Sands, Salcombe, at the mouth of the Kingsbridge Estuary (G. Force, pers. comm.); the fishermen reported that shad are occasionally caught at this time of year and over the winter, in the area around Salcombe Bar.

3.1.2.2 Twaite shad

In November 1998, a twaite shad was netted over a sandy seabed, about half a mile off Clerks Rock, Teignmouth (D. Clifton, pers. comm.) and in February 2000 a trawler caught twenty-five twaite shad of 30-45 cm, between Exmouth and Teignmouth (D. Pestle, pers. comm.). Twaite shad have been caught off Start Point, Devon; one was caught in March 1999 in a trawl fifteen miles offshore (Plymouth Trawler Association, pers. comm.) and within three miles of the coast a trawler netted eleven in March 2000 (I. Todd, pers. comm.).

Anglers have caught twaite shad in the Torbay area (S. Taylor, pers. comm.). In July 1999, an angler caught a twaite shad at Hopes Nose, Torquay (A. White, pers. comm.) and in July 2001 a twaite shad of 940 g was caught at Torquay (D. Creaney, pers. comm.).

In November 2001, fishermen operating at the mouth of the Kingsbridge Estuary at Salcombe Bar, caught a twaite shad of approximately 40 cm (G. Force, pers. comm.).

Twaite shad were reported from the Axe, Exe and Dart catchments; in July 2000, a twaite shad was caught in the Exe Estuary between Topsham and Turf Locks (K. May, pers. comm.). At Colyford on the River Axe a twaite shad was caught in 1963 (M. Bulleid, information from P. Maitland) and in 1995 an angler caught a twaite shad in Totnes Weirpool, River Dart (D. Pakes, pers. comm.).

3.1.2.3 Unidentified shad

In 1995, an angler caught two shad in the River Otter (Anon).

During March 2000, one or two shad were caught per day by pair trawlers operating in Teignmouth Bay and at the mouths of the Exe and Dart estuaries (I. Todd, DEFRA Officer, pers. comm.). From mid-January until early March 2000, up to 30 kg of shad was landed per day at Brixham. DEFRA Officers commented of this period at Brixham; “Shad appear on the market most days, sometimes in very large quantities”. A. Chadwick (pers. comm.) reported catching one or two shad per year in the Exe Estuary, in July and August, whilst netting for salmonids.

In December 1999, a shad of approximately 3 lb was caught, from Princess pier, Torquay (J. Herlihy, pers. comm.). In January and February 2000, shad were commonly taken in trawls offshore of Torquay (D. Clifton, pers. comm.).

In March 2000, an inshore trawler made a haul of twenty-one shad in Start Bay, between Start Point and Berry Head (I. Todd, DEFRA Officer). Fishermen from Polperro also reported large catches of shad in trawls offshore of Start Point, during January and February 2000; “A box of shad would turn up at Looe market every day…” (G. Joliff, pers. comm.).

There are several records of shad being caught by salmon netsmen in the Dart Estuary. R. Scoble reported that shad are caught in small numbers in the Dart every year and have been since at least the 1970s. Another netsman commented that shad of up to 3 lb, but typically 1-1.5 lb, are caught most years on the Dart. Shad have been caught upstream of Stoke Gabriel, Duncannon, Lie Out Point and Farmers Quay on the Dart (R. Scoble and B. Sokell, pers. comm.). Recently, in June 2001, an immature shad of approximately 0.5 lb in weight was caught at Duncannon and an adult shad of approximately 2 lb was netted at Lie Out Point.

3.1.3 Cornwall Area South Coast

3.1.3.1 Allis shad

In September 1998, an allis shad was netted at the mouth of the River Yealm (D. Roper, pers. comm.). The only record from the River Yealm dates from 1965, when an adult shad, believed to be allis, was caught at Woodburn Bridge (K. James, pers. comm.).

There are several records of allis shad being landed at Plymouth Fish Market, having been caught offshore of Plymouth (D. Herdson, M. Dawkins and P. Marshall, pers. comm.). Most allis shad are caught in trawls, sometimes as far offshore as the mid-English Channel.

In the 1950s, when the water level was considerably higher than at present day, shad were ‘frequently caught on rod and line’ immediately above Shaugh Bridge on the River Plym (Evans, pers. comm.).

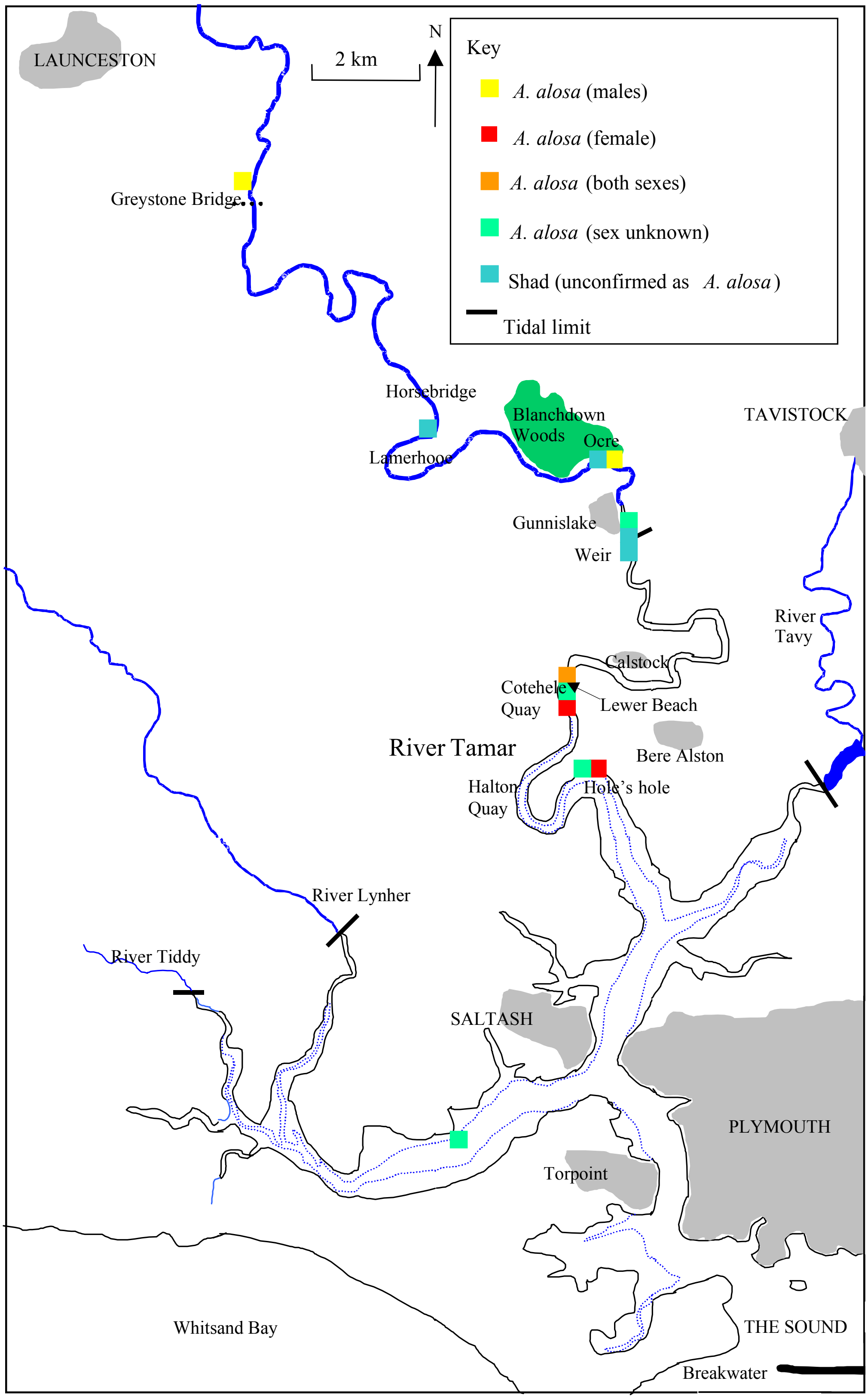


Figure 9: The distribution of shad records from the Tamar Catchment

There are over twenty instances of allis shad being caught by anglers/salmon netsmen in the Tamar Estuary and river, with a further twenty-one records to date where shad species was not identified (Tables 36-38, Appendix). Only allis shad have been positively identified from the Tamar.

Catches and observations (via video footage at Gunnislake Fish Pass) are made between May and October, with the majority of shad caught/observed between May and July (Figures 65 and 66, Appendix). Numerous records exist from 1997-2001 (Table 38, Appendix), although the Tamar salmon netsmen reported having caught allis shad in the Tamar each year for the last fifty years (A. Scoble and A. Jewitt, pers. comm.). Netsmen catch both adult and immature allis shad from Holes Hole to Calstock in the Tamar Estuary. Most shad are caught from the salmon netting stations in the estuary at Holes Hole, Halton Quay, Lewer Beach and Cothele Quay (Figure 9 and Figures 42, 45 and 46, Appendix).

River anglers catch adult allis shad most years in freshwater in the upper estuary and river. Four records exist of shad (two of which were allis) being caught from Weir Run, immediately below Gunnislake weir (P. Mercer and R. Burrows, pers. comm.) and allis shad have been caught on the first riffle section above Gunnislake Weir (P. Mercer and R. Hill, pers. comm.). Allis shad catches have been recorded further upstream at Blanchdown Pool (SX 435728) and Greystone Bridge (SX 367806; P. Pallinger, pers. comm.) [Figures 43 and 44, Appendix]. Shad (unconfirmed as allis) have also been caught at Ocre (SX 432728) and between Lamerhooe and Horsebridge (SX 399741; R. Hill, pers. comm.) [Figure 9].

From 1999 to 2001, shad of 40 to 60 cm in length have been recorded swimming upstream at the Gunnislake Fish Counter: the body size taken in conjunction with the other records of shad in the Tamar, suggests that these fish are allis shad. Most shad observed at Gunnislake fish counter are seen during May and June, although shad have been observed moving through the fish pass in July and August. On 21 June 2001 three large shad (c.45-60 cm), thought to be allis shad, were observed in a leat adjacent to Gunnislake weir; low flows had probably drawn the shad into the backwater, where the flow was greater than the main river channel (personnal observations).

Shad eggs, thought to be those of allis shad, were found from June to August in 2000 and May and June 2001 in Cottage Run, below Gunnislake weir. Eggs were more abundant in 2000 than 2001.

Allis shad have been caught by netsmen from the Lynher Estuary at Sheviock and Saltash (P. Stapleton, N. Chapman, B. Burrows and D. Martin, pers. comm.). There are no records from the freshwater Lynher.

Allis shad have been caught in large numbers along the south coast of Cornwall, particular offshore of Looe (Figure 40, Appendix). Significant numbers of shad, including allis, are landed at Looe. Pair trawlers, operating up to seven or eight miles offshore of Looe, caught up to 7 kg of allis shad per day during January and February 2000. Allis shad caught in trawls were typically 30 cm long (A. Toms, pers. comm.), which indicates immature fish rather than adults. Thirty allis shad 30-35 cm long were caught in a trawl offshore of Looe in February 2000 (L. Portman, pers. comm.). A catch in June 2000 contained nine allis shad of 25-30 cm in length (A. Drysdale, pers. comm.) and in November 2000 17 kg of mixed shad, including twenty allis shad, were caught in a pair trawl within three miles of Looe (Simmons, pers. comm.); most of the allis shad caught were 30-35 cm in length although there was one adult, approximately 48 cm long.

Allis shad, including adults and immature fish, are regularly caught by netsmen at Golant, in the Fowey Estuary. Allis shad have been recorded from the Fowey in the years; 1990, 1991, 1993-95, 1997-2000 via the net catch return forms of estuary netsmen (A. Williams, G. Thomas, M. Coon, S. Sweet, R. Lashbrook, S. Tabb and R. Tabb, pers. comms.).

Allis shad turned up in ones and twos in nets off Dodman Point, in November 1998 and throughout January 1999, and on one occasion fishermen landed two large adults (D. Herdson, pers. comm.). In June 2001, a small allis shad was caught in Mevagissey Bay, east of Dodman Point, (M. Ellis, pers. comm.).

J. Bridger reported catching adult and immature allis shad in nets off Restronguet Point, Carrick Roads, during summer months in the 1940s, and more recently in 1993. In September 2000, four immature allis shad were caught in a seine net at Groyne Point in the Helford Estuary, by researchers conducting a survey of juvenile bass (D. Goodwin, pers. comm.). An angler caught an allis shad from the shore at Falmouth, in June 1982 (Cornwall Wildlife Trust Records).

In June 1963, two allis shad were caught on hand lines off Cadgwith, on the Lizard Peninsula (B. Bolitho, Cornwall Wildlife Trust Records). Allis shad are occasionally landed at Newlyn Fish Market. DEFRA Officers reported an allis shad caught by beam trawl and landed at Newlyn in October 1997. During February 1999, several allis shad were netted in Mounts Bay (J. Lees and D. Poulding, pers. comm.) and in January 2000, two allis shad were caught in a gill net in Mounts Bay (N. de Rozarieux, pers. comm.). In May 2000 several allis shad were caught twenty miles south of Lizard Point (D. Poulding, pers. comm.).

An adult allis shad of 50 cm was caught in a beam trawl offshore of Lands End in June 2000 (D. Poulding, pers. comm.). In June the following year an allis shad was caught in a beam trawl off Lands End and nine very large allis shad, of which at least one had recently spawned, were caught offshore of the Scilly Isles (D. Poulding, pers. comm.).

3.1.3.2 Twaite shad

There are numerous records of twaite shad landings at Plymouth, between 1998 and 2001, mostly by trawlers (P. Marshall, M. Dawkins, D. Pestle, D. Herdson and S. Ralph, pers. comms.) [Figures 49 and 50, Appendix]. Twaite shad are mainly landed in quantities of ones and twos, between November and March. Unfortunately, information about catch location was often unavailable, although one trawl is known to have caught twaite shad seven miles SSW of Plymouth over a sand/gravel seabed. In March 2000, a twaite shad was caught in the middle of the English Channel in a pair trawl (P. Marshall, pers. comm.), whilst other trawls within a mile of Plymouth breakwater are known to have caught twaite shad (M. Dawkins, pers. comm.). An angler landed a twaite shad of approximately 30 cm at Penlee Point, outside Plymouth Breakwater, in September 1999. D. Martin (pers. comm.) reported catching twaite shad in the Lynher Estuary, in the 1960s, mainly during August.

In the winter months of 2000, staff at Looe fish market reported large twaite shad of approximately 40 cm in length being used by fishmongers as ‘display fish’. There are several records of twaite shad from Looe Bay and shad regularly appear on the fish market during the winter. In October 2000, a twaite shad of 46 cm was caught in Looe Bay about five miles offshore (A. Drysdale, pers. comm.). The following month one trawler in Looe Bay caught five twaite shad of 35-50 cm (Bodmin Seafoods staff, pers. comm.) and another landed seventeen kilos of mixed shad (containing twenty-four twaite) within three miles of the shore (Simmons, pers. comm.). In the same month a third catch of eleven twaite shad was made within five miles of Looe (A. Drysdale, pers. comm.).

In February 2000, three twaite shad were caught in a trawl, eight miles offshore of Falmouth (Local Inshore Trawler co., pers. comm.). Around Falmouth Bay twaite shad are referred to as ‘Mother Herring’. In April 2000, a further two twaite shad were caught in a trawl, six to seven miles north-east of the Manacles (P. Green, pers. comm.). Local angling club records include a twaite shad caught in 1975 from the Manacles and a second in 1982, at Porthkerris (information from Cornwall Wildlife Trust).

Deeble and Stone (in Cornish Wildlife Trust Records) reported that twaite shad are caught from early to mid-summer in the Fal, Ruan, Tresillian, Truro and Percuil Rivers. J. Bridger (pers. comm.) reported having caught twaite shad from the 1940s onwards in summer, in the Carrick Roads at Restronguet Point. In July 1999, two fish of approximately 3 cm, believed to be juvenile twaite shad, were caught in the Helford Estuary at Groyne Point (D. Goodwin and P. Gainey, pers. comm.), which indicates that there may be a spawning site somewhere in the area.

In February 1999 ten twaite shad were netted in Mounts Bay and in February 2001, a twaite shad was caught by hake fishermen, in a beam trawl north-west of the Scilly Isles (J. Lees and D. Poulding, pers. comm.).

3.1.3.3 Unidentified shad

In the winter months of 2000, large quantities of shad were landed at Looe Fish Market (L. Portman and M. Sheppard, pers. comm.); in February one haul offshore of Looe produced thirty shad. In the summer months of 1990, A. Drysdale (pers. comm.) recalled catching two shad, each weighing about 2 lb, in the tidal part of the River Looe.

In 1994 a shad was caught in the Fowey River adjacent to Restormel Castle, Lostwithiel (M. Coon, pers. comm.).

Shad are often caught in trawls and gill nets along the south coast of Cornwall. Records exist from St Austell Bay, the waters around Dodman Point and Mevagissey Bay (C. Gilbertson, Anon., D. Herdson, M. Ellis and R. Waters, pers. comms.). Many shad were caught in 1996, in pilchard nets within a few hundred yards of the shore, at several locations between Black Head and Par Sands, St Austell Bay (C. Gilbertson, pers. comm.). A box of about thirty ‘mixed shad’ was caught off Mevagissey and landed at Plymouth Fish Market in 1998 (Anon., 1998). Catches of shad in gill nets off Mevagissey are mostly made between September and November, with occasional catches in summer months (C. Gilbertson, pers. comm.). In April 2000, two shad were caught inshore at Mevagissey, one by rod from the pier and one in a herring net, a few hundred yards off the quay (C. Gilbertson, pers. comm.). Nineteen shad of 20-25 cm in length, were caught on mackerel feathers off Pentewan Point, Mevagissey Bay, in May 2001 (R. Waters, pers. comm.).

Shad were occasionally caught in trawls in Falmouth Bay, in the early 1980s (P. Gainey, pers. comm.). In March 2000, two shad were caught in a trawl in Falmouth Bay (Local Inshore Trawler co., pers. comm.). P. Green (pers. comm.) reported catching shad regularly in ones and twos in Falmouth Bay and R. Wing (of Wings Fish, Indian Queens, which sources much of its fish from Falmouth Bay trawlers), estimated that on average, one or two shad are seen per month at Wings Fish Wholesalers. From August to October 2000, shad of approximately 25 cm in length were caught by anglers from Prince's Pier, Falmouth (B. Morris, pers. comm.).

In January 1999, five adult shad were netted off Lizard Point (D. Poulding, pers. comm.). Anglers have caught shad from Porthallow and Porthkerris Coves on the Lizard Peninsula (B. Morris, pers. comm.), Prussia Cove, Mounts Bay (T. Cornish, Cornwall Wildlife Trust Records) and close inshore at Mousehole (C. Cass, pers. comm.).

Four shad were caught off Penzance in February 2000 (S. Davis, pers. comm.). In March and April 1991, nine shad were landed at Newlyn and offshore of Newlyn a shad was caught in February 2000 (A. Wheeler, pers. comm.). Hake fishermen caught exceptionally large quantities of shad off Lands End and around the Scilly Isles in November 2000, although these were not identified to species. One boat, the *Ajax*, netted 25 stones (160 kg) of shad (amongst which allis shad were confirmed) and the *Golden Harvest* netted one and a half tonnes of shad in one haul (D. Poulding, pers. comm.). The size of these fish varied from immature fish of approximately 25 cm to adults of up to 55 cm in length.

In April 1991, two shad were caught north of Wolf Rock, off Lands End and in October 1997 a beam trawler caught a shad south of Wolf Rock (D. Poulding, pers. comm.). The '*Cathryn Flemart'* caught two shad southwest of Lands End, in November 1993. In late summer and autumn 1998, up to 15 shad per haul were caught in gill and drift nets north of the Scilly Isles (B. McCabe, pers. comm.).

3.1.4 Cornwall Area North Coast

3.1.4.1 Allis shad

A record from June 1907 states that several allis shad were caught at Egloshayle in the Camel Estuary, and that ‘frequent catches were made in the Camel Estuary’ (J. Clark, Cornwall Wildlife Trust Records). More recently, an allis shad of 38 cm was caught in June 2001, at St Georges Cove in the Camel Estuary (M. Biddle, pers. comm.). Mr Biddle also reported of an allis shad of approximately 5 lb caught from the Camel Estuary by a fellow netsman.

3.1.4.2 Twaite shad

Fishermen using inshore bass and gill nets, occasionally catch twaite shad along the north coast of Cornwall. One fishermen described catching them ‘in late autumn and after Christmas’, from Trevaunance Cove, St Agnes, to Perranporth (B. Garland, pers. comm.). Garland reported catching a twaite shad of 760 g in bass nets off Perranporth Beach, in January 2000. In January 2001, nine shad including seven twaite, were caught in a bass net between Whipsiderry and Porth Beaches, Newquay (P. Trebilcock, pers. comm.).

3.1.4.3 Unidentified shad

P. Gay (pers. comm.) recalled catching shad, whilst netting for ‘school peel’ in the Hayle Estuary during September 1991; catches were occasional and included fish of up to approximately 35 cm in length. In January 2000, Environment Agency Enforcement Officers encountered a shad in an illegal net at Gwithian Towans Beach, Gwithian (D. French, pers. comm.). Small shad, typically 25 cm long, are occasionally caught in sandeel nets, close inshore in St. Ives Bay (M. Gilbert, pers. comm.).

On the north coast of Cornwall, fishermen operating bass and gill nets occasionally catch shad. From July to October, shad are regularly caught in gill nets off the north coast of Cornwall at St. Ives, St Agnes, Perranporth and Newquay (S. Neve, pers. comm.). Another bass fishermen, recalled catching shad in bass nets at St Agnes and at Holywell Bay (K. Bennetts, pers. comm.). On two occasions in August 1995, a shad was caught in bass nets, close inshore at Trevellas and Trevaunance Coves, St Agnes (C. Whitworth, pers. comm.). A Newquay-based netsmen, reported catching up to a dozen shad per night on calm spring and summer evenings (from May to August), in beach seines at Porth and Mawgan Porth Beaches, north of Newquay (R. Eglinton, pers. comm.). In January 2000, a shad was caught in bass nets within 50 m of the shore at each of two locations; Perranporth and Whipsiderry Beaches (P. Trebilcock, pers. comm.). In January the following year Mr Trebilcock caught nine shad, including two adult allis shad, whilst bass netting between Whipsiderry and Porth Beaches and a further ten shad in Newquay Bay, in April 2001.

A former warden for the River Camel recalled occasionally catching shad in the Camel Estuary, during autumn months in the early 1980s (F. Bartlett, pers. comm.). T. Platt, a former Camel Estuary netsman, reported that in the years 1980-1998 catches of shad were very occasional, averaging at fewer than one fish per season: “Shad were mainly caught in drift nets during July and August”.

3.1.5 Devon Area North Coast

3.1.5.1 Allis shad

Allis shad have been netted at Appledore at the mouth of the Taw/Torridge estuaries; in June 2000, N. Tucker (netsman) caught an adult female of 1605 g (Figure 47, Appendix) and an immature allis shad was netted in June the following year (J. Cox, pers. comm.). In 2000, D. Barnes caught six adult allis shad in Bideford Bridge Pool (Figure 41, Appendix) , with a further two allis shad in 2001. The details of allis shad caught in the Torridge Estuary in 2000 and 2001, are shown in Table 6.

Table 6: *A. alosa* records from the Torridge Estuary during 2000 and 2001

Date	Location	Total body length (cm)
6 June 2000	Appledore	52.3*
3 July 2000	Bideford Bridge Pool	63.5
18 July 2000	Bideford Bridge Pool	45.7
18 July 2000	Bideford Bridge Pool	53.3
19 July 2000	Bideford Bridge Pool	55.9
31 July 2000	Bideford Bridge Pool	46.8*
29 August 2000	Bideford Bridge Pool	59.7
4 June 2001	Appledore	32.4*
18 July 2001	Bideford Bridge Pool	39.4
19 July 2001	Bideford Bridge Pool	44.5

Measurements were made by the netsmen in inches and converted to centimetres.
‘*’ indicates that the fish was identified and measured by the Project Officer.

3.1.5.2 Twaite shad

Twaite shad were caught by anglers in 1976 at Minehead and in 1979 from the shore at Bossington, North Devon (Bristol City Fed. of Sea Anglers).

D. Barnes reported making catches of twaite shad each year, in the Bideford Bridge Pool, Torridge Estuary (Figure 51, Appendix). Table 7 shows the details of twaite shad caught at Bideford during the 2000 netting season.

Table 7: *A. fallax* records from Bideford Bridge Pool during 2000

Date	Length (cm)
18 July	43.2
19 July	35.6
19 July	45.7
2 August	40.6
2 August	45.7
2 August	50.8
3 August	43.9
23 August	40.6
23 August	48.3

3.1.5.3 Unidentified shad

Salmon netsmen operating in the Torridge Estuary have reported catching shad in the summer months (J. Daniel, D. Barnes, J. Cox and P. Carter, pers. comm.). J. Daniel catches 'a few per season' during July and August at Instow at the mouth of the Torridge. J. Cox (netsman) commented; "There seems to be good years and bad for shad. I've only ever caught small shad but the other netsmen have occasionally caught adults". D. Barnes has caught many shad (both species) at Bideford Bridge Pool, in the Torridge Estuary; "On average I catch about six to eight shad per year. Between 1996 and 2000 I've caught about twenty-four shad".

In August 1998, a shad was caught by an angler at Ilfracombe Pier (A. Storton, pers. comm.). Shad are occasionally caught in bass nets around Lundy Island, N. Devon (B. Thomas, pers. comm.).

3.1.6 North Wessex Area

3.1.6.1 Allis shad

An angler caught an immature allis shad from a boat off the coast of Minehead, in 1989 (Bristol City Fed. Sea Anglers Records).

3.1.6.2 Twaite shad

A twaite shad of 1040 g was caught in a trawl over Gore Sands, Burnham-on-Sea, in April 2000 (G. Gillam, pers. comm.). In July that year, D. Metcalfe (pers. comm.) reported catching a small twaite shad of approximately 25 cm in a net at Western-super-mare.

3.1.6.3 Unidentified shad

At Minehead, two shad of approximately 20 cm were caught in a drift net within half a mile from the shore, in December 2000 (James, pers. comm.); Mr James recalled catching approximately two hundred small shad off Minehead in the 1980s, whilst netting for herring.

Netsmen in the Bristol Channel and Severn Estuary catch shad in the spring. Shad are occasionally caught over Scar Sands in the Bristol Channel (B. Thomas, pers. comm.). One netsman, who claimed to have netted in the area for over sixty years reported catching shad at Longley Sands, Bollow, each May; " Most of the fish we catch are twaite, but some are allis shad" (F. Gibson, pers. comm.).

3.1.7 Summary of estuarine and freshwater records

Shad were recorded from fifteen estuaries and three rivers in south-west England (Table 8 and Figure 10). Allis shad were recorded from ten estuaries and twaite shad from four. Significant records of allis shad came from the Tamar catchment and also from the estuaries of the Fowey and Torridge. Significant numbers of twaite shad were also recorded from the Torridge Estuary.

Table 8: The frequency of occurrence of shad in estuaries and rivers in south-west England, based on records post 1970, collected during this project.

Numbers given in brackets are cumulative numbers of fish recorded.

Estuary	*A. alosa*	*A. fallax*	Unid.	River	*A. alosa*	*A. fallax*	Unid.
Camel	1 (1)		3 (4)	Camel			
Dart	2 (10)		1 (3)	Dart		1 (1)	
Exe	2 (3)	1 (1)		Exe			
Fal / Helford	1 (4)	2 (2)	1 (>1)	Fal / Helford			
Fowey	5 (>13)		4 (>18)	Fowey			1 (1)
Frome / Piddle			1 (1)	Frome / Piddle			
Hayle			1 (>1)	Hayle			
Kingsbridge	1 (2)	1 (1)		Kingsbridge			
Looe			1 (2)	Looe			
Lynher	3 (5)		2 (2)	Lynher			
Otter			1 (2)	Otter			
Plym			1 (3)	Plym			
Tamar	19 (>39)		4 (11)	Tamar	6 (8)		17 (17)
Torridge	8 (10)	5 (7)	1 (1)	Torridge			
Yealm	1 (1)			Yealm			

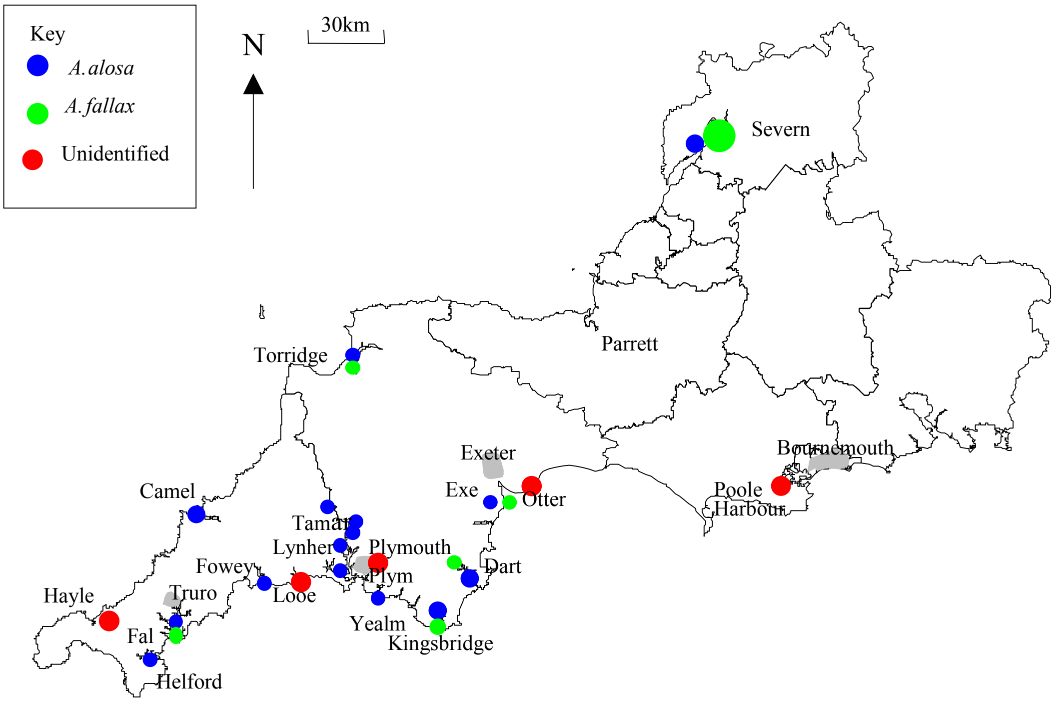


Figure 10: The distribution of post 1970 shad records in estuaries/rivers in south-west England.

3.1.8 Reports of shad from other regions

Catches have been reported from the south coast and south-east of England in particular. Shad have been landed in large quantities at Hastings and Newhaven during the winter months; from February to April 2000 two tonnes of shad were landed to one merchant (C. Browning, pers. comms.). Records were received from the Thames area where anglers and fishermen have been catching twaite shad more frequently in recent years. Numerous records of shad landings were received from the Portsmouth area (D. Jenkins, pers. comm.), where shad were caught from the Solent and around the Isle of Wight. Relatively few shad reports exist from the north and east of England, although reports were received of numerous shad caught by trawlers in the Farne Deeps, off Northumberland (Burns, pers. comm.).

3.2 Catch Information

3.2.1 Method of capture

The most common capture method for both species of shad was trawling, particularly during the winter months (Table 9). Bass and drift nets seem to catch shad throughout the year, although several fishermen operating bass nets claimed that shad were much more common in inshore waters during the warmer months. Records from anglers were much more numerous during summer months than during the winter. Although this may reflect the inshore movements of shad during the summer months, recreational anglers also fish more frequently during the warmer months.

Table 9: Relative frequency of different marine capture methods among post-1970 records of *A. alosa* and *A. fallax* (n = 169)

Capture Method	Species						Total number caught per method	
	Shad (unidentified)		Allis shad		Twaite shad			
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Rod/Line	1	20	0	10	0	7	1	37
Net-unspecified	12	4	8	3	8	2	28	9
Seine/ Pilchard/ Bass/Drift/ Gill net	9	6	2	5	6	2	17	13
Otter/Beam/ Pair Trawl	6	3	7	5	21	1	33	9
Unknown	0	0	1	2	1	0	2	2

(Winter: November-April, Summer: May-October)

Table 10: The total number of *A. alosa* and *A. fallax* (reported) caught at sea in South West Region, between January 1990 and November 2001

Fishery	Abundance	Shad (unidentified)	Allis	Twaite
Inshore	Number	32	7	58
	Other comments	'Few', 'Occasional', '1-2 per year', 'Several' (2), 'Many', '6-12 per night', 'Upto 10-15 per haul'	-	'Many'
Offshore	Number	29	114	140
	Other comments	'Occasional', '1-2 per day' (2), '1-4 per day', 'frequent', 'many', '6-12 per day', '7kg per day', '15kg per day, '30kg per day', 'box per day', '159 kg', '1.5 tonnes'.	-	'Catch of 17 kg'
Net	Number	32	5	3
	Other comments	-	-	-
Anglers	Number	44	1	5
	Other comments	'Occasional', '2-3 per year'	-	-
TOTAL	**Number only**	**137**	**127**	**206**

Table 10 indicates that although the frequency of occurrence in inshore and offshore nets is similar, the number of shad of both species taken in offshore nets is much greater than that taken in inshore nets. This is probably due to the difference in scale of these two fisheries. The number of trawlers and the potential number of fish caught by trawlers is far greater than the number of inshore nets and the fish they catch, which may explain why more shad are caught offshore.

The numbers of fish presented in Table 10 is of limited value, because inevitably, many fish go unrecorded. Furthermore, method of capture may be a significant factor in determining whether catches are reported. For example, anglers may be more inclined to report catches than commercial fishermen.

3.2.2 Water depth

Information gathered about the depth of water from which catches were made was always anecdotal; water depth measurements may have been obtained from a depth-finder or they may have been estimated. As such the results presented here should be treated with caution.

Most trawls operated in deep water. Records were received of shad caught at 6-7 fathoms (36-42 m) and considerably deeper at 90-110m in the Farne Deeps, Northumberland. Nine allis shad were caught in a series of beam trawls, which operated in water 100-200 m deep. Another fisherman reported catching a twaite shad in a bottom trawl over a sand/gravel seabed, in 55 m of water.

Since the beam trawl fishes at 0.5 m above the seabed, the shad were assumed to have been caught either as the equipment was being lowered or raised. However, anglers have reported catching shad very near to the seabed; one angler was float fishing off Torquay pier in 16-18 ft (5-6 m) of water and caught a shad 2 ft (0.6 m) off the bottom.

The majority of bass-net operators indicated that netting typically took place very close inshore (<200 m). Bass netsmen from the Salcombe area reported catching allis and twaite shad over a sandy seabed, in 30ft (c. 10 m) of water. Like anglers, several inshore netsmen reported catching shad on or near the seabed. De Rozarieux (pers. comm.) reported catching a shad 4m off the seabed, whilst gill netting in 50 m of water. P. Trebilcock (pers. comm.) reported catching shad in bass nets "on the bottom, about 50 m from the shore".

3.2.3 Target species

It is worth mentioning that at certain times of the year shad are caught with other species, to the extent that some fishermen use shad as an indicator of the arrival of other species. In summer months shad are caught with scad (*Trachurus trachurus*), pilchards (*Sardina pilchardus*), herring (*Clupea harengus*), mackerel (*Scomber scombrus*), garfish (*Belone belone*), bass (*Dicentrarchus labrax*) and red mullet (*Mullus surmuletus*).

Numerous sea anglers reported catching shad whilst spinning for bass, feathering for mackerel and float fishing with mackerel bait; out of fourteen shad caught by these methods eleven were identified only as 'shad' and three were confirmed as twaite. This is interesting given that dietary studies (Section 3.4.6) revealed that twaite shad are far more piscivorous than allis. It is therefore possible that twaite shad will be encountered more frequently by anglers, which may lead to a false assumption that allis shad are scarcer.

3.2.4 Time of year

Both species were caught in offshore (>1 mile) trawls and seine nets during the winter months, particularly January-March (Figure 11). During February 2000, shad caught offshore were landed in quantities of up to 30 kg per day at Brixham and Looe. Catches offshore tended to be between October and March, most catches of shad taking place in January and February. Catches in offshore nets tended to be more seasonal than catches in inshore drift nets, although this may be a product of unequal fishing effort throughout the year. Fishermen operating trawls in the winter months, may resort to inshore netting activity or scalloping as one fishermen did, in the summer months.

Shad were caught throughout the year in inshore drift nets, including bass and gill nets (Figure 12). Most catches were in January, but significant numbers of catches were also made during the summer and autumn months, from July to November. Catches of shad by sea anglers were very seasonal with nearly all catches taking place in the summer, between May and October (Figure 13). However, this may reflect the increased angling effort during the warmer months, rather than an increase in abundance of shad inshore.

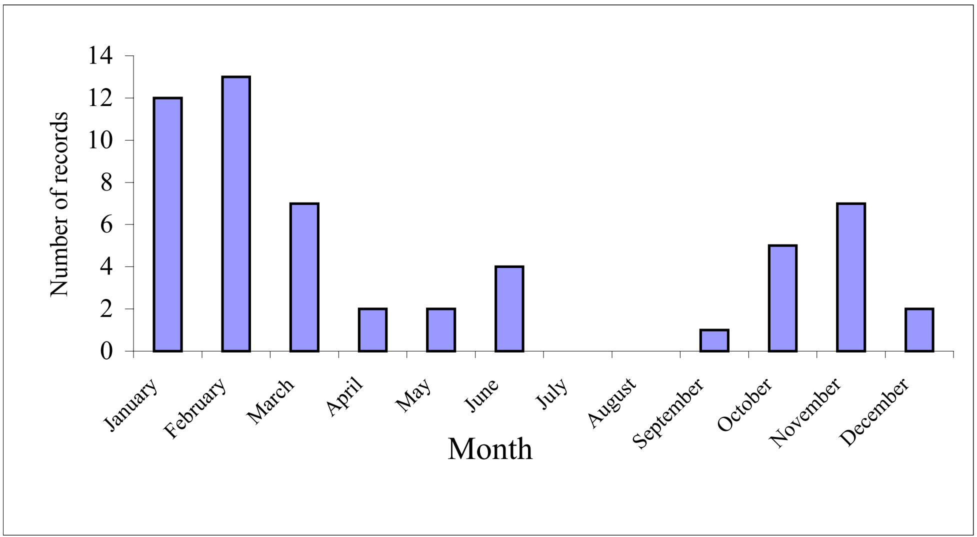


Figure 11: The relative abundance of shad at different times of year, as represented by the frequency of occurrence in offshore net (trawl, seine or drift nets fishing greater than one mile from the shore) catches at sea, around south-west England

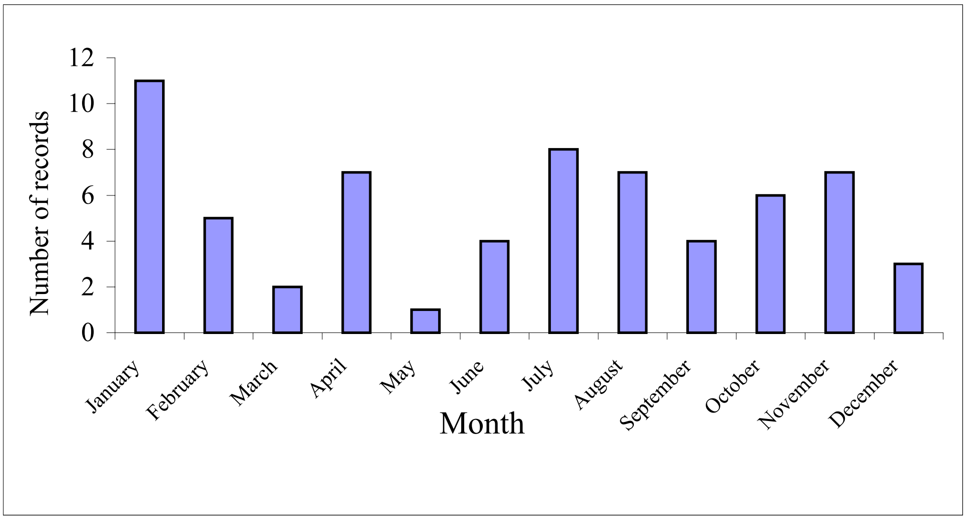


Figure 12: The relative abundance of shad at different times of year, as represented by the frequency of occurrence in inshore net (seine or drift nets fishing within one mile from the shore) catches at sea, around south-west England

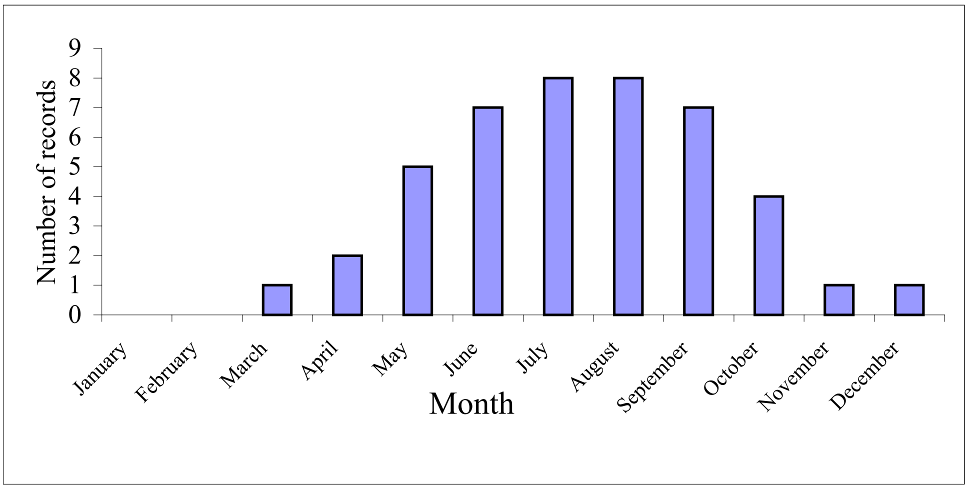


Figure 13: The relative abundance of shad at different times of year, as represented by the frequency of catches by anglers at sea, around south-west England

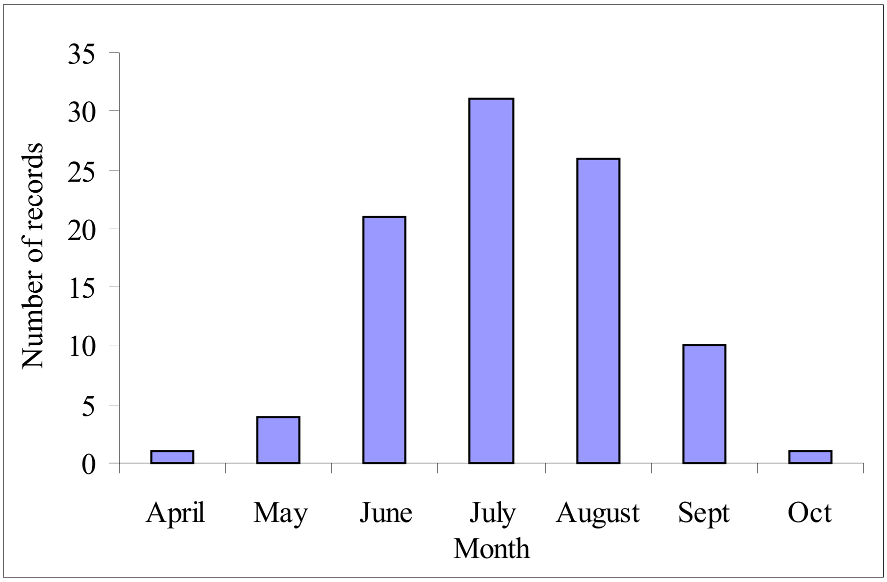


Figure 14: Number of post-1990 records of shad caught from estuaries and rivers in south-west England, during different months of the year

Figure 14 shows the number of records from estuaries and rivers in south-west England, in each month. Most records collated were between June and August. However, due to the restricted salmon-netting season, records from netsmen are confined to this period.

3.3 Biology

3.3.1 Gill rakers

3.3.1.1 Allis shad

The relationship between total body length and the number of gill rakers is shown in Figure 15. The gill rakers on the first gill arch of sixty-four allis shad from estuaries and coastal waters were counted. The number of gill rakers of allis shad varied from 84 to 143, with the number of gill rakers increasing with total body length. In allis shad the coefficients of least square regression relating the number of gill rakers on the first gill arch (Br) to total body length (Lt) in cm was: Br = 0.9039 Lt + 73.532 (n = 64). The relationship in adult allis shad (>40.0 cm) was: Br = 0.448 x Lt + 96.811 (n = 33). The mean number of gill rakers of adult allis shad from south-west England was 118.91 (n = 33, SE = 1.75).

The number of gill rakers in adult allis shad recorded from the River Tamar ranged from 105 to 128. The sample size was very small (n = 8) so comparisons between allis shad from the River Tamar and other populations should be treated with caution. For adult allis shad from the River Tamar the coefficient of least square regression, relating the number of gill rakers on the first gill arch (Br) to total length (Lt) in cm was: Br =

0.0852 Lt + 112.64 (n = 8). The mean number of gill rakers in adult allis shad from the River Tamar was 117.25 (n = 8, SE = 2.68).

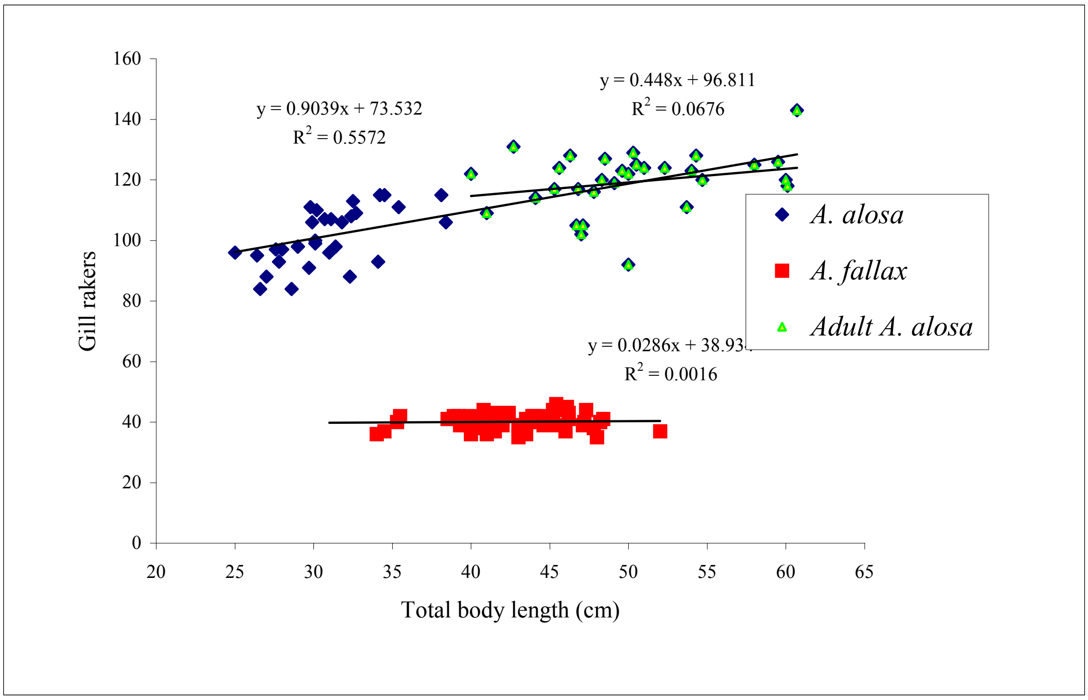


Figure 15: The relationship between total body length and the number of gill rakers for *A. alosa* and *A. fallax*

3.3.1.2 Twaite shad

The gill rakers on the first gill arch of sixty-five twaite shad were counted. The number of gill rakers varied very little, ranging from 35-46. For twaite shad between 35 and 55 cm in length, the number of gill rakers was not observed to increase with body length, as indicated by the coefficient of least square regression shown in Figure 15. The mean number of gill rakers on the first gill arch in twaite shad was 40.15 (n = 65, SE = 0.31). Because twaite shad mature at a smaller size than allis shad, the area of the graph where gill rakers would be expected to increase with body size is not included. This is because twaite shad below 31.0 cm were not encountered during this study.

3.3.1.3 Allis and twaite shad hybrids

No evidence of hybridisation was found, as indicated by an absence of fish with an intermediate number of gill rakers.

3.3.2 Dorsal and anal fin rays

3.3.2.1 Allis shad

The number of dorsal and anal fin rays varied among allis shad specimens; the mean number of dorsal fin rays was 19.42 (Range = 17-21, SE = 0.11, n = 53) and the mean number of anal fin rays was 24.25 (Range = 22-27, SE = 0.14, n = 52) [Figures 16 and 17]. Neither the number of dorsal or anal fin rays were related to body length (Respective correlations: $R^2 = 0.0011$, P = N.s, df = 52 and $R^2 = 0.0107$, P = N.s., df = 51). No significant correlation was found between the number of dorsal and anal fin rays in allis shad (Correlation: $R^2 = 0.125$, P = N.s., df = 51).

3.3.2.2 Twaite shad

The mean number of dorsal fin rays in twaite shad was 19.30 (Range = 18-21, SE = 0.11, n = 53) and the mean number of anal fin rays was 21.15 (Range = 18-23, SE = 0.15, n = 52) [Figures 16 and 17]. Neither the number of dorsal or anal fin rays were related to body length (Respective correlations: $R^2 = 0.0006$, P = N.s, df = 52 and $R^2 = 0.0485$, P = N.s., df = 51). No significant correlation was found between the number of dorsal and anal fin rays in twaite shad (Correlation: $R^2 = 0.112$, P = N.s., df = 51).

3.3.2.3 Differences between allis and twaite shad

A two-tailed T-test confirmed that there are significant differences between the mean number of anal fin rays in allis and twaite shad (P = 2.39 E –27; df = 102) [Figure 17]. Furthermore, this difference cannot be attributed to a difference between the mean size of allis and twaite shad encountered during the project, because correlation showed that there was no relationship between the number of anal fin rays and total body length. This observation applies to the range of fish included in this study i.e. allis shad of 25.0-60.7 cm and twaite shad of 31.0-52.0 cm.

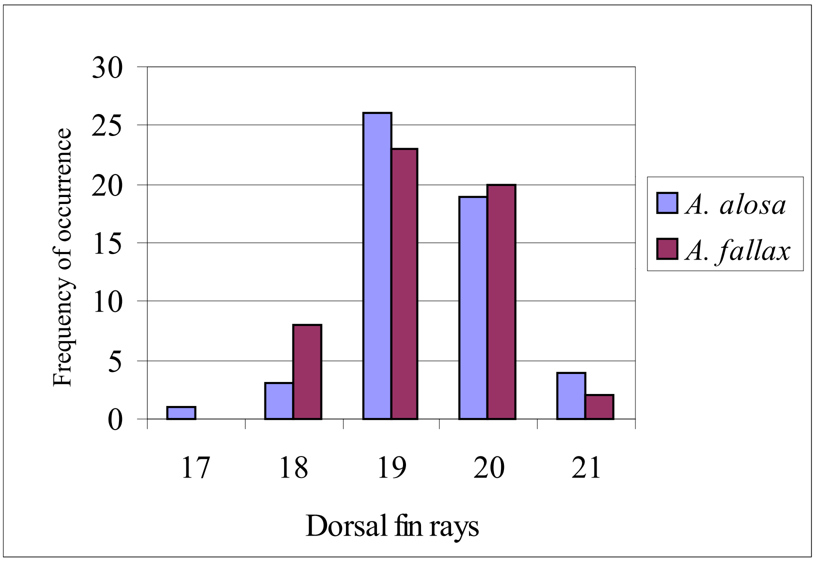


Figure 16: The number of dorsal fin rays in *A. alosa* and *A. fallax*

A two-tailed T-test showed that there was no significant differences among the mean number of dorsal fin rays in allis and twaite shad (P = 2.39 E –27; df = 102).

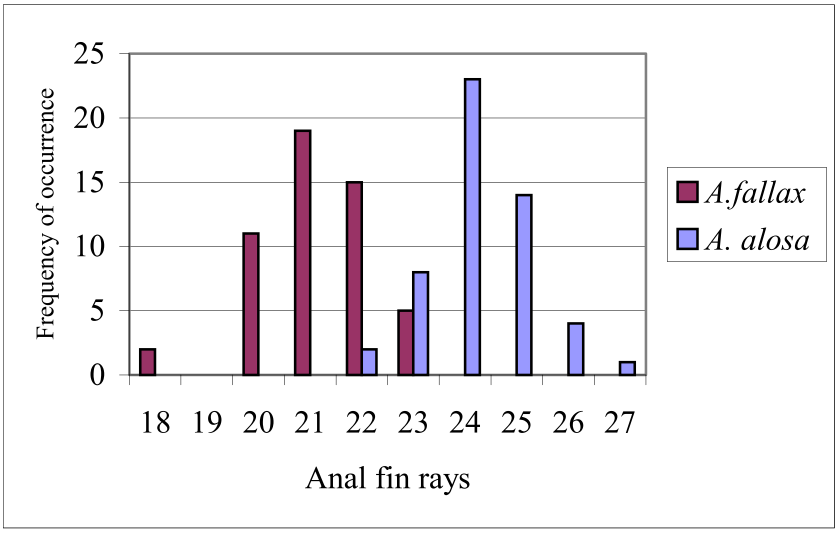


Figure 17: The number of anal fin rays in *A. alosa* and *A. fallax*

3.3.3 Flank spots

Differences in the visibility of flank spots between fish with scales intact, partially descaled fish and fully descaled fish, made counting the number of flank spots an inexact science. Fish with just one flank spot showing when fully scaled often had more spots underneath, which became visible upon removing the scales.

3.3.3.1 Allis shad

Figure 18 shows the relationship between flank spots (taken as an average from the left and right flanks) and total body length for each species. The chart shows that in allis shad, the number of flank spots is related to body size, although not linearly. A one-tailed T-test showed that the mean number of flank spots per flank in immature allis shad is significantly greater than in adults ($P = >0.001$; $df = 89$).

In immature allis shad (<40.0 cm) the number of flank spots (averaged for right and left flanks) ranged from 1 to 19.5 ($n = 66$), with a mean of 9.54 spots and a modal number of one spot.

In adult allis shad, the mean number of flank spots per flank was 4.62 ($n = 25$; Range = 0-21.5), although the most usual number of flank spots was one. This spot was located immediately behind the operculum and was relatively large (typically 15 mm in diameter). Fish with a larger number of flank spots were often lacking scales; in life, scales probably obscured all but the first of the spots along the flank. These observations suggest that in allis shad flank spots are present in immature fish but are lost once sexual maturity is reached. An alternative explanation is that the scales become thicker with age and obscure the spots which are visible in immature fish.

In allis shad flank spots were often very faint and smaller than in twaite shad. The vertical position of spots on the flank often varied in allis shad to the extent that a second, albeit shorter, row of spots was visible below the first in some fish. The spots in this second row were usually positioned mid-way between spots in the row above. Spots in the second row were usually fainter and often less well defined than spots in the first row (Figure 48, Appendix).

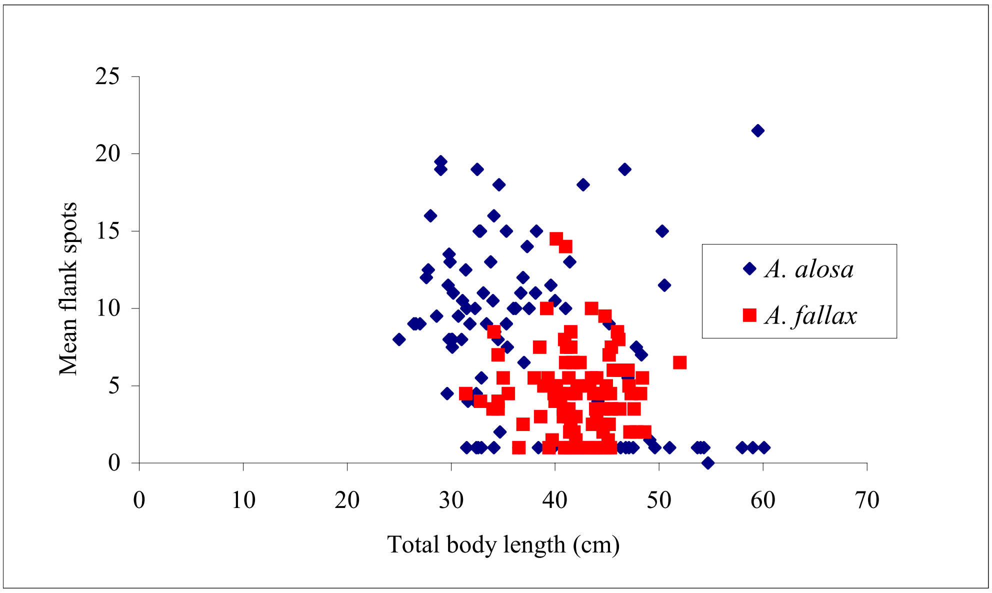


Figure 18: The relationship between flank spots and body length for *A. alosa* and *A. fallax*

3.3.3.2 Twaite shad

The number of flank spots per flank in twaite shad ranged from 1 to 15 (mean = 4.47; n = 95). Flank spots in twaite shad were usually well-defined and in a single row along the flank. They were usually larger (Up to c.10 mm in diameter) and darker than flank spots in immature allis shad (Up to c. 5 mm).

3.4 Ecology and Life History

3.4.1 Reproduction

3.4.1.1 Gonadosomatic indices

3.4.1.1.1 Allis shad caught from estuaries and rivers

The gonadosomatic index (GSI) of adult allis shad caught from rivers and estuaries is shown in Table 11; the number of fish caught was relatively small so the following data should be treated with caution. The maximum GSI recorded for a female allis shad was 16.91 % (n = 6) from the River Tamar, on 1 June 2000. The maximum GSI recorded for a male allis shad was 10.20 % (n = 6), caught on the 13 May 1999, also from the River

Tamar. Males were caught from May-August; the highest GSIs were recorded in May. Females were caught in June and July; high GSIs were recorded from both months.

Table 11: Records of *A. alosa* in spawning condition

Date	Catchment	Sex	Length (cm)	Weight (g)	GSI
4 July 1998	Tamar	Female	60.0	1500	2.47
13 May 1999	Tamar [a]	Male	44.0	1030	10.20
12 May 2000	Tamar [a]	Male	47.1	820	9.10
1 June 2000	Tamar	Female	53.7	1460	16.91
6 June 2000	Torridge	Female	52.3	1605	15.71
14 June 2000	Tamar	Female	59.0	1260	11.82
27 July 2000	Tamar	Female	60.1	1405	5.60
31 July 2000	Torridge	Male	46.8	805	3.82
17 August 2000	Fowey	Male	49.6	910	5.30
1 June 2001	Tamar	Male	46.3	870	0.60[b]
5 June 2001	Tamar	Male	49.1	1090	0.18[b]
2 July 2001	Tamar	Female	58.0	1350	13.45

a = Caught in freshwater; b = spent fish

On 1 and 5 June 2001, two adult male allis shad with very low GSIs (0.60 and 0.18 %, respectively) were caught in the Tamar Estuary; recent spawning marks were visible on the scales of both these fish. It is likely that they had recently spawned.

3.4.1.1.2 Allis shad caught at sea

The GSI of adult allis shad (two females, two males and twelve of unknown sex) caught at sea ranged from 0.02 – 4.17 % (Mean = 0.70 %, SE = 0.23, n =16).

Nine adults caught approximately 30 miles south-west of the Scilly Isles, on 11 June 2001 were probably spent, owing to the extremely small size of the gonads, in relation to the size of the fish and the time of year. However, scales were unavailable; only one fish had readable scales, revealing a fish of 6+. Their body lengths ranged from 42.7 cm to 59.5 cm and weights from 710 g to 1950 g. The GSI of these fish ranged from 0.09-0.66 %.

3.4.1.1.3 Twaite shad

All but one of the twaite shad specimens examined during this study were from the sea (twaite shad were recorded in estuaries, but specimens were not available for examination). The GSI of male and female twaite shad is shown in Figure 19. The GSI of adult females from coastal waters averaged 2.43 % in January 2000 (n = 10) and 3.54 % in February 2000 (n = 18, range = 0.73 - 8.69 %). The maximum GSI was 10.80 %, recorded in April 2000 at Burnham-on-Sea. GSI was recorded from four males only (Range = 0.54-2.64).

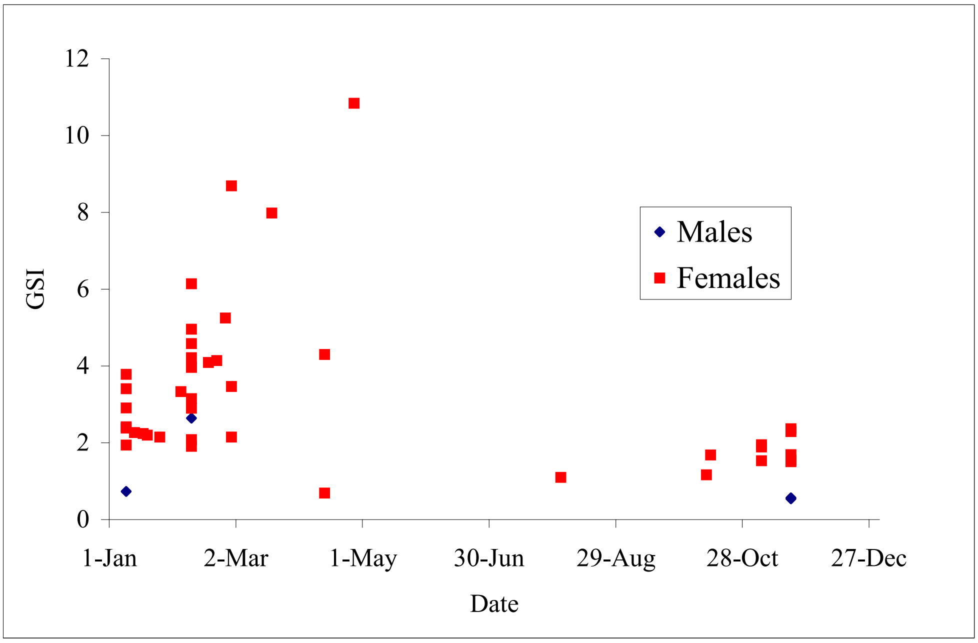


Figure 19: Gonadosomatic index of *A. fallax* at different times of year

3.4.1.2 Relationship between fecundity and body size

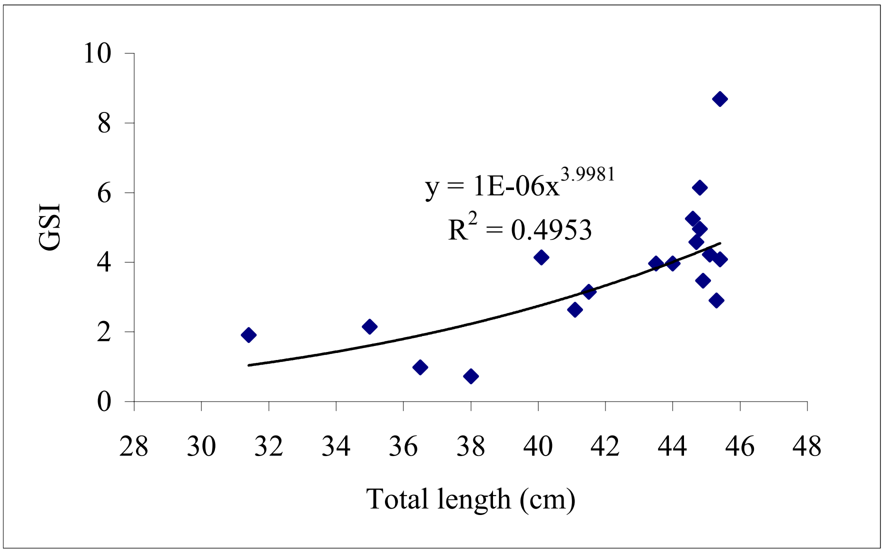


Figure 20: The relationship between total body length and GSI in *A. fallax* caught at sea, during February 2000

In twaite shad, there was a positive relationship between body size (length and weight) and GSI (Figures 20 and 21). Fecundity (as GSI) was more closely linked to body weight than length. Data was not available to investigate the relationship between total body length and GSI in allis shad.

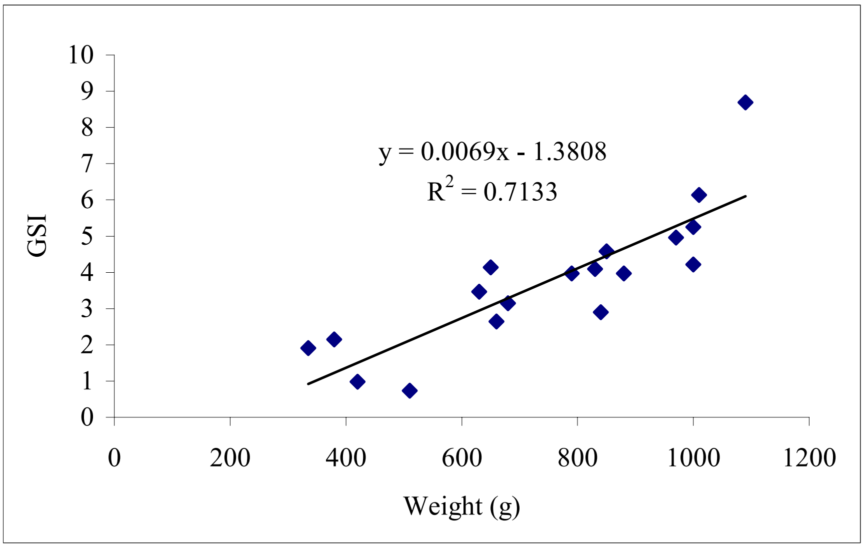


Figure 21: The relationship between total body weight and GSI in *A. fallax* caught at sea during February 2000

3.4.2 Spawning

3.4.2.1 Number of spawnings

The scales of adult allis (n = 12) and twaite shad (n = 41) were examined to determine the age of first spawning and the number of previous spawnings (Tables 12-15). Most of the allis shad scales examined were from mature fish in spawning condition from estuaries and rivers, whereas all but two of the twaite shad aged were from the sea.

Of the twelve scale-samples examined, spawning marks were visible on the scales of four fish and six of the twelve (ten, discounting two fish caught at sea) showed erosion at the edge of the scales, consistent with fish on a spawning migration. Two females aged six and seven, were judged to have spawned at the ages of five and six respectively; in addition to this the scales of both fish showed evidence of erosion at the edge, i.e. they were preparing to spawn for the second time. Two males aged four and five, were judged from scale analysis and reproductive state to have spawned; the presence of plus growth laid down on top of the spawning marks indicated that these two fish were recovering from spawning.

3.4.2.1.1 Allis shad

Table 12: Spawning history of twelve *A. alosa* caught from the River Tamar (1), Tamar (6), Torridge (2) and Fowey (1) estuaries and from the sea (2)

Length	Date	Sex	Annuli	Spawning marks	Erosion at scale edge?	Age
44.1	9/1/01	M	3	0	No	3+
46.3	1/6/01	M	3	1	No	4+
46.7	9/1/01	M	3	0	No	3+
46.8	31/7/00	M	4	0	Yes	5
47.1	12/5/00	M	3	0	No	4
49.1	5/6/01	M	4	1	No	5+
49.6	17/8/00	M	4	0	Yes	5
52.3	6/6/00	F	5	0	Yes	6
53.7	1/6/00	F	4	0	Yes	5
58.0	2/7/01	F	4	1	Yes	6
59.0	14/6/00	F	4	0	No	5
60.1	27/7/00	F	5	1	Yes	7

The age and spawning history was estimated from the scales of seven adult males; four were recorded from estuaries (Tamar (2), Torridge (1) and Fowey (1)), one from the River Tamar and two from the sea. The two caught at sea were aged 3+ and had not spawned before. Two of the males caught from rivers and estuaries were aged 4/4+ and three were aged 5/5+. Two were judged to have already spawned in the year they were caught and two of the other three males caught from estuaries/freshwater had erosion/absorption at the scale edge, indicative of fish on a spawning migration.

Age-estimates were carried out for five adult females, of which four were from the Tamar Estuary and one from the Torridge Estuary. The estimated ages ranged from five to seven. The scales of two of the five females had spawning marks from the previous year, as well as erosion/absorption at the scale edge. Of the five fish, four showed erosion/absorption at the edge of their scales.

3.4.2.1.2 Twaite shad

The results of scale analysis are presented in Table 13. The maximum number of spawning marks observed was five; this was observed in two females aged 7+ and 9 and a fish of unknown sex aged 7+. The number of fish sampled was insufficient to justify calculating the relative abundance in catches of fish by the number of times they had spawned. In any case, 39 of the 41 twaite shad examined were marine-caught fish (i.e. not on a spawning migration), making calculation of the relative abundance of different spawning frequencies impossible. Of the three males observed (which were included in 'all fish' in Table 13), one was aged 5+ and had spawned twice and the other two were aged 6+; one had spawned three times and the four times.

Table 13: The frequency of occurrence of spawning marks at age in *A. fallax*

		Age													
		3(+)		4(+)		5(+)		6(+)		7(+)		8(+)		9(+)	
		F	All	F	All	F	All	F	All	F	All	F	All	F	All
	0		2												
Number of	1	1	8	3	6	1	2								
spawning	2					5	7		2						
marks	3						1	3	6	1	1				
	4							1	2	1	1				
	5									1	2			1	1
Total		1	10	3	6	6	10	4	10	3	4	0	0	1	1

F = Female; All = all fish (Females, males and unknown sex)

3.4.2.2 Age at first spawning

3.4.2.2.1 Allis shad

Although the number of fish observed was very small, the age at first spawning was calculated for ten allis shad caught from rivers and estuaries (Table 14). Where fish showed erosion/absorption at the edge of their scales, this was interpreted as a fish on a spawning migration. Similarly, if the reproductive state, as detected by calculating the GSI, revealed that the fish was in spawning condition the fish was judged to be on a spawning migration, regardless of whether the scales showed erosion/absorption at the edge.

Table 14: The frequency of age at first spawning in *A. alosa*

	Age at first spawning		
Sex	4	5	6
Male	2	3	0
Female	0	3	2

Since only ten fish were available to calculate the age at first spawning, the results should be treated with caution. Males were observed to spawn for the first time at the ages of four and five, and females at the ages of five and six.

3.4.2.2.2 Twaite shad

Table 15: The frequency of age at first spawning in *A. fallax*

	Age at first spawning (%)			
Sex	3	4	5	Total
Males	2 (66)	1 (33)	0	3
Females	3 (17)	13 (72)	2 (11)	18
All[a]	13 (33)	22 (56)	4 (10)	39

[a] includes fish of unknown sex

The number of fish in the analysis was fairly small (39) and sex was determined in only 21 of these fish. Only three males were encountered; two first spawned at the age of three, the other at four. Most females (72 %) first spawned at the age of four, with a small number at the ages of three (17 %) and five (10%) [Table 15].

Of all the fish examined, including those of undetermined sex, the most frequently observed age at first spawning was four, with a significant number of fish spawning for the first time at the age of three. A small number of fish spawned for the first time at the age of five. Because many of the fish were unsexed and the sample size was small, it is not known whether these findings are a true representation of the population. Furthermore, because fish were caught at sea it is possible that fish in this analysis were derived from several different populations between which the age at first spawning may vary. In summary, the only information that can be reported with a reasonable degree of confidence is that the age at first spawning in twaite shad ranged from three to five years old and in females the modal age at first spawning was four.

3.4.2.3 Results of survey for spawning behaviour

No signs of spawning activity were detected. However, after the initial survey it was decided that until spawning sites are located on the River Tamar and more is known about the timing of spawning in response to environmental stimuli, nocturnal surveys for spawning activity were not efficient or practical methods for detecting evidence of shad spawning.

3.4.2.4 Results of kick-sampling surveys

Table 16: Results of kick sampling surveys on the River Tamar in 2000

Date sampled	Site number	Site name	NGR	Sampling effort (minutes)	Eggs present?
12/06/2000	1	D/s Gunnislake Weir	SX 436712	70	Yes
14/06/2000	2	Morwell Wood	SX 440704	30	No
14/06/2000	3	U/s Gunnislake Bridge	SX 435726	70	No
19/06/2000	1	D/s Gunnislake Weir	SX 436712	60	Yes
20/06/2000	1	D/s Gunnislake Weir	SX 436712	50	Yes
27/06/2000	4	Blanchdown Wood	SX 431728	40	No
04/07/2000	1	D/s Gunnislake Weir	SX 436712	45	Yes
21/07/2000	1	D/s Gunnislake Weir	SX 436712	50	Yes
28/07/2000	1	D/s Gunnislake Weir	SX 436712	55	Yes
04/08/2000	1	D/s Gunnislake Weir	SX 436712	45	Yes
29/08/2000	1	D/s Gunnislake Weir	SX 436712	50	No

The results of kick-sampling surveys in 2000 and 2001 are shown in Tables 16 and 17. Shad eggs were found at one site, downstream of Gunnislake Weir in 2000 and were there again in 2001. The temporal distribution of eggs at Gunnislake precludes all the eggs arising from a single spawning event. The spawning site was approximately 40 m long, although eggs were more abundant in the centre of the site in a 20 m band.

Although the river is freshwater at this site, it is below the tidal limit (This spawning site is presented in Figures 52 and 53, Appendix). Sampling was therefore limited to low tide; at high tide the riffle section became a deep glide.

In 2000, eggs were present for at least a 54 day period, from 12 June until 4 August. High flows prevented preliminary egg identification fieldwork on the Severn (it was unsafe to enter the rivers), thus delaying the start of kick sampling on the Tamar. It is possible that eggs were present earlier than the 12 June. In 2001, eggs were present much earlier and over a shorter period, from 14 May to 21 June.

These eggs were identified as alosid-type by their characteristic transparency and oil droplet. The eggs ranged from 2.4 – 2.6 mm in diameter. In some of the eggs activity by the developing embryo was observed. Samples of eggs were collected, hatched out and photographed.

During the 2001 kick-sampling surveys the catch per unit effort (CPUE) was calculated for each sample occasion to establish the relationship between egg abundance and environmental conditions (namely water temperature). The results are shown in Table 17. Correlations revealed that tidal range and water flow did not significantly affect the CPUE of kick-sampled eggs below Gunnislake Weir (R^2 = <0.001 and 0.007, respectively), and that water temperature accounted for the greatest proportion of the variation in CPUE; the relationship between egg abundance and water temperature is shown in Figure 22.

Table 17: Results of kick sampling surveys on the River Tamar in 2001

Date	Survey effort (mins)	Eggs collected	CPUE (eggs per minute)
4 May	30	0	0
8 May	30	0	0
14 May	40	16	0.40
21 May	30	2	0.07
24 May	30	36[a]	0.60
30 May	45	7	0.16
1 June	20	1	0.05
4 June	20	4	0.20
7 June	30	1	0.03
13 June	30	2	0.07
18 June	30	0	0
21 June	35	9	0.26
25 June	30	0	0

[a]Two people surveyed on this day

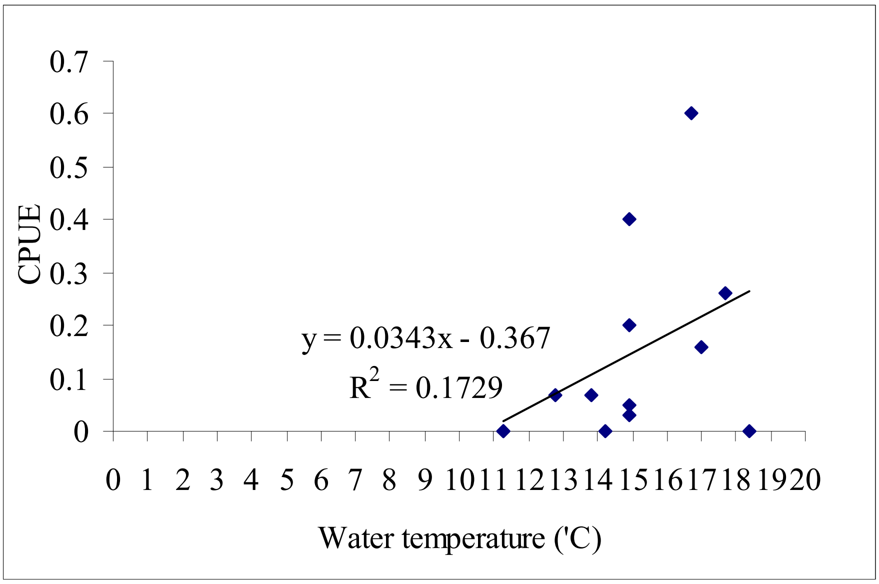


Figure 22: The relationship between CPUE and water temperature in 2001 egg surveys

3.4.3 Ontogeny

3.4.3.1 Results of hatching and rearing alosid-type larvae at Launceston

The first fry hatched on the 6 July and all larvae had hatched by 7 July (Twelve larvae in total hatched out). The larvae would readily eat the liquid food from the surface of the water but did not appear to eat the brine shrimp. However, after a few days the larvae appeared too weak to reach the surface easily and did not survive beyond fifteen days.

The larvae were noted to be identical to pictures of allis shad larvae in Quignard and Douchement (1991) and fit the description in Aprahamian *et al* (in prep.) [Figures 54-60, Appendix]. Unfortunately, photographs did not provide conclusive proof that enabled the larvae to be identified as allis shad. A taxonomic key for the identification of shad larvae had not been developed at the time of the project.

At six days old the larvae were transparent with star-shaped chromatophores distributed on the ventral sides of the gut, yolk sac and body, even beyond the anus which was situated in a very posterior position on the body. The head was relatively short and blunt with large pigmented eyes. The gill arches bore short gill filaments, which were clearly visible, and the caudal fin contained primary rays. The larvae were 9-10 mm long at this stage (Quignard and Douchement, 1991, found that at 6 days old allis shad larvae were 8-9 mm in length).

At twelve to fifteen days the larvae were 11-12 mm long (this also concurs with Quignard and Douchement 1991). The otoliths, one large and one small, were visible within the auditory organ at this stage. The operculum was small with a large pair of uncovered gills.

On 4 August a second batch of approximately twenty-five eggs were collected from the spawning site at Gunnislake and placed in an aerated flask containing dechlorinated tap water (treated with Tetra Aquasafe). Only one larva hatched; the other eggs had decomposed, probably due to higher temperatures than during the first rearing.

3.4.3.2 Results of hatching and rearing alosid-type larvae at Calverton Hatchery

Of the 200 eggs sent up to the Agency fish hatchery at Calverton, approximately 75 successfully hatched. However, many of the eggs removed initially were non-viable; as a proportion of viable eggs, approximately 75 % hatched. Mr Alan Henshaw, a Fish Rearing Officer at the hatchery with experience of rearing twaite shad, confirmed that the eggs were alosids, although there were differences between the eggs from Gunnislake and twaite shad eggs. The Gunnislake eggs were slightly ovoid in shape, whereas twaite shad eggs reared at the hatchery in 2001 were fairly symmetrical. Normal cell development was observed in >80% of the eggs.

Upon hatching, the larvae were identified as alosids by comparison to twaite shad larvae (Figures 61 and 62, Appendix). Also, during development, the swim bladder did not inflate until 15-20 days after the first feed; this is an unusual developmental trait, observed by Mr Henshaw only in alosids. The translucent, silvery-blue larvae were pelagic and had an unusual sinuous swimming style which further indicated alosids, since this is also is an observation unique to alosids among the species reared at Calverton hatchery.

After hatching, a high proportion of eggs (c.80-90 %) survived the yolk-sac absorption stage. Larvae fed upon newly-hatched *Artemia sp*. and took some solid food such as frozen *Artemia sp*. in the later stages of development. The oldest larvae survived to around 6 weeks, although the death of the larvae was suspected to be due to the treatment of some tench larvae that shared the rearing tray.

Although identified as alosids, the samples collected during the rearing process were not conclusively identified as allis shad larvae during the timescale of this project. Attempts will be made to identify these samples as allis shad.

3.4.4 Demography

3.4.4.1 Catch frequency of different size and age classes

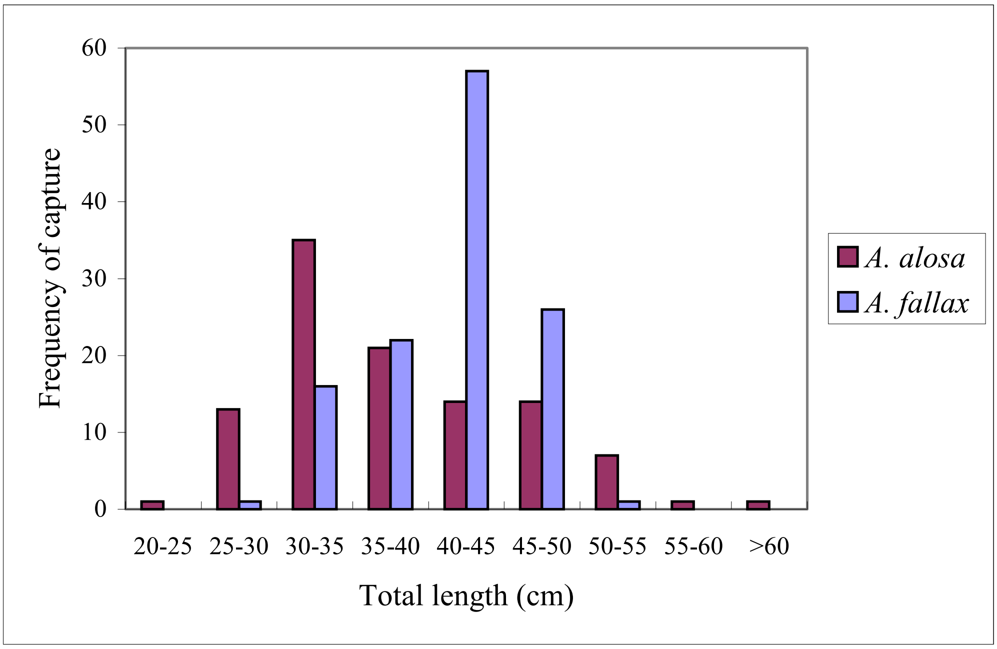


Figure 23: The frequency of capture of *A. alosa* and *A. fallax* size classes at sea

The most frequently encountered size class differs considerably between allis and twaite shad; twaite shad were on average, much larger than allis shad when encountered at sea (Figure 23).

3.4.4.1.1 Allis shad

Figure 23 shows that at sea the most frequently encountered size class of allis shad was 30-35 cm. Significant catches were also made of fish in the 25-30 cm, 35-40 cm, 40-45 cm and 45-50 cm size classes.

Observations on the ages of allis shad from estuaries and rivers, judged to be on a spawning migration (based on reproductive state and scale analysis), are presented in Section 3.4.2. Eleven allis shad that were not on a spawning migration (judged so, based on reproductive state, season of capture and scale analysis) were aged by scale analysis; five were caught at sea and six from estuaries (Table 18). These fish included three males, one female and seven fish of undetermined sex. The body lengths ranged from 26.6 cm to 46.7 cm. All eleven fish were aged 3+. Allis shad of 0+, 1+ and 2+ age classes were not encountered during this project.

Table 18: Immature (3+) *A. alosa* caught from estuaries

Date of capture	Length (cm)	Weight (g)	Sex
11/08/00	26.6	120	-
11/9/00	28.6	147	-
4/6/01	32.4	250	-
19/7/01	37.5	450	F
1/6/01	38.4	420	-
9/9/01	39.6	540	M

3.4.4.1.2 Twaite shad

Figure 23 shows that at sea the most frequently encountered size class of twaite shad was 40-45 cm. Significant catches were also made of fish in the 30-35 cm, 35-40 cm and 45-50 cm size classes.

Forty-one twaite shad were aged from scale analysis (Table 19 and Figure 24). Fish from age-classes 3+, 4+, 5+, 6+, 7+ and 9+ were observed, of which fish between 3+ and 6+ were more frequently caught than age-classes of 7+ and older. No fish of the 0+, 1+ and 2+ age-classes were encountered. Sample sizes were too small to separate the frequency of occurrence (capture) of age-classes by sex. Table 19 shows the frequency of capture of females of each age class; females aged 3+ to 9 were recorded.

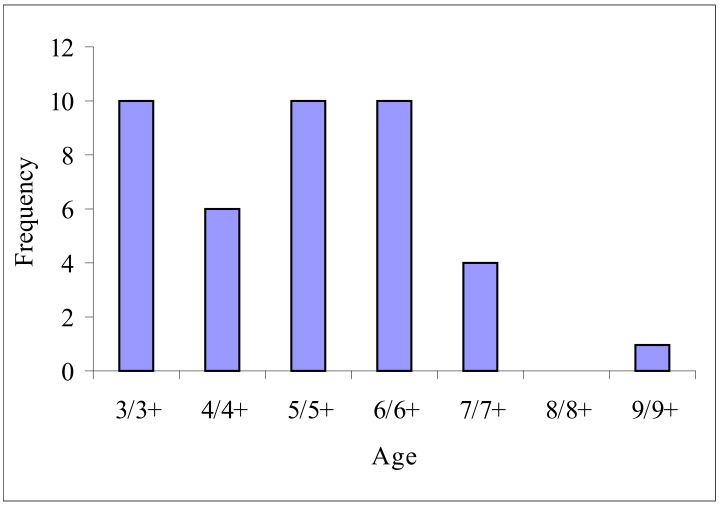


Figure 24: The frequency of occurrence of *A. fallax* age classes at sea (39) and in estuaries (2)

Table 19: The frequency of occurrence of *A. fallax* age-classes at sea (39) and in estuaries (2)

Age	Frequency	Percent
3/3+	10	24.4
4/4+	6	14.6
5/5+	10	24.4
6/6+	10	24.4
7/7+	4	9.8
8/8+	0	0
9	1	2.4
-	41	100

3.4.4.2 Sex ratio

3.4.4.2.1 Allis shad

The number of fish available to be sexed was very small, but of eight fish in reproductive condition caught from the Tamar catchment or showing signs of recent spawning, there was an equal number of males and females. One fish of each sex (one in spawning condition, the other with spawning marks on its scales) was caught from the Torridge Estuary. A male fish in spawning condition was caught from the Fowey Estuary, and an immature fish of each sex was recorded from the Dart Estuary. Of five fish caught at sea, three were female and two were male. Although sample sizes are very small, there was no indication of an unbiased sex ratio in allis shad from south-west England.

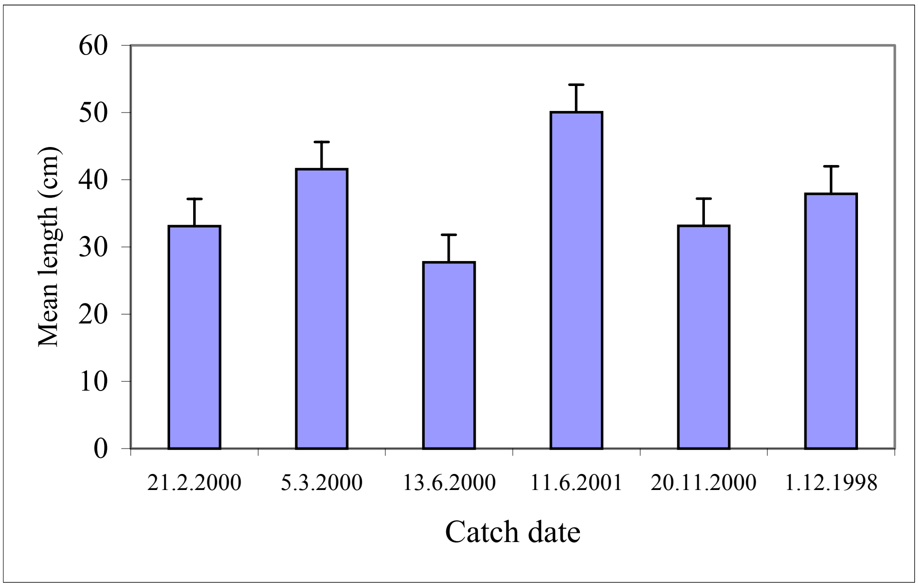
3.4.4.2.2 Twaite shad

Only one twaite shad caught from estuaries was available for examination; this was a female, caught from the Torridge Estuary. Sixty-one fish caught at sea were sexed; the sex ratio was very biased in favour of females (Table 39, Appendix). Fifty-five fish were females and only five were males, indicating a male to female ratio of 1:11. Sexual dimorphism (females are larger) could explain the apparent scarcity of males in the population: their smaller size would reduce the chance of being caught in nets. Also, smaller body size made sexing the fish more difficult, making males more likely to be among the fish that were too small to sex.

3.4.4.3 Range in body size per catch

3.4.4.3.1 Allis shad

On six occasions, catches of between nine and twenty-one allis shad were made. On each occasion measurement of the fish revealed that all the individuals in the catch were of similar size, suggesting that shoals were comprised of individuals from a single age-class (Figure 25). A one-way Analysis of Variance (ANOVA) was performed to test for differences in the mean length of fish from each catch. This showed that there were significant differences between the mean size of fish in different hauls (df= 86; P=<0.001); this is indicated by the least significant difference (LSD) in Figure 25. When the difference between two catch means is greater than the LSD, for example in catches on 21/2/2000 and 5/3/2000 (Figure 25) then the mean length of fish in the two catches is significantly different. In other words, fish within each catch are significantly similar in size, which suggests that shoals of allis shad were comprised of fish of similar age.



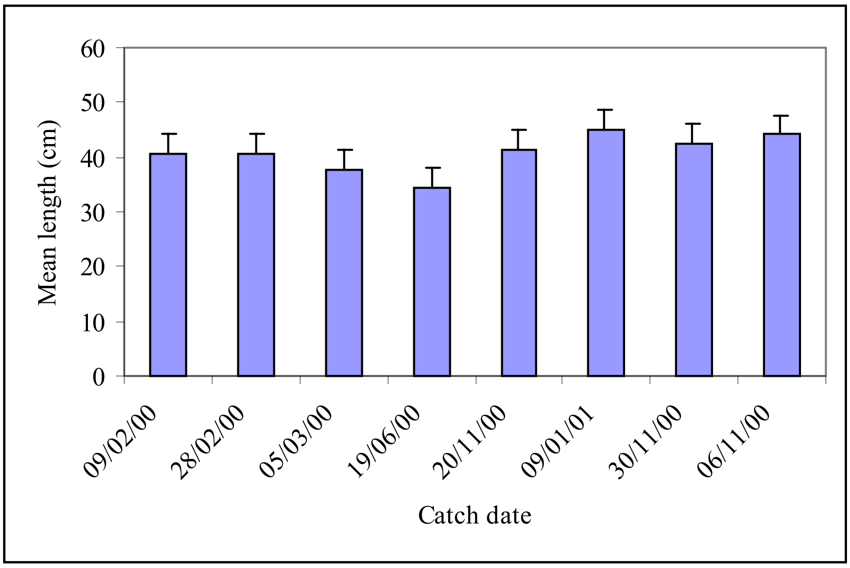
Bars indicate least significant difference between the means of the six catches

Figure 25: Mean length of *A. alosa* in six marine catches

3.4.4.3.2 Twaite shad

It is unclear whether shoals of twaite shad were composed of fish of a similar age-class but fish from a particular catch tended to be of a similar length (Figure 26). A one-way ANOVA (df = 87; P = <0.001) showed that there were significant differences between the mean size of twaite shad from different catches. In other words the mean size of fish in each catch was significantly different to that in other catches; this would not be expected if shoals were composed of fish of a mixture of sizes, indicating that fish sizes within each catch are similar.

However, fish of different ages could be similar in size, as well as size differences between the sexes, which means that males and females of the same age will vary greatly in size. Trawls often involve long tows over a large area, so it is possible that the catch is formed from a number of different age-distinct shoals. To further complicate matters, there is the potential for shad from different hauls to be mixed up on the boat or in the fish market.



Bars indicate least significant difference between the means of the six catches

Figure 26: Mean length of *A. fallax* in eight marine catches

3.4.5 Growth

The majority of shad encountered during this study were from the sea, rather than spawning populations in specific rivers (particularly twaite shad). This should be borne in mind when making comparisons between the growth rate of shad from south-west England and populations elsewhere.

3.4.5.1 Maximum lengths and weights

The small number of fish encountered during the project and the lack of information regarding which population marine-caught fish belong to, prevented comparison of the maximum sizes recorded in this study to that recorded in studies of spawning populations. Furthermore, the opportunistic nature in which fish became available for examination meant that fish in different reproductive states were measured, whereas in other studies data sets are compiled of fish caught during a spawning migration and therefore in spawning condition. As such fish caught at sea (which was often the case in this study) are likely to be relatively light compared to fish in spawning condition. Coincidently, the maximum weights and lengths recorded during this study were from marine-caught fish.

3.4.5.1.1 Allis shad

The maximum length recorded for a male allis shad was 49.6 cm, whilst that of a female was 60.7 cm. The heaviest male weighed 1090 g and the heaviest female was 2500 g.

Of fish recorded from estuaries and rivers in spawning condition, the maximum length recorded for a male in spawning condition was 49.6 cm, whilst that of a female was 60.1 cm. Maximum weights were 1090 g for a male and 1605 g for a female.

3.4.5.1.2 Twaite shad

The maximum length recorded was 44.6 cm for a male twaite shad and 52.0 cm for a female. Maximum weights were 700 g for a male and 1450 g for a female. Twaite shad caught from estuaries were not available to be weighed, sexed and measured, except for one specimen of a female that was not in spawning condition (Length; 43.9 cm, weight; 620 g).

3.4.5.2 Length and weight at age

The length and weight at age of allis and twaite shad is shown in Tables 20-23. As described in other studies, females of both species were longer and heavier at age than males. Comparison of length and weight at age between shad caught from south-west England and spawning populations in France (both species), UK and Ireland (twaite shad) are shown in Section 4.4.5.1. Larger sample sizes are needed to determine growth rates in allis and twaite shad from south-west England; the results presented here are limited to the fish available for examination during this two year study.

3.4.5.2.1 Allis shad

Table 20: Mean length (cm) at age of *A. alosa*

Sex	Age						
	3+	4	4+	5	5+	6	7
Male	43.5 (3, 3.6)	47.1 (1)	46.3 (1)	48.2 (2, 2.0)	49.1 (1)	-	-
Female	37.5 (1)	-	-	56.4 (2, 3.7)	-	55.2 (2, 4.0)	60.1 (1)
Unsexed	33.4 (7, 4.7)	-	-	-	-	-	-

Sample size and standard deviation is shown in brackets

Table 21: Mean weight (g) at age of *A. alosa*

Sex	Age						
	3+	4	4+	5	5+	6	7
Male	677 (3, 125)	860 (1)	870 (1)	858 (2, 74)	1090 (1)	-	-
Female	450 (1)	-	-	1360 (2, 141)	-	1478 (2, 180)	1365 (1)
Unsexed	289 (7, 122)	-	-	-	-	-	-

Sample size and standard deviation is shown in brackets

3.4.5.2.2 Twaite shad

Table 22: Mean length (cm) at age of *A. fallax*

Sex	Age							
	3+	4+	5+	6	6+	7	7+	9
Male	-	-	40.8 (1)	-	43.4 (2, 1.8)	-	-	-
Female	42.0 (1)	44.1 (3, 1.9)	43.8 (6, 1.8)	-	46.4 (4, 2.3)	48.0 (1)	48.5 (2, 0.1)	47.3 (1)
Unsexed	41.1 (9, 1.3)	40.7 (3, 1.2)	43.5 (3, 2.6)	41.8 (2, 1.8)	45.6 (2, 0.3)	-	46.2 (1)	-

Sample size and standard deviation is shown in brackets

Table 23: Mean weight (g) at age of *A. fallax*

Sex	Age							
	3+	4+	5+	6	6+	7	7+	9
Male	-	-	505 (1)	-	623 (2, 53)	-	-	-
Female	625 (1)	802 (3, 78)	748 (6, 111)	-	788 (4, 200)	1450 (1)	900 (2, 57)	1040 (1)
Unsexed	611 (9, 56)	592 (3, 71)	622 (3, 174)	646 (2, 100)	880 (1)	-	765 (1)	-

Sample size and standard deviation is shown in brackets

3.4.5.3 Weight-length relationship

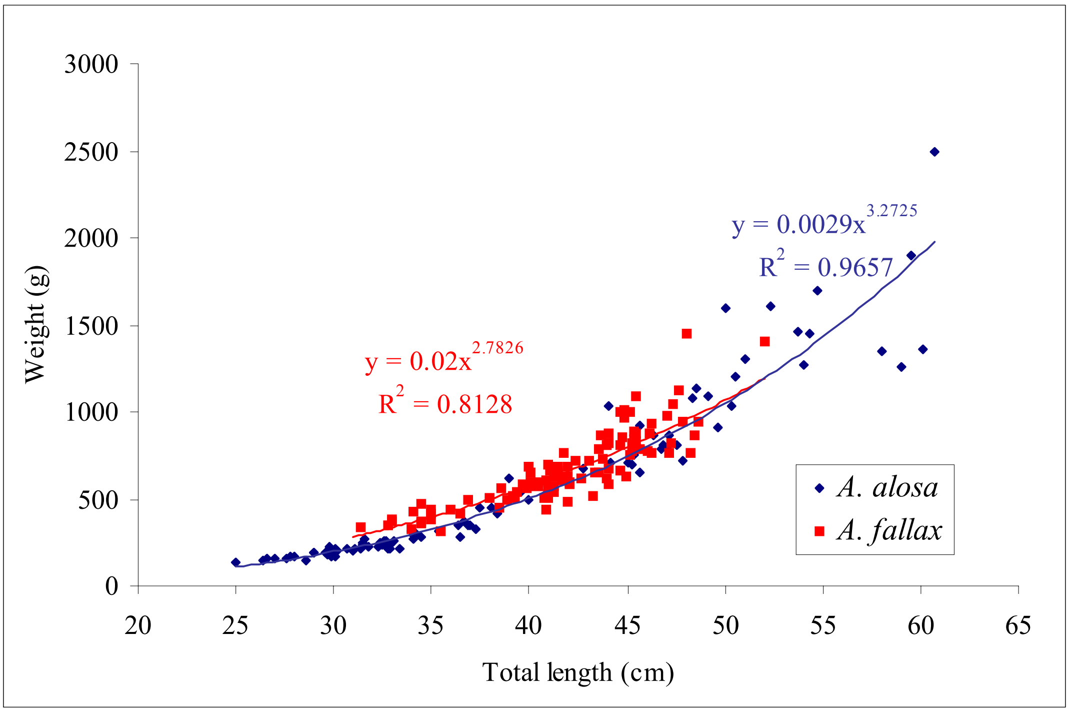
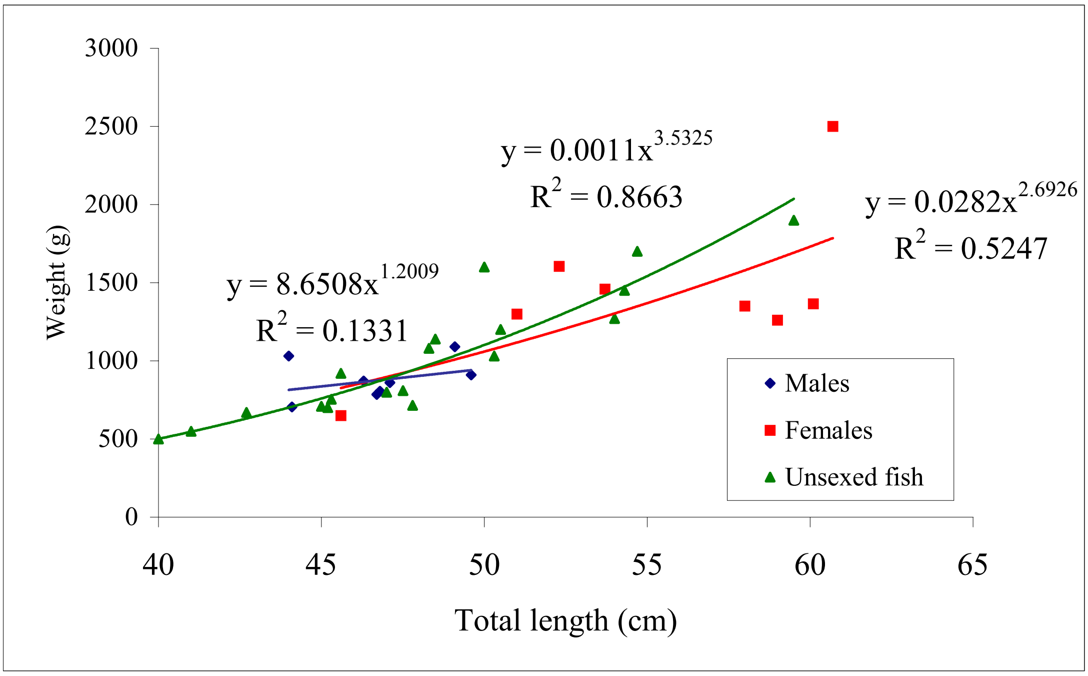
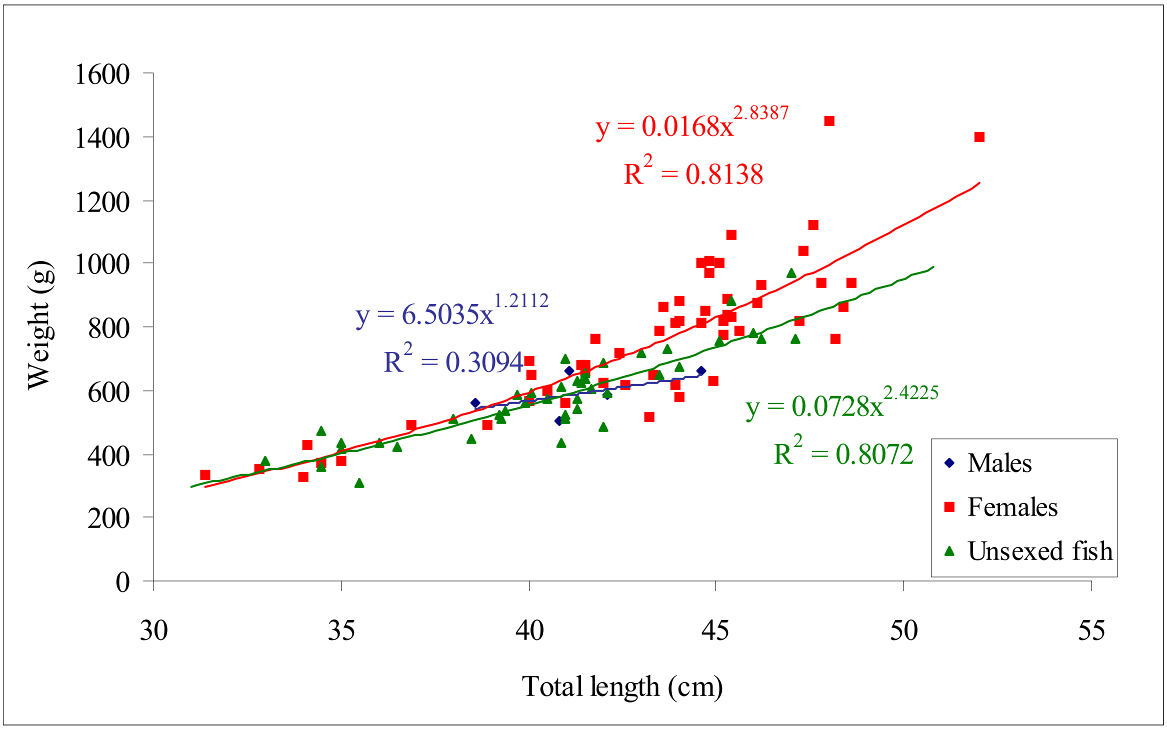


Figure 27: The relationship between total body length (cm) and weight (g) for *A. alosa* and *A. fallax*



Trendline equation for all fish (pooled males [n=8], females [n=8] and unsexed [n=37]); $y = 0.0073x^{3.0385}$ (R^2=0.7764)

Figure 28: The relationship between body length (cm) and weight (g) of adult male and female *A. alosa*



Trendline equation for all fish (pooled males [n=5], females [n=54] and unsexed [n=44]); $y = 0.02x^{2.7826}$ (R^2=0.8128)

Figure 29: The relationship between body length (cm) and weight (g) of adult male and female *A. fallax*

The majority of records of allis and twaite shad from around south-west England do not separate fish by sex. Therefore a combined set of parameters was calculated for adult males and females of each species.

Figure 27 shows that among the 91 allis and 103 twaite shad weighed and measured during this project, there was little difference between the relative weight (weight in relation to length) of each species; twaite shad were slightly heavier at length than allis. However, the range in body lengths and weights recorded was greater for allis shad (25.0-60.7 cm) than twaite (31.4-52.0 cm). Figures 28 and 29 show the weight at length of allis and twaite shad. With the exception of female twaite shad, the number of sexed fish of both species was small. Comparisons between the relative weight of fish caught from south-west England and studies of European spawning populations is contained within Section 4.4.5.

3.4.6 Diet

3.4.6.1 Marine diet

3.4.6.1.1 Allis shad

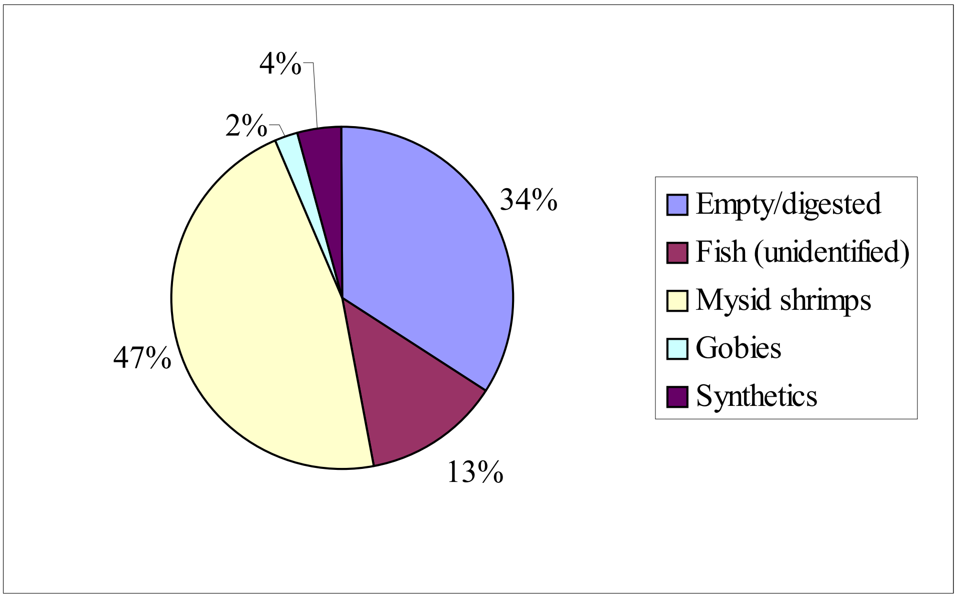


Figure 30: The percentage frequency occurrence of food items in the marine diet of *A. alosa*

Of the stomach contents from forty-four marine-caught allis shad that were examined, 34 % were either empty or contained unidentifiable material. Mysids (*Neomysis integer*) dominated the marine diet of allis shad; mysids were recorded from 50.0 % of all allis shad examined (constituting 47.0 % of all food items) and occurred in 78.6 % of the stomachs that contained identifiable food items (Figure 30). Of the stomachs containing identifiable material, fish remains were found in 21.4 %. None of the fish found in the stomachs could be identified to species level, but one fish was thought to be a goby, based upon the shape of the fish and position of the eyes and fins.

A small proportion of the fish had ingested small pieces of nylon, plastic or rubber.

A comparison of body size in relation to diet was made between fifteen allis shad caught in the same haul, in which total body length ranged from 29.7 cm to 36.9 cm. Allis shad that had eaten mysids (n = 7) did not differ significantly in size to shad that had preyed upon fish (n = 8; 2-tailed t-test, P = 0.60), although sample sizes were insufficient to draw firm conclusions.

3.4.6.1.2 Twaite shad

In 53.9 % of marine-caught twaite shad examined (n = 76), the stomach was empty or contained unidentifiable material. Fish was the principal food of twaite shad, especially sprats (*Sprattus sprattus*); fish was recorded from 43.4 % of the twaite shad examined (and constituted 41.0 % of all food items). Of the stomachs containing identifiable food items fish was recorded from 94.3 % (Figure 31). Sprats were found in 27.6 % of the fish examined and accounted for 60.0 % of food items. It is likely that sprats account for an even higher proportion of the twaite shad diet, because based on the known frequency of occurrence of sprat in the diet, most of the fish remains that could not be identified to species level were probably also sprat. The predation upon sprats by twaite shad was observed among fish caught from several locations and periods of the year.

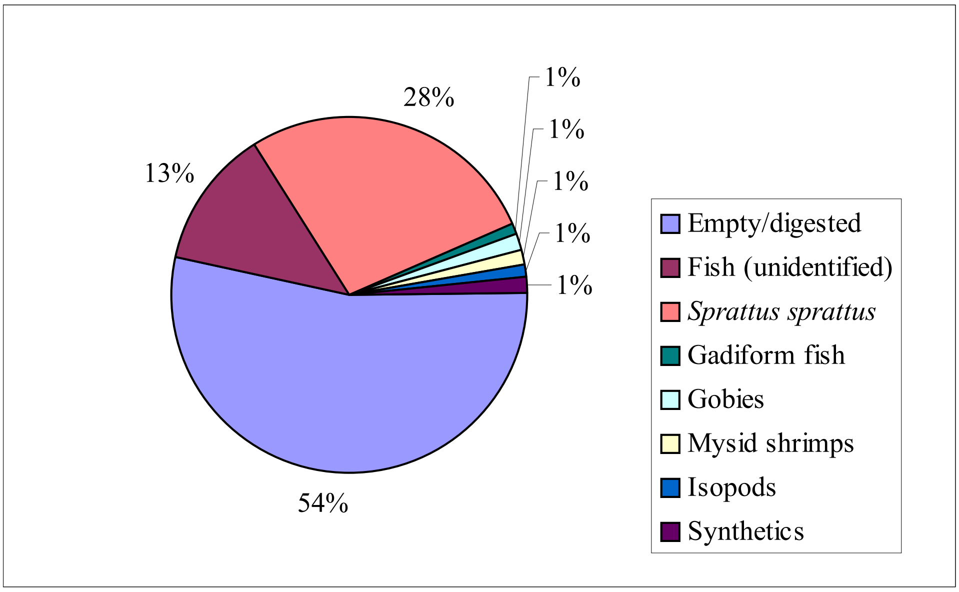


Figure 31: The percentage frequency of occurrence of food items in the marine diet of *A. fallax*

The relationship between predator and prey body lengths for twaite shad and sprats is shown in Figure 32; there does not appear to be any relationship between the size of predator and prey, although the sample size and the range in size of fish examined is small.

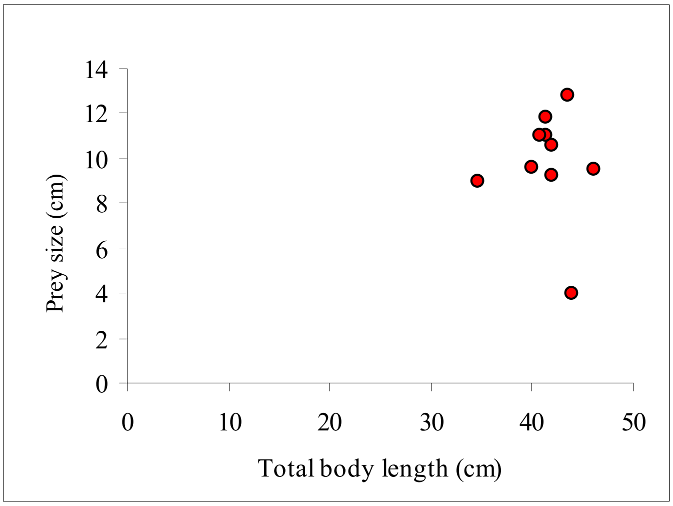


Figure 32: The relationship between *A.fallax* body size and sprats in stomach samples (n = 10)

A small gadiform, thought to be a pouting (*Trisopterus luscus*), was recorded from one shad and a small goby, identified on the basis of body shape and the position of the eyes and fins, was recorded from another. Mysids (*Neomysis integer*) were recorded from the stomach of one fish. Also recorded, was an isopod belonging to the Cirolanidae family, possibly *Cirolana* sp. Synthetic material was found in the stomach of a single twaite shad specimen.

3.4.6.2 Estuarine/freshwater diet

3.4.6.2.1 Allis shad

The gut contents of fifteen allis shad from estuarine waters, plus one from freshwater, were examined. The frequency of occurrence of different food items in the stomach of allis shad is shown in Figure 33.

The gut of the allis shad recorded from freshwater was empty.

The diet of allis shad in estuaries appeared to include a wider range of food items than allis shad at sea. Amphipods, such as *Gammarus* sp., and decapods, including chameleon shrimp (*Praunus flexuosus*) and common shrimp (*Crangon vulgaris*) were recorded from the stomach of allis shad from estuaries. As is the case in the diet of allis shad at sea, mysid shrimps dominated the diet of allis shad caught in estuaries. Fish were not recorded in the stomachs of allis shad from estuaries. Larger dietary items, such as *Gammarus* sp. and *Crangon* sp., tended to occur in the gut of larger individuals (body length > 49.6 cm).

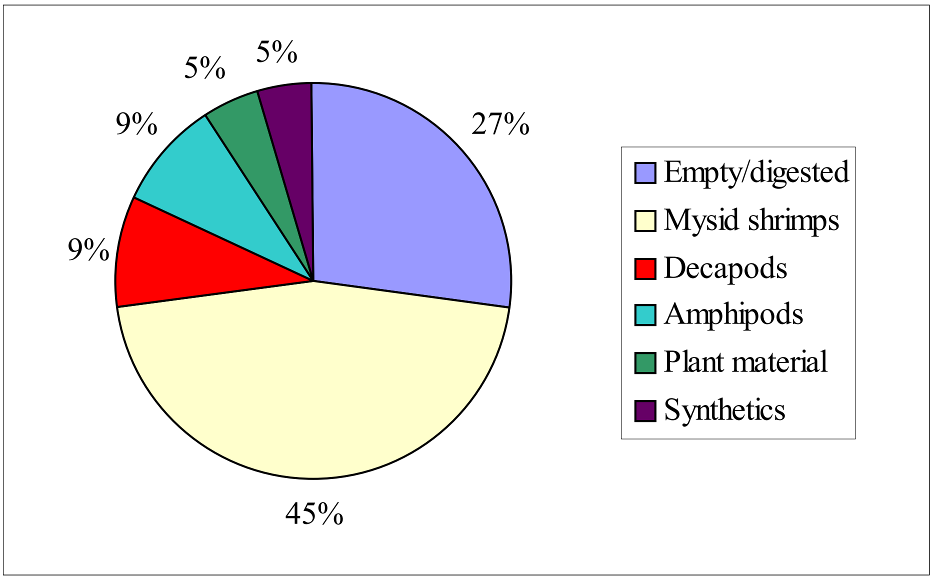


Figure 33: Estuarine diet of *A. alosa*

3.4.6.2.2 Twaite shad

Only two twaite shad from estuaries were available for examination. The gut of one of these fish was empty; in the other sprats composed 50 % of the gut contents and mysid shrimps made up the other 50 %. Sprats were recorded in the gut of most of the marine *A. fallax* examined, but in contrast with this specimen, none of the marine *A. fallax* were found to have eaten mysids.

3.4.6.3 Dietary diversity

The Shannon-Wiener Function was calculated for each species to provide a measure of dietary diversity. The Shannon-Wiener measure (H') increases with the number of species in the diet; Krebs (1999) observed that in practice, for biological communities H' does not seem to exceed 5.0.

Shannon-Wiener Function

$$H' = \sum_{i=1}^{s} (p_i)(\log_2 p_i)$$

where H'= Index of species (dietary) diversity
s = Number of species
p_i = Proportion of total sample belonging to the *i*th species

The only three distinct food items identified in the marine diet of allis shad were fish (unidentified), gobies and mysid shrimps. From twaite shad, sprats, fish (unidentified), gadiform fish, gobies, mysids and isopods were identified. However, 'unidentified fish' is not really a distinct food item because they could be the remains of sprats, gobies or gadiform fish. When calculating a dietary diversity value for twaite shad, 'unidentified fish' and sprats have been pooled into one category (sprats were far more abundant than the other fish types identified).

In allis and twaite shad the Shannon-Wiener Function of marine dietary diversity was calculated as 0.279 and 0.230 respectively, which indicates a very low degree of dietary diversity.

3.4.6.3.1 Estuarine

The Shannon-Wiener Function of estuarine dietary diversity in allis shad was calculated as 0.346. Although, these calculations were based upon a relatively small sample size, the results indicate that the diet of allis shad in estuaries is more diverse than at sea. Insufficient twaite shad from estuaries were recorded to permit calculation of dietary diversity.

3.4.7 Parasitology

Three species of parasite were recorded from allis shad and two from twaite shad. *Contracaecum aduncum* (synonyms: *Thynnascaris aduncum, Hysterothylacium aduncum*), a nematode from the alimentary tract, and *Clavellisa emarginata*, a parasitic copepod of the gills, were recorded from both species. A monogenean, suspected to be *Mazocreas* sp., was recorded from the gills of allis shad.

It should be noted that fish were examined opportunistically and as such, were caught at different times of year and may be derived from different stocks. The results should therefore be treated with caution.

3.4.7.1 Contracaecum aduncum

Second and third stage larvae of *C. aduncum* were recorded from the stomach and pyloric caecae of allis and twaite shad. These larvae ranged from 9 to 51 mm in length. In addition, encysted *C. aduncum* were recorded from the body cavity of adult allis and twaite shad; the cysts were attached to the gonads, stomach and body cavity wall.

C. aduncum was recorded from most adult allis shad, but very few immature fish. The prevalence of *C. aduncum* in twaite shad was also greater in larger fish, suggesting that in shad, infection by *C. aduncum* increases with age. A one-way ANOVA showed that in both allis and twaite shad mean body length was significantly greater in fish infected with *C. aduncum* than in uninfected fish, and that among infected fish the prevalence of infection was greater in larger fish. Figure 34 shows the relationship between *C. aduncum* infection and total body length for allis and twaite shad. Parasite load was recorded as either 'none', 'low' (fewer than ten parasites counted in 60 seconds) or 'high' (greater than ten parasites counted in 60 seconds).

In allis shad, prevalence of infection was greatest in adults in the estuarine and freshwater environments, whilst that in the marine environment was slightly less (Table 24). In twaite shad, the prevalence of infection was also low in the marine environment, although the lack of available specimens from other locations makes it impossible to compare marine infection to that in estuaries and freshwater.

Table 24: The prevalence of infection of *C. aduncum* in *A. alosa* and *A. fallax* in relation to life stage and location (sample size in brackets)

Life stage	Location	*Alosa alosa*	*Alosa fallax*
Immature (age 2 & 3)	Estuary	0 % (4)	-
Immature & Adult	Sea	46.5 % (43)	-
Immature	Sea	24.1 % (29)	-
Adult	Sea	92.9 % (14)	43.2 % (88)
Adult	Estuary	100 % (9)	100 % (1)
Adult	Fresh water	100% (1)	-

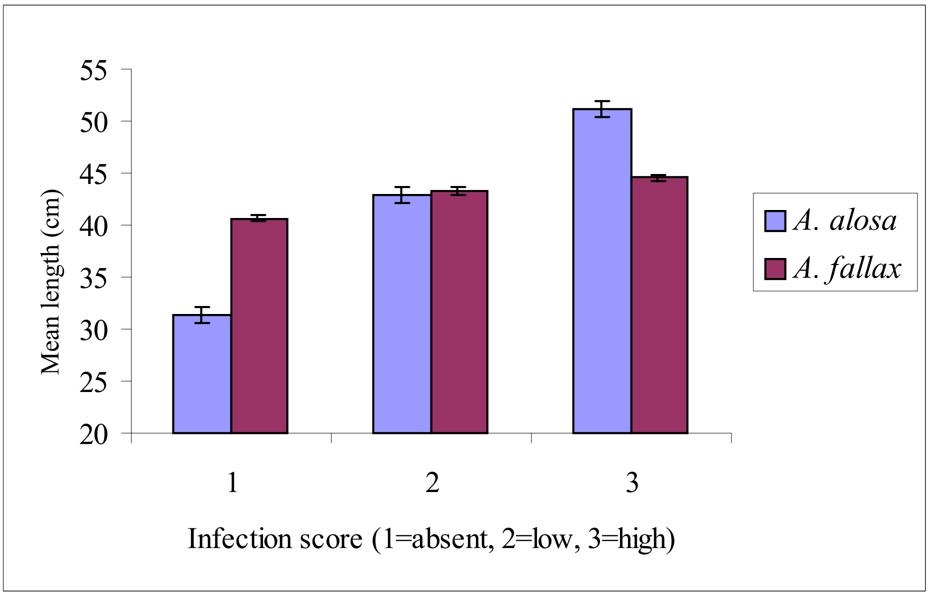


Figure 34: The relationship between *C. aduncum* infection and mean body length in *A. alosa* and *A. fallax*

3.4.7.2 Clavellisa emarginata

C. emarginata was recorded from four allis shad (9.3 % of allis shad examined, n = 43) and four twaite shad (7.5 % of twaite shad examined, n = 53). In allis shad, infected fish included both adult and immature fish, although the mean number of *C. emarginata* was greater in the adult fish (12.0) than in the immature fish (2.7). Similarly, in twaite shad, the greatest density of *C. emarginata* was recorded in a large fish (6 parasites; fish length 48.4 cm), compared to low relative densities recorded from smaller fish (1.0 parasites; fish lengths 40.9-44.6 cm, n = 3).

3.4.8 Migration

3.4.8.1 River Tamar Observations

3.4.8.1.1 Water temperature

During 2000 and 2001, thirteen shad (identified on the basis of forked tail, body shape, fin positions and dark spot behind operculum, and specifically allis shad on the basis of size, and angler and netsmen catches) were observed heading upstream at the Gunnislake Fish Counter, River Tamar (Figures 65 and 66, Appendix). In 2000, video footage from May until August was viewed for shad sightings; most fish were seen migrating in June. In 2001, resources limited viewing video footage to May only, when six shad were seen migrating. Shad have been recorded migrating upstream at Gunnislake Fish Pass between May and August (Table 25).

Table 25: Temporal distribution of shad records at the Gunnislake Fish Pass

Month	Dates of shad records			
	1990	1999	2000	2001
May				6
June	1		5	-
July			1	-
August		1	1	-

'-' = no footage viewed

A further twelve records exist for shad, caught by anglers in the River Tamar. The water temperature at times when shad were recorded from the Tamar was compared to hourly temperature readings from a 'Tinytag Plus' data logger at Gunnislake weir (Figures 35 and 36).

The hourly water temperature when twelve shad were observed migrating upstream over the Gunnislake fish counter in 2000 and 2001, ranged from 14.5 ^{o}C (13/6/00) to 17.7 ^{o}C (3/8/00), with ten of the twelve fish moving upstream between 16.0 ^{o}C and 17.7 ^{o}C (mean = 16.7 ^{o}C). Allis shad were caught in the river when the water temperature was between 13.8 ^{o}C and 17.7 ^{o}C (mean 15.2 ^{o}C, n = 7).

Shad eggs were found from 12 June to 4 August 2000, although eggs may have been present earlier than this. The average water temperature for this period was 16.2^{o}C (Range; 13.1 ^{o}C-20.2 ^{o}C). In 2001, eggs were found between 14 May and 21 June; the average water temperature for this period was 14.7 ^{o}C (Range; 11.3 ^{o}C-17.7^{o}C).

3.4.8.1.2 Water flow

Figures 35 and 36 show that shad were observed migrating upstream at Gunnislake Weir and were present in the river during periods of low flow.

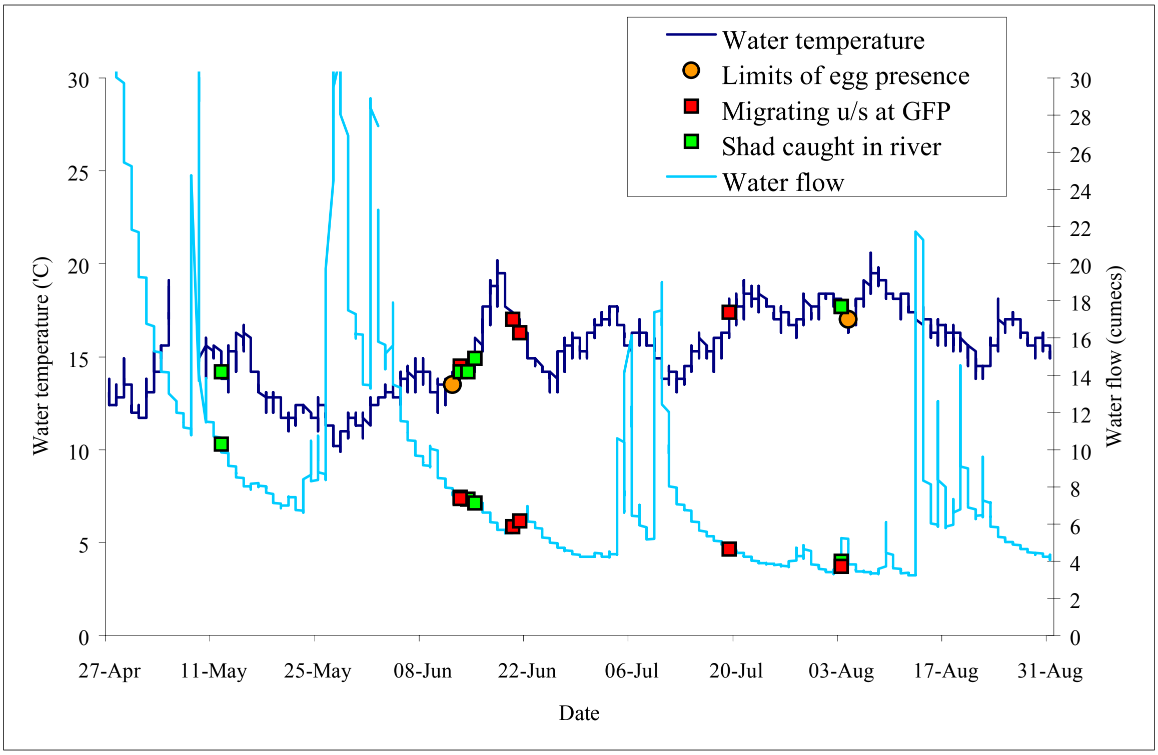


Figure 35: Mean hourly water temperature and water flow at Gunnislake Weir during 2000, with water temperature and water flow at which shad (*A. alosa*) were recorded (GRP = Gunnislake Fish Pass)

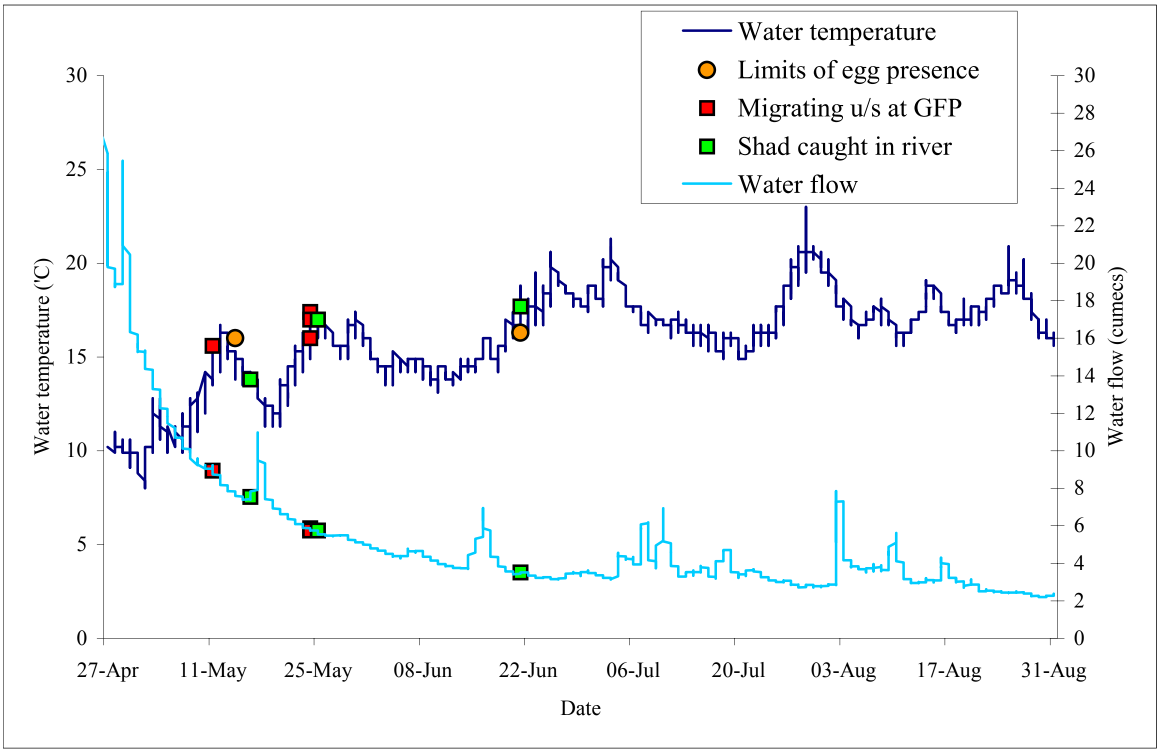


Figure 36: Mean hourly water temperature and water flow at Gunnislake Weir during 2001, with water temperature and water flow at which shad (*A. alosa*) were recorded (GRP = Gunnislake Fish Pass)

2000

High flows were observed during mid to late April 2000, with four other periods of high flows until 31 August. Shad were observed in the river in the periods following high flows, with six records between 13 and 21 June 2000. In 2000, the average water flow when shad migrated upriver at Gunnislake was 5.810 cumecs (n = 6, range = 3.784 - 7.366 cumecs; Seasonal Q64 – Q31). Flow strength during the period May-August, 1956-2002, exceeded this value 40 % of the time. The average water flow on days when shad were recorded both migrating upriver and were caught in the river, was 6.555 cumecs (n = 12, range = 3.784 - 10.252; Seasonal Q64 – Q20), which flow strength was exceeded 36 % of the time during the period May-August, 1956-2002. The average water flow during the period 12 June and 4 August, when eggs were present at Gunnislake was 5.630 cumecs.

2001

In 2001, low flows (<10 cumecs) prevailed from the beginning of May and continued throughout the summer. Shad were observed on video footage at Gunnislake Fish Pass, migrating upstream in May. As in 2000, the flows were dropping at the time of shad migration. In 2001, the average water flow for shad migrating upriver at Gunnislake was 6.271 cumecs (n = 6, range = 5.572 - 8.949 cumecs; Seasonal Q43 – Q23). Flow strength during the period May-August, 1956-2002, exceeded this value 37 % of the time. The average water flow on days when shad were recorded both migrating upriver and were caught in the river, was 6.085 cumecs (n = 8, range = 3.513 – 8.949; Seasonal Q67 – Q23), which flow strength was exceeded 38 % of the time during the period May-August, 1956-2002. The average water flow at Gunnislake during the period of egg presence, from 14 May to 21 June, was 5.305 cumecs.

3.4.8.1.3 Tidal state

In 2000, four out of five shad observed migrating upstream at the Gunnislake Fish Counter were moving on, or shortly after spring tides. However, two of the fish moved through the fish pass at high water and two at low water. In 2001, six shad were observed migrating upstream at Gunnislake; five of these were on a spring tide and one was midway between spring and neap tides. These six fish were observed migrating upstream at a range of tidal states, from low to high water.

3.4.8.1.4 Diel distribution of shad records at Gunnislake fish pass

In 2000 and 2001, shad were observed migrating upstream at Gunnislake Fish Pass at all times of the day and night, but mostly during the day (Figure 37). A larger data set would help to clarify the diurnal pattern of migration at Gunnislake.

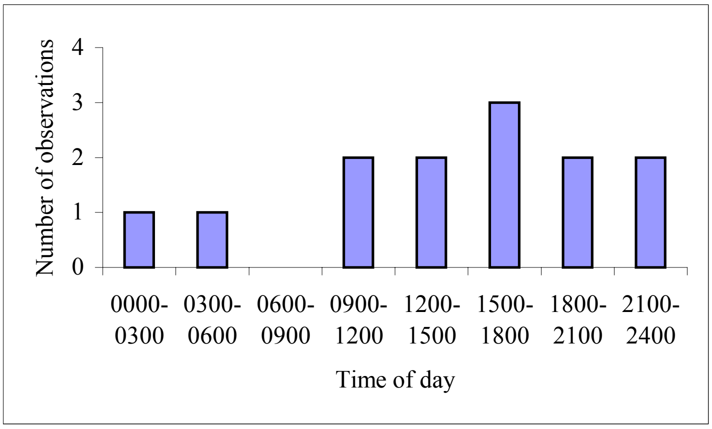


Figure 37: Diurnal timing of upstream adult migration

3.4.8.1.5 Detection of shad by Gunnislake Resistivity Counter

The thirteen shad observed migrating upstream at Gunnislake Fish Pass during 2000 and 2001 (plus one observed in 1999) were measured by converting screen lengths, as observed by viewing video footage from the overhead cameras, to actual lengths using the measured distances between three electrodes sited on the fish pass. The calculated sizes of fish, observed migrating upstream at the fish pass, are consistent with the documented range in size of adult *A. alosa* (42.7-66.2 cm; mean = 53.7 cm).

Salmonids with screen lengths similar to those of shad, were randomly selected from the same months in which shad were observed migrating over Gunnislake Fish Pass (May-August); the deflection-body length relationship in shad was then compared to the sample group of salmonids. The deflection recorded by the fish counter as shad migrate over the electrodes was noticeably lower than for other species of a similar body length, namely sea trout (Figure 38). A one-way ANOVA confirmed that conductivity deflection by shad ($n = 13$) is significantly lower in relation to body length than in salmonids ($n = 26$; $P = 0.001$, $df = 38$). These observations suggest that shad could be detected on the basis of the deflection in conductivity that is created when they pass over the electrodes.

This information could be useful where there is a need to gather evidence of shad presence in a river, using video footage of migrating fish from resistivity fish counters. However, deflection varies considerably and there is a degree of overlap between shad and salmonids in terms of the deflection-body length relationship, which precludes accurately selecting shad from fish counter data. In any case, without video footage it would be difficult to ascertain whether records were of large shad or medium sized sea trout (salmonids), based solely on the size of the deflection. At best, this information could be used to narrow down potential fish counter records to those with a deflection of suitable size, which could then be checked by viewing video footage.

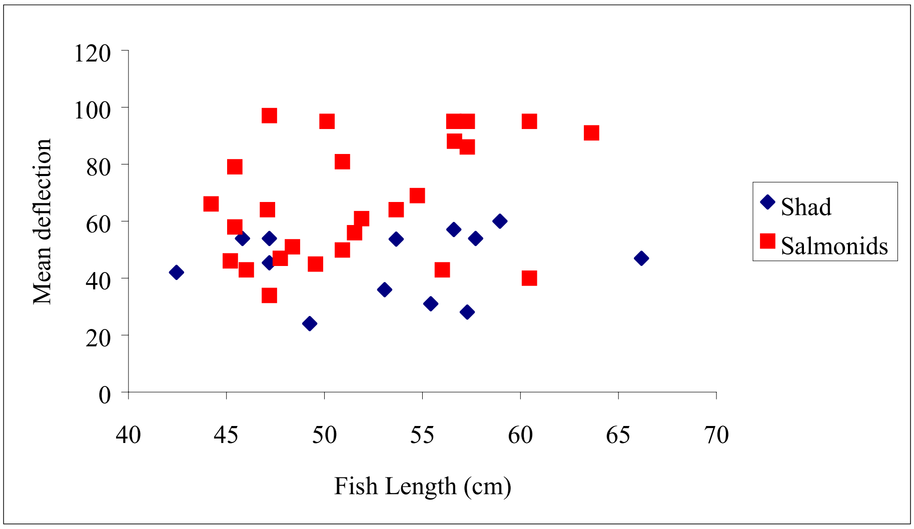


Figure 38: The relationship between conductivity deflection of shad and salmonids on the Gunnislake Resistivity Fish Counter

3.4.8.2 Results of juvenile-fish surveys

On 11 September 2000 four shad (one of which was identified from gill rakers as an allis shad) were caught during a survey in the Helford Estuary at Groyne Point (SW 741262). The specimen was an immature fish aged 3+ and measuring 28.6 cm. As such, no inferences can be drawn from this record about the likelihood of allis shad spawning in the Helford. Interestingly, in 1999 two 3 cm long, juvenile shad were also caught at Groyne Point. Unfortunately, Groyne Point was not surveyed in 2001. Shad were not caught at other sites in the Helford or during any of the surveys in the Fal, Camel, Tamar or Hayle estuaries.

Observations by Donovan Kelly suggest that juvenile clupeomorphs are caught at low tide, which was the case at Groyne Point. Although shad were not caught during the 31 August 2001 seine netting survey in the Tamar Estuary, which was carried out at low tide, the catch was dominated by clupeomorphs. Notably fewer clupeomorphs were caught from sites surveyed at high tide in the Tamar, Camel, Fal and Helford estuaries. The trawls carried out in the Tamar Estuary as part of the National Marine Monitoring Programme, caught almost no pelagic fish at all.

4 ANALYSIS AND DISCUSSION

4.1 Distribution

4.1.1 Marine

Both species appear to be indigenous to the coastal waters of south-west England. Catches were recorded from almost everywhere around the South West peninsula, although most records originated from the south coast of Dorset, Devon and Cornwall and the north coast of Cornwall. Noticeably fewer records were reported from north Devon and Somerset; this is probably due to a lower level of fishing effort in this area.

Most catches were made in trawls within a few miles of the coast. Significant catches were made in Lyme Bay, Torbay, offshore of Plymouth, Looe Bay, Mounts Bay and off Lands End and the Scilly Isles; it is probably no coincidence that there are major fishing ports adjacent to all of these locations. On the north and south coasts of Cornwall shad are often caught close to the shore in gill nets. There are relatively fewer marine records north of the River Camel; again, this may reflect a low level of fishing activity in this area.

This study has produced the most detailed information on allis and twaite shad distribution in south-west England to date. Significant advances have been made in identifying rivers and estuaries used by shad, which is one of the objectives listed on the Shad Biodiversity Action Plan. Both species were caught regularly at sea, where twaite shad appeared to be slightly more abundant among catches than allis. Allis shad catches at sea usually involved immature fish, whereas twaite shad were mostly adults. Typically shad were caught in small numbers, although occasionally large quantities of shad were landed, particularly during 2000; one trawler fishing off the Isles of Scilly landed one and a half tonnes of shad.

4.1.2 Estuarine and freshwater

Shad were recorded from fifteen estuaries and three rivers in south-west England; allis shad were recorded from ten estuaries and twaite shad from four. During the project twaite shad were often recorded from coastal waters, but estuaries yielded very few records; only one record was collated of a twaite shad in freshwater at Totnes weirpool on the River Dart in 1995. No evidence was found during the project to indicate that twaite shad spawn in the rivers of south-west England. Allis shad were also recorded extensively around the coast, but were recorded significantly more than twaite shad from estuaries. Adult allis shad in spawning condition were recorded from three estuaries; the Fowey, Tamar and Taw/Torridge. In addition, adults were reported anecdotally in the Camel, Dart, Exe and Fal estuaries. The most important finding of this project was the significant presence of allis shad in the River Tamar.

4.1.2.1 Tamar

The River Tamar was the only river in the South West from which significant records were collected; allis shad in spawning condition were recorded in the river up to fifteen miles upstream of the tidal limit. A small number of allis shad are caught by anglers in the river each year and at Gunnislake Fish Pass shad (thought to be allis) have been observed migrating upstream every year from 1999-2001. To date, six catches, involving eight allis shad, and seventeen incidences of unidentified shad have been recorded from the freshwater Tamar. Nineteen records, involving thirty-nine allis shad, have been collected from the Tamar Estuary, where salmon netsmen have reported catching allis shad every year.

All of the allis shad examined from the Tamar river and estuary were sexually mature and in spawning condition. Furthermore, shad eggs were found on a run/glide downstream of Gunnislake weir each year from 2000 to 2002. Upon hatching and subsequent rearing, these eggs produced larvae that exactly matched descriptions in literature of allis shad larvae.

This is the first study to present such strong evidence that allis shad spawn in the River Tamar. Only two records from recent years existed previously; at Gunnislake weir a shad was caught in 1990, although not identified to species (Reay, cited in Aprahamian *et al* 1998) and more recently allis shad have been caught below the weir (Potts and Swaby 1996b).

Twaite shad were not recorded in the Tamar but allis shad were recorded extensively throughout the estuary and river. This is consistent with previous studies; Potts and Swaby (1996b) recorded allis shad but made no mention of twaite shad occurring in the Tamar.

4.1.2.2 Fowey

Allis shad were recorded from the Fowey Estuary at Golant, including one adult specimen in spawning condition. Salmon netsmen have caught shad on the Fowey most years since at least 1990; catches are probably adult allis shad based upon the reported weight of the fish. An unidentified shad was also caught in the Fowey River in 1994. Potts and Swaby (1996b) reported that in 1993 two allis shad were recorded from the Fowey Estuary. It is possible that the importance of the Fowey Estuary to allis shad is under-represented by the numbers caught: there are considerably fewer salmon netsmen operating in the Fowey Estuary than in other salmon-fished estuaries in south-west England, such as the Tamar. Furthermore the netsmen on the Fowey operate on a part-time basis from the beginning of July until the end of September. Evidence suggests that immature allis shad use the Fowey Estuary as a feeding area and that adults may spawn in the estuary or river.

Twaite shad were not recorded from either the Fowey Estuary or River, nor are there any existing records of twaite shad occurring in the Fowey.

4.1.2.3 Fal and Helford

No evidence was found to suggest that allis shad breed in either the Fal or Helford estuaries, although the first confirmed records in recent years of allis shad in the Helford Estuary, were collected during this study. Four shad were caught in September 2000, one of which was formally identified as an immature allis shad. Anecdotal evidence indicates that adult allis shad are present in the Carrick Roads (J. Bridger, pers. comm.) at certain times of year. Turk (in Potts and Swaby 1993) reported that allis shad were recorded from July to September in the 1890s in the Helford. The size and rich ecology of the Fal and Helford estuaries makes them an ideal feeding ground for immature shad, although as yet, there is no evidence of allis shad spawning in the rivers that flow into the Fal and Helford estuaries (i.e. Carnon, Truro, Tresillian, Fal, Ruan and Percuil).

Adult twaite shad were not recorded from either the Fal or Helford estuaries during the project, although they were recorded from Falmouth Bay. Anecdotal evidence suggests that twaite shad are common in the Fal and Helford estuaries in late summer (J. Bridger, pers. comm.). Others remark that in early to mid summer twaite shad are locally common in the Fal Estuary (Potts and Swaby 1993) and associated creeks of the Fal, namely the Tresillian River, Truro River and Percuil River (Deeble and Stone, pers. comm.).

Two juvenile twaite shad were recorded in a juvenile bass survey in the Helford Estuary (D. Goodwin and P. Gainey, pers. comm.). However, the Helford Estuary has no rivers of sufficient size to permit a spawning migration. One explanation is that twaite shad spawn in one or more of the rivers feeding the Fal Estuary and the juveniles utilise the Fal and Helford Estuaries.

4.1.2.4 Torridge

There is no mention in the literature of allis shad occurring in the Torridge Estuary. However, six records of adult allis shad, involving eight fish, were collated by this study in 2000, with a further two recorded in 2001. Examination of a fish caught in June 2000 revealed that it was in spawning condition. It is possible that allis shad spawn in the River Torridge, although further investigation is needed to locate the spawning sites and collect evidence of a spawning population.

Of all the estuaries in south-west England the Torridge produced the most records of twaite shad. Five records, involving seven twaite shad, were collected from the Torridge Estuary in 2000. Only one specimen caught in late summer was available for examination; this specimen was not in spawning condition. The twaite shad caught were of sufficient size to be sexually mature, although without examination it was not possible to assess the spawning condition. Potts and Swaby (1993, 1996c) list the Taw and Torridge estuaries as used by twaite shad. It is unclear if twaite shad spawn in the River Torridge or simply use the Torridge Estuary as a feeding ground.

4.1.2.5 Dart

This study produced the first two confirmed records of allis shad in the Dart Estuary, albeit two immature fish aged 3+. Although no adult specimens were available for examination, anecdotal information from salmon netsmen on the Dart suggests that adult allis shad are caught each year in the estuary, from June to August, which makes this river worthy of further investigation. A record exists of a twaite shad caught at Totnes on the River Dart in 1995 (D. Pakes, pers. comm.). Twaite shad were also formerly recorded at the mouth of the Dart (Cunningham 1906, in Potts and Swaby 1993).

4.1.2.6 Exe

Allis shad were recorded from the Exe Estuary during the project. Specimens were not available for examination, but reported sizes suggest adult fish. Allis shad have been previously reported from the Exe by Potts and Swaby (1993, 1996b) and Kennedy (1981). The use of the Exe by allis shad for spawning is unclear, since no records exist above the tidal limit. There are a number of weirs on the River Exe that allow passage to salmonids but may impede the migration of allis shad.

A single twaite shad was recorded from the Exe Estuary during the project; scale analysis revealed that the fish was sexually mature and had spawned three times. Kennedy (1978) and Potts and Swaby (1993, 1996c) have also recorded twaite shad from the Exe Estuary. The spawning status of twaite shad in the Exe is unclear; numerous weirs that are passable to salmonids may be impassable to shad and prevent twaite shad migration.

4.1.2.7 Camel

This study provides the first confirmed evidence of allis shad in the Camel Estuary in recent years; an immature allis shad (aged 3+) was recorded in 2001. Anecdotal evidence from salmon and sea trout netsmen in the Camel Estuary suggests that adult shad are caught in nets each year. It is unclear whether allis shad spawn in the Camel. Historically allis shad were recorded from the Camel Estuary in 1907 (Clark 1909 and Turk, in Potts and Swaby 1993).

4.1.2.8 Other rivers

One allis shad was recorded at the mouth of the Yealm. There are no other allis shad records from the Yealm. Two immature allis shad were reported from the mouth of the Kingsbridge Estuary; anecdotal evidence from gill netsmen suggests that catches are frequently made in the estuary. Potts and Swaby (1993) did not list either shad species as present in the Salcombe and Kingsbridge Estuaries. Allis shad have been reported from the Lynher Estuary by netsmen at Saltash; these fish may form part of the run of allis shad observed migrating into the Tamar Estuary each year. Anecdotal evidence from sea trout netsmen suggests that allis and twaite shad occur in the Hayle, although these reports were unsubstantiated (P. Gay, pers. comm.). A shad of unknown species was recorded from the River Otter, but no further records were provided by the present study. Occasionally allis shad are recorded in the River Severn, although there is no evidence to suggest a viable spawning population.

Unconfirmed records were received from salmon and sea trout netsmen of twaite shad caught at the mouth of the Kingsbridge Estuary and in the Hayle Estuary.

4.2 Catch Information

Large numbers of shad were caught in offshore trawls during the winter, whereas in summer shad were recorded inshore from drift nets and by anglers. The increased catches of shad in winter trawls is thought to be due to an increased abundance of shad in offshore waters, although it could just reflect an increase in offshore fishing activity during the winter. Shad have been caught in water over 100 m deep and evidence suggests that shad tend to be caught near the seabed. It is possible that in winter shad occur near the seabed in deep water, like other pelagic species, and move up in the water column and inshore at other times. However, shad were recorded during the winter months from inshore drift nets. The seasonal migrations and preferred habitat of shad at sea remains unclear. Shad tended to be caught with pelagic species such as pilchard, herring and mackerel.

From January to March shad were occasionally caught in large numbers, mainly in trawls. Several people commented that shad were much more abundant during winter 2000, than in previous years. Most records came from fishermen and fishmongers, although DEFRA and Sea Fisheries Officers also provided many records.

4.2.1 Catch differences between species

There did not appear to be any difference between the timing of catches or abundance of allis and twaite shad in offshore nets, but in inshore drift nets twaite shad were encountered more frequently than allis. Allis shad were caught in inshore nets on six occasions, whereas twaite shad catches were recorded twenty-two times. The number of shad caught since 1990 supports this observation; only six allis shad have been reported from inshore nets, compared to fifty-five twaite shad. The total number of catches of allis shad, in South West coastal waters was 34, compared to 66 in which twaite were caught. Including reports of shad which were not identified to species, the total number of reported catches of shad between January 1990 and December 2001 was exactly 200.

Using data on coastal catches since 1990, the number of allis shad was 127, compared to 206 twaite shad over the same period. This further suggests that twaite shad are the more common species around the coast of south-west England.

Catches of shad by sea anglers are rarely reported to species level, but the majority of fish identified are twaite. As discussed in Section 3.2.3, this may reflect the greater piscivory of twaite shad compared to allis and therefore the increased likelihood of anglers catching twaite shad on lures and fish baits.

A major difference between the two species was the age, which is discussed in more detail in Section 4.4.4. Most allis shad caught at sea around the South West were immature, whereas most twaite shad were adults. In contrast, allis shad, including adults, were recorded from estuaries (and rivers) far more than twaite shad during the project.

4.3 Biology

4.3.1 Gill rakers

4.3.1.1 Allis shad

The relationship between number of gill rakers on the first gill arch and total body length of adult allis shad was compared to findings from other studies (Figure 39). This comparison revealed that the regression model, relating the number of gill rakers on the first gill arch to total body length of adult allis shad from south-west England (n = 33) was similar to studies of populations in northern and western France, particularly the River Charente (Veron 1999). Data from other rivers, such as the Aulne and Vilaine, were too small to permit comparison.

In the case of allis shad from the River Tamar (n = 8), the coefficient relating number of gill rakers to total body length was similar to that recorded in the Rivers Charente and Vilaine (Veron 1999), although the sample size was small. Coefficients from rivers further afield such as the River Sebou, Morocco, and the River Aude and Rhone, southern France, were less similar to the findings of this study. The mean number of gill rakers in adult allis shad recorded from south-west England (118.91) and from the River Tamar (117.25) was most similar to studies of the River Vilaine and Loire populations, (119.00 and 122.10 respectively; Vilaine, Veron 1999; Loire, Mennesson-Boisneau and Boisneau 1990). Studies from more southerly populations of allis shad, from other rivers along the west coast of France, generally reported a higher mean number of gill rakers (123.85 [Adour, Douchement 1981] - 129.3 [Loire, Douchement 1981]).

The observation that allis shad from south-west England are meristically similar to populations in north-west France could be because allis shad caught from around the south-west coast of England spawn in north-west France, or simply that environmental conditions are similar for the two groups.

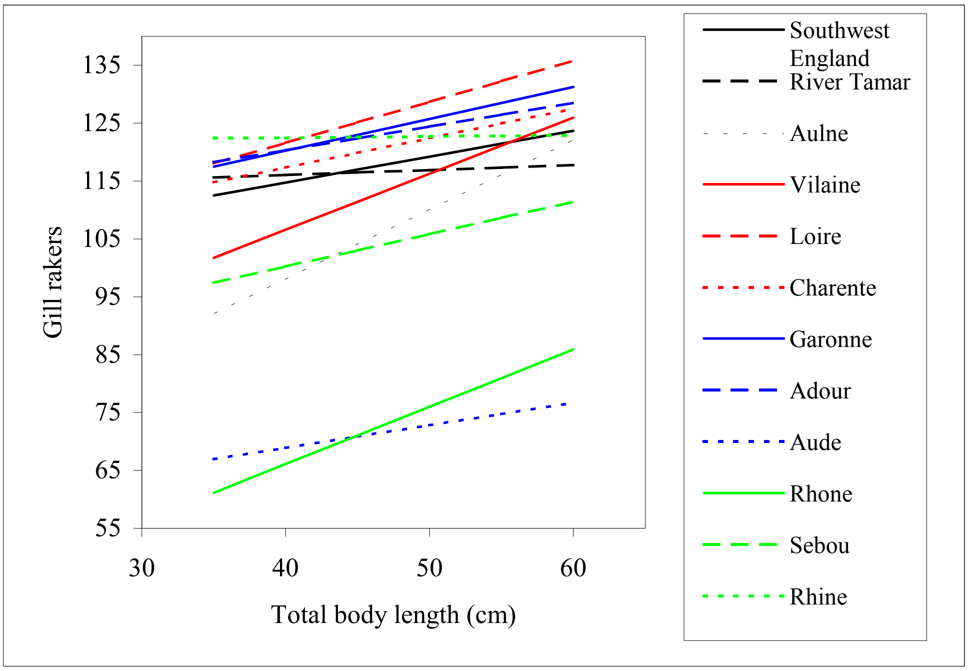


Figure 39: The relationship between number of gill rakers on the first gill arch and total length for *A. alosa* populations

4.3.1.2 Twaite shad

The relationship between number of gill rakers on the first gill arch and total length for twaite shad was very weak because juvenile twaite shad (in which fewer gill rakers would be expected) were not encountered. As a result, the number of gill rakers did not increase with body size in the sample of twaite shad recorded during this study.

Since the number of gill rakers appeared unrelated to total body length, a mean number of gill rakers was calculated. This was found to be 40.15, which is lower than reported in any other study of anadromous twaite shad populations (40.53-52.63 [Aprahamian *et al* in prep.]). However, because not all twaite shad recorded from coastal waters around south-west England were sexually mature, the number of gill rakers may have been low in comparison with other studies, which typically sample adult fish on their spawning migration.

The mean number of gill rakers observed in this study is most similar to that of the River Barrow, Ireland (40.53 [O'Maoileidigh *et al* 1988, O'Maoileidigh 1990]) and the River Rhine, Germany (40.67 [Hoek 1899]). Aprahamian *et al* (in prep.) observed that twaite shad populations from southern Europe have fewer gill rakers than those from northern populations and suggested that the lower gill raker counts for populations in the Barrow and Rhine are an exception to this general trend.

The Severn population has a mean number of 44.52 gill rakers (calculated using the coefficient in Aprahamian 1982, from a mean total length of 37.87 cm). Comparatively, twaite shad populations from the River Charente and River Garonne on the west coast of France have mean gill raker numbers of 42.00 and 42.44 respectively (Veron 1999, Douchement 1981). This suggests that twaite shad caught from around the south-west coast of England are meristically more similar to Irish and French populations, than to the Severn population, based on the number of gill rakers.

4.3.2 Dorsal and anal fin rays

There is little variation in the mean number of dorsal or anal fin rays among French populations of allis shad. The findings of this study (mean number of dorsal fin rays = 19.42, mean number of anal fin rays = 24.25) are similar to findings reported from populations in the Rivers Aulne (Veron 1999), Loire and Garonne (Douchement 1981). The meristic characteristics measured by Veron (1999) in the River Aulne population are almost identical to those measured in this study. Veron found that the mean number of dorsal fin rays was 19.20 and the mean number of anal fin rays was 24.20.

The number of dorsal and anal fin rays in twaite shad caught from around south-west England (mean number of dorsal fin rays: 19.30, anal fin rays: 21.15) was most similar to that reported by Douchement (1981) on the Loire population. The findings in this study were also similar to those reported for the Barrow (O'Maoileidigh *et al* 1988, O'Maoileidigh 1990), Charente (Veron 1999) and Loukos, Morocco (Sabatie 1993).

In common with most other studies, the number of anal fin rays in allis and twaite shad differs significantly, whereas the number of dorsal fin rays is similar. In allis shad there were typically 22-27 anal fin rays (Mode = 24) compared to 18-23 anal fin rays in twaite (Mode = 21). The percentage of shad examined in which the number of anal fin rays fell into the overlap zone between the morphometric range of each species (i.e. 22 or 23 anal fin rays) was just 6.73 %. In other words, based on the findings of this study, if shad were identified solely by counting anal fin rays, the correct identification of shad species could be expected on 93.27 % of occasions. This is significant because it provides a method of species identification, based on external characteristics and could therefore be used as a diagnostic feature. However, counting anal fin rays is no less difficult to the layperson than counting gill rakers, due to the small fin rays at the anterior end of the anal fin, and ultimately counting the gill rakers is a conclusive diagnostic feature.

4.3.3 Flank spots

Literature indicates that twaite shad have a row of dark flank spots which are absent in allis shad, and allis shad usually have a single dark spot on the shoulder immediately behind the gills (Buller and Falkus 1992). In contrast, the results of this study show that twaite shad actually have fewer spots than allis at some life history stages, although the spots maybe better defined. Observations showed firstly, that immature allis shad may have a row of flank spots and secondly, that twaite shad may have a single spot, which is currently described in literature as a diagnostic feature of allis shad. Records were received in which species identification was attempted solely on the presence or absence of flank spots, yet the results of this study suggests that this is a poor diagnostic feature.

Observations suggest that in allis shad, flank spots are a feature of immature fish, whereas twaite shad retain their flank spots when mature. In the marine environment both species are pelagic and live in shoals. The presence of spots along the flank is possibly a form of disruptive colouration (Lagler *et al* 1977); the dark spots could make it difficult for predators to distinguish the body outline by drawing attention away from the characteristic shape of the eye. Twaite shad usually spawn more than once and return to the marine environment after each spawning. As such, flank spots may constitute disruptive colouration that breaks up the body outline, which would benefit both immature and adult fish. Allis shad on the other hand usually spawn just once, so in the marine environment disruptive colouration, such as flank spots, would benefit immature fish far more than adults.

Differences between the two species were observed with respect to the number, pattern, size and pigmentation of flank spots which could, if quantifiable, provide a method of telling the two species apart. However, it is unlikely that a diagnostic process involving flank spots could be sufficiently reliable, compared to gill raker or anal fin ray counts.

4.4 Ecology and Life History

4.4.1 Reproduction

4.4.1.1 Allis shad

The presence of allis shad in spawning condition and fish that had recently spawned, around the South West strongly suggests that spawning takes place in one or more local rivers. The high GSI values recorded from allis shad during this study suggests that fish are more likely to be spawning locally rather than in rivers of northern France, where the nearest recognised spawning populations occur. Female allis shad from the River Tamar had gonadosomatic indices (GSIs) comparable with those of females in the Loire and Gironde-Garonne-Dordogne systems. The GSI of female allis shad from the Tamar ranged from 2.5 and 16.9 %, compared to 6.0 to 17.8 % in the Loire and 9.1 to 22.5 % in the Gironde-Garonne-Dordogne system (Douchement 1981).

Whilst these values show that females in spawning condition are present in the River Tamar, the relatively small number of cases recorded does not provide a reliable comparison with other allis shad populations. Furthermore, shad are only available for examination when caught by netsmen or anglers and since the netting seasons are restricted, so are the times at which shad can be caught. It is possible that shad migrating upstream early in the season, in April and May, are not caught because salmon netsmen are not permitted to fish at this time. GSI values may be greater during April and May than later in the season, but go unrecorded.

No information was available from other studies on testicular weights of male allis shad in spawning condition; the GSI of two Tamar specimens in spawning condition were 9.1 % and 10.2 %.

4.4.1.2 Twaite shad

With the exception of one specimen, twaite shad recorded from estuaries or rivers in south-west England were unavailable for examination, so it was not possible to compare the marine GSIs encountered in this study to values recorded in freshwater from other twaite shad populations. Claridge and Gardner (1978) observed a mean GSI of 13.9 % for females in mid-May, whilst Douchement (1981) recorded a GSI of 20.6 % in the Loire and even higher indices in other French populations.

Two female twaite shad specimens caught at sea in February and March 2000 had GSIs that suggested they were entering spawning condition; one fish caught from Perranporth, North Cornwall, on 28 February had a GSI of 8.7 %; the other caught from the mid-English Channel on the 6 March had a GSI of 8.0 %. The only other twaite shad with a GSI indicative of spawning condition (10.8 %) was a female caught at Burnham-on-Sea on 27 April 2000. Although it is possible that these three fish would breed in rivers in south-west England, there is no evidence to support this. The two fish caught on the north coast may be part of the Severn population, whilst the fish caught at mid-channel may belong to a French population.

The fecundity of twaite shad (measured as GSI) was found to be more closely related to body weight than to total body length. Aprahamian (1982) made similar findings on twaite shad from the River Severn; total weight and age accounted for a significant proportion of the variability in fecundity, whereas the inclusion of total length and spawning history did not significantly improve the relationship.

4.4.2 Spawning

4.4.2.1 Number of spawnings

4.4.2.1.1 Allis shad

Evidence of repeat spawning was found in two female allis shad aged six and seven, caught from the Tamar Estuary. Other allis shad that showed no signs of repeat-spawning, were from younger age classes, between four and six. Without examining many more allis shad from the Tamar and other rivers/estuaries in the South West, it is not possible to determine the proportion of repeat spawners. Douchement (1981) and Sabatie (1993) found that allis shad have a primarily semelparous life history, although other studies have found evidence of iteroparity in allis shad (e.g. Douchement 1981, Mennesson-Boisneau and Boisneau 1990, Taverny 1991).

4.4.2.1.2 Twaite shad

Thirty-six of the forty-one mature twaite shad examined were repeat spawners. This concurs with several other studies that describe twaite shad as having an iteroparous life history (e.g. Douchement 1981, Aprahamian 1982, and unpublished data, O'Maoileidigh 1990, Mennesson-Boisneau and Boisneau 1990, Taverny 1991). Most twaite shad examined had spawned either once or twice before, with a maximum of five spawnings recorded. On the River Severn, Aprahamian (1982) reported a high proportion of twaite shad spawning for a second and third time, with a maximum of seven spawnings recorded.

Twaite shad that had yet to spawn for the first time were poorly represented among catches from south-west England. This may mean they were either absent or less abundant than fish that spawned. Alternatively, these fish may have been small enough to avoid capture in commercial nets. However, the minimum size of allis shad encountered during the study was significantly smaller than in twaite shad, which suggests that the minimum size of twaite shad in net catches was not necessarily determined by the size of the mesh.

Most authors reported that the majority of twaite shad females in the spawning population were on their first or second spawning-migration (e.g. Douchement 1981 [Loire, Gironde-Garonne-Dordogne and Adour], Aprahamian 1982, in prep. [Severn and Wye], O'Maoileidigh 1990 [Barrow], Mennesson-Boisneau and Boisneau 1990 [Loire], Taverny 1991 [Gironde-Garonne-Dordogne]). The spawning history of twaite shad caught from south-west England appears to be typical of twaite shad populations described by other researchers.

4.4.2.2 Age at first spawning

4.4.2.2.1 Allis shad

The mean age of first spawning (determined from spawning condition and counts of spawning marks on the scales) in males was 4.6 years old (n=5), whereas in females it was 5.40 years old (n=5). This adds further support to the theory that allis shad were present in these estuaries and rivers for spawning purposes, since the age of allis shad recorded from south-west England was similar to that of spawning populations elsewhere.

In anadromous populations of allis shad the majority of females mature at ages five and six years and the males at four and five years (Douchement 1981 [Gironde-Garonne-Dordogne, Adour], Sabatie 1993 [Sebou, Morocco], Taverny 1991 [Gironde-Garonne-Dordogne]). In the River Loire, Mennesson-Boisneau and Boisneau (1990) found that the mean age at first spawning was 4.9 years for females and 4.3 years for males.

4.4.2.2.2 Twaite shad

In twaite shad from south-west England, scale analysis revealed that the majority of females spawned for the first time at the age of four; the age at first spawning ranged between three and five. Most other studies report a similar average age at first spawning of four, in female twaite shad, e.g. O’Maoileidigh 1990 (Barrow, Ireland), Douchement 1981 (Loire, Gironde-Garonne-Dordogne and Adour, France) and Taverny 1991 (Gironde-Garonne-Dordogne, France). Aprahamian (in prep.) reported that in the Severn and Wye, females matured in either their fourth or fifth year, in approximately equal proportions. Mennesson-Boisneau and Boisneau (1990) reported that female twaite shad on the River Loire mature at between two and five years old, although the modal age (year) of first spawning was four.

The age at first spawning in males was unclear due to a small sample size. Only three mature male twaite shad were encountered during the study; the age at first spawning ranged from three to four. Researchers studying the Wye, Severn and Barrow populations (Aprahamian in prep., O'Maoileidigh 1990) reported a mean age at first spawning in males of four, whereas researchers studying French twaite shad populations in the Loire, Gironde-Garonne-Dordogne and Adour (Douchement 1981, Taverny 1991) reported that the majority of males first spawned in their third year.

4.4.2.3 Spawning behaviour

Spawning behaviour was not observed in the River Tamar, but taking into account the size of the potential spawning area, the rural nature of the land adjacent to the river and the observation by other researchers that shad spawn in the early hours of the morning (e.g. Cassou-Leins and Cassou-Leins 1981), it is possible that spawning may have gone unnoticed. After an unsuccessful trial survey of a stretch of the River Tamar, alternative methods were adopted to gather evidence of a shad spawning presence in the Tamar.

4.4.2.4 Spawning grounds

Kick sampling for eggs was successful at one site on the River Tamar, below Gunnislake Weir. Only allis shad have been recorded from the Tamar, so the shad eggs found were suspected to belong to allis shad rather than twaite.

Although, the spawning site is just below the tidal limit the water at this location is fresh. Allis shad has been described spawning in freshwater, whereas twaite shad spawn in the lower and middle part of the river (e.g Boisneau *et al* 1992). The channel substrate at the site is a mixture of sand (20 µm to 2 mm) and pebbles (2 to 20 cm), which has been described in other studies as being typical of allis shad spawning sites (e.g. Roule 1923, Ellison 1935, Le Clerc 1941, Mohr 1941, Dottrens 1952, Hoestlandt 1958, Cassou-Leins and Cassou-Leins 1981, Dautrey and Lartique 1983, Boisneau and Boisneau 1990, de Groot 1990, Boisneau *et al* 1992, Fantin and Dartiguelongue 1996).

If the shad eggs collected from Gunnislake in 2002 are confirmed as those of allis shad, this report provides evidence of an allis shad spawning site below the tidal limit. Currently, literature describes allis shad as spawning well into freshwater (Boisneau *et al* 1992), but based upon the findings of this project future searches for allis shad spawning sites will need to target the lower parts of a catchment, including the upper estuary.

Several researchers report a typical water depth of between 0.5 and 1.5 m at allis shad spawning sites; the depth at the Gunnislake spawning site falls within this range at low tide but at high tide it is deeper (2-3m). At low tide the flow type at the site is primarily a run/glide, with a riffle upstream; Boisneau *et al* (1982) described allis shad spawning sites as located 'in swift currents at the end of pools and beginning of shallows'.

At Morewell Wood an algal film covered the channel substrate which may have prevented egg-survival by depleting available oxygen, making this an unsuitable spawning site for allis shad. The absence of eggs at the two sites above Gunnislake

Weir, upstream of Gunnislake Bridge and Blanchdown Woods, may in part be due to the presence of Gunnislake Weir acting as a partial barrier to shad. Although shad have been caught above the weir and observed migrating through the fish pass it is possible that on encountering such an obstruction, the majority of shad spawn at the nearest suitable location below the weir.

4.4.2.4.1 Human disturbance of spawning sites

At high tide on 31 May 2001, a Day-tripper boat approximately 40 ft (12.2 m) long with inboard engines, was seen turning around directly over the spawning site at Gunnislake. In doing so, clouds of sediment were disturbed by the engines. This activity could potentially dislodge significant numbers of shad eggs and cover eggs with sediment that could prevent hatching. Anglers frequently used the spawning area at Gunnislake during the period of egg presence, although this was thought to cause minimum disturbance to spawning grounds.

4.4.2.5 Timing of spawning

The presence of eggs at Gunnislake between 12 June and 4 August 2000 is evidence that allis shad spawned between these two dates; however eggs may have been present earlier than 12 June 2000. In 2001, eggs were present from 14 May until 21 June. This suggests that the spawning period may change from one year to the next, depending on the prevailing environmental conditions. It is unlikely that spawning took place continuously between the first and last dates of egg presence each year: spawning was probably limited to periods of high water temperatures, with egg presence an indicator that spawning had occurred during the previous 5-7 days. The relationship between egg incubation period, water temperature and conditions suitable for spawning is discussed in Section 4.4.3.

Populations of allis shad in the Adour, Gironde and Loire, France, have been observed spawning as late as June and exceptionally July (Prouzet *et al* 1994, Cassou-Leins and Cassou-Leins 1981, Rochard 1992, Mennesson-Boisneau and Boisneau 1990), but never as late as August. The spawning migration of these same populations was observed to start in March and exceptionally in February, with the peak of spawning in April and May. Without knowing the absolute temporal limits of egg presence at Gunnislake, it is difficult to estimate the peak time of spawning. Based on the temporal distribution of allis shad catches and sightings in the Tamar during 2000 and 2001, the peak of spawning activity was probably between May and July. This is later than observed in French allis shad populations.

4.4.2.5.1 Factors affecting timing of spawning

The mean water temperature at Gunnislake during the period in which eggs were found was 16.2 ^{o}C during 2000 (Range; 13.1 ^{o}C - 20.2 ^{o}C) and 14.7 ^{o}C during 2001 (Range; 11.3 ^{o}C – 17.7 ^{o}C). In French allis shad populations the temperature at the onset of spawning has been reported to be in the range of 15 ^{o}C to 18 ^{o}C (Cassou-Leins and Cassou-Leins 1981), ~15 ^{o}C (Boisneau *et al* 1990) and 17 ^{o}C to 19 ^{o}C (Duhamel du

Monceau 1772, Roule 1925). This is consistent with temperatures measured at Gunnislake. Boisneau *et al* (1990) found that spawning activity was not correlated with temperature, but was inversely related to flow. Eggs were present at Gunnislake during 2000 and 2001 during periods of low flow (2000 mean; 5.630 cumecs, 2001 mean; 5.305 cumecs).

4.4.3 Ontogeny

Temperature is crucial to incubation time and the survival of shad eggs. Hoestlandt (1958) mentions that at temperatures below 16 ^{o}C allis shad embryos die in the eggs, while at temperatures below 18 ^{o}C the larvae are not in good condition and have difficulty in emerging from the egg (Cassou-Leins and Cassou-Leins 1981). The upper survival limit would appear to be ~26 ^{o}C, with all eggs dying at a temperature of 26.3 ^{o}C (Cassou-Leins and Cassou-Leins 1990).

The water temperature at Gunnislake during the period when eggs were found ranged from 13.1 ^{o}C - 20.2 ^{o}C in 2000 and 11.3 ^{o}C to 17.7 ^{o}C in 2001. In 2000, water temperatures only remained consistently above 16 ^{o}C (the lower limit of egg survival, according to Hoestlandt 1958) for 27 days of the 54 day period of egg presence. The temperature climbed and consistently remained above 16 ^{o}C at Gunnislake for three periods when eggs were present during 2000; 17-21 June, 1-5 July and a longer period, from 19 July until the 4 August, which was the last day eggs were recorded. However, temperatures consistently remained above 18 ^{o}C on only four days of the 54 day period of egg presence; 18 and 19 June, 22 July and 1 August. In 2001, water temperatures only remained consistently above 16 ^{o}C for ten days during the 39 day period over which eggs were present; 12 and 13 May, 24-27 May, 29-31 May, 16 June and 19 June onwards.

Cassou-Leins and Cassou-Leins (1981) found that at 18 ^{o}C the incubation time for allis shad eggs was 168 hours (7 days), falling to 126 hours (5.25 days) at 20 ^{o}C. Considering these incubation times, the periods of elevated water temperature do not seem long enough to permit successful larval development and hatching. It is possible however, that allis shad spawning in the River Tamar are acclimatised to lower temperatures than more southerly populations in northern France. If this were true, allis shad eggs could successfully develop at temperatures lower than Hoestlandts' minimum threshold temperature of 16 ^{o}C.

It is possible that although water temperatures were sufficiently high to initiate the spawning migration, they were not conducive to the successful development of more than a small proportion of eggs at the spawning site, based on a threshold temperature for successful larval development of 18 ^{o}C (Cassou-Leins and Cassou-Leins 1981). The temperatures during 2000 were probably lower than average, due to a cool summer; water temperatures may be expected to climb above 18 ^{o}C for longer periods in years when the summer is warm. The low water temperatures which prevailed during May, and much of June and July 2000, is a likely explanation for the lateness of allis shad spawning in the Tamar, compared to French populations. Suitable temperatures (for development of the eggs) were not available in the Tamar until later in the year than could be expected in French rivers.

In 2001, water temperatures did not climb higher than 16 ^{o}C and remain so, until 19 June, by which time allis shad had been spawning intermittently for over a month. At no time during the period of egg-presence did water temperatures reach 18 ^{o}C, which suggests that in 2001, although eggs were present and spawning had taken place, the proportion of eggs that hatched was probably very low.

In 2000, high flows prevented spawning until mid-June, by which time water temperatures had reached the lower limit for successful egg development. In 2001 however, low flows prevailed from the beginning of May and lasted throughout the summer. As such, allis shad were physically able to reach the spawning site at Gunnislake at any time during the spring/summer, but water temperature was not ideal for egg development. If the spawning instinct is so strong as to supersede less than ideal conditions, spawning may take place before the optimum water temperature is reached as may have occurred in 2001.

Eggs collected from Gunnislake in 2002 and sent to the Agency fish hatchery for rearing developed normally at 16-18 ^{o}C. These eggs were typically alosid (transparent, oil droplet, 25–35 mm; Figure 63, Appendix), although were observed to differ from symmetrical twaite shad eggs in being slightly ovoid (Henshaw, pers. comm.). This may be because the twaite shad eggs from which comparisons were drawn (Figure 64, Appendix), were collected from adults at the hatchery, whereas the eggs from Gunnislake were collected from the river bed where the river substrate and collection procedure may have mis-shaped the eggs. Upon hatching, the larvae exhibited characteristics that identified them as alosids. Larvae had an unusual sinuous swimming style that has been observed in twaite shad (Henshaw, pers. comm.). Also, the inflation of the swim bladder occurred some 15-20 days after the larvae first started to feed which, again, has only been observed in twaite shad. Compact food in the larvae derived from Gunnislake in 2002 could be seen half way along the body, whereas in the larvae of other species compact food can be seen in the anterior part of the digestive tract.

4.4.4 Demography

The range in body length of fish within each catch was small compared to the range in body length observed for each species during the whole study, particularly in allis shad catches. This suggests that at sea, shoals are comprised of similar sized fish. However, sample sizes were too small to reach firm conclusions about the range in lengths or ages within catches.

4.4.4.1 Allis shad

In allis shad from south-west England, including the River Tamar, a roughly equal sex ratio was observed, although sample sizes were small. In the Loire, Menneson-Boisneau and Boisneau (1990) reported that the sex ratio of the allis shad population varied from 0.84:1 to 4.5:1 (males to females). In three of six years no significant difference was observed, but in the other three years there were significantly more males than females. No deviation from an equal sex ratio was reported in the Gironde-Garonne-Dordogne system by Taverny (1991) or Cassou-Leins and Cassou-Leins (1981), from the Douro (Eiras 1981) or Lima (Alexandrino 1996).

The modal size of allis shad among marine catches was 30-35 cm. The age of allis shad in marine catches was strongly skewed in favour of immature fish (3+ year olds), as would be expected in a species that usually spawns only once. No fish younger than 3+ were caught during the project; this is probably due to the unsuitability of commercial nets for catching small fish. It is also possible that allis shad below the age of 3+ were absent from the coast of south-west England. The age of the spawning population was between four and seven, which is consistent with other studies; the age of allis shad on a spawning migration is discussed in Section 4.4.2.

4.4.4.2 Twaite shad

The sex ratio in twaite shad from marine catches was strongly biased in favour of females. Sexual dimorphism may be a contributory factor, as females were larger than males; males may pass through the mesh of nets without being caught, whereas larger females cannot. This is one explanation for the unequal sex ratio observed in net catches. However, males are outnumbered even among smaller fish. An alternative explanation is that males constituted the majority of the smaller fish that could not be or were not sexed, on account of their size.

No other studies have reported such a large bias in favour of females. From the rivers Wye, Severn and Barrow, Aprahamian (in prep.) and O'Maoileidigh (1990) reported no significant differences from a 1:1 sex ratio. Similar findings were reported for twaite shad from the Loire (Douchment 1981) and from the Lima, Portugal (Alexandrino 1996).

The modal size of twaite shad among marine catches was 40-45 cm. The age range of twaite shad was 3+ to 9; the most frequently recorded age classes were 3+ to 6+. In twaite shad, spawning may occur many times which explains why fish of between 3+ and 6+ are equally common among marine catches. No information was available on the age-structure of spawning populations in south-west England since none were found. Aprahamian (in prep.) found that in the most northerly population (Severn, England) the spawning stock consisted of females mainly aged between five and seven years old and males of four to six years old, with a maximum of twelve and ten years, respectively. At the southern limit of their range (Sebou, Morocco) the spawning population consisted of fish aged three or four years old, with a maximum age of six and five years for females and males, respectively (Sabatie 1993).

Since the capture methods for the two species were the same, the difference in the observed frequency of occurrence of size-classes between the two species suggests that in twaite shad the minimum size of fish netted is not necessarily determined by the size of the mesh used.

4.4.5 Growth

4.4.5.1 Length and weight at age

Studies of allis shad populations from the Loire (Douchement 1981, Mennesson-Boisneau and Boisneau 1990), Gironde-Garonne-Dordogne (CTGREF 1979, Cassou-

Leins and Cassou-Leins 1981, Douchement 1981, Dautrey and Lartigue 1983, Taverny 1991) and Adour (Douchement 1981, Prouzet *et al* 1994) were used to generate age-length and age-weight data against which to compare the findings on allis shad from south-west England.

In the case of twaite shad, studies of populations in the Severn, Wye, Tywi (Aprahamian in prep.), Barrow (Bracken and Kennedy 1967; O'Maoileidigh 1990), Seine (Roule 1922), Loire (Mennesson-Boisneau and Boisneau 1990, Douchement 1981), Gironde-Garonne-Dordogne (CTGREF 1979, Douchement 1981; Taverny 1991) and Adour (Douchement 1981) were used to generate comparative age-length data.

4.4.5.1.1 Allis shad

Tables 26 and 27 show that the length at age of adult allis shad from around south-west England is similar to that recorded in studies of Atlantic populations. As might be expected, the growth rate of allis shad caught from south-west England was more like French populations than populations in southern Europe, although the sample sizes were very small. The growth rate of males and females was akin to that reported from the Loire and Gironde-Garonne-Dordogne (Douchement 1981, Mennesson-Boisneau and Boisneau 1990, CTGREF 1979, Cassou-Leins and Cassou-Leins 1981, Dautrey and Lartigue 1983 and Taverny 1991).

Table 26: Mean length (mm) and standard deviation at age (n=3) of male *A. alosa* from south-west England, compared to other Atlantic populations

River/Area, Country	Actual/ Backcalculated	Age (Year)		Reference
		4	5	
SW England	Actual[A]	471.0	482 (20)	-
Loire, France	Backcalculated	430.5 (36.1)	493.2 (28.5)	Douchement (1981)
	Actual	478.8 (30.6)	532.2 (27.9)	Mennesson-Boisneau & Boisneau (1990)
Gironde-Garonne-Dordogne, France	Backcalculated	455.7 (14.8)	499.8 (11.4)	CTGREF (1979)
	Backcalculated	418.7 (22.1)	488.4 (19.3)	Cassou-Leins & Cassou-Leins (1981)
	Backcalculated	436.1 (31.8)	496.7 (26.0)	Douchement (1981)
	Backcalculated	493.2 (34.2)	555.3 (29.8)	Dautrey & Lartigue (1983)
	Backcalculated	419.9 (34.3)	511.9 (29.8)	Taverny (1991)
Adour, France	Backcalculated	460.6 (29.4)	491.4 (19.0)	Douchement (1981)
	Actual	488.0 (23.5)	510.6 (27.8)	Prouzet *et al* (1994)
Lima, Portugal	Actual	469.8 (16.4)[B]	550.2 (11.7)[B]	Alexandrino (1996)

[A] Fish with plus growth on their scales that were not close to their anniversary were also observed; 3+; 435 mm (n=3, SD=36), 4+; 463 mm (n=1), 5+; 491 mm (n=1)
[B] 95 % Confidence intervals

Although length at age was similar to other studies, male and female allis shad caught from south-west England weighed considerably less at age than French populations (Tables 28 and 29). The extent of these differences precludes attributing them to the fact that fish caught from south-west England were not exclusively spawning stock (whereas measurements in other studies were taken during the spawning migration), because weight differences bridge a years growth, i.e. female allis shad aged six and seven weighed less than fish aged five from the Loire and Adour. Furthermore, fish in spawning condition from rivers and estuaries in south-west England were much lighter at age than fish recorded from the Loire, Gironde-Garonne-Dordogne catchment and Adour.

The observation that allis shad from south-west England are lighter at age than fish from French populations, can be interpreted in a number of ways; firstly, the environmental conditions (e.g. water temperature) or food availability (e.g. abundance of mysid shrimp) around south-west England may be less favourable than in western France, where fish attain a greater body weight at age. Alternatively, fish encountered in south-west England may be a distinct spawning stock that attain smaller body mass than French populations. Larger sample sizes are needed to clarify the growth rate of allis shad from south-west England.

Table 27: Mean length (mm) and standard deviation at age (n=5) of female *A. alosa* from south-west England, compared to other Atlantic populations

River/Area, Country	Actual/ Backcalculated	Age (Year)			Reference
		5	6	7	
SW England	Actual [A]	564 (37)	552 (40)	601	-
Loire, France	Backcalculated	528.0 (39.3)	538.4 (24.3)	-	Douchement (1981)
	Actual	574.3 (24.5)	614.7 (22.3)	649.1 (19.3)	Mennesson-Boisneau & Boisneau (1990)
Gironde-Garonne-Dordogne, France	Backcalculated	522.5 (23.9)	559.8 (17.1)	575.5 (31.9)	CTGREF (1979)
	Backcalculated	547.3 (32.4)	580.6 (9.4)	598.1 (5.1)	Cassou-Leins & Cassou-Leins (1981)
	Backcalculated	530.0 (32.5)	573.2 (25.1)	-	Douchement (1981)
	Backcalculated	595.8 (40.0)	625.3 (43.7)	564.9	Dautrey & Lartigue (1983)
	Backcalculated	530.5 (40.2)	571.5 (23.4)	601.0	Taverny (1991)
Adour, France	Backcalculated	521.9 (38.6)	554.7 (31.6)	-	Douchement (1981)
	Actual	548.5 (2.3)	590.2 (22.8)	610.2 (20.8)	Prouzet *et al* (1994)
Lima, Portugal	Actual	585.9 (16.0) [B]	643.4 (11.3) [B]	666.0 (18.2) [B]	Alexandrino (1996)

[A] Fish with plus growth on their scales that were not close to their anniversary were also observed; 3+; 375 mm (n=1) [B] 95 % Confidence intervals

Table 28: Mean weight (g) and standard deviation at age (n=3) of male *A. alosa* from south-west England, compared to other Atlantic populations

River/Area, Country	Age (Year)		Reference
	4	5	
SW England [A]	860	858 (74)	-
Loire, France	1310 (254)	1658 (265)	Mennesson-Boisneau & Boisneau (1990)
Adour, France	1099 (30)	1352 (18)	Prouzet *et al* (1994)

[A] Fish with plus growth on their scales that were not close to their anniversary were also observed; 3+; 677g (n=3, SD=125), 4+; 870 g (n=1), 5+; 1090 g (n=1)

Table 29: Mean weight (g) and standard deviation at age (n=5) of female *A. alosa* from south-west England, compared to other Atlantic populations

River/Area, Country	Age (Year)			Reference
	5	6	7	
SW England	1360 (141)	1478 (180)	1365	-
Loire, France	1716 (345)	2174 (363)	2665 (489)	Mennesson-Boisneau & Boisneau (1990)
Gironde-Garonne-Dordogne, France	1880 (344)	2172 (323)	2565 (230)	Taverny (1991)
Adour, France	1701 (27)	2266 (24)	2599 (54)	Prouzet *et al* (1994)

4.4.5.1.2 Twaite shad

Female twaite shad caught from south-west England were larger at age, in terms of body length, than populations in the Severn, Wye, Tywi, Barrow and Gironde-Garonne-Dordogne (Table 30), although the sample size was small (n=18). The growth rate was similar to that reported in the Seine (Roule 1922) and Loire (Mennesson-Boisneau and Boisneau 1990). The weight at age of twaite shad from south-west England was also greater than populations in the Severn, Wye and Tywi; weight at age more closely resembled the relationship reported for French populations in the Loire (Mennesson-Boisneau and Boisneau 1990) and Gironde-Garonne-Dordogne (Taverny 1991) [Table 31]. Insufficient numbers of males were caught from south-west England to permit a comparison of growth rate to other populations.

The relatively fast growth rate of twaite shad from south-west England suggests that fish are not part of the Severn, Wye or Tywi stock. The apparently fast growth rate and large body mass suggests that fish from south-west England are derived from French populations, notably the Loire. Alternatively, it is possible that these fish are part of an unknown spawning population in one of the rivers of southern England. As in allis shad, larger sample sizes are needed to clarify the growth rate of twaite shad from south-west England.

Table 30: Mean length (mm) and standard deviation at age (n=18) of female *A. fallax* from south-west England compared to other Atlantic populations

River/ Area, Country	Actual/ Back-calculated	Age (Year)						Reference
		(3+) 4	(4+) 5	(5+) 6	(6+) 7	(7+) 8	9	
SW England	Actual	420	441 (19)	438 (18)	467 (21)	485 (1)	473	-
Severn, England	Actual	370.2 (19.8)	399.8 (18.7)	415.5 (6.6)	-	-	-	Claridge & Gardner (1979)
	Back-calculated	349.4 (28.6)	387.5 (19.8)	407.9 (18.4)	421.1 (20.6)	435.8[B] (21.3)	448.5[B] (21.9)	Aprahamian (in prep.)
Wye, Wales	Actual	358.5 (15.0)	382.3) (16.0)	395.9 (16.4)	418.2 (8.4)	434.1	451.1 (28.3)	Aprahamian (in prep.)
Tywi, Wales	Actual	-	-	411.8 (21.9)	430.3 (24.0)	411.1 (36.0)	-	Aprahamian (in prep.)
Barrow, Ireland	Back-calculated	332.2 (31.1)	365.1 (21.7)	435.3	455.7	-	-	O'Maoileidigh (1990)
Seine, France	Actual	450.0	447.5	-	-	-	-	Roule (1922)
Loire, France	Actual	452.3 (33.3)	453.4 (23.2)	-	-	-	-	Mennesson-Boisneau & Boisneau (1990)
	Back-calculated	388.1 (25.9)	428.9 (16.2)	462.8 (15.9)	-	-	-	Douchement (1981)
Gironde-Garonne-Dordogne, France	Back-calculated	358.3 (17.1)	399.0 (13.7)	430.7 (33.0)	-	-	-	CTGREF (1979)
	Back-calculated	372.1 (20.7)	412.5 (21.1)	-	-	-	-	Douchement (1981)
	Back-calculated	347.8 (32.2)	369.3 (18.2)	-	-	-	-	Taverny (1991)
Adour, France	Back-calculated	361.2 (15.7)	408.0 (16.8)	445.0 (16.3)	468.8 (8.9)	490.5 (5.0)	-	Douchement (1981)
Lima, Portugal	Actual[B]	412.5 (11.2)	455.5 (15.8)	-	-	-	-	Alexandrino (1996)

[A] With few exceptions, the twaite shad observed in this study were not caught close to an anniversary and had plus growth on their scales. For the purposes of comparison 3+ fish from south-west England were compared to fish aged 4 from spawning populations, and so on.
[B] 95 % Confidence intervals

Table 31: Mean weight (g) and standard deviation at age (n=18) of female *A. fallax* from south-west England, compared to other Atlantic populations

River/Area, Country	Age (Year)						Reference
	(3+) 4	(4+) 5	(5+) 6	(6+) 7	(7+) 8	9	
SW England	625	802 (78)	748 (111)	920 (343)	900 (57)	1040	-
Severn, England	283	526 (103	568 (81)	-	-	-	Claridge & Gardner (1979)
	535 (101)	596 (102)	661 (109)	725 (133)	834 (159)	921 (176)	Aprahamian (in prep.)
Wye, Wales	446 (58)	556 (76)	556 (97)	635 (81)	745	775 (247)	Aprahamian (in prep.)
Tywi, Wales	-	-	582 (93)	568 (85)	576 (149)	-	Aprahamian (in prep.)
Seine, France	565	798	-	-	-	-	Roule (1922)
Loire, France	870 (184)	848 (162)	-	-	-	-	Mennesson-Boisneau & Boisneau (1990)
Gironde-Garonne-Dordogne, France	696 (78)	885 (214)	842 (414)	-	-	-	Taverny (1991)

4.4.5.2 Length-weight relationship

In this study twaite shad were relatively heavier at length than allis (Figure 27), although the maximum size recorded was greater for allis shad. This is not consistent with most other studies, where both male and female allis shad have been reported to be relatively heavier than twaite shad of similar length (e.g. Douchement 1981, Mennesson-Boisneau and Boisneau 1990, Alexandrino 1996). Only Sabatie (1993) reported twaite shad length-weight parameters exceeding those of allis (Sebou, Morocco).

There are several explanations for this observation; firstly, twaite shad are relatively heavier at length, or allis shad are relatively lighter at length around south-west England compared to respective populations elsewhere. An alternative explanation is that the data set a) does not represent fish caught from throughout the year, or b) does not contain fish of each species from a comparable range of body lengths.

4.4.5.2.1 Allis shad

As in Section 4.4.5.1, the length-weight relationship of allis shad caught from south-west England was compared to that of allis shad populations elsewhere, using growth parameters from studies in the Loire (Douchement 1981, Mennesson-Boisneau and Boisneau 1990) and the Gironde-Garonne-Dordogne (CTGREF 1979, Cassou-Leins and Cassou-Leins 1981, Douchement 1981, Dautrey and Lartique 1983, Taverny 1991).

In adults of both sexes, body weight was relatively less in allis shad from south-west England compared to populations in the Gironde-Garonne-Dordogne, Loire and Adour (Table 32). Sample sizes were small, however. In immature allis shad (<40.0 cm) the length-weight relationship of fish caught from south-west England was smaller than in

French populations in the Aude and Rhone, but greater than in the Adour (Douchement 1981) [Table 33].

Table 32: Length-weight relationship of adult *A. alosa* from south-west England (Length range; males; 440-496 mm, females; 456-607 mm) and in French populations

			Weight (g) at total body length (mm)			
Population	Sex	n	450	500	550	600
SW England	Male	8	836.4	949.2	-	-
	Female	8	797.4	1059.0	1368.8	1730.2
	All	16	802.1	1056.1	1354.6	1700.1
Gironde-Garonne-	Male	51	900.9	1241.7	1659.8	-
Dordogne, France	Female	58	883.7	1277.4	1782.6	2416.6
(Douchement 1981)	All	109	892.3	1259.5	1721.2	2276.5
Loire, France	Male	89	961.7	1308.7	1729.3	-
(Douchement 1981)	Female	26	-	1379.7	1810.7	2320.7
	All	115	-	1344.2	1770.0	-
Adour, France	Male	120	974.9	1275.6	1626.7	-
(Douchement 1981)	Female	21	-	1376.1	1816.8	-
	All	141	-	1325.9	1721.8	-

Table 33: Length-weight relationship of immature *A. alosa* from south-west England and in French populations (Length range 250.0 - 431.4 mm)

			Weight (g) at total body length (mm)			
Population	Sex	n	260	290	320	350
SW England	Male	-	-	-	-	-
	Female	-	-	-	-	-
	All	59	131.6	180.6	240.2	311.4
Adour, France	Male	31	149.7	204.7	-	-
(Douchement 1981)	Female	31	78.5	107.3	-	-
	All	62	114.1	156.0	-	-
Aude, France	Male	79	156.8	222.1	304.0	404.6
(Douchement 1981)	Female	71	158.2	221.6	300.4	396.2
	All	150	157.5	221.9	302.2	400.4
Rhone, France	Male	23	155.5	218.3	296.3	391.3
(Douchement 1981)	Female	24	155.7	221.3	303.9	405.6
	All	47	155.6	219.8	300.1	398.5

The observation that allis shad are relatively lighter at length, and at age, suggests that fish caught from south-west England do not grow as large as fish from French populations. The smaller maximum size recorded from fish caught in south-west England, as compared to other populations further suggests a smaller body mass at age and at length than allis shad from populations further south. For reasons discussed in Section 5.4.5.1.1, it is unlikely that differences in reproductive state between marine and spawning stock can explain the lower relative weight of allis shad in this study. Compilation of a larger data set should provide results of greater statistical reliability.

4.4.5.2.2 Twaite shad

Although the length and weight at age of twaite shad from south-west England was greater than in other populations, the length-weight relationship was similar (using females as a comparison). The weight at length of twaite shad from south-west England was similar to populations in the Severn, Wye (Aprahamian in prep.), Loire and Gironde-Garonne-Dordogne (Douchement 1981) [Table 34]. Most twaite shad recorded in this study were not in spawning condition, so weight at length could be expected to increase as fish enter spawning condition.

Table 34: Length-weight relationship of *A. fallax* from south-west England and in other North European populations (Length range 341-520 mm)

Population	Sex	n	Weight (g) at total body length (mm)			
			330	350	400	450
SW England	Male	5	449.1	482.3	567.0	653.9
	Female	54	343.5	405.9	593.0	828.5
	All	103	336.1	395.9	574.0	796.6
Severn, England (Aprahamian in prep.)	Male	1329	335.4	399.9	596.3	848.3
	Female	3784	369.2	429.8	639.6	908.2
	All	5113	352.3	414.9	618.0	878.3
Wye, Wales (Aprahamian in prep.)	Male	77	308.7	373.4	575.3	842.4
	Female	150	379.4	439.2	612.0	820.3
	All	227	344.0	406.3	593.7	831.4
Loire, France (Douchement 1981)	Male	63	340.6	398.7	570.0	781.3
	Female	76	373.5	442.7	651.4	915.8
	All	139	357	420.7	610.7	848.6
Gironde-Garonne-Dordogne, France (Douchement 1981)	Male	66	282.0	329.1	-	-
	Female	165	340.2	400.9	581.6	807.6
	All	231	311.1	365.0	-	-

4.4.6 Diet

4.4.6.1 Allis shad

At sea and in estuaries allis shad fed almost exclusively on *Neomysis integer* (mysids). This concurs with many other researchers that recorded mysids in the diet of allis shad (Ehrenbaum 1936, Mohr 1941, Bracken and Kennedy 1967, Wheeler 1969, Quero *et al* 1989, Maitland and Lyle 1991, 1995, Taverny 1991). However, only Taverny (1991) reported that Mysidacea was the principal food of allis shad. Other researchers found that copepods were prevalent in the allis shad diet (Eiras 1981, Maitland and Lyle 1995) and most studies report a more diverse diet than that observed during this study (Taverny 1991, Maitland and Lyle 1995). A larger sample size incorporating fish caught throughout the year may have shown a more diverse diet.

Many different types of crustaceans and a few species of fish are reported to make up the diet of allis shad. Malacostraca, including Euphausiacea, Mysidacea, Isopoda, Amphipoda and Decapoda, and Copepoda of the Order Calanoidea have been reported from the diet of allis shad. Small fish species reported include sprats (*Sprattus sprattus*) and anchovies (*Engraulis encrasicolus*).

The estuarine diet of allis shad from south-west England was slightly more diverse than the marine diet, although sample sizes were fairly small; Taverny (1991) and Maitland and Lyle (1995) observed that fish are an important component of the diet, particularly in summer and autumn months. Apart from Mysidacea, unidentified fish and gobies were recorded in the marine diet.

In the estuarine diet, *Crangon* sp., *Praunus* sp. (Decapoda) and *Gammarus* sp. (Amphipoda) as well as mysid shrimps. Larger dietary items, such as amphipods and decapods tended to occur in larger individuals, which suggests that prey selection of even relatively small items is size dependent in allis shad. Once allis shad attain sufficient size they may become facultative filter-feeders, capable also of snapping up particles singly. Smaller fish (3+ year class, c. 25-30 cm) were observed to feed almost exclusively on mysids, suggesting a greater dependence on filter-feeding at this age.

A small proportion of allis shad caught at sea and in estuaries had ingested synthetic materials such as plastics, nylon or rubber. It is likely that fish mistakenly ingest synthetics whilst feeding on particulate prey items. A similar explanation is applicable to the plant material that was recorded from one estuary-caught allis shad specimen.

Only one allis shad from freshwater was examined and the gut was empty. Eiras (1981) reported that during the freshwater spawning migration, adult allis shad do not feed. A whitish or greenish fluid has been reported in the stomach of migrating allis shad by Quignard and Douchement (1991).

4.4.6.2 Twaite shad

Only one estuarine twaite shad specimen was available for examination, preventing a reliable comparison of the estuarine and marine diet of twaite shad. However, the gut of the estuarine fish contained mysids and sprats in equal proportions, whereas mysids were infrequently recorded from the marine diet. In the marine phase the diet of twaite shad consisted almost entirely of sprats. Items also recorded in the marine diet included a gadiform fish (of the *Trisopterus* genus), gobies (unidentified), sea slaters (*Cirolana* sp.) and mysid shrimps (*N. integer*).

Other researchers reported that the diet of adult twaite shad at sea consisted of small fish and Crustacea, mainly Mysidacea, Isopoda and Euphausiacea (Murie 1903, Redeke 1939, Colette, in Mohr 1941, Rae and Wilson 1952, 1956a, 1956b, 1961, Rae and Lamont 1961, 1962, Svetovidov 1952, Bracken and Kennedy 1967, Wheeler 1969, Minchin 1977, Taverny 1991).

Some studies found fish to be the main dietary item of twaite shad, whilst in others crustaceans were reported to dominate. Aprahamian (1989) found that the diet of twaite shad caught in Cardigan Bay, West Wales, and in the Severn Estuary was dominated by mysids, with fish being of lesser importance. In contrast, Taverny (1991) reported that in the Golfe de Gascogne, France, small fish dominated the diet throughout the year, whereas mysids were only a major component during the winter and spring months. Taverny (1991) also found that sprat was one of the main fish species, with anchovy also important in the diet. The fish-dominated diet of twaite shad in south-west England appears to be more similar to French populations than fish in the Severn population.

Maitland and Lyle (1995) reported that the food of twaite shad in the Cree Estuary, Scotland, was dominated by fish, with Malacostraca of secondary importance. In the Tagus Estuary, Portugal, Assis *et al* (1992) found that fish species dominated the diet of twaite shad.

Other invertebrate food items reported in the diet of twaite shad are *Gammarus* sp. (Amphipoda), *Crangon* sp. (Decapoda), Diptera, Coleoptera and Lepidoptera (Uniramia), *Neris diversicolor* (Annelida) and various molluscs (Gastropoda and Cephalopoda) [Assis *et al* 1992].

4.4.6.3 Summary

The examination of fish stomach contents in this study was carried out opportunistically and as such did not provide dietary samples from fish caught at all times of year. Had this been possible the dietary diversity of the two species may have been significantly different. However, the results of this study suggest that the diet of each species is dominated by one food item; mysid shrimp (*N. integer*) in allis shad and sprats in twaite shad. Given the importance of these food items in the diets of allis and twaite shad, future investigations into the status of shad in south-west England should consider assessment of the status of these two prey species.

4.4.7 Parasitology

Three species of parasite were recorded from allis shad; a nematode of the alimentary tract, *Contracaecum aduncum*, *Clavellisa emarginata*, a parasitic copepod of the gills, and a monogenean, thought to be *Mazocreas* sp.. *C. aduncum* and *C. emarginata* were also recorded from twaite shad.

4.4.7.1 Contracaecum aduncum

C. aduncum has been recorded from allis shad in the North Sea (Punt 1941), Gironde-Garonne-Dordogne system, France (Taverny 1991) and other European populations (Fatio 1890, Markowski 1937, Almaca 1986). *C. aduncum* has been recorded from twaite shad populations in a number of locations, including the North Sea (Punt 1941), north-east Atlantic and North European seas (Petter and Cabaret 1995), River Severn (Aprahamian 1985), Mid-Loire (Mennesson-Boisneau and Boisneau 1986) and Gironde-Garonne-Dordogne system (Taverny 1991).

C. aduncum was recorded from most adult, but few immature allis shad, which suggests that infection by *C. aduncum* increases with age. The prevalence of infection in twaite shad was also greater in larger fish. Taverny (1991) found that the prevalence of infection in juveniles of allis and twaite shad from estuaries, was much lower than in adults in freshwater, although it is not clear whether differences were due to fish age, environment or both.

The prevalence of infection in estuaries and freshwater was similar in adult allis shad from freshwater, estuarine and marine environments (data was not available for infection rates in estuary-caught twaite shad). Aprahamian (1985) found that the prevalence of infection in adult twaite shad entering freshwater declined, compared to fish in the estuary.

At sea, the prevalence of infection of *C. aduncum* in adult fish was much lower in twaite shad (43.2 %) than in allis (92.9 %). Taverny (1991) reported very similar findings for *C. [Hysterothylacium] aduncum* from the Golfe de Gascogne, albeit in freshwater; 94.5 % of allis shad were infected, compared to 32.0 % of twaite shad.

4.4.7.2 Clavellisa emarginata

C. emarginata has been recorded from allis shad in the North Sea (Boxshall 1974, in Aprahamian *et al*, in prep.), Gironde-Garonne-Dordogne system (Taverny 1991) and East European populations (Markevich 1952, Kabata 1979). In twaite shad, *C. emarginata* has been recorded in the Severn (Aprahamian 1985), Gironde-Garonne-Dordogne system (Taverny 1991) and various other European rivers.

The prevalence of infection of *C. emarginata* at sea was similar in allis and twaite shad caught from south-west England (9.3 % and 7.5 % respectively). No studies mention the prevalence of *C. emarginata* in allis shad but in adult twaite shad Aprahamian (1985) found that the prevalence of infection in the Severn Estuary was 30.4 %, declining to 12.3 % in freshwater.

The density of *C. emarginata* in allis shad from the sea was 0.7 parasites per fish, compared to 1.6 in estuarine fish. By comparison, Aprahamian (1985) found that the density of *C. emarginata* in estuarine twaite shad was 2.5 parasites per fish.

The density of parasites in allis shad adults (> 40 cm) compared to immature fish, irrespective of catch location, was 1.5 parasites per fish in adults, compared to 0.8 in immature fish. This suggests that as with *C. aduncum*, older fish are more heavily infected with *C. emarginata*.

4.4.7.3 Mazocraes sp.

Mazocreas alosae have been recorded from allis shad in the Severn, Wye and at Plymouth (Finlayson 1981). *M. harengi* has also been reported from allis shad in Devon (Bayliss (1939) and more specifically at Plymouth (Dollfus (1956). A similar distribution has been reported for these species in twaite shad, with additional reports from the Gironde-Garonne-Dordogne (Taverny 1991). *Mazocreas* sp. were recorded during this study from allis shad caught around the Isles of Scilly, Cornwall.

4.4.8 Migration

4.4.8.1 Adult spawning migration

In the River Tamar the highest GSI values of female allis shad were recorded in June. Males in spawning condition were only recorded during May and during early June 2001, two males, believed to be spent, were caught from the estuary. This suggests that male allis shad attain spawning condition earlier in the year than females. Collection of further data would clarify the relationship between peak spawning condition and time of year. De Groot (1990) observed that in the Rhine, Germany, allis shad males arrived in small schools a few weeks earlier in the season than females. Claridge and Gardner (1978) recorded male twaite shad arriving slightly earlier than females during the spawning migration on the River Severn.

Shad, thought to be allis, were observed migrating upstream at the Gunnislake Fish Pass between 13 June and 3 August 2000 and between May 11 and May 25 2001; in 2000 most records were collected during June, whereas in 2001 May appeared to be the main month of adult migration. It is possible that the shad observed migrating upstream at Gunnislake Fish Pass did not represent the peak spawning migration: i.e. fish may have moved earlier in the season when video footage of the fish pass was not being collected.

The temporal distribution of records for adults in spawning condition suggests that the peak spawning migration of allis shad in the Tamar was between mid-May and late June, although prevailing environmental conditions in each year will dictate the timing of the spawning season. This is later than in other spawning populations of allis shad, but concurs with Aprahamian's (in prep.) observation that northerly populations of allis shad tend to spawn later than those at more southerly latitudes.

Historically, the peak spawning migration of allis shad recorded from the River Severn was observed to be in April and May (Salmon Fisheries Commission 1861). The peak timing of the spawning migration in French populations of allis shad is also April to May (Cassou-Leins and Cassou-Leins 1981, Mennesson-Boisneau and Boisneau 1990, Rochard 1992, Prouzet *et al* 1994), compared to February to March in southern European populations (Lahaye 1962, Sabatie 1993, Alexandrino 1996).

Twaite shad were seldom caught during the spring or summer months; the highest GSI value was recorded from a female caught at Burnham-on-sea on 28 April 2000. This fish was possibly migrating into the Severn Estuary. Insufficient data prevents speculation about the timing of spawning in twaite shad caught from south-west England. In the Severn, Wye (Aprahamian 1981, 1982) and Gironde (CTGREF 1979) spawning was reported as occurring between April and June, whilst in the Loire, Mennesson-Boisneau and Boisneau (1990) reported a slightly later spawning run between May (sometimes April) and July. Peak spawning in all these populations was reported to occur in May.

4.4.8.1.1 Factors affecting adult spawning migration

Water flow and temperature influence the timing of allis shad migrations (Roule 1925, Mohr 1941, Bracken and Kennedy 1967, Cassou-Leins and Cassou-Leins 1981, Dautrey and Lartique 1983, Belaud *et al* 1985, Steinbach *et al* 1986, de Groot 1990, Mennesson-Boisneau *et al* 1993, Bellariva and Belaud 1998). Figures 35 and 36 suggest that water flows are very important, although rising water temperatures probably initiate the spawning run.

At times when shad were observed migrating the mean water temperature at Gunnislake Fish Pass was 16.7 ^{o}C. The earliest catches of allis shad from the River Tamar corresponded to water temperatures of 13.8 ^{o}C. This concurs with Bellariva and Belaud's (1998) observation that on the Garonne River, between 25 and 75 % of all allis shad within each year were migrating at mean water temperatures between 13 and 17 ^{o}C. Several researchers recorded a positive relationship between increasing water temperature and the number of allis shad migrating (e.g. Cassou-Leins and Cassou-Leins 1981, Dautrey and Lartique 1983, Belaud *et al* 1985).

At Gunnislake, shad were observed migrating upstream only at times of low flows and never when river flows were high. The maximum flow observed for migrating shad was very similar in 2000 and 2001, which suggests that allis shad are prevented from migrating above a threshold limit of water flow. The maximum flow value observed during times of shad migration (8.949 cumecs) was exceeded on just 23 % of the flows during the period May to August; this suggests that for much of the time during the period May to August flows are suitable for shad migration. Bracken and Kennedy (1967), Steinbach *et al* (1986) and Bellariva and Belaud (1998) also observed that increased water flow results in a decrease or cessation of migrating allis shad.

The combination of water temperatures and flows accounts for the observed differences between the timing of spawning in 2000 and 2001 in the River Tamar, based on the upstream movement of fish at Gunnislake and the deposition of eggs below Gunnislake weir. In 2000, high flows prevailed until mid-June, at which time water temperatures climbed above 16 ^{o}C. As a result, the peak upstream movement of adults was mid-June, with eggs remaining until the beginning of August. In contrast, low flows prevailed throughout 2001, from early May onwards and water temperatures reached 16 ^{o}C for brief periods in May. Consequently, peak upstream movement of adults was observed during May in 2001, with eggs present during May and June.

Most of the fish observed migrating upstream at Gunnislake Fish Pass were moving on, or shortly after spring tides, which may have facilitated movement up to Gunnislake Weir. Aprahamian (1988) observed that to effect upstream progress, pre-spawning adult twaite shad tend to use the flood tide in the main channel. However, migration at the fish pass was observed both at low and high tides, suggesting that if shad used the flood spring tides to reach Gunnislake, once there they waited below the weir before continuing upstream. Similar behaviour was observed by Steinbach *et al* (1986), who noted that radio-tagged shad stopped their spawning migration upon encountering a weir.

The diurnal variation in migration times observed among shad migrating upstream at Gunnislake Fish Pass, suggested that shad (probably allis) were preferentially moving upstream during the hours of daylight (0900-2400), although the number of fish seen was small (n=13). Gregory (2000) observed that shoals of twaite shad migrating upstream on the River Wye moved between 0300 and 2000 hrs.

These results suggest that daily timing of passage is temperature or light intensity dependent. Diurnal variation in the migratory passage of shad has been linked to variations in water temperature. For example, in the Loire, Steinbach *et al* (1986) found that water temperature had a pronounced effect on allis shad swimming speed, with migrations inhibited at times when temperatures fell below 12^{o}C. Boisneau *et al* (1985) made a similar observation at 11 ^{o}C. The most likely explanation is that once water temperatures have risen to above the threshold necessary to trigger the spawning migration, upstream movement occurs at times that permit avoidance of temperature extremes. In alewives (*Alosa pseudoharengus*), Richkus (1974) reported that when temperatures were low, movements occurred in the afternoon, but under warmer conditions peaks of movement occurred in the morning, at daily temperature minima.

4.4.8.2 Juvenile seaward migration

Sampling for juvenile shad was not successful, possibly because the methods used, locations sampled and the timing of fieldwork were designed to catch juvenile bass, rather than shad. Although 0+ year-class shad were not caught, a routine bass survey on the Helford Estuary did catch four immature allis shad (one of which was aged 3+). The decision to collaborate with the existing routine bass monitoring programmes to survey estuaries for juvenile shad, was based largely upon the low costs incurred by this project. Although manpower and equipment costs were saved, the findings of this study suggest that it is not practical to combine efforts to sample for juvenile (0+ and 1+ group) bass and shad, due to spatial and temporal differences in the occurrence of bass and shad in estuaries.

Sampling for juvenile bass often took place at high-tide sites, whereas clupeomorphs such as pilchard, sprat and herring are invariably caught at low-tide sample sites (D. Kelly, pers. comm.). The bulk of juvenile bass sampling was carried out in mid-summer, from June until August, but the peak seaward migration of juvenile shad has been reported to be later than this. In the Gironde Estuary, seaward of 0+ group allis shad commenced in October, peaked in December and ceased by the end of February (Albiges *et al* 1985, Elie *et al* 1988, Sertier *et al* 1990, Taverny 1991). Other reports found that the largest 0+ juveniles arrive at the river mouth around August and the smallest remain in fresh water until September or October (Quignard and Douchement 1991). Claridge and Gardner (1978) found that the downstream migration of 0+ twaite shad was closely correlated with decreasing water temperature; peak downstream migration of twaite shad moving into the Severn Estuary occurs in August and September (Claridge and Gardner 1978).

Bass sampling sites and the timing of juvenile bass surveys, was not compatible with the sample methods needed to detect 0+ group shad. Low-tide sites should be favoured, rather than high-tide sites. Taverny (1991) noted that during their period in the estuary juveniles tend to be found at the surface and close inshore: netting methods should accommodate this behaviour.

The absence of shad in other surveys, such as in the Hayle and Tamar estuaries could be attributed simply to low survey effort. The methods were considered appropriate for the detection of juvenile shad as indicated by the detection of other clupeomorph species. Failure to detect them could be due either to insufficient survey effort or to the absence of juvenile shad at the survey site. Bottom trawls in the Tamar Estuary failed to detect pelagic fish of any species and is not considered an appropriate method for future juvenile shad surveys.

It is difficult to predict the best time to sample for juvenile allis shad in the Tamar Estuary for two main reasons. Firstly, the observation that allis shad spawn at a site immediately below the tidal limit means that the distance between the spawning site and the main estuary is very small in comparison with the same distance in French rivers containing spawning populations of allis shad. Secondly, if downstream migration of 0+ group shad is temperature-related, the timing of the migration will vary between rivers depending upon the prevailing temperatures in that particular river. Based on the findings of studies to date, the best time to sample for juvenile allis shad in the Tamar Estuary is between August and October, with the peak of sampling effort in September.

5 CONCLUSIONS

This project has gone some way to satisfying the BAP targets for allis and twaite shad. In south-west England the estuaries with a significant shad presence have been identified enabling follow-up surveys to be undertaken. The River Tamar in particular appears to be important for allis shad, and in the future attempts should be made to clarify the spawning status of allis shad in the Tamar. English Nature have been informed of the discovery of shad eggs at Gunnislake; evidence suggests this could be the only known spawning site for allis shad in the UK and the identification of these eggs is a high priority. As a direct result of the project, allis shad have been added as a designated interest feature to the Tamar Estuary Special Area of Conservation (SAC), affording the species special protection and ensuring that favourable management plans for the Tamar catchment are produced and implemented. Future planning, discharge and abstraction consents and the management of net fisheries in the Tamar catchment, will need to consider the high level of protection afforded to allis shad under the Habitats Directive 1992.

Further work is needed to clarify the spawning status of shad in south-west England, particularly in the River Tamar. The spawning status of shad in the South West is currently unclear, although during this project evidence was collected from several rivers that suggests spawning takes place locally, particularly allis shad.

The monitoring scheme used during this project was reasonably successful, particularly the use of posters at key locations, such as fish markets, and appeals for information in specialist publications targeting commercial fishermen. Shad recording forms were also fairly successful. A good source of information during the project was the estuary salmon netsmen; future investigations into shad spawning status in South West estuaries should seek to involve netsmen. The distribution of information and guidance to fishermen resulted in a number of catches being reported; a leaflet would make this task easier, as well as the continued use of posters. Collaboration between DEFRA and the Environment Agency also produced valuable information and specimens to the project.

The information on shad distribution collected during this project has been used in an Agency R&D Project to compile an atlas of freshwater fishes. Distribution records have been forwarded to the National Marine Aquarium and will also be made electronically available to all Agency staff. The appropriate conservation authorities have been informed of the findings of this study in order to ensure appropriate protection of spawning sites and establish future actions for shad conservation on a national and regional level.

The opportunistic collection and examination of shad specimens during the project has provided some useful information but due to the catch-dependent nature of biological and ecological study and the relatively short duration of this project, the sample sizes recorded were often inadequate to draw firm conclusions. The continued study of shad biology and ecology, and ideally genetics, in the South West will provide the larger sample sizes needed to interpret data confidently; the publication of further findings on the biology and ecology of shad in south-west England should be delayed until larger sample sizes have been collected.

6 RECOMMENDATIONS

6.1 Recording Shad

- **Problem**: The incidence of shad catches at sea was considerably greater than was reported to the Project Officer. Often shad were caught and discarded at sea or used as crab pot bait. If shad did appear for sale at fish markets they were sold as 'mixed fish' and it was at this stage that shad were most likely to be reported to the Project Officer. DEFRA Officers were often unable to record shad due to the additional workload that this would incur.
- **Recommendation**: Catches of shad from fishing boats should be routinely recorded; DEFRA Officers are ideally placed to do this. DEFRA Officers should receive guidance on recording shad, which should be co-ordinated by the relevant conservation organisation. By recording shad from the boats, information on where and how the shad were caught can be recorded. This information is often unavailable when shad are reported from the fish markets.

Local, Regional, National	Priority	Cost	Feasibility
National	Medium	Staff time	Medium

- **Problem**: Little is known about shad habitat preferences in the marine environment around south-west England. Information about the exact locations of marine catches is usually not available and catch location is often approximated. Other studies suggest that water depth and temperature are important in determining the marine distribution of shad, but these factors have not been investigated in south-west England.
- **Recommendation**: Where possible, information from fishing boats should include the location of fishing (or at least the start and finish locations of trawls), water temperature and water depth. This information could be collected opportunistically by DEFRA Species Catch Recorders, working aboard commercial fishing vessels.

Local, Regional, National	Priority	Cost	Feasibility
National	Medium	Staff time	Medium

- **Problem**: It is difficult for the layperson to tell allis and twaite shad apart; current literature adds to the confusion because often, it wrongly states that the two species differ by the presence or absence of flank spots.
- **Recommendation**: The findings of this study regarding shad identification should be extended and published. The exact relationship between age, size, flank spots, fin rays, gill rakers and species needs clarification so as to provide fishermen and DEFRA Officers best practice guidelines for identifying the two species. The national leaflets currently being developed should incorporate the findings of this study. Findings should also be summarised and distributed to fish markets in poster format. The success of the poster at fish markets was such that it should be reprinted and used nationally.

Local, Regional, National	Priority	Cost	Feasibility
National	High	Alter and reprint leaflets and poster – limited cost	High

- **Problem**: At present, the recording of shad is not carried out nationally and little is known about shad distribution in other parts of the UK. There is no standard procedure for the storage of records, making it difficult for Agency staff and conservation authorities to access complete data sets. There is no procedure or resources for the continued recording of shad catches in the South West after this project finishes.
- **Recommendation**: Guidelines for the standardised collection and validation of records should be produced by the relevant conservation organisation; records should be stored on a spreadsheet managed by the relevant conservation organisation. Contact information and instructions on how to access records should be advertised on the Internet.

Local, Regional, National	Priority	Cost	Feasibility
National	High (a project is looking into this)	Staff time to discuss with DEFRA and establish logistics of data collection and exchange	Medium

6.2 Marine Research

- **Problem**: The relatively small number of fish examined during this study was insufficient to draw firm conclusions about many biological and ecological characteristics. However some of the findings warrant further research, such as the apparently specialist diet and the growth rates of both shad around the South West.
- **Recommendation**: Further analysis of specimens from south-west England should be undertaken, including sexing, ageing, measuring and weighing fish, and determining reproductive state, stomach contents and parasite load. Growth rate in particular should be investigated further. This should be done by requesting information from commercial fishermen and collecting specimens on an opportunistic basis from fish markets etc.

Local, Regional, National	Priority	Cost	Feasibility
Regional/local	Medium	Staff time and expertise	Medium

- **Problem**: This study implied a strongly female-biased sex ratio in twaite shad. If this is actually the case it has severe implications for populations dynamics.
- **Recommendation**: The sex ratio of twaite shad caught from around south-west England should be monitored by examining fish from commercial catches. The relationship between sex and body length, particularly the overlap between male and female body lengths in marine catches, if any, should be investigated further. To do

this, an improved methodology is needed for sexing fish, particular immature fish (e.g. microscopic examination of gonad tissue).

Local, Regional, National	Priority	Cost	Feasibility
National	Low	Medium	Medium

- **Problem**: The dietary data of allis and twaite shad was inadequate. Mysids dominated the diet in allis shad, and twaite shad preyed almost exclusively upon sprats. Further information is needed on the diet of shad from around south-west England, in order to give a complete picture of the diet throughout the year and in different environments i.e. estuaries and coastal waters.
- **Recommendation**: Further stomach analysis of shad caught at different times of year would provide useful information on the range and relative contribution of dietary items. This is particularly useful when predicting where shad will occur and how changes in abundance of prey species will affect shad populations.

Local, Regional, National	Priority	Cost (low, medium, high)	Feasibility
All	Low	Medium. Staff expertise needed	Medium

6.3 Tamar Catchment

- **Problem**: Recent reductions in the length of the salmon and sea trout netting season has led to negative attitude towards the Environment Agency among some netsmen. As such, some were not willing to assist with the project and were reluctant to provide information about historical shad catches. However, many of the netsmen were extremely helpful and went to great lengths to assist the project. Due to the limited nature of R&D Projects communication with the netsmen could stop when the project finishes.
- **Recommendation**: Regular contact with salmon netsmen should be maintained. They are a valuable source of information such as the frequency of shad catches from one year to the next, the timing of migrations and the size and condition of fish. Netsmen should be kept informed of the findings of this study and future work on shad in their river. Letters of thanks and feedback to the netsmen is essential to maintain their goodwill toward future studies.

Local, Regional, National	Priority	Cost	Feasibility
Local	High	Low	High

- **Problem**: Although shad have been recorded migrating upstream at the Gunnislake Fish Counter, video footage is currently collected during periods of salmon and sea trout migration. Furthermore, analysis of fish counter 'events' uses a filter that omits smaller fish, which may include shad.
- **Recommendation**: Video footage should be collected at the Gunnislake fish counter from April until August, particularly during periods of low flows and when

water temperatures exceed 14 ^{o}C. Time permitting, video analysis should include all events, not just those that the filter indicates are salmon or sea trout. The hourly recording of water temperature and flow at Gunnislake should continue, as should recording the flow and water temperature at times of shad migration. When the cumulative sample size is sufficient, this information will provide a means of predicting the conditions under which upstream adult migration will take place.

Local, Regional, National	Priority	Cost	Feasibility
Local	Low	Low	High

- **Problem**: Although shad have been observed successfully traversing Gunnislake Fish Pass, it is not known whether Gunnislake Weir is an obstacle to a proportion of migrating shad. The shad seen migrating upstream at the fish pass may be a fraction of the total number of shad spawning in the Tamar catchment. At present the size of the spawning population of allis shad on the Tamar and the impact of the weir on selection of spawning sites is unknown.
- **Recommendation**: The water flow and dimensions of Gunnislake Fish Pass should be compared to weirs traversed by allis shad from spawning populations elsewhere e.g. River Loire, France. The behavioural response of shad as they encounter the weir could be investigated by radio tagging shad caught in the estuary and monitoring their movements up to Gunnislake weir.

Local, Regional, National	Priority	Cost	Feasibility
Local	Medium	High	Low

- **Problem**: Little is known about the adult holding areas in the Tamar Estuary and River. Tamar Estuary netsmen have caught adult allis shad from Holes hole, Halton Quay, Cotehele, Lewer Beach and Calstock, but the exact locations of adult holding pools is not known. It is important to identify the sites used by migrating adults to ensure that these sites are recognised within estuary management and development plans and receive the appropriate level of protection.
- **Recommendation**: Netting in the estuary for adult shad, either by the Environment Agency, or by liasing with salmon netsmen, would help to identify the areas used by adults on their migration. This netting could be incorporated into a radio-tracking study to investigate the distribution of spawning allis shad in the Tamar catchment.

Local, Regional, National	Priority	Cost	Feasibility
Local	Medium	Medium	Low

- **Problem**: Although allis shad have been recorded from the Tamar Estuary and river, the location of spawning sites is still not known, with the exception of one site below Gunnislake Weir, where shad eggs were found in 2000 and 2001.
- **Recommendation**: River Habitat Survey (RHS) should be used to list potential spawning habitat (and adult holding areas); this can be done by sending a summary of suitable features to the national RHS database. This will provide a list of suitable

sites, provided the river has been surveyed in the first instance. Sites should be surveyed for eggs using kick-sampling methods. Environmental information including water temperature, flow, salinity, pH and suspended solids should be collected; some of this information will be available from various Environment Agency functions.

Local, Regional, National	Priority	Cost	Feasibility
Local	Medium	Medium	Medium

- **Problem**: During 2000, 2001 and 2002, shad eggs suspected to be allis, were found below Gunnislake Weir. If the eggs are identified as allis shad, this will be the only known spawning site in the UK, but it is not yet recognised as such by conservation organisations. Meanwhile, threats exist from boats (pleasure cruisers in particular) which could disturb silt and mud, preventing the development of larvae and hatching of eggs.
- **Recommendation**: The owners of pleasure cruisers in the Tamar should be made aware of the importance of Gunnislake to allis shad. Special protection should be allocated to the site at Gunnislake, preventing activities detrimental to the survival and development of shad eggs. By arrangement of the appropriate conservation organisations, signs should be erected to mark the location of the site to river users and request that they avoid it.

Local, Regional, National	Priority	Cost	Feasibility
Local	High	Medium	Medium

- **Problem**: The evidence for successful allis shad spawning in the Tamar is good, but still inconclusive. To date, juvenile (0+ group) allis shad have not been recorded from the Tamar Estuary.
- **Recommendation**: Close links should be maintained with groups that undertake ongoing survey work in the Tamar Estuary to ensure samples are investigated for juvenile shad. These groups include Plymouth Marine Laboratory, CEFAS, Environment Agency National Marine Monitoring Programmes and salmon netsmen.

Local, Regional, National	Priority	Cost	Feasibility
Local	High	Low	High

- **Problem**: Although allis shad are caught by salmon netsmen and anglers each year in the Tamar catchment, and there is evidence of spawning in the Tamar, the status of allis shad in the Tamar as a distinct spawning population needs clarification.
- **Recommendation**: Allis shad from the River Tamar should be included in an ongoing genetic study to determine their similarity to other populations. This may provide evidence that allis shad in the Tamar are a separate spawning population, whilst identifying their phylogenetic relationship with other European populations. The Environment Agency should request assistance from salmon netsmen and

inform them about the genetics project. Adult allis shad should be obtained from the salmon netsmen on the Tamar from which tissue samples can be taken.

Local, Regional, National	Priority	Cost	Feasibility
Local	Medium	Medium	Medium

6.4 Identification of Shad Eggs, Larvae and Juveniles

- **Problem**: Confirmation of allis shad spawning in the Tamar. In 2002 eggs were collected from Gunnislake, R. Tamar, and transported to the Agency Fish Hatchery, Calverton. Here, the eggs were confirmed as being of the genus *Alosa.* Eggs were successfully hatched and the larvae were kept alive for approximately six weeks. These larvae were preserved opportunistically, but have not so far been identified to species level.
- **Recommendation**: The larvae samples obtained in 2002 from eggs collected at Gunnislake should be formally identified, using DNA techniques if necessary/possible. If these larvae cannot be identified due to small size or preservative used, further attempts should be made to confirm the eggs as allis shad in 2003. When water flows drop below 10 cumecs and water temperature exceeds 15 ^{o}C, the site below Gunnislake should be surveyed for eggs. If eggs are present in high enough numbers (>100 eggs collectable in 2 hours), 500 eggs should be collected, sealed in oxygenated bags and, keeping the eggs cool, transported to the Agency Fish Hatchery as soon as possible. Here they can be hatched and reared to an age compatible with species identification (either by visual identification or DNA) as done for twaite shad (from the River Severn) in 2000.

Local, Regional, National	Priority	Cost	Feasibility
Local	High	Medium	Medium

6.5 Investigation of Shad Spawning Status in other Rivers

- **Problem**: At present there is no guidance on how to assess the importance of shad presence in a catchment, where records exist. For example, if a single fish is recorded what information should be collected and what, if anything, should be done next? If several fish are recorded showing signs of recent spawning, what should be done? What constitutes sufficient evidence of spawning activity to warrant further investigation? There is a need to produce guidelines for conservation organisations regarding the appropriate course of action in response to varying degrees of shad presence in a catchment.
- **Recommendation**: Survey guidelines should be produced (overseen by the UK BAP group) for assessment of shad spawning status in UK rivers. The guidelines should include how to identify adults and juveniles of each shad species and how to identify a fish in spawning condition or a fish that has recently spawned. The appropriate course of action should be suggested in response to different levels of shad presence recorded in a catchment. The guidance should include details of river habitat surveys for locating potential spawning sites, egg surveys, juvenile netting

surveys and assessments of the upstream limit of migration, as well as advice on when to undertake various survey work.

Local, Regional, National	Priority	Cost	Feasibility
National	Medium	Low, staff expertise	High

- **Problem**: Current literature suggests that allis shad spawn at the top of catchments, but the findings of this project suggest that spawning may take place as far downstream as the upper estuary. Potentially, this could result in the oversight of spawning sites located at the bottom of catchments.
- **Recommendation**: Egg surveys undertaken to clarify the spawning status of shad in a catchment should include the upper estuary and lower river reaches, particularly if there are potential barriers to migration preventing/hindering access to the middle and upper reaches of the river.

Local, Regional, National	Priority	Cost	Feasibility
National	Medium	Low, staff expertise	High

- **Problem**: The ability of shad to access freshwater spawning areas in rivers of south-west England may be compromised in some catchments by impassable barriers, such as weirs and navigation locks. The upstream limit to migration and the freshwater range of rivers that are potentially available to shad needs clarification. This is particularly important on rivers such as the Torridge, where numerous shad are caught each year in the estuary.
- **Recommendation**: Using shad swimming speeds and data on the migratory capabilities of shad, catchments with significant shad presence should be surveyed with respect to potential barriers to navigation. The height and length (e.g. fish passes) of each potential obstruction should be measured, as well as the water velocity at times of likely shad migration; using information from studies of shad swimming speed and endurance an assessment should be made on the navigability of the obstruction to shad. The likely upstream limit to migration should be located for each catchment, along with the range of available spawning habitat. Ideally the survey should also identify partial barriers along the migration route that are impassable to shad above a threshold flow; this will provide an estimate of the available freshwater habitat to shad under a range of flow regimes. The upstream migratory limit should be calculated on the catchments of the Tamar, Fowey, Exe, Dart and Torridge initially. A lower priority should be given to the catchments of the Camel, Fal (and rivers draining into the Carrick Roads), Frome/Piddle, Hayle, Looe, Lynher, Taw and Yealm.

Local, Regional, National	Priority	Cost	Feasibility
Regional	Medium	Medium	Medium

- **Problem**: During this study it was noted that surveying for juvenile shad was not necessarily compatible with other types of survey work. Although savings in costs and resources were achieved by combining survey effort with existing programmes such as juvenile bass netting, the methodology was not necessarily suitable for catching juvenile shad.
- **Recommendation**: Netting surveys for juvenile shad should be carried out at or around low tide. In the Helford Estuary, shad have been caught at a 'low tide site' and observations suggest that clupeomorphs such as herring, pilchard and sprat are caught in greater abundance at low tide than at other times. Trawls are judged to be unsuitable for catching juvenile pelagic fish such as shad; during a recent survey in the Tamar Estuary very few pelagic fish were caught in trawls. Future surveys for juvenile shad should use seine netting.

Local, Regional, National	Priority	Cost	Feasibility
All	-	-	-

- **Problem**: This project found limited evidence to suggest that allis shad spawn in the River Fowey, Cornwall. An adult male with spawning marks on its scales (and also an immature allis shad of 3+) was recorded from the Fowey Estuary in August 2000, although anecdotal information from net-catch returns suggests that adult allis shad are caught each year by salmon netsmen.
- **Recommendation**: The Environment Agency should continue to liase with salmon netsmen in the Fowey Estuary and record the numbers of shad caught. In addition egg surveys should be undertaken in the upper estuary and the lower reaches of the river. The River Habitat database should be used to generate a list of potential spawning sites. Starting with sites in the estuary and working upstream, kick-sampling should be carried out at each suitable site to search for shad eggs. The timing of surveys should coincide with periods of low flows and temperatures of 14 ^{o}C and above, from May until July. If eggs are found, netting should be carried out for juveniles in the estuary (e.g. at Golant), from August to October.

Local, Regional, National	Priority	Cost	Feasibility
Local	Medium	Medium	Medium

- **Problem**: During this project allis and twaite shad, including adult allis shad in spawning condition, were recorded in the estuary of the River Torridge, Devon. The number and size of shad recorded in 2000 and 2001 suggests a significant presence in the estuary, worthy of further investigation. With the exception of three adult specimens (two allis shad showing spawning marks on their scales and one twaite shad), the other shad recorded by netsmen were not examined. It is unclear whether either species spawns in the River Torridge.
- **Recommendation**: If net buy-backs permit, Environment Agency staff should continue to liase with salmon netsmen in the Torridge Estuary over the number and species of shad caught. Netting should be carried out at pools upstream of Bideford during summer months to determine whether shad in spawning condition of either species are present in the upper estuary/lower river and identify shad holding areas. The River Habitat database should be used to generate a list of potential spawning sites. Starting with sites in the estuary and working upstream, kick-sampling should

be carried out at each site to search for shad eggs. The timing of surveys should coincide with periods of low flows and temperatures of 14 ^{o}C and above, from May until July. If eggs are found, netting should be carried out for juveniles in the estuary (e.g. at Bideford), from August to October.

Local, Regional, National	Priority	Cost	Feasibility
Local	Medium	Medium	Medium

- **Problem**: In 1999, two 3 cm long fish believed to be twaite shad were caught from Groyne Point in the Helford Estuary, Cornwall. The following year, four allis shad (one aged 3+) were caught at the same location. Anecdotal information suggests that adult shad are caught from the Fal Estuary. However, the spawning status of allis and twaite shad in the Fal/Helford remains unclear.
- **Recommendation**: The Environment Agency should continue to liase with the Helford Voluntary Marine Conservation Association (HVMCA), who historically have undertaken juvenile bass netting programmes in the Fal and Helford estuaries. The site at Groyne Point should be netted under similar conditions and at a similar time of year to previous surveys. This may provide evidence of 0+ group shad. It is unlikely that shad spawn in the small rivers draining into the Helford Estuary although there may be spawning sites in one of the rivers leading into the Fal Estuary. Owing to the number of these rivers, surveys for eggs should be postponed until further evidence is available to refine the search area.

Local, Regional, National	Priority	Cost	Feasibility
Local	Medium	Medium	Medium

- **Problem:** Anecdotal information suggests that adult shad are caught in the Camel Estuary by salmon netsmen, although this is yet to be confirmed. An immature allis shad was recorded from the Camel Estuary in 2001 but there is no firm evidence of either shad species spawning in the River Camel.
- **Recommendation:** The Environment Agency should continue to liase with salmon netsmen and anglers in the Camel Estuary and record the number of shad caught. A request should be made to the netsmen to retain any shad caught (until sufficient information is collected at which time netsmen should be encouraged to return shad alive whenever possible) and contact the Agency; Agency staff should record the species, sex, age, spawning history and reproductive state of shad. Egg surveys and juvenile netting programmes should be postponed until evidence is collected to suggest that shad spawn in the Camel catchment.

Local, Regional, National	Priority	Cost	Feasibility
Local	Medium	Medium	Medium

- **Problem:** Anecdotal information suggests that adult shad are caught in the Dart Estuary by salmon netsmen, although this is yet to be confirmed. Two allis shad aged 3+ were recorded from the Dart Estuary in 2001; these fish were not in spawning condition although several netsmen reported catches of ‘large shad’ most years. It is unclear whether shad spawn in the River Dart.

- **Recommendation:** The Environment Agency should continue to liase with salmon netsmen and anglers in the Dart Estuary and record the number of shad caught. A request should be made to the netsmen to retain any shad caught (until sufficient information is collected at which time netsmen should be encouraged to return shad alive whenever possible) and contact the Agency; Agency staff should record the species, sex, age, spawning history and reproductive state of shad. Egg surveys and juvenile netting programmes should be postponed until evidence is collected to suggest that shad spawn in the Dart catchment.

Local, Regional, National	Priority	Cost	Feasibility
Local	Medium	Medium	Medium

- **Problem:** Salmon netsmen in the Exe Estuary reported catching large shad most years, including large fish indicative of adults. The scales of one fish were sent to the Project Officer in 2000; this fish was likely to be a twaite shad on account of three spawning marks on the scales. However, the size of fish reported anecdotally suggests that allis shad may also be caught. The spawning status of shad in the Exe is unclear.
- **Recommendation:** The Environment Agency should continue to liase with salmon netsmen and anglers in the Exe Estuary and record the number of shad caught. A request should be made to the netsmen to retain any shad caught (until sufficient information is collected at which time netsmen should be encouraged to return shad alive whenever possible) and contact the Agency; Agency staff should record the species, sex, age, spawning history and reproductive state of shad. Egg surveys and juvenile netting programmes should be postponed until evidence is collected to suggest that shad spawn in the Exe catchment.

Local, Regional, National	Priority	Cost	Feasibility
Local	Medium	Medium	Medium

- **Problem:** Shad have been reported anecdotally from a number of estuaries, in which the spawning status of shad is unclear. These include the Frome/Piddle, Hayle, Kingsbridge, Lynher, Looe and Yealm.
- **Recommendation:** Information about shad in these catchments should continue to be collected opportunistically. The Environment Agency should continue to liase with salmon netsmen, anglers and other groups in these catchments and record incidents of shad catches. Where possible the species, sex, age, spawning history and reproductive state of shad should be recorded by Agency staff.

Local, Regional, National	Priority	Cost	Feasibility
Local	Low	Medium	Medium

6.6 Actions in other Agency Regions

- **Problem**: Shad were reported from other parts of the country, particularly from south and south-east England, from the Solent to the Thames Estuary. These catches were too far from South West Region to permit collection and examination of specimens.
- **Recommendation**: Shad should be recorded in the Southern, Thames and Anglian Environment Agency Regions. Good contacts were established with DEFRA staff at Portsmouth, where shad were occasionally landed having been caught in the Solent area; these contacts should be maintained to facilitate recording shad in the future.

Local, Regional, National	Priority	Cost	Feasibility
Regional	High	Low	High

REFERENCES

Albiges, C. *et al* (1985) Interet et bases d' un schema d' organisation pour la gestion des stocks de poissons et d' agnathes amphihalins. *Coll. Restauration des Rivieres a Saumon*, Bergerac, France, 20p.

Alexandrino, P. (1996) Genetic and morphological differentiation among some Portuguese populations of allis shad, *Alosa alosa* (L., 1758) and twaite shad, *Alosa fallax*. *Publicaciones Especiales- Instituto Espanol De Oceanografia*, **No. 21**, 15-24.

Almaca, C. (1986) Fish and their environment in large European river ecosystems. Tejo and Guadiana. *Sciences de l'Eau*, **7**, No.1, 3-19.

Aprahamian, M.W. (1981) Aspects of the biology of the twaite shad, *Alosa fallax fallax* (Lacepede), in the Rivers Severn and Wye. Second British Freshwater Fish Conference, University of Liverpool.

Aprahamian, M.W. (1982) Aspects of the biology of the twaite shad, *Alosa fallax fallax* (Lacepede), in the Rivers Severn and Wye. PhD thesis, University of Liverpool.

Aprahamian, M.W. (1985) The effect of the migration of *Alosa fallax* (Lacepede) into fresh water, on the branchial and gut parasites. *J. Fish Biol*., **27**, 521-532.

Aprahamian, M.W. (1988) The biology of the twaite shad, *Alosa fallax fallax* (Lacepede), in the Severn Estuary. *Journal of Fish Biology* **33** (Suppl. A): 141-152.

Aprahamian, M.W. (1989) The diet of juvenile and adult twaite shad *Alosa fallax* (Lacepede) from the rivers Severn and Wye (Britain). *Hydrobiologia*, **179**, 173-182.

Aprahamian, M.W. and Aprahamian, C.D. (1990) Status of the genus *Alosa* in the British Isles; past and present. *Journal of Fish Biology* **37 (Suppl. A)**: 257-258.

Aprahamian, M.W. and Aprahamian, C.D. (in prep.) *Alosa alosa* and *Alosa fallax*. *Environment Agency Research and Development Report.*

Aprahamian, M.W., Lester, S.M. and Aprahamian, C.D. (1998) Shad Conservation in England and Wales. *Environment Agency Research and Development Technical Report W110.*

Assis, C.A., *et al* (1992) Diet of the twaite shad *Alosa fallax* (Lacepede) (Clupeidae) in the River Tagus Estuary, Portugal. *J. Fish Biol.,* **41**, 1049-1050.

Bagliniere, J.L., Sabatie, M.R., Aprahamian, M.W., Alexandrino, P., Aprahamian, C.D., Assis, C.A., Cassou-Leins, J.J., Le Corre, M. Mennesson-Boisneau, C., Martin-Vandembulcke, D., Rochard, E. and Teixeira, C. (2001) A guide to scale interpretation and age estimation for the East-Atlantic and West-Mediterranean shads (*Alosa* spp.). *Bull. Fr. Peche Piscic*. **357/360**, 485-531.

Belaud, A. *et al* (1985) Observations sur le comportement migratoire des aloses (*Alosa alosa* L.) dans le canal artificiel de l'usine de Golfech*. Annales de Limnologie*, **21**, No.2, 161-172.

Bellariva, J-L. and Belaud, A. (1998) Environmental factors influencing the passage of allis shad *Alosa alosa* at the Golfech Fish Lift on the Garonne River, France. In *Fish Migration and Fish Bypasses*, (ed. Jungwirth, M., Schmutz, S. and Weiss, S.), pp.171-179. Fishing News Books, London.

Blanc, M., Banarescu, P., Gaudet, J. L. and Hureau, J. C. (1976). *European Inland water Fisheries*. London: Fishing News (Books) Ltd.

Boisneau, P., Mennesson-Boisneau, C. and Bagliniere, J.L. (1985) Observations sur l'activite de migration de la grande alosa *Alosa alosa* L. en Loire (France) [Observations on the migratory activity of shad *Alosa alosa* L. in the Loire (France)]. *Hydrobiologia*, **128**, No.3, 227-284.

Boisneau, P., Mennesson-Boisneau, C. and Guyomard, R. (1992) Electrophoretic identity between allis shad, *Alosa alosa* (L.), and twaite shad, *A. fallax* (Lacepede). *J. Fish Biol*., **40**, 731-738.

Bracken, J. and Kennedy, M. (1967) Notes on some Irish estuaries and inshore fishes, with distributions of shads by E. Twomey. *Irish Fisheries Investigations*, **Series B,** No. 3, 4-8.

Buller, F. and Falkas, H. (1992) *Freshwater fishing*, pp.232-234. Cresset Press.

C.T.G.R.E.F. (1979). Etude halieutique de l'estuaire de la Gironde., Groupement de Bordeaux. 189p.

Cassou-Leins, F. and Cassou-Leins, J.J. (1981) Recherches sur la biologie et l'halieutique des migrateurs de la Garonne et principalement de l'alose, *Alosa alosa* L. [Research on the biology and halieutics of migratory species in the Garonne, mainly of *Alosa alosa* L.], Institute National Polytechnique de Toulouse.

Cassou-Leins, F. and Cassou-Leins, J.J. (1990) Reserve naturelle de la Frayere d'aloses. *Synthese Quinquennale. Rapport ENSA.* Toulouse: 57p.

Caswell, P. (unpublished) Use of River Habitat Survey to determine the spawning habitat characteristics of shad. *Unpublished Environment Agency Report*.

Caswell, P. and Aprahamian, M.W. (2000) Physical characteristics of the spawning habitat of twaite shad (*Alosa fallax fallax*). *Environment Agency Presentation, International Symposium of Freshwater Fish Conservation*, 30 October-4 November 2000, Agarve, Portugal.

Claridge, P.N. and Gardner, D.C. (1978) Growth and movements of the twaite shad, *Alosa fallax* (Lacepede), in the Severn Estuary. *J. Fish Biol*., **12**, 203-211.

Dautrey, R. and Lartique, J.P. (1983) Recherches sur la migration des aloses (*Alosa alosa*) et des truites de mer (*Salmo trutta*) en Garonne (Site de Golfech), Institut National Polytechnique de Toulouse, France.

Day, F. (1890) Notes on the Fish and Fisheries of the Severn. *Proceedings of the Cotswold Naturalists Field Club* **9**: 202-219.

De Groot, S.J. (1990) The former allis and twaite shad fisheries of the lower Rhine, the Netherlands. *J. Appl. Ichthyology,* **6**, 252-256.

Dottrens, E. (1952) *Les poissons d'eau douce*. Paris and Neuchatel, Delachaux et Niestle.

Douchement, C. (1981) Les Aloses des fleuves francais *Alosa fallax* Lacepede 1803 et *Alosa alosa* Linne, 1758. Biometrie, ecobiologie, Autonomie des populations. Universite des Sciences et Techniques du Languedoc Montpellier.

Duhamel du Monceau, M. (1772) *Traite general des peches et histoires des poissons qu'elles fournissent*. Paris.

Ehrenbaum, E. (1936) *Handbuch der Seefischerei Nordeuropas*. E. Schweizbart, Stuttgart.

Eiras, J.C. (1981) Sur une population d'*Alosa alosa* L., poisson migrateur amphibiotique, thalassotrophe, bloquee en eau douce au Portugal. *Cybium, 3e serie*, **5**, No. 1, 69-73.

Elie, P. *et al* (1988) Etude du suivi halieutique de l' estuaire de la Gironde, 1987. *Rapp. EDF / CEMAGREF Div. ALA Bordeaux*, 212p.

Ellison, F.B. (1935) Shad. *Transactions of the Woolhope Naturalists' Field Club*, pp.135-139.

Fantin, D. and Dartiguelongue, J. (1996) Ettude preliminaire de la reproduction des aloses en 1995 entre Tuilieres et Mauzac sur la Dordogne., E.D.F. Energie Aquitaine.

Fatio, V. (1890) Histoire naturelle des Poissons, Part 2. In *Faune des vertebres de la Suisse*, **5**, p.29. Georg. Geneve-Bale.

Furnestin, J. (1952) L'Alose d'El Kansera, cas d'une adaptation totale d'une espece anadrome aux eaux douces. *Comptes Rendues de l'Academie des Sciences de Paris* 240: 355-357.

Gregory, J. (2000) An appraisal of hydroacoustic techniques for monitoring the spawning migration of shad in the River Wye. *Environment Agency Technical Report W226.*

Hillman, R. (2003) The Distribution, Biology and Ecology of Shad in South-West England Project Record W1-047/PR.

Hoek, P.P.C. (1899) Neure Lachs und Maifischstudien. *Tijdschrift der Nederladsche dier kundige Vereeniging,* **2**, 6, 156-242.

Hoestlandt, H. (1958) Fecondation artificielle et incubation de l'alose du Rhone: *Paralosa rhodanensis* Roule. *Ann. Stat. Centr. Hydrobiol. Appl*., **2**, 223-228.

Kabata, Z. (1979) Parasitic copepoda of British Fishes. *The Royal Society, London*. **152**.

Kennedy, C.R. (1978). The biology, specificity and habitat of the species of *Eubothrium* (Cestoda: Pseudophyllidea), with reference to their use as biological tags: a review. *J. Fish Biol*., **12**, 393-410.

Kennedy, C.R. (1981) The occurrence of *Eubothrium fragile* (Cestoda: Pseudophyllidae) in twaite shad, *Alosa fallax* (Lacepede) in the River Severn. *J. Fish Biol*., **19**, 171-177.

Krebs, C.J. (1999) *Ecological Methodology*. Jim Green (*publ*.). Canada.

Lagler, K.F. *et al* (1977) *Ichthyology,* pp.123. John Wiley and Sons. New York.

Lahaye, J. (1962) L'ovogenese chez *Alosa finta*. *Rev. Trav. Inst. Peches marit*., **26**, No.4, 457-466.

Le Clerc, M. (1941) Note sur les essais de multiplication artificielle de l'alose dans le bassin de la Loire. *Bulletin Francais de Pisciculture,* **123**, 27-37.

Maitland, P.S. and Lyle, A.A. (1991) Conservation of freshwater fish in the British Isles: The current status and biology of threatened species. *Aquatic Conservation: Marine and Freshwater Ecosystems,* **1**, No.1, 25-54.

Maitland, P.S. and Lyle, A.A. (1995) Shad and smelt in the Cree Estuary, S. W. Scotland. *Report to Scottish Natural Heritage*.

Manyukas, Y.L. (1989) Biology of the Atlantic shad, *Alosa alosa fallax*, in Kurshskiy Bay. *J. Ichthyol* 29 (**8**): 125-128.

Markevich, A.P. (1952) Parasitic copepods of fish in the Black Sea. *Pratsi. Inst. Zool. Akad. Nauk Ukrain RSR* **8**, 205-225.

Markowski, S. (1937) Uber die entwicklungsgeschichte und biologie des nematoden *Contracaecum aduncum* (Rudolphi, 1802). *Bull. Ac. Polon., Ser. B*., **2**, 227.

Matallanas, J., Ibanez, M., San Millan, M. D. & Riba, G. (1981). Catalogo de los Pesces marinos. *Trabajos de Deptartamento de Zoologia, Barcelona.* **1,** 1-138.

Mennesson-Boisneau, C., Boisneau, P. and Bagliniere, J.L. (1986) First observations on the biological characteristics of adult allis shad (*Alosa alosa*) in the middle Loire catchment. *Acta Oecologica Oecol. Applic*., **7**, 337-353.

Mennesson-Boisneau, C. and Boisneau, P. (1990) Recherches sur les Aloses (*Alosa* sp.) dans le basin de la Loire: migration, repartition, reproduction, caracteristiques biologiques et taxonomie des aloses (*Alosa* sp.), **143**. Universite de Rennes, France.

Mennesson-Boisneau, C. *et al* (1993) Migration de reproduction des aloses dans le bassin de la loire de 1986 a 1991, Incidences des obstacles [Shads spawning migration in the Loire Basin. Incidences of obstacles.], Department d'Hydrobiologie INRA.

Mileriene, E. (1997) Investigations on the fish fauna in the Lithuanian parts of Kurshiu (Curonian) lagoon, Food and Agriculture Organization of the United Nations: 74-78.

Minchin, D. (1977) Fish and benthos from the southern Irish Sea. *Irish Nat. J.*, **19**, 128-129.

Mohr, E. (1941) Maifische (Clupeiden). *Handbuch der Binnenfischerei Mitteleuropas*. R. Demoll and H. N. Maier. Stuttgart, Schweizerbart'sche Verlaggsbuchhandlung, **3-A**, No.7, 527-551.

Murie, J. (1903) Thames Estuary Sea Fisheries. I Kent and Essex, Kent and Essex Sea Fisheries Committee, London.

O'Maoileidigh, N. (1990) A study of fish populations in the Killarney Lakes, National University of Ireland, University College Dublin.

O'Maoileidigh, N., Cawdery, S., Bracken, J.J. and Ferguson, A. (1988) Morphometric, meristic character and electrophoretic analyses of two Irish populations of twaite shad, *Alosa fallax* (Lacepede). *J. Fish Biol*., **32**, 355-366.

Pethon, P. (1979). Sjeldne saltvannsdfisker fra sydostnorske farvann i årene 1970-78. *Fauna (Blindern)* **32,** 145-151.

Petter, A.J. and Cabaret, J. (1995) Ascaridoid nematodes of teleostean fishes from the eastern North Atlantic and seas of the north of Europe. *Parasite*, **2**, No.2, 217-230.

Philippart, J.-C. & Vranken, M. (1981). Pour la conservation de notre faune ichtyologique. *Bulletin des Réserves Naturelles et Ornithologiques de Belgique* **28,** 41-50.

Philippart, J. C. & Vranken, M. (1982). *Les poissons d'eaux douce menaces au region wallone.* Leige: Universite Liege, Ministere des Affaires Wallones.

Poll, M. (1947). Poissons marins. Faune de Belgique. Bruxelles, Musee Royal D' Histoire Naturelle de Belgique, Bruxelles.

Potts, G.W. and Swaby, S.E. (1993) Review of the status of estuarine fishes. *English Nature Research Reports,* No. 34. Peterborough, English Nature.

Potts, G.W. and Swaby, S.E. (1996a) Fish: other species. Region 9. Southern England: Hayling Island to Lyme Regis. In *Coasts and seas of the United Kingdom*. (eds. Barne,

J. H., Robson, C. F., Kaznowska, S. S., Doody, J.P., Davidson, N. C. and Buck, A. L.), Peterborough: Joint Nature Conservation Committee.

Potts, G.W. and Swaby, S.E. (1996b) Fish: other species. Region 10. Southwest England: Seaton to the Roseland Peninsula. In *Coasts and seas of the United Kingdom*. (eds. Barne, J. H., Robson, C. F., Kaznowska, S. S., Doody, J.P., Davidson, N. C. and Buck, A. L.), Peterborough: Joint Nature Conservation Committee.

Potts, G.W. and Swaby, S.E. (1996c) Fish: other species. Region 11. The Western Approaches: Falmouth Bay to Kenfig. In *Coasts and seas of the United Kingdom* (eds. Barne, J. H., Robson, C. F., Kaznowska, S. S., Doody, J.P., Davidson, N. C. and Buck, A. L.), Peterborough: Joint Nature Conservation Committee.

Prouzet, P. *et al* (1994) Caracterisation biologique et variation des captures de la grande alose (*Alosa alosa*) par unite d'effort sur le fleuve Adour (Pyrrennes-atlantiques, France) [Biological characteristics and catch variation of allis shad (*Alosa alosa*) from commercial catches in the Adour River (Pyrenees atlantiques, France)]. *Aquatic Living Resources* **7** (1): 1-10.

Punt, A. (1941) Recherches sur quelques Nematodes Parasites de Poissons de la Mer du Nord. *Memoires de musee Royal D'Histoire Naturelle de Belgique* **98**, 110.

Quero, J-C. *et al* (1989) Les poissons de Golfe de Gascogne, Institute Francais de Recherche pour l' Exploitation de la Mer.

Quignard, J.P. and Douchement, C.I. (1991) *Alosa alosa* (Linnaeus 1758) and *Alosa fallax fallax* (Lacepede 1803). In *The freshwater fishes of Europe Vol. 2* (ed. H. Hoestlandt), (i) 89-126; (ii) 225-253. Aula-Verlag, Wiesbaden.

Rae, B.B. and Wilson, E. (1952) Rare and exotic fishes recorded in Scotland during 1951. *The Scottish Naturalist,* **64,** No.2, 102-111.

Rae, B.B. and Wilson, E. (1956a) Rare and exotic fishes recorded in Scotland during 1954. *The Scottish Naturalist*, **68**, 23-38.

Rae, B.B. and Wilson, E. (1956b) Rare and exotic fishes recorded in Scotland during 1955. *The Scottish Naturalist,* **68**, 92-108.

Rae, B.B. and Wilson, E. (1961) Rare and exotic fishes recorded in Scotland during 1956. *The Scottish Naturalist*, **70,** No.1, 22-33.

Rae, B.B. and Lamont, J.M. (1961) Rare and exotic fishes recorded in Scotland during 1957. *The Scottish Naturalist,* **70,** No.1, 34-42.

Rae, B.B. and Lamont, J.M. (1962) Rare and exotic fishes recorded in Scotland during 1959. *The Scottish Naturalist*, **70,** No.2, 111-119.

Reay, P.J. (1998) Shad (*Alosa* spp.) in the Tamar; Scoping report and costed methodology for a proposed survey. *Report to Environment Agency, South West Region*.

Redeke, H.C. (1939) Uber den Bastard Clupea *Alosa finta* Hoek. *Arch. Neerl. Zool*., **3** (Suppl.), 148-158.

Richkus, W.A. (1974) Factors influencing the seasonal and daily patterns of alewife (*Alosa pseudoharengus*) migration in a Rhode Island river. *J. Fish. Res. Bd. Can*., **31**, 1485-1497.

Rochard, E. (1992) Mise au point d'une methode de suivi de l'abondance des amphibians dans le systeme fluvio-estuarien de la Gironde, application a l'etude ecobiologique de l'esturgeon (*Acipenser sturio*) [Set up of a method to survey the abundance of fish in the river-estuary system of the Gironde, application to the ecological study of the sturgeon, *Acipenser sturio*.], Rennes.

Roule, L. (1923) Notes sur les Aloses de la Loire et de L'Aquitaine. *Bull. Soc. Cent. Agric. Peche,* **30,** Nos.1-3, 14-22.

Roule, L. (1925) *Les poissons des eaux de la France*. Paris, Presses Universitaires de France.

Sabatie, M.R. (1993) Recherches sur l'ecologie et la biologie des aloses du Maroc (*Alosa alosa* Linne, 1758 et *Alosa fallax* Lacepede, 1803). Exploitation et taxinomie des populations atlantiques; bioecologie des aloses de l'oued Sebou [Ecological and biological researches on shad in Marocco (*Alosa alosa* Linne, 1758 et *Alosa fallax* Lacepede, 1803), fishing and taxonomy of Atlantic populations, bioecology of shad in Sebou River], Univ. Brest: 326.

Saemundsson, B. (1949) *Zoology of Iceland. IV. Marine Pisces*.

Salmon Fisheries Commission (1861) Report of the Commissioners appointed to inquire into Salmon Fisheries (England and Wales); together with the minutes of evidence, HMSO London.

Sertier, M. *et al* (1990) Etude de suivi halieutique de l' estuaire de la Gironde 1989, *Rapp. CEMAGREF div. ALA Bordeaux / EDF*, 230p.

Sostoa, A.d. and Sostoa F.J.d. (1979). Notas sobre la ictiofauna continental del Delta del Ebro (NE de la Peninsula Iberica). *Misc. Zool*. (**5**): 178-179.

Steinbach, P. *et al* (1986) Radio-pistage de grandes aloses adultes in Loire [Radio-tracking of Atlantic shads in the River Loire]. *Bull. Fr. Peche Piscic*., **302**, 106-117.

Svetovidov, A.N. (1952) *Fauna of USSR. Fishes: Clupeidae (Seldevye (Cupeidae))*, Traduit par Israel, Program. Sci. Translation, Jerusalem 1963.

Taverny, C. (1991) Peche, biologie, ecologie des Aloses dans le Systeme Gironde-Garonne-Dordogne [Fishing, biology, ecology of shads in the system of Gironde, Garonne-Dordogne], University of Bordeaux.

Veron, V. (1999) Les populations de grande Alose (*Alosa alosa, L*) et d' Alose feinte (*Alosa fallax*, Lacepede) des petits fleuves francais du littoral Manche Atlantique;

Caracterisation morphologique, biologique et genetique. *Diplome d'agronomie approfondie*.

Wheeler, A. (1969) *The fishes of the British Isles and North West Europe*. London, Macmillan.

Wheeler, A., Blacker, R.W. and Pirie, S.F. (1975) Rare and little-known fishes in British seas in 1970 and 1971. *J. Fish Biol*., **7**, 183-201.

APPENDICES

A1.1 Shad Records

A1.1.1 Allis shad

Table 35: Size and age of *A. alosa* recorded from coastal waters

Id. No.	Date	Sex	Total length (cm)	Fork length (cm)	Weight (g)	Actual age (years)
318	13/6/00	-	25.0	22.0	140	-
317	13/6/00	-	26.4	23.0	145	-
320	13/6/00	-	27.0	23.6	160	-
322	13/6/00	-	27.6	24.0	155	-
316	13/6/00	-	27.8	24.1	168	-
319	13/6/00	-	28.0	24.1	172	-
323	13/6/00	-	29.0	25.3	188	-
321	13/6/00	-	29.0	24.9	187	-
175	21/2/00	-	29.6	25.6	190	-
425	20/11/00	-	29.7	25.2	185	-
315	13/6/00	-	29.8	25.6	210	-
185	21/2/00	-	29.8	26.7	230	-
433	20/11/00	-	29.9	25.5	170	-
173	21/2/00	-	30.0	26.2	200	-
178	21/2/00	-	30.1	26.6	210	-
430	20/11/00	-	30.1	26.1	200	-
437	20/11/00	-	30.1	25.9	170	-
429	20/11/00	-	30.2	25.9	200	-
438	20/11/00	-	30.7	26.8	210	-
64	19/1/00	-	31.0	28.0	200	-
436	20/11/00	-	31.1	26.8	210	-
424	20/11/00	-	31.4	27.0	215	-
184	21/2/00	-	31.5	28.2	250	-
402	20/11/00	-	31.5	27.3	240	-
182	21/2/00	-	31.6	28.2	270	-
426	20/11/00	-	31.8	27.5	220	-
252	5/3/00	-	32.0	-	-	-
200	1/12/98	-	32.3	29.1	-	-
435	20/11/00	-	32.3	28.2	230	-
179	21/2/00	-	32.4	28.3	250	-
432	20/11/00	-	32.5	27.9	240	-
186	21/2/00	-	32.6	28.9	260	-
434	20/11/00	-	32.7	28.0	255	-

Table 35: Continued

Id. No.	Date	Sex	Total length (cm)	Fork length (cm)	Weight (g)	Actual age (years)
169	21/2/00	-	32.8	29.0	210	-
399	20/11/00	-	32.9	28.3	240	3+
170	21/2/00	-	32.9	29.9	210	-
255	5/3/00	-	33.0	-	-	-
181	21/2/00	-	33.1	29.2	260	-
183	21/2/00	-	33.4	26.9	210	-
202	1/12/98	-	33.8	30.9	-	-
176	21/2/00	-	34.0	29.5	310	-
279	22/5/00	-	34.0	-	-	-
168	21/2/00	-	34.1	30.1	270	-
180	21/2/00	-	34.1	30.0	290	-
427	20/11/00	-	34.2	29.4	300	-
431	20/11/00	-	34.5	29.5	285	-
196	1/12/98	-	34.6	30.3	-	-
201	1/12/98	-	34.7	30.1	-	-
204	1/12/98	-	34.7	30.5	-	-
198	1/12/98	-	35.2	31.0	-	-
192	1/12/98	-	35.3	31.0	-	-
193	1/12/98	-	35.3	31.7	-	-
428	20/11/00	-	35.4	30.9	320	-
197	1/12/98	-	35.6	31.0	-	-
190	1/12/98	-	36.0	31.8	-	-
188	1/12/98	-	36.2	31.5	-	-
174	21/2/00	-	36.4	32.4	350	-
171	21/2/00	-	36.5	32.2	280	-
172	21/2/00	-	36.7	31.9	370	-
400	20/11/00	-	36.9	31.6	350	3+
401	20/11/00	-	37.0	31.6	345	-
177	21/2/00	-	37.3	33.2	330	-
203	1/12/98	-	37.5	33.7	-	-
51	1/12/98	-	38.0	-	480	-
458	20/6/01	-	38.1	33.1	455	3+
194	1/12/98	-	38.2	33.5	-	-
381	23/10/00	-	39.0	-	615	-
205	1/12/98	-	39.8	35.5	-	-
9	5/4/00	-	40.0	35.0	500	-
250	5/3/00	-	40.0	-	-	-
67	16/11/98	-	41.0	35.9	550	-
187	1/12/98	-	41.2	36.1	-	-
195	1/12/98	-	41.4	36.6	-	-
199	1/12/98	-	41.5	36.6	-	-
191	1/12/98	-	42.0	37.6	-	-

Table 35: Continued

Id. No.	Date	Sex	Total length (cm)	Fork length (cm)	Weight (g)	Actual age (years)
503	11/6/01	-	42.7	37.6	670	-
253	5/3/00	-	43.0	-	-	-
254	5/3/00	-	44.0	-	-	-
423	9/1/01	M	44.1	38.8	705	3+
80	10/1/99	-	45.0	-	-	-
380	29/10/00	-	45.0	-	710	-
257	5/3/00	-	45.0	-	-	-
251	5/3/00	-	45.0	-	-	-
249	5/3/00	-	45.0	-	-	-
139	6/3/00	-	45.2	39.8	700	-
498	11/6/01	-	45.3	39.0	755	-
210	7/3/00	F	45.6	39.7	650	-
500	11/6/01	-	45.6	40.0	920	-
56	1/12/98	-	46.0	-	809	-
422	9/1/01	-	46.7	40.8	785	3+
55	1/12/98	-	47.0	-	-	-
248	5/3/00	-	47.0	-	-	-
8	5/4/00	-	47.0	43.0	800	-
211	7/3/00	-	47.5	41.7	810	-
398	20/11/00	-	47.8	41.7	715	-
501	11/6/01	-	48.3	42.8	1080	-
490	1/10/00	F	48.5	42.6	1140	-
288	2/6/00	-	50.0	-	1600	-
497	11/6/01	-	50.3	43.4	1030	-
502	11/6/01	-	50.5	44.2	1200	-
478	2/6/01	F	51.0	44.6	1300	-
499	11/6/01	-	54.0	47.1	1270	-
496	11/6/01	-	54.3	47.4	1450	-
81	10/1/99	-	54.5	-	1750	-
208	26/1/99	-	54.7	-	1700	-
504	11/6/01	-	59.5	51.9	1900	-
209	26/1/99	-	60.7	-	2500	-

Table 36: Estuarine records of *A. alosa*

Id. No.	Date	Sex	Total length (cm)	Weight (g)	Age	Catchment
325	20/07/2000	-	25.0	200	-	Tamar
15	15/06/1998	-	25.4	-	-	Tamar
362	11/08/2000	-	26.6	120	3+	Fowey
278	11/09/2000	-	28.6	147	3+	Helford
466	15/05/1994	-	-	c.227	-	Fowey
46	28/07/1998	-	30.0	-	-	Fowey
454	04/06/2001	-	32.4	250	3+	Taw/Torridge
45	03/07/1998	-	35.6	-	-	Fowey
472	19/07/2001	F	37.5	450	3+	Dart
455	01/06/2001	-	38.4	420	3+	Camel
474	18/07/2001	-	c.39.4	-	-	Torridge
468	06/05/1993	-	-	c.568	-	Fowey
473	09/08/2001	M	39.6	540	3+	Dart
68	23/03/1998	-	40.6	-	-	Yealm
475	19/07/2001	-	44.5	-	-	Torridge
313	28/06/2000	-	45.0	-	-	Exe
330	18/07/2000	-	45.7	-	-	Torridge
508a	14/11/2001	-	-	c.681	-	Kingsbridge
508b	14/11/2001	-	-	c.795	-	Kingsbridge
50	28/06/1998	-	-	800	-	Tamar
476	01/06/2001	M	46.3	870	4+	Tamar
336	31/07/2000	M	46.8	805	5	Torridge
477	05/06/2001	M	49.1	1090	5+	Tamar
363	17/08/2000	M	49.6	910	5	Fowey
467	15/05/1994	-	-	c.1022	-	Fowey
14	08/07/1998	-	-	c.1134	-	Tamar
4	08/07/1998	-	-	c.1134	-	Tamar
469	16/05/2001	-	-	c.1135	-	Tamar
3	08/07/1998	-	-	c.1247	-	Tamar
57	01/10/1998	-	50.0	-	-	Tamar
59	01/10/1998	-	50.0	-	-	Tamar
304	06/06/2000	F	52.3	1605	6	Torridge
331	18/07/2000	-	53.3	-	-	Torridge
286	01/06/2000	F	53.7	1460	5	Tamar
333	19/07/2000	-	55.9	-	-	Torridge
464	15/07/1994	-	-	c.1362	-	Fowey
453	02/07/2001	F	58.0	1350	6	Tamar
303	14/06/2000	F	59.0	1260	5	Tamar
277	29/08/2000	-	59.7	-	-	Torridge
5	04/07/1998	F	60.0	1500	-	Tamar
328	27/07/2000	F	60.1	1365	7	Tamar
308	12/06/2000	-	-	c.1700	-	Tamar
324	08/07/2000	-	-	c.1816	-	Tamar
329	03/07/2000	-	63.5	-	-	Torridge

Table 37: Freshwater records of *A. alosa*

Id. No.	Date	Sex	Total length (cm)	Weight (g)	Age	Catchment
47	30/06/1997	-	-	c.1134	-	Tamar
359	03/08/2000	-	-	c. 908	-	Tamar
86	13/05/1999	M	44.0	1030	-	Tamar
285	12/05/2000	M	47.1	860	4	Tamar

Table 38: Freshwater records of suspected but unconfirmed *A. alosa*

Id. No.	Date	Total length (cm)	Weight (g)	Catchment
305	14/06/2000	-	c.1250	Tamar
306	15/06/2000	-	c.1250	Tamar
307	13/06/2000	-	c.1020	Tamar
482	24/05/2001	42.5	-	Tamar
361	19/07/2000	45.8	-	Tamar
365	03/08/2000	47.2	-	Tamar
366	12/06/2000	49.3	-	Tamar
491	21/06/2001	2 @ c. 50.0	-	Tamar
479	11/05/2001	53.1	-	Tamar
484	25/05/2001	53.7	-	Tamar
226	-	54.0	-	Fowey
258	9/08/1999	55.4	-	Tamar
350	21/06/2000	56.0	-	Tamar
371	16/06/2000	57.3	-	Tamar
483	25/05/2001	57.7	-	Tamar
349	13/06/2000	59.0	-	Tamar
491	21/06/2001	c. 60.0	-	Tamar
480	24/05/2001	60.5	-	Tamar
481	24/05/2001	66.2	-	Tamar

A1.1.2 Twaite shad

Table 39: Size and age of *A. fallax* recorded from coastal waters

Id. No.	Date	**Sex**	Total length (cm)	Weight (g)	**Age**
78	6/9/99	-	30.0	-	-
243	5/3/00	-	31.0	-	-
109	9/2/00	F	31.4	335	-
119	9/2/00	F	32.8	350	-
354	19/6/00	-	33.0	375	-
355	19/6/00	-	33.0	380	-
267	13/4/00	F	34.0	330	-
242	5/3/00	-	34.0	-	-
238	5/3/00	-	34.0	-	-
114	9/2/00	F	34.1	430	-
121	9/2/00	-	34.5	470	-
440	20/11/00	-	34.5	360	-
102	9/2/00	F	34.5	370	-
72	23/11/98	-	35.0	-	-
356	19/6/00	-	35.0	435	-
357	19/6/00	-	35.0	415	-
138	28/2/00	F	35.0	380	-
439	20/11/00	-	35.5	310	-
358	19/6/00	-	36.0	435	-
247	5/3/00	-	36.0	-	-
137	28/2/00		36.5	420	-
112	9/2/00	F	36.9	490	-
237	5/3/00	-	37.0	-	-
240	5/3/00	-	37.0	-	-
241	5/3/00	-	38.0	-	-
167	21/2/00	-	38.0	510	-
404	20/11/00	-	38.5	450	-
120	9/2/00	M	38.6	560	-
391	17/01/01	F	38.9	490	-
447	31/11/00	-	39.2	520	-
409	20/11/00	-	39.3	510	4+
412	20/11/00	-	39.4	535	3+
207	1/2/99	-	39.5	-	-
448	31/11/00	-	39.7	585	3+
410	20/11/00	-	39.9	560	-
450	31/11/00	-	39.9	-	-
239	5/3/00	-	40.0	-	
118	9/2/00	F	40.0	690	-
268	13/4/00	F	40.0	570	-
393	20/11/00	-	40.1	590	3+
166	21/2/00	F	40.1	650	-
281	27/4/00	-	40.5	575	6

Table 39: Continued

Id. No.	Date	**Sex**	Total length (cm)	Weight (g)	**Age**
418	20/11/00	F	40.5	600	5+
73	19/9/98	F	40.5	-	-
452	9/1/00	M	40.8	505	5+
189	1/12/98	-	40.8	-	-
379	6/11/00	-	40.9	435	5+
411	20/11/00	-	40.9	610	3+
206	1/2/99	-	41.0	-	-
488	21/10/01	-	41.0	700	-
407	20/11/00	-	41.0	510	-
246	5/3/00	-	41.0	-	-
446	31/11/00	-	41.0	525	-
129	27/1/00	F	41.0	560	-
101	9/2/00	M	41.1	660	-
395	20/11/00	-	41.3	630	4+
394	20/11/00	-	41.3	575	3+
451	31/11/00	-	41.3	540	-
396	20/11/00	-	41.4	625	3+
392	4/2/01	F	41.4	680	-
105	9/2/00	F	41.5	660	-
441	31/11/00	-	41.5	635	4+
445	31/11/00	-	41.5	655	3+
107	9/2/00	F	41.5	680	-
159	28/2/00	-	41.5	635	-
405	20/11/00	-	41.7	605	-
94	25/1/00	F	41.8	760	-
245	5/3/00	-	42.0	-	-
377	6/11/00	-	42.0	485	-
378	6/11/00	F	42.0	625	3+
397	20/11/00	-	42.0	685	-
413	20/11/00	M	42.1	585	6+
406	20/11/00	-	42.1	595	3+
420	9/1/01	F	42.4	720	4+
495	11/10/01	F	42.6	615	-
280	27/4/00	-	43.0	717	6
60	13/11/98	-	43.0	-	-
419	20/11/00	F	43.2	515	6+
117	9/2/00	F	43.3	650	-
111	9/2/00	F	43.5	790	-
408	20/11/00	-	43.5	650	5+
494	11/10/01	F	43.6	865	5+
403	20/11/00	-	43.7	730	3+
340	3/8/00	F	43.9	620	5+
389	9/1/01	F	43.9	810	4+
128	13/1/00	F	44.0	580	-

Table 39: continued

Id. No.	Date	**Sex**	Total length (cm)	Weight (g)	**Age**
244	5/3/00	-	44.0	-	-
52	1/12/98	-	44.0	672	-
103	9/2/00	F	44.0	880	-
116	9/2/00	F	44.0	820	-
388	9/1/01	F	44.6	810	5+
417	20/11/00	M	44.6	660	6+
164	25/2/00	F	44.6	1000	-
110	9/2/00	F	44.7	850	-
106	9/2/00	F	44.8	970	-
115	9/2/00	F	44.8	1010	-
136	28/2/00	F	44.9	630	-
53	1/12/98	-	45.1	753	-
108	9/2/00	F	45.1	1000	-
415	20/11/00	F	45.2	820	5+
390	9/1/01	F	45.2	775	5+
113	9/2/00	F	45.3	890	-
104	9/2/00	F	45.3	840	-
442	31/11/00	-	45.4	880	6+
386	17/2/01	F	45.4	830	-
160	28/2/00	F	45.4	1090	-
383	13/10/00	F	45.6	785	-
444	31/11/00	-	46.0	780	5+
421	9/1/01	F	46.1	875	4+
449	31/11/00	-	46.2	765	7+
414	20/11/00	F	46.2	935	6+
54	1/12/98	-	47.0	973	-
79	19/3/99	F	47.0	-	-
443	31/11/00	-	47.1	760	-
376	6/11/00	F	47.2	820	-
287	27/4/00	F	47.3	1040	9
135	6/3/00	F	47.6	1120	-
387	9/1/01	F	47.8	940	6+
266	26/4/00	F	48.0	1450	7
61	13/11/98	-	48.0	-	-
416	20/11/00	F	48.2	760	6+
375	6/11/00	F	48.4	860	7+
505	7/7/01	F	48.6	940	7+
63	19/1/00	F	52.0	1400	-

Table 40: Estuarine records of *A. fallax*

Id. No.	Date	Sex	Total length (cm)	Weight (g)	Age	Catchment
334	19/07/2000	-	c.35.6	-	-	Torridge
337	02/08/2000	-	c.40.6	-	-	Torridge
275	23/08/2000	-	c.40.6	-	-	Torridge
332	18/07/2000	-	c.43.2	-	-	Torridge
340	03/08/2000	F	43.9	620	5+	Torridge
506	12/11/2001	-	-	c.681	-	Kingsbridge
338	02/08/2000	-	c.45.7	-	-	Torridge
335	19/07/2000	-	c.45.7	-	-	Torridge
360	25/07/2000	-	45.8	-	6+	Exe
276	23/08/2000	-	c.48.3	-	-	Torridge
339	02/08/2000	-	c.50.8	-	-	Torridge

A1.2 Photographs of *A. alosa* and *A. fallax* Caught during the Project

Figure 40: Immature *A. alosa*, caught from Looe Bay, Cornwall

Figure 41: Adult male *A. alosa* caught at Bideford, Torridge Estuary

Figure 42 Adult female *A. alosa* caught from Cotehele, Tamar Estuary

Figure 43: Adult male *A. alosa*, caught at Greystone Bridge, River Tamar. Note heavy colouration around head and ventral keel

Figure 44: Ventral view of *A. alosa* from Greystone Bridge, River Tamar

Figure 45: Adult female *A. alosa*, caught at Cotehele, Tamar Estuary

Figure 46: Ventral view of *A. alosa* from Cotehele, Tamar Estuary

Figure 47: Adult female *A. alosa* at Appledore, Torridge Estuary

Figure 48: *A. fallax*, above and *A. alosa*, below (Size is given as total body length)

Figure 49: ***A. fallax*** **landed from coastal waters offshore of Plymouth**

Figure 50: Adult female ***A. fallax*** **from coastal waters offshore of Plymouth**

Figure 51: Adult female ***A. fallax*** **caught at Bideford, Torridge Estuary**

A1.3 Gunnislake Spawning Site

Figure 52: Kick Sampling Site 1; downstream of Gunnislake Weir (u/s view)

Figure 53: Kick Sampling Site 1; downstream of Gunnislake Weir (d/s view)

A1.4 Alosid-type Larvae Hatched from Eggs Collected from Gunnislake, R. Tamar

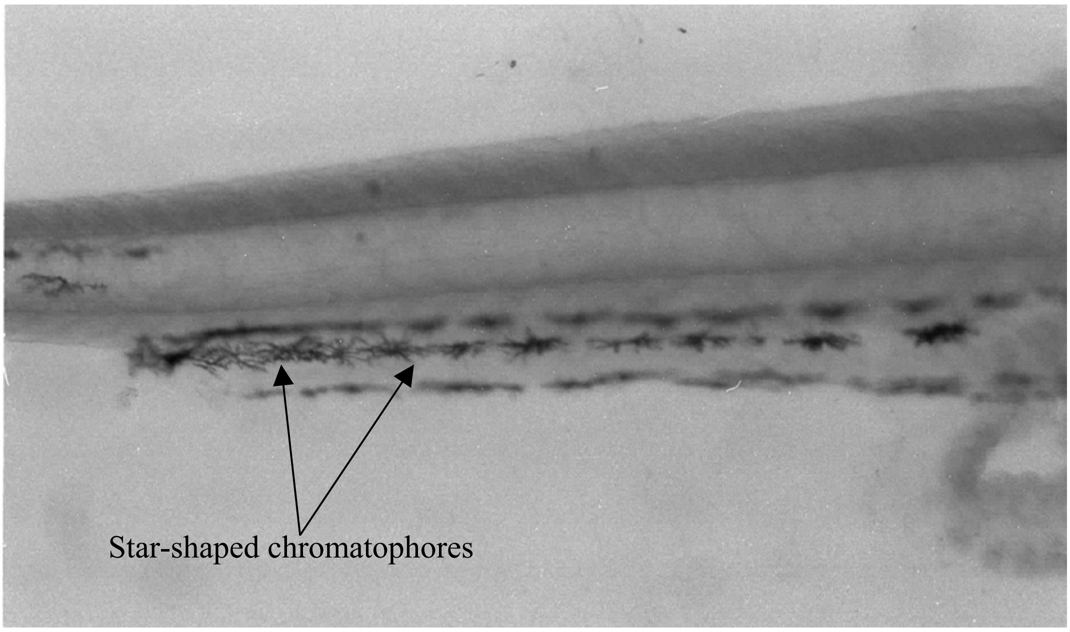


Figure 54: Side view of the mid-posterior section of a 6-day old larva, showing star-shaped chromatophores (x 60)

Figure 55: Tail of 12 day old larva, showing chromatophore (x 50)

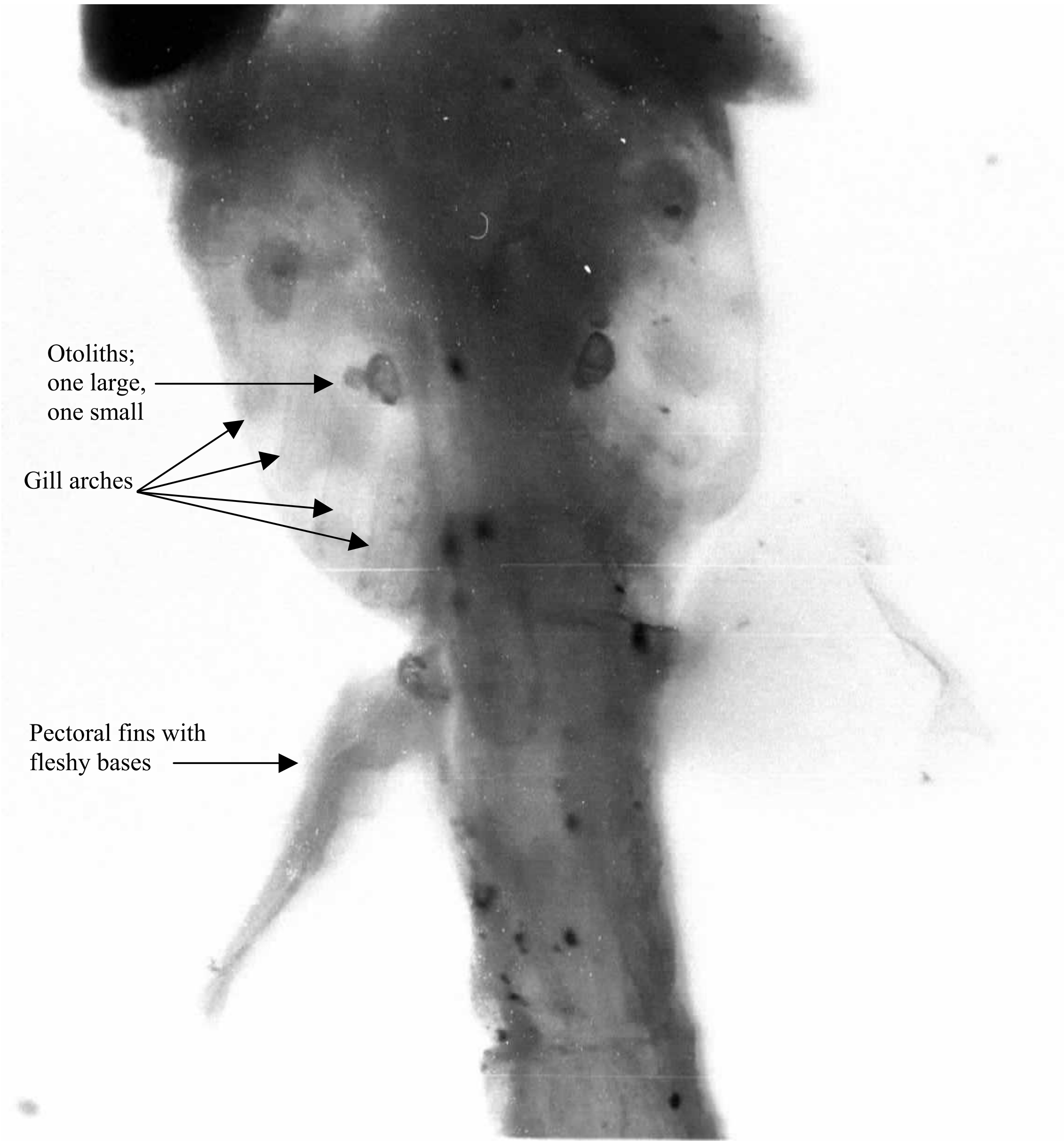


Figure 56: Head of 15 day old larva. Notable features include the presence of otoliths, one large and one small, visible gill arches and large pectoral fins with fleshy bases (x 70)

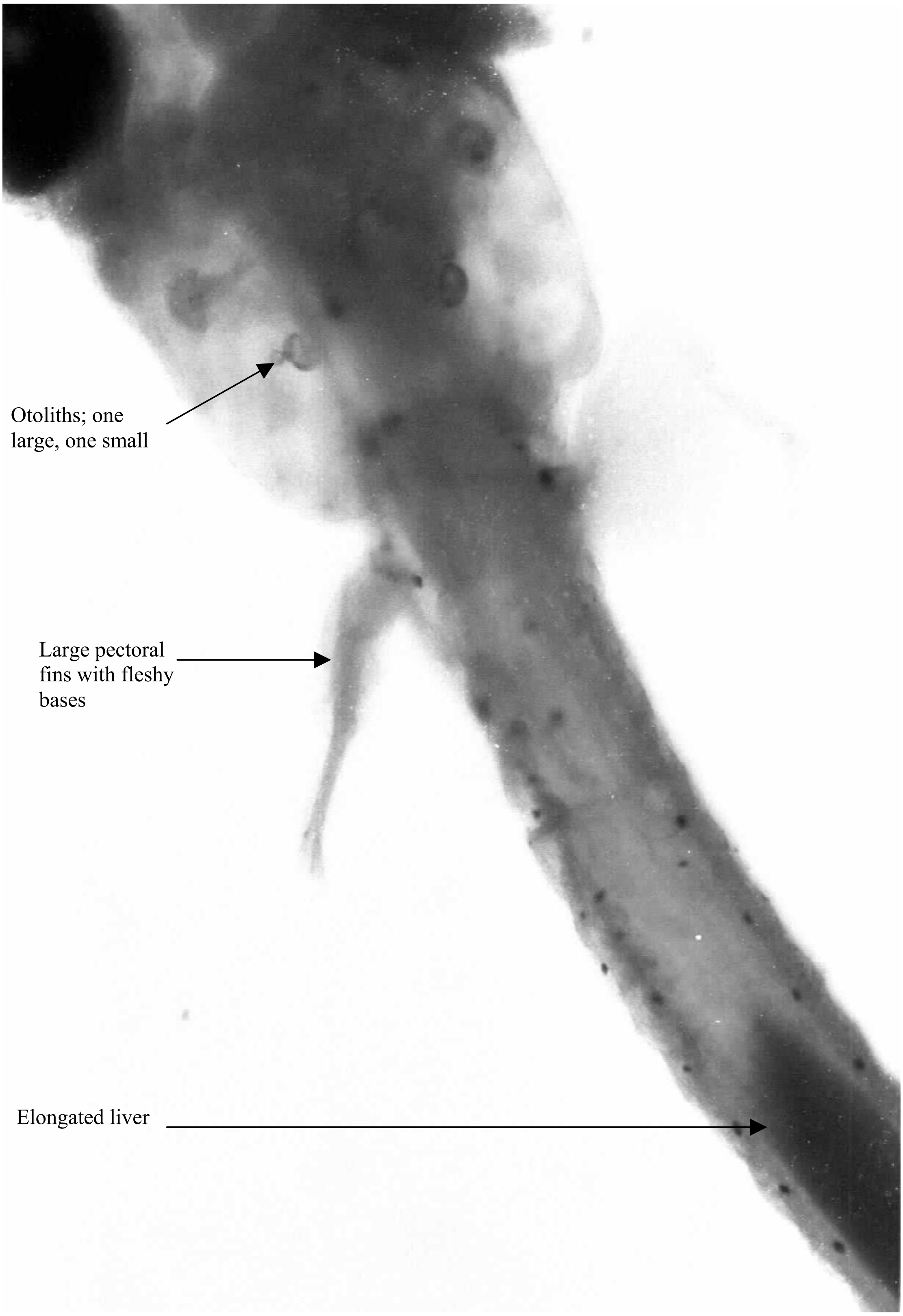


Figure 57: Head and anterior trunk of 15 day old larva (x 70)

Figure 58: Head of 15 day old larva (x 55)

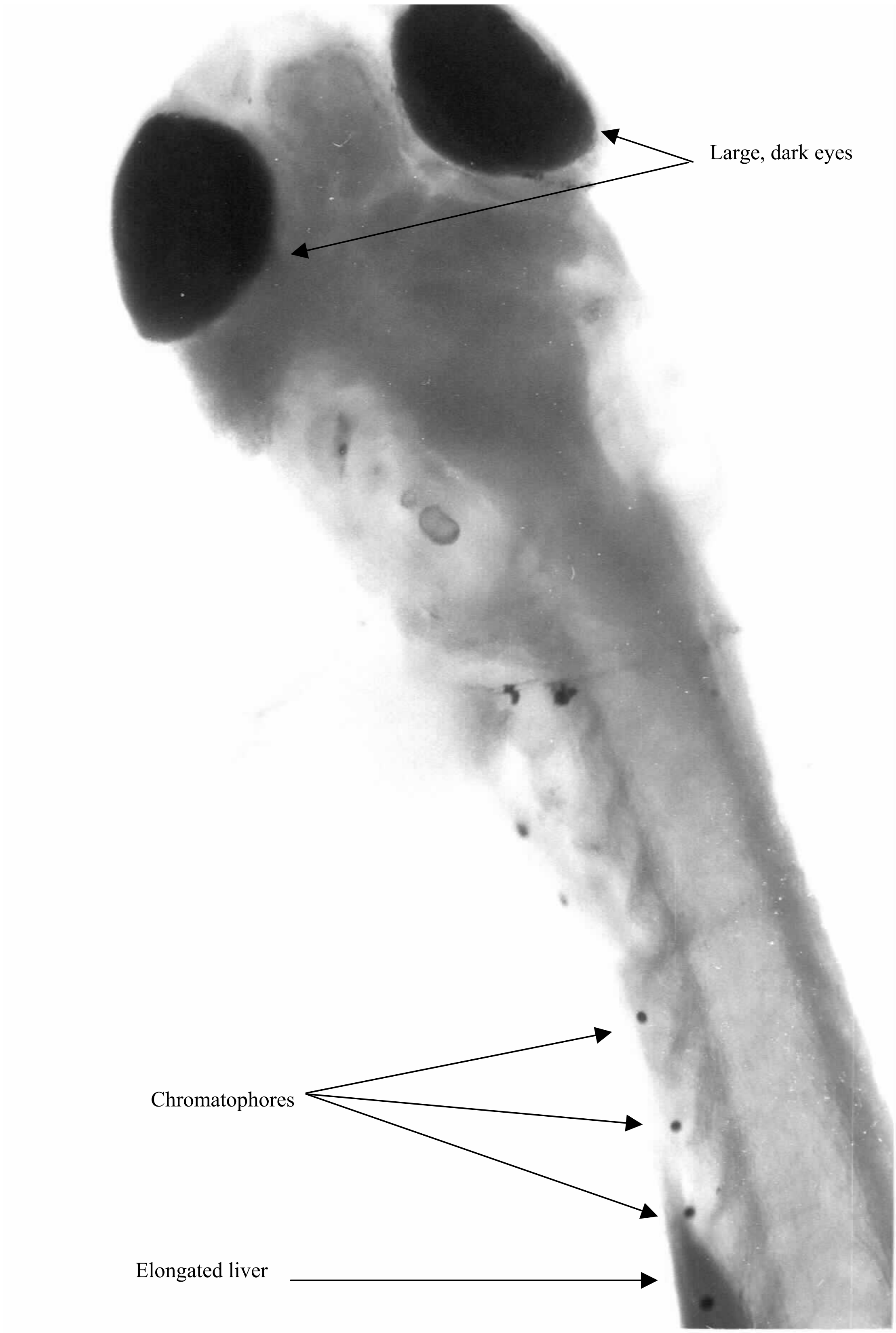


Figure 59: 15 day old larva showing large, dark eyes (x 60)

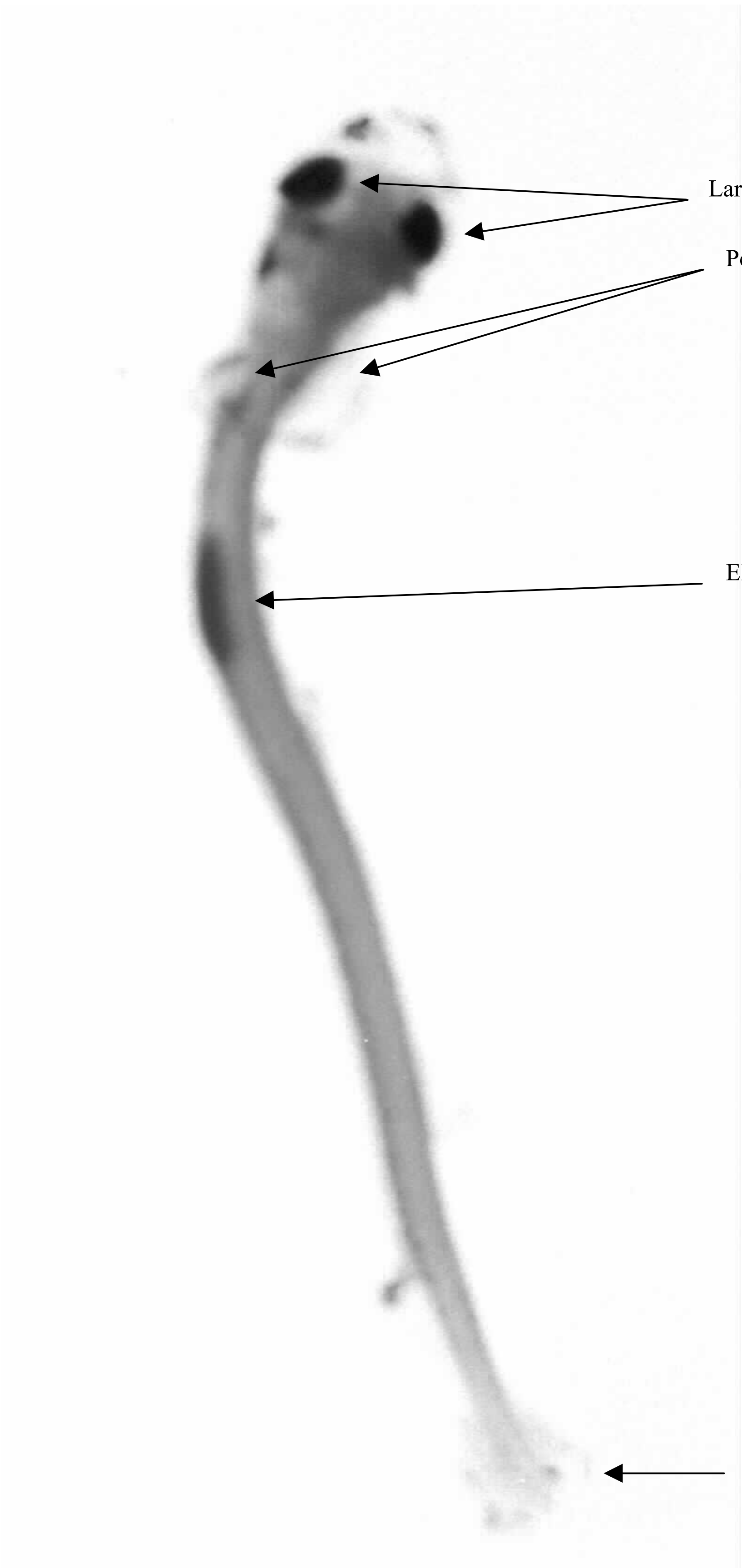


Figure 60: 12 day old larva (x18) [length 11.5 mm]

A1.5 Twaite Shad Larvae Reared at Calverton Fish Hatchery

Figure 61: Twaite shad larvae (x 20)

Figure 62: Head of twaite shad larvae (x 40)

A1.6 Shad Eggs Collected from Gunnislake, R. Tamar in 2002

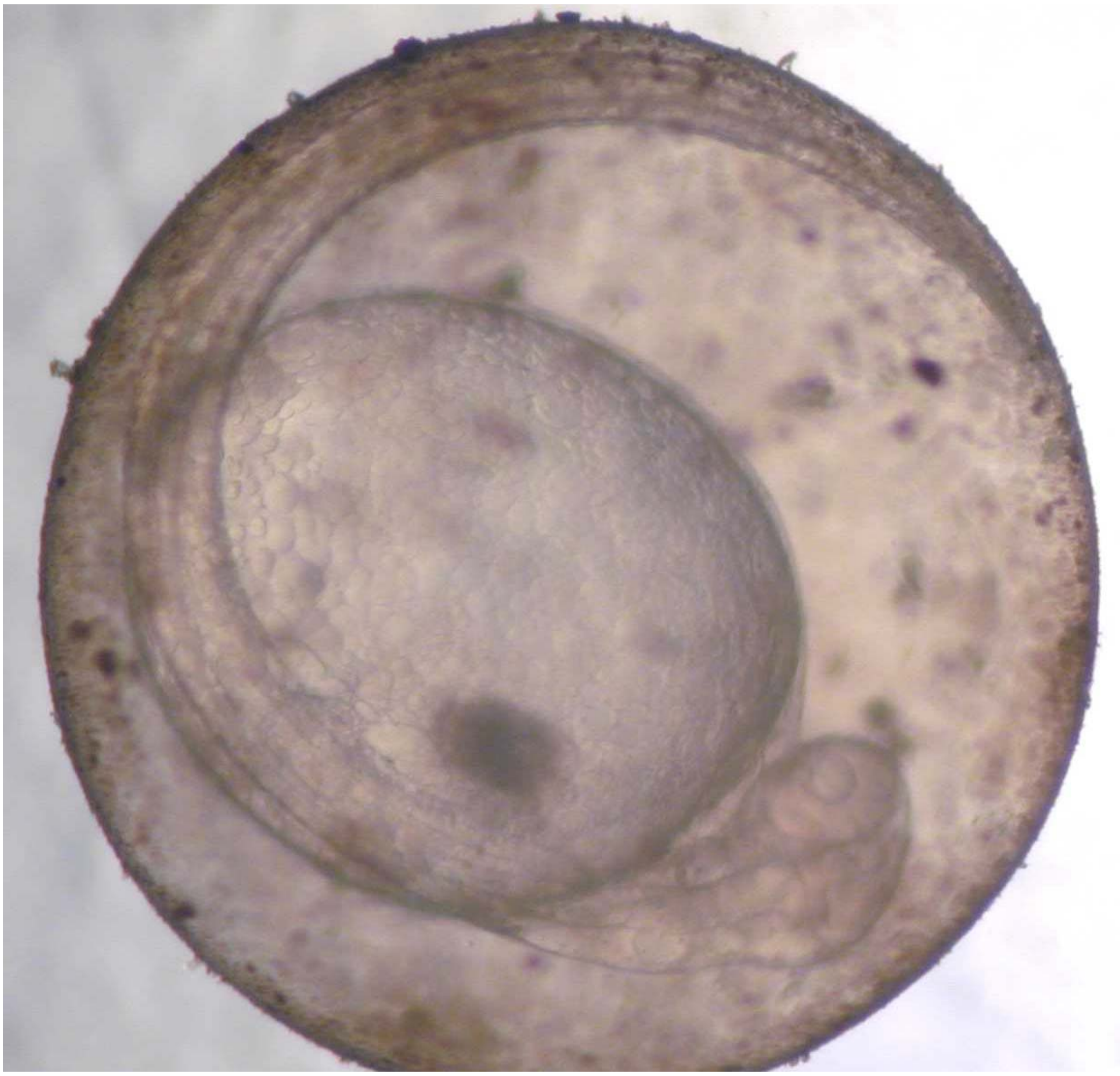


Figure 63: Shad egg (x 60) containing developing embryo, collected from Gunnislake, R. Tamar

A1.7 Twaite Shad Eggs Reared at Calverton Fish Hatchery

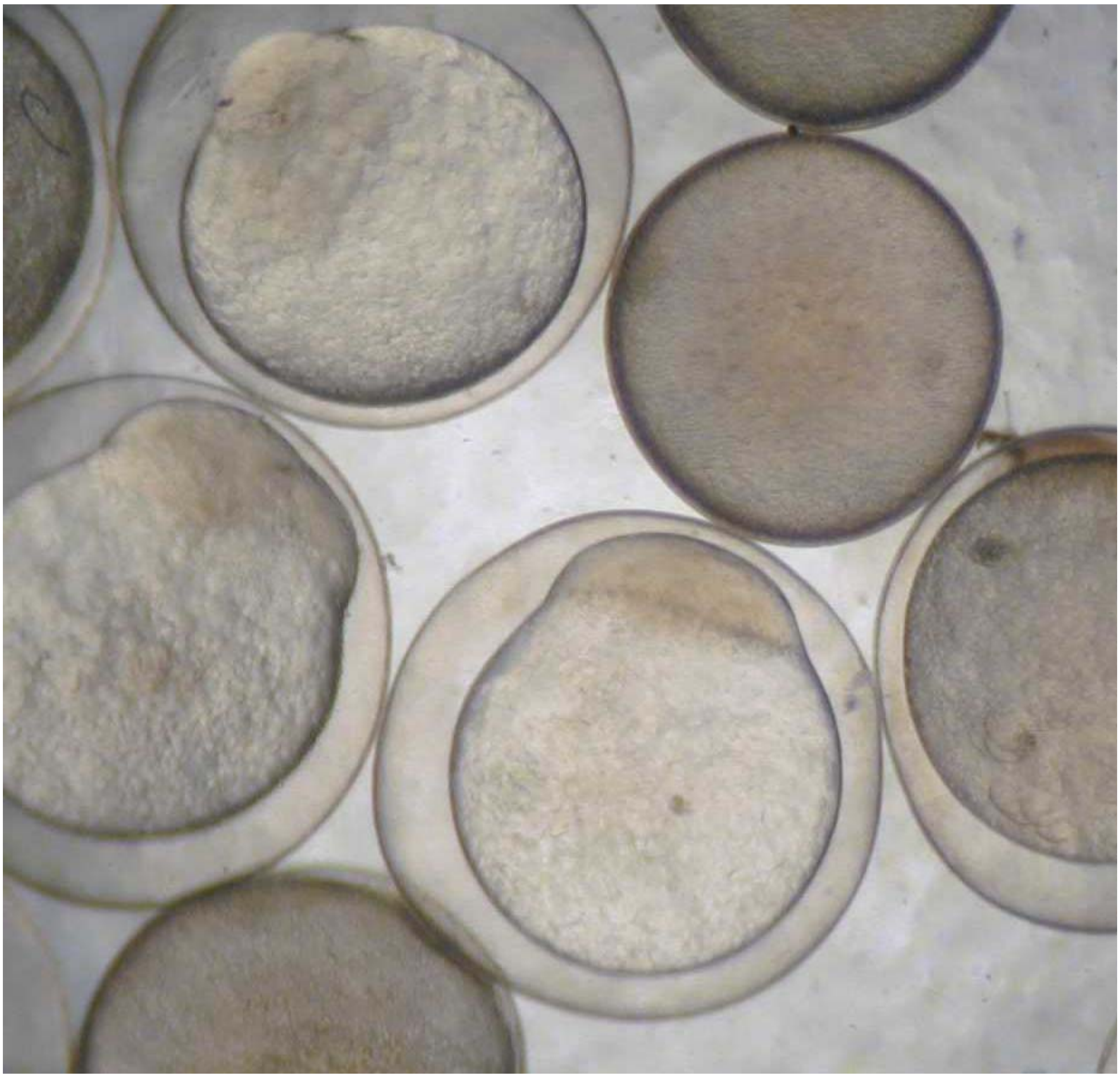


Figure 64: Twaite shad eggs (x30)

A1.8 Shad Migrating Upstream at Gunnislake Fish Pass

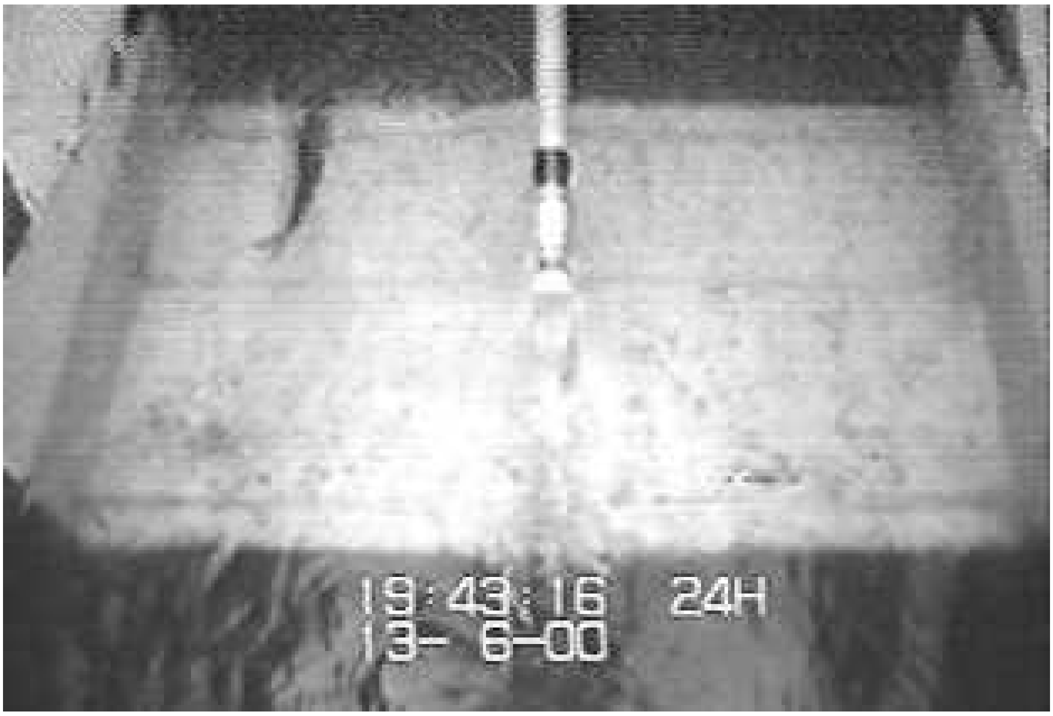


Figure 65: Shad migrating upstream at Gunnislake Fish Pass (overhead camera)

Figure 66: Shad migrating upstream at Gunnislake Fish Pass (surface-skimming camera)