

Evidence for a population collapse of European eel (*Anguilla anguilla*) in the Bristol Channel

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*A 30-year study of the estuarine population of yellow eel, *Anguilla anguilla*, abundance in Bridgwater Bay, Somerset, UK, shows that the population number has collapsed. Since 1980, the decline has averaged 15% per year. The abundance of eel in 2009 is estimated at only 1% of that in 1980. This is one of the greatest systematically quantified crashes of a fish population ever reported. Collections of eels impinged on cooling water filter screens were made monthly at Hinkley Point power station between 1980 and 2010 and from Oldbury power station between 1996 and 1998. Eels are always present in the Severn Estuary, although there are large seasonal variations in abundance. At Oldbury, in the upper estuary, eels are least abundant in January. In contrast, in the outer estuary in Bridgwater Bay, eels are most abundant between November and March. The size-distribution of yellow eels ranged from <200 to >700 mm indicating an age-range since the glass eel stage of 2 to >25 years. The mean size-range has not changed since the 1980s indicating that the population collapse is not caused by a sudden recruitment failure. It is suggested that there has been a continual long-term failure of recruitment to compensate for losses. The reason for this is unidentified, but is unlikely to be changes in the North Atlantic Oscillation or other natural environmental variability. A major effort to improve eel survival to adulthood is required if this species is not to gently fade to extinction. This would likely involve a cessation of elver fishing, a reduction in the volume of estuarine water extracted for power station cooling and other purposes during which eels are entrained and killed, and the removal of obstructions which increase mortality during migration.*

Keywords: eel population decline, long-term sampling, North Atlantic Oscillation Index, power station monitoring, salinity, seasonal variation, water temperature

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INTRODUCTION

The Severn Estuary is the second largest estuary in the United Kingdom covering an area of 557 km² that contains an intertidal area of 100 km². When included with the Bristol Channel, the region becomes the largest estuarine system in the UK, with an area of 4800 km² (Collins & Williams, 1981). The estuary experiences the third highest tidal range in the world, exceeding 14.5 m at Avonmouth. This extreme tidal range supports a diversity of habitats, some of which are unique in the UK (Langston *et al.*, 2003). The estuary has been proposed as a Special Area of Conservation (pSAC) (Langston *et al.*, 2003) due partly to the fact that it provides an important habitat and migratory corridor for fish, including the European eel, *Anguilla anguilla*.

The life cycle of the European eel has seven principal stages. After hatching from eggs in the Sargasso Sea, the leptocephali are orientated eastwards by the Gulf Stream towards European and North African coasts. Having arrived on the continental shelf, leptocephali metamorphose into

glass eels which colonize coastal and inland waters. Glass eels move into estuaries from coastal waters by means of passive tidal transport (Deelder, 1984; Tesch, 2003). At this stage their skin begins to develop pigmentation and they metamorphose into elvers. While some individuals remain in estuaries, or are recruited to coastal stocks, others migrate upstream into freshwater during their first year, or as juvenile yellow eels in subsequent years (White & Knights, 1997b). It has also been shown that some eels never migrate into freshwater and spend their entire growth phase at sea or within estuarine waters (Daverat *et al.*, 2006). Those that migrate into freshwaters move upstream on the flood tides (Creutzberg, 1958) and are positively attracted to freshwater discharges (Deelder, 1958). After completing this growth phase, yellow eels metamorphose into silver eels and migrate back to the Sargasso Sea to spawn.

Since the early 1980s, recruitment of glass eels to European waters has shown a marked decline of up to 90% (Moriarty, 1996; Dekker, 2000; ICES, 2002) and stocks are now considered to be in danger of collapse (Moriarty & Dekker, 1997; ICES, 2006). The upper Severn Estuary has traditionally supported a glass eel fishery but this has also declined in recent decades (White, 1994; White & Knights, 1994). The reduction in eel stocks is reflected in the fact that, from March, 2009, *A. anguilla* has been included in Appendix II of the

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Convention of International Trade in Endangered Species of wild fauna and flora (CITES, 2007). No single cause for this decline has been identified (Dekker *et al.*, 2003) but it is likely that a combination of factors are responsible. These may include habitat loss and degradation (Moriarty & Dekker, 1997; Feunteun, 2002), parasitism (Kirk, 2003; Aguilar *et al.*, 2005), overfishing (Dekker, 2003), pollution (Amiard-Triquet *et al.*, 1987; Knights, 1997; McCleave, 2001; Feunteun, 2002; Robinet & Feunteun, 2002), climatic changes in oceanic conditions (Castonguay *et al.*, 1994; Desaunay & Guerault, 1997; McCleave *et al.*, 1998; Knights, 2003; Friedland *et al.*, 2007; Bonhommeau *et al.*, 2008) and man-made barriers and impaired passage between marine and freshwater habitats (Moriarty & Dekker, 1997; White & Knights, 1997a; McCleave, 2001).

Despite the marked decline in the recruitment of glass eels and the general view that yellow eel stocks are declining throughout Europe, Bark *et al.* (2007) have shown that yellow eel populations have remained stable in some UK river systems. They concluded that, despite declining levels of recruitment, many west coast rivers were still at, or near their carrying capacity. Indeed, this was found to be the case for tributaries of the River Severn that enter the upper estuary, where eel numbers remained stable from 1984 to 2004.

The current status of yellow eel populations in many rivers across Europe is well documented. In the UK, yellow eels are widely distributed throughout the catchment of the River Severn but they are also present within the Severn Estuary and Bristol Channel (Claridge *et al.*, 1986; Potter *et al.*, 2001). Much less is known about the current status of these estuarine stocks due to the difficulty of sampling eels in this estuary.

Data on eel abundance have been obtained for 29 years by monthly sampling from the cooling-water intake screens of the nuclear power station at Hinkley Point. Additional data have been obtained, over a three year period, from a similar installation at Oldbury in the upper Severn Estuary (Figure 1). This study describes the long-term variation in the number of yellow eels entrained at power stations within the Severn Estuary and Bristol Channel. It examines the

relationship between the abundance of yellow eels and local variations in water temperature, salinity, tide and with changes in oceanic conditions related to the North Atlantic Oscillation Index (NAOI).

The NAOI is calculated as the difference between normalized sea level pressure over Gibraltar and south-west Iceland (Jones *et al.*, 1997) and was acquired from <http://www.cru.uea.ac.uk/cru/data/nao.htm>. This pressure difference exerts strong control over the climate of the northern hemisphere, especially in the winter. Jones *et al.* (1997) have suggested therefore, that the North Atlantic Oscillation Winter Index (NAOWI) is often a more useful measurement, calculated as the December to March average of NAOI monthly measurements. A positive index indicates low pressure over Iceland and high pressure towards Gibraltar. These conditions bring strong westerly winds to northern Europe that result in mild, wet winters. A negative index is generated when low pressure exists over Gibraltar and high pressure develops over south-west Iceland. This often results in northerly winds from north-west Europe and very cold winter weather. Changes in oceanic conditions, thought to be linked to the NAOI index, have been implicated in the decline of glass eel recruitment across Europe (Knights, 2003; Friedland *et al.*, 2007). Any subsequent impact on yellow eel stocks will depend on the oceanic conditions that prevailed at the time of recruitment to the estuary as glass eels.

MATERIALS AND METHODS

Yellow eels were collected from the cooling-water intake screens at Hinkley Point B power station, in the Bristol Channel, monthly between January 1981 and December 2009. Sampling was not carried out during October 1983 and 1988 or during December 1987 and 1999 because of power station maintenance. In addition, a preliminary study was made in October and November 1980 to test for tidal and diurnal changes in the rate of capture. A further intensive study using daily samples was undertaken between November 1993 and February 1994 to study changes in the rate of

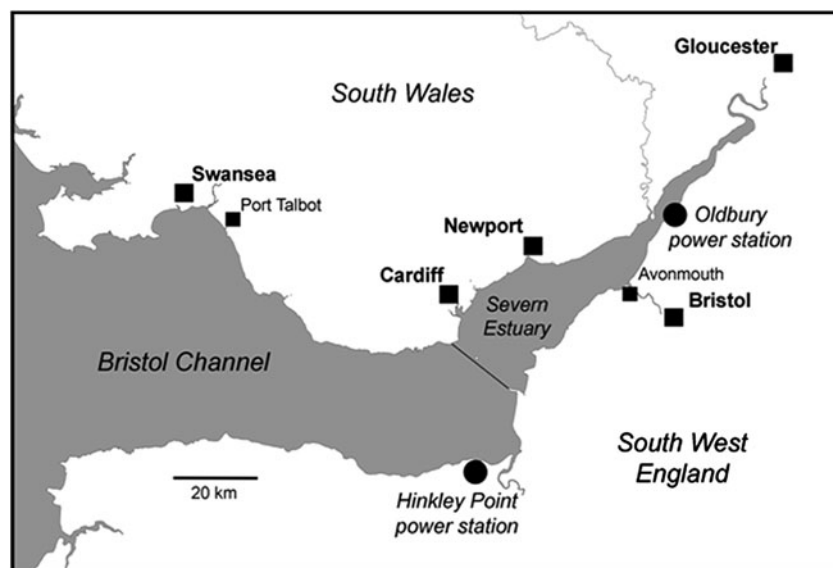


Fig. 1. The Severn Estuary and Bristol Channel showing the locations of Hinkley Point and Oldbury Nuclear power stations.

capture with tidal height. Collections were also obtained from the screens at Oldbury power station in the Severn Estuary approximately once every two weeks between January 1996 and December 1998, except in July and August of 1998. At both power stations (Figure 1), yellow eels were captured and recorded as part of a long-term fish monitoring survey.

The strong tidal currents of the Bristol Channel make traditional sampling techniques difficult. Previous attempts to beam trawl within the estuary have been unsuccessful due to the depth and instability of the sediment in the estuary. The water-intake pipes of power stations provide a permanent sampling point and an effective sampling mechanism that allows long-term quantitative sampling of estuarine fish communities (Henderson & Holmes, 1991).

Hinkley Point

The cooling-water intake at Hinkley Point B power station consists of a 3.45 m diameter pipe situated 640 m offshore rising vertically up from the seabed. Minimum water depth at the intake is 3 m. Water is pumped into the station by means of four centrifugal pumps each delivering a constant $7.5 \text{ m}^3 \text{ s}^{-1}$ (Henderson, 1989) and filtered through four metal screens ($10 \times 10 \text{ mm}$ square mesh). On each visit, the samples were obtained from two operational filter screens. The capture rates of conger eels, *Conger conger*, the only other eel in the Bristol Channel, were also recorded to help establish whether any long term changes in the abundance of anguillids were species specific. The screens retain all yellow eels and conger eels of standard length greater than approximately 250 mm (Turnpenny, 1981).

To minimize possible tidal effects, the standard monthly sampling date at Hinkley Point was not fixed, but chosen to fall halfway between spring and neap tides, with sampling beginning at high-water. The number of eels recorded from two screens over a 6 hours period represents a total water volume of $3.24 \times 10^5 \text{ m}^3$, which equates to $15 \text{ m}^3 \text{ s}^{-1}$. This volume did not vary over the entire sampling period. Depending on the tidal cycle, sampling commenced between 11:00 and 13:00 hours and was completed during daylight.

Mean monthly water temperature data, recorded by Hinkley Point power station, was obtained from <http://www.cefas.co.uk/data/sea-temperature-and-salinity-trends.aspx>. Salinity was measured, on each sampling date, using a refractometer one hour before low water.

Sampling during October and November 1980 and between November 1993 and March 1994 was undertaken in a similar fashion to the regular monthly work, but was not planned to cover an average tide working from high to low water. Rather these studies were designed to encompass the full range of tidal and day/night conditions.

Oldbury

The cooling-water intake at Oldbury power station is located near the shore of the inner Severn Estuary on the seabed within a deep water channel. Water is pumped into the station by means of four pumps, each delivering a constant $6.63 \text{ m}^3 \text{ s}^{-1}$ (Henderson, 1989) and filtered through four metal drum screens consisting of $10 \times 10 \text{ mm}$ square mesh. Fish, crustaceans, seaweed and other debris that collect on the screens, are washed off into hoppers and sluiced into collecting baskets for disposal. The total number of yellow eels

washed off the screens over a period of 24 hours was recorded by sorting through debris in the collecting baskets. The number was adjusted to a standardized intake water volume of $1.72 \times 10^6 \text{ m}^3 \text{ day}^{-1}$, which equates to a flow, as delivered by three pumps, of $20 \text{ m}^3 \text{ s}^{-1}$.

Mean monthly water temperatures were obtained from continuous records supplied by the power station staff at Oldbury and salinity values derived from measurements of conductivity obtained on each sampling occasion.

The von Bertalanffy growth curve calculated for yellow eels from the Severn Estuary (Bird *et al.*, 2008) was used to estimate the ages of all yellow eels from Hinkley Point. The total numbers of eels present in all samples were compared with the NAOWI that corresponded to the year these individuals are likely to have entered the estuary as glass eels.

RESULTS

Size and age distribution

Figure 2 shows the size distribution of elvers (black bars) and yellow eels (grey bars) observed at Hinkley Point between 1980 and 2009 inclusive. The modal size-class was 300–340 mm and the maximum recorded length was 770 mm. The yellow eel size distribution was found to fit by regression (adjusted $R^2 = 0.82$) a log normal distribution of the form:

$$f = 21.34e^{(-0.5((\ln(x/359.22))/0.28)^2)}$$

where f is the frequency and x the length in mm.

Sufficient observations were available for Hinkley Point to examine the change in mean length through time. Over the three decades commencing 1980, 1990 and 2000 the means and standard deviations were $411.3 \pm 92.0 \text{ mm}$; $414.0 \pm 144.5 \text{ mm}$ and $398.5 \pm 99.85 \text{ mm}$ respectively. Analysis of variance using log-transformed data found no significant difference in the mean size of the eels ($F_{2,136} = 0.183$, $P = 0.83$).

Bird *et al.* (2008) from a study of otoliths found the average lengths of eel at age 2, 5, 10 and 20 years after the glass eel

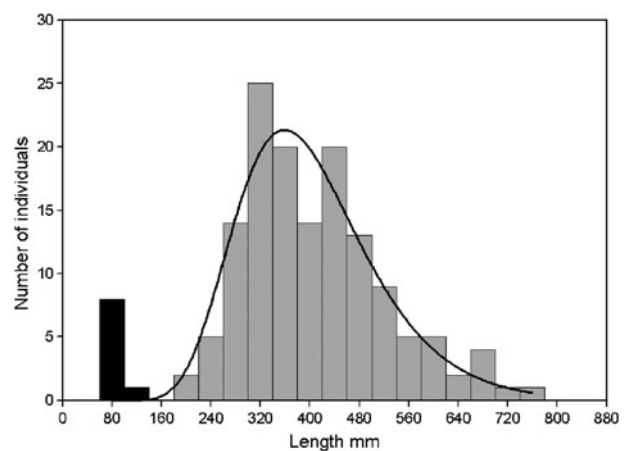


Fig. 2. Length–frequency of eels caught at Hinkley Point 1980–2009. Data allocated into 40 mm size-classes. Elvers and newly pigmented eels are shown in black, the yellow eel population in light grey. A log normal distribution was fitted to the yellow eel size distribution by regression.

stage to be 199, 323, 439 and 498 mm, respectively. Assuming that Bridgwater Bay eels conform to the growth curve observed at Oldbury, Hinkley Point eels ranged from 2 to > 25 years in age. Both Oldbury and Hinkley hold populations with a similar size distribution.

Seasonal variation in captures

Yellow eels are present in Bridgwater Bay in all months of the year, but are far more abundant during autumn and winter, showing two seasonal peaks in November and March and an annual minimum in May (Figure 3).

Data from Oldbury power station between 1996 and 1998 showed that the maximum number of yellow eels in the monthly samples was not consistently associated with any particular season, but they tended to be in lowest abundance between January and March (Figure 4). Peaks in abundance occurred in July 1996, May 1997 and April 1998.

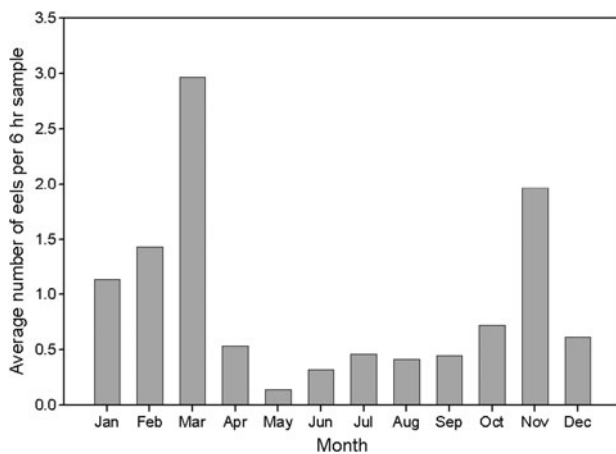


Fig. 3. The average seasonal capture (in 6 hour monthly samples) of yellow eels at Hinkley Point, Bridgwater Bay. Data collected between January 1981 and December 2009.

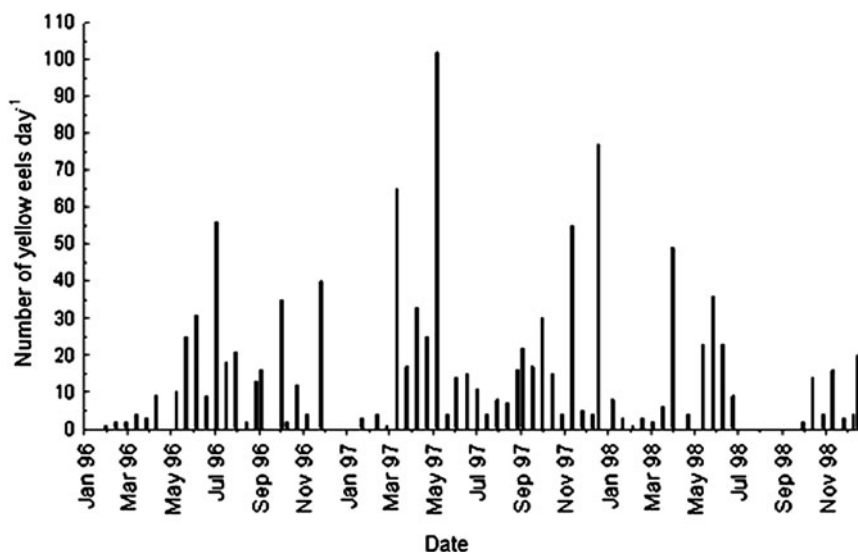


Fig. 4. The number of European yellow eels recovered from the water-intake screens at Oldbury nuclear power station in the Severn Estuary. Eels were collected approximately every two weeks and are the total number of individuals entrained over the previous 24 hours. Note that no samples were obtained in July and August 1998.

Salinity and temperature

There was no relationship between the number of eels in monthly samples from Hinkley Point and either the mean monthly water temperature or the salinity (Figure 5). The records from Oldbury show that comparatively few yellow eels were present at this site during the winter when the water temperature was below 5°C. This probably reflects low levels of activity and reduced energetic requirements of eels in cold water. Similarly, few yellow eels were present at Oldbury when the salinity was <15‰. This is below the salinity minimum for Hinkley Point of 18‰.

Diurnal and tidal variation in capture rates at Hinkley Point

In October and November 1980 hourly sampling programmes of 22 and 23 hours duration respectively, were undertaken to test for the effects of tidal height and daylight on eel capture. A general linear model of the form:

$$\text{Eel number} = \text{tidal height} + \text{month} + \text{light}$$

with tidal height as a continuous variable and light and month as fixed categorical variables demonstrated that only tidal height was a significant explanatory variable (Table 1). Eel capture rate increased as the tidal height decreased.

Between 9 November 1993 and 11 February 1994 an intensive study was undertaken to study the change in eel abundance with tidal height. Hourly samples at Hinkley Point power station were typically collected for 6 consecutive hours per day for 41 days giving a total of 242 hourly samples. The plots of the number of eels captured against tidal height for each month are given in Figure 6 and clearly show that eels are usually only caught when the tidal height is lower than 6 m chart datum. The maximum rates of capture occurred at low spring tides (tidal heights < 2.5 m chart datum).

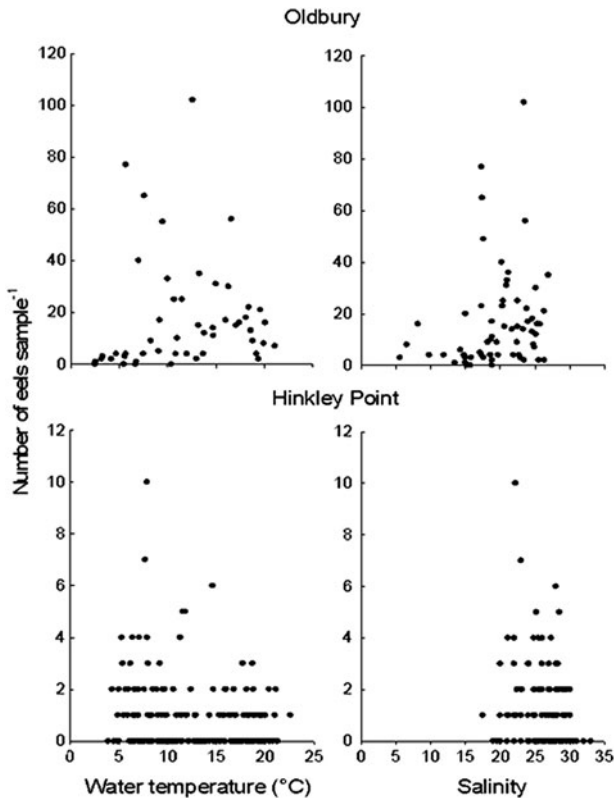


Fig. 5. The relationship between the numbers of European yellow eels entrained at Oldbury and Hinkley Point nuclear power stations and the water temperature and salinity. At Oldbury the eels were collected in samples extending over 24 hours, while at Hinkley Point samples were obtained over 6 hours (see Materials and Methods for further details).

Abundance and the North Atlantic Oscillation

When the annual value of the NAOWI was plotted against the estimated total number of glass eels that would have entered the estuary in that year, no significant correlation between the NAOWI and glass eel recruitment was found (Spearman rank correlation coefficient = 0.242, $P = 0.231$).

Long-term decline in abundance

Figure 7A shows the long-term decline in the number of yellow eels captured each year since January 1981. This decline was modelled by fitting using regression analysis the exponential equation:

$$Abundance = 53.17e^{-.1619t}$$

where *Abundance* is the total number captured over 12 monthly samples and *t* is time in years. The adjusted

Table 1. Unique effects analysis of variance table generated using a general linear model, to test for the effect of tide and light on the number of eels captured at Hinkley Point.

Source	DF ₁	DF ₂	SS	MS	F	$P > F$
Tide height	1	41	4.147	4.147	4.943	0.032
Month	1	41	1.652	1.652	1.969	0.168
Light	1	41	0.013	0.013	0.015	0.903

coefficient of determination (R^2) was 0.75 indicating that an exponential model gave a good fit to the data. This equation gives an estimated average decline in abundance of about 15% per annum giving a total decline since 1980 of about 99%.

For the standard monthly sampling, the greatest numbers of yellow eels collected at Hinkley Point between 1981 and 2010 were obtained in 1981 and 1982 when 44 and 61 individuals were recorded, respectively (Figure 7A). The annual total declined markedly in 1983 and, despite subsequent small fluctuations from year to year, the total number of yellow eels continued to decline thereafter. Each year since 1991, the annual total never exceeded 10 and since 2002 it never exceeded 5. In 2009 no eels were caught during the standard sampling programme. In contrast, the number of conger eels captured over the same period, using the same sampling methodology, does not show a consistent decline but mostly ranged between 4 and 18 (Figure 7B). The only notable deviation occurred in 2002 when an exceptional 53 conger eels were captured (Figure 7B). The reason for this peak is unknown.

There is additional evidence that abundance in 1980 was also appreciably higher than that observed since 2000 as samples collected in October and November 1980 recorded 47 and 18 yellow eels respectively. On 2 October 1980 over the 3 hours around low water, 34 yellow eels were caught, more than has subsequently been recorded during regular sampling for any year since 1982.

DISCUSSION

The size-range of eels caught at Hinkley Point in the lower estuary are similar to those reported by Bird *et al.* (2008) for Oldbury in the inner estuary and indicate that yellow eels from 2 to more than 25 years of age are living in estuarine waters, at least for part of the year. The pattern of capture at Hinkley Point with maximum rates occurring at low water spring tides suggests that eels occupy intertidal habitat when available. This view is supported by the historically frequent capture of eel by the fixed net fishermen at Stolford who set nets to capture fish retreating from the Stert flats on the receding tide. In addition, it is also possible eels are moving down estuary and out of the River Parrat at low water and concentrating in the vicinity of the intake.

The long-term study at Hinkley Point is based on 6 hourly samples collected typically between 12:00 and 18:00 hours. Initial studies in October and November 1980 found a powerful tidal influence and no diurnal differences in the rate of capture. It has also been found that the capture of many demersal fish is not influenced by the day/night cycle at Hinkley Point (Henderson & Holmes, 1991). There are good reasons why European eels are likely to be active throughout the diurnal cycle at Hinkley Point. First, tidal conditions in the Bristol Channel result in suspended solids of up to 3 g l^{-1} and this restricts light penetration to a depth of only 50 cm below the surface. Secondly, the available evidence suggests that eels favour living on the intertidal flats. They must leave this region at low tide irrespective of the time of day.

The rate of capture at Hinkley Point is highly seasonal with yellow eel occupying the intertidal flats in greatest abundance during the autumn and winter. We have no information as to where these eels move to in the summer, but their association with shallow waters suggests they may be entering the upper

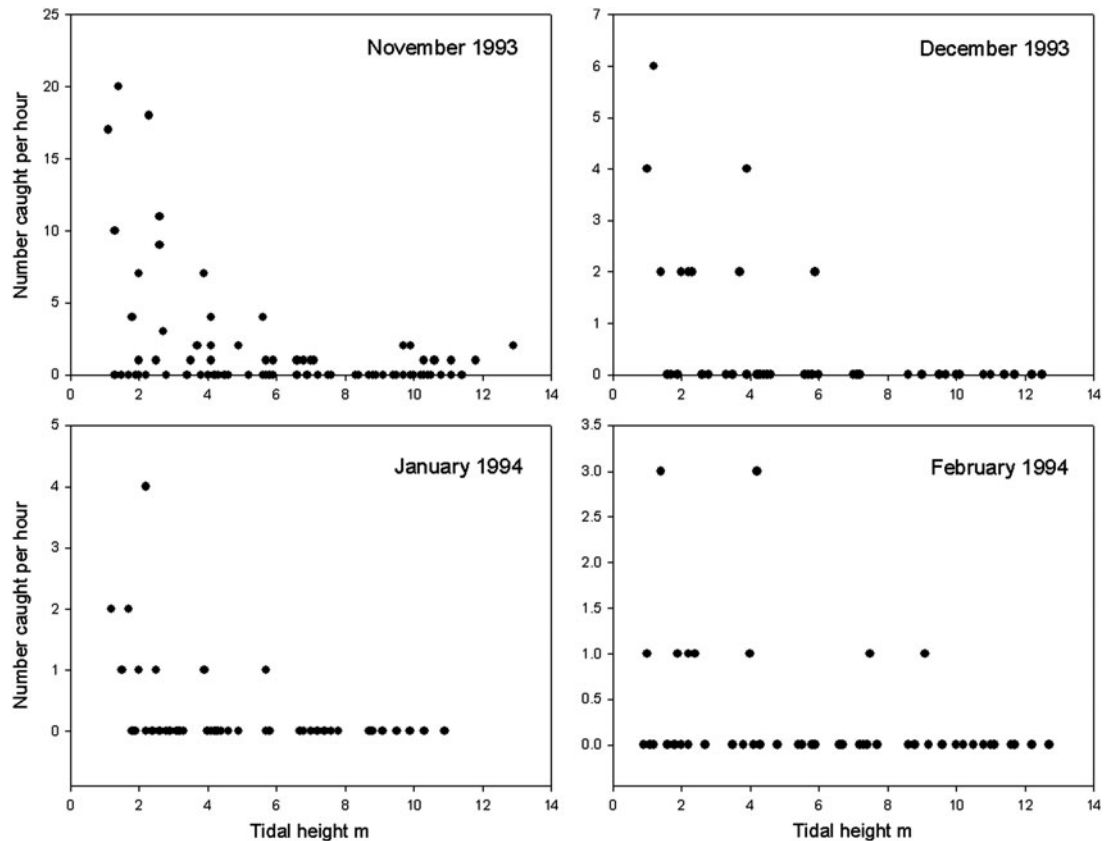


Fig. 6. The variation in hourly catch rates of eel with tidal height for the months November to February 1993–1994. For each day, 6 samples of 1 hour duration were collected, generally between 10:00 and 17:00 hours.

estuary of the River Parrat or even freshwaters in the Somerset levels. It is notable that few eels are caught at Oldbury during January (Figure 4) suggesting that, during winter, yellow eels may migrate down estuary to more marine, warmer, waters. The records from Oldbury show that comparatively few yellow eels were present in samples from this site when the water temperature was below 5°C (Figure 5). This probably reflects low levels of activity and reduced energetic requirements of eels in cold water. Similarly, few yellow eels were present when the salinity was <15‰ (Figure 5).

Regular monitoring for 29 years at Hinkley Point power station provides unequivocal evidence that a severe decline in yellow eel abundance has occurred in the Bristol Channel since the 1980s (Figure 7A). The average rate of decline appears to be approximately 15% per annum which is amongst the greatest long-term rates of population decline ever reported for a fish. Abundance in Bridgwater Bay is presently estimated to have declined by 99% from the 1980 level. Hutchings & Reynolds (2004) in a review of 230 exploited marine fish populations reveal a median reduction of 83% in breeding population size from known historic levels. The greatest reduction they report is 99.9% over 30 years for a Canadian population of cod, *Gadus morhua*. This is, however, for a single stock and the species as a whole, while greatly diminished, has not suffered this level of attrition. The decline in eel that we report is one of the greatest ever reported for a fish and can justifiably be termed a population collapse. The decline of yellow eels within the Bristol Channel is unlikely to be an artefact caused by a loss of sampling efficiency, if this were the case a similar decline would be

observed in other species of similar form, the number of conger eels shows no such decline (Figure 7B). Further, as recently reported by Henderson & Bird (2010), many fish and crustaceans in Bridgwater Bay have maintained stable or increasing populations over the last 30 years. Dekker (2000) has similarly observed a steep decline in glass eel recruitment in most European estuaries from 1980 onwards. The yellow eel population of the Bristol Channel has paralleled this European decline.

Given the great decline in abundance, it was anticipated that the mean size and age structure of the yellow eel population in Bridgwater Bay would have changed over the last 30 years. A collapse in eel recruitment would be expected to result in a population with a progressively increasing average age and individual length. A comparison of the size distribution over three decades commencing 1980, 1990 and 2000 revealed no significant difference in mean size. Over each decade yellow eel size distribution ranged from 200 to >600 mm total length. This surprising observation suggests that there has not been a sudden recruitment failure. For the size structure to have remained stable over such a long period indicates that both the age specific rates of population increase, generated by recruitment and immigration and the age specific rates of population decline, from mortality and emigration, have remained approximately constant. It is possible that as eel numbers declined individual growth accelerated so that the age of eels in each size-category declined. However, such a response would almost inevitably change the size distribution. The observed decline covers all ages (sizes) and is therefore most likely to be because for an

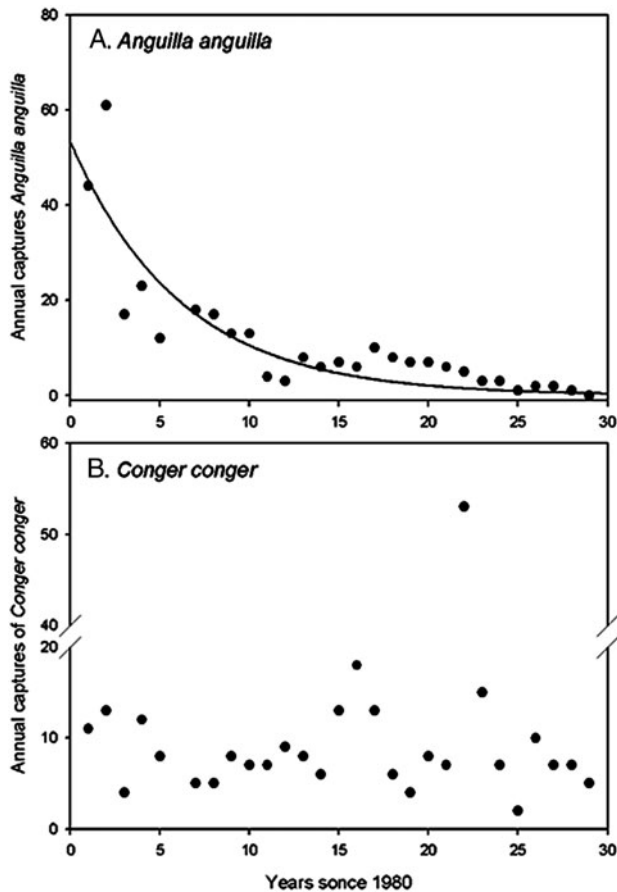


Fig. 7. The change in the rate of capture of eels at Hinkley Point B nuclear power station since 1980. (A) The decline in the annual catch of yellow eel, *Anguilla anguilla*—the exponential curve was fitted by regression; (B) the annual catch of conger eel, *Conger conger*.

extended period of at least 29 years losses have consistently exceeded the gains without any violent change in recruitment, growth or mortality rate. If the observed population decline was only restricted to eels in the Severn Estuary then a change in local recruitment or immigration would be viewed as plausible or even likely. However, the widespread reports of eel decline strongly suggest that there has been a long-term failure of recruitment to compensate for losses. Our data suggest that this recruitment failure has probably been ongoing for considerably more than the last 30 years.

There have been reports that eel recruitment may be influenced by environmental variables with the widespread decline in glass eel recruitment across Europe as a result of a change in oceanic conditions, that has affected the abundance and survival of eels during their marine phase (Castonguay *et al.*, 1994; Desaunay & Guerault, 1997; McCleave *et al.*, 1998; Friedland *et al.*, 2007; Bonhommeau *et al.*, 2008). The present study has found no evidence that the decline in abundance of yellow eel is related to changes in the North Atlantic Oscillation.

The dramatic decline of yellow eels within the Bristol Channel contrasts with the findings of Bark *et al.* (2007) for the tributaries of the upper Severn Estuary, in which sampling was carried out during 1998, 1999 and from 2002 to 2004. This study concluded that the estuary's upper tributaries were at, or approaching their carrying capacity and stressed the importance of later life stage recruitment from estuaries

in maintaining freshwater stocks. It would appear from the data presented in Figure 7 that if the River Severn relies on recruitment of yellow eels from its estuary and the Bristol Channel, then a future decline in the associated riverine stock may be expected. In the short term, however, the freshwater population of the River Severn may remain stable if it is regulated primarily by in-stream density-dependence. This occurs when previous levels of high recruitment result in an over-saturation of suitable habitats within a river. Subsequent years of reduced recruitment result in vacant habitats, reduced competition and a lower rate of mortality and as a result, the population remains stable (Feunteun *et al.*, 2003). This has shown to be the case in a long-term study of Rio Esva (Asturias, north-western Spain), where despite the decline in abundance of yellow eels within the estuary following a decline of glass eel recruitment, freshwater population numbers have increased (Lobon-Cervia & Iglesias, 2008).

The present study gives support to the view that we are presently witnessing a general collapse in European eel populations. Our data offers no indication as to the cause of this disaster. However, it does suggest that the collapse has been underway for 30 or more years and is not linked to any quasi-cyclical event such as the North Atlantic Oscillation. It is possible that the decline of the European eel is the result of a combination of factors which have reduced eel survival and now made the eel life-style non-sustainable. It does seem likely that the actions of man are involved in this collapse and that a major improvement in eel survival to adulthood must be engineered if the European eel is not to fade away to extinction. This would likely involve action on a number of fronts all of which increase survival. First, there needs to be a cessation of elver fishing, which in recent years has become highly lucrative as the price of elvers increased with their scarcity. Second, a reduction in the volume of estuarine water extracted for power station cooling and other purposes. This would reduce the number of elvers which pass through the condenser circuits and are killed. It would also reduce the number of large eels migrating back to the sea that are impinged and killed on the filter screens. The standard use of fish return systems on cooling water intakes would also reduce accidental deaths on filter screens. Finally, there needs to be an assessment for all water bodies of the presence of obstructions such as weirs and pumps which increase mortality during migration. By making water bodies more eel friendly and diverting them away from danger considerable reductions in mortality may be possible. These actions would need to be undertaken over Western Europe if a positive impact were to be produced on such a widely distributed species.

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REFERENCES

- Aguilar A., Alvarez M.F., Leiro J.M. and Sanmartin M.L.** (2005) Parasite populations of the European eel (*Anguilla anguilla* L.) in the Rivers Ulla and Tea (Galicia, northwest Spain). *Aquaculture* 249, 85–94.
- Amiard-Triquet C., Amiard J.C., Andersen A.C., Elie P. and Metayer C.** (1987) The eel (*Anguilla anguilla* L.) as a bioindicator of metal pollution—factors limiting its use. *Water Science and Technology* 19, 1229–1232.
- Bark A., Williams B. and Knights B.** (2007) Current status and temporal trends in stocks of European eel in England and Wales. *ICES Journal of Marine Science* 64, 1368–1378.
- Bird D.J., Rotchell J.M., Hesp S.A., Newton L.C., Hall N.G. and Potter I.C.** (2008) To what extent are hepatic concentrations of heavy metals in *Anguilla anguilla* at a site in a contaminated estuary related to body size and age and reflected in metallothionein concentrations? *Environmental Pollution* 151, 641–651.
- Bonhommeau S., Chassot E. and Rivot E.** (2008) Fluctuations in European eel (*Anguilla anguilla*) recruitment resulting from environmental changes in the Sargasso Sea. *Fisheries Oceanography* 17, 32–44.
- Castonguay M., Hodson P.V., Moriarty C., Drinkwater K.F. and Jessop B.M.** (1994) Is there a role of ocean environment in American and European eel decline? *Fisheries Oceanography* 3, 197–203.
- CITES** (2007) *Proposals for amendment of appendices I and II. Fourteenth meeting of the conference of the parties*. CoP 14 Document 68, 62 pp.
- Claridge P.N., Potter I.C. and Hardisty M.W.** (1986) Seasonal changes in movements, abundance, size composition and diversity of the fish fauna of the Severn Estuary. *Journal of the Marine Biological Association of the United Kingdom* 66, 229–258.
- Collins N.R. and Williams R.** (1981) Zooplankton of the Bristol Channel and Severn Estuary. The distribution of four copepods in relation to salinity. *Marine Biology* 64, 273–283.
- Creutzberg F.** (1958) Use of tidal streams by migrating elvers (*Anguilla vulgaris* Turt.). *Nature* 181, 857–858.
- Daverat F., Limburg K.E., Thibault I., Shiao J.C., Dodson J.J., Caron F.O., Tzeng W.N., Iizuka Y. and Wickstrom H.** (2006) Phenotypic plasticity of habitat use by three temperate eel species, *Anguilla anguilla*, *A. japonica* and *A. rostrata*. *Marine Ecology Progress Series* 308, 231–241.
- Deelder C.L.** (1958) On the behaviour of elvers (*Anguilla vulgaris* Turt.) migrating from the sea into fresh water. *Journal du Conseil International pour l'Exploration de la Mer* 24, 135–146.
- Deelder C.L.** (1984) *Synopsis of biological data on the eel*. FAO Fisheries Synopsis Document 80, 73 pp.
- Dekker W.** (2000) The fractal geometry of the European eel stock. *ICES Journal of Marine Science* 57, 109–121.
- Dekker W.** (2003) Did lack of spawners cause the collapse of the European eel, *Anguilla anguilla*? *Fisheries Management and Ecology* 10, 365–376.
- Dekker W., Casselman J.M., Cairns D.K., Tsukamoto K., Jellyman D.J. and Lickers H.** (2003) Worldwide decline of eel resources necessitates action: Québec declaration of concern. *Fisheries* 28, 28–30.
- Desaunay Y. and Gueraud D.** (1997) Seasonal and long-term changes in biometrics of eel larvae: a possible relationship between recruitment variation and North Atlantic ecosystem productivity. *Journal of Fish Biology* 51, 317–339.
- Feunteun E.** (2002) Management and restoration of European eel population (*Anguilla anguilla*): an impossible bargain. *Ecological Engineering* 18, 575–591.
- Feunteun E., Laffaille P., Robinet T.T., Briand C., Baisez A., Olivier J.M. and Acou A.** (2003) A review of upstream migration and movements in inland waters by anguillid eels: toward a general theory. In Aida K., Tsukamoto K. and Yamauchi K. (eds) *Eel biology*. Tokyo: Springer-Verlag, pp. 192–222.
- Friedland K.D., Miller M.J. and Knights B.** (2007) Oceanic changes in the Sargasso Sea and declines in recruitment of the European eel. *ICES Journal of Marine Science* 64, 519–530.
- Henderson P.A.** (1989) On the structure of the inshore fish community of England and Wales. *Journal of the Marine Biological Association of the United Kingdom* 69, 145–163.
- Henderson P.A. and Bird D.J.** (2010) Fish and macro-crustacean communities and their dynamics in the Severn Estuary. *Marine Pollution Bulletin* 61, 100–114.
- Henderson P.A. and Holmes R.H.A.** (1991) On the population dynamics of dab, sole and flounder within Bridgwater Bay in the lower Severn Estuary, England. *Netherlands Journal of Sea Research* 27, 337–344.
- Hutchings J.A. and Reynolds J.D.** (2004) Marine fish population collapses: consequences for recovery and extinction risk. *BioScience* 54, 297–309.
- ICES** (2002) *Report of the EIFAC/ICES working group on eels*. ICES Document CM 2002: 13, 55 pp.
- ICES** (2006) *Reports of the EIFAC/ICES working group on eels*. ICES Document CM 2006: 16, 101 pp.
- Jones P.D., Jonsson T. and Wheeler D.** (1997) Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and south-west Iceland. *International Journal of Climatology* 17, 1433–1450.
- Kirk R.S.** (2003) The impact of *Anguillicola crassus* on European eels. *Fisheries Management and Ecology* 10, 385–394.
- Knights B.** (1997) Risk assessment and management of contamination of eels (*Anguilla* spp.) by persistent xenobiotic organochlorine compounds. *Fisheries Management and Ecology* 13, 171–212.
- Knights B.** (2003) A review of the possible impacts of the long-term oceanic and climatic changes and fishing mortality on recruitment of anguillid eels of the Northern Hemisphere. *Science of the Total Environment* 310, 237–244.
- Langston W.J., Chesman B.S., Burt G.R., Hawkins S.J., Readman J. and Worsfold P.** (2003) *Characterisation of the South West European Marine Sites: the Severn Estuary pSAC, SPA*. 13, 1–206. Plymouth, UK: Marine Biological Association of the United Kingdom occasional publication No. 13.
- Lobon-Cervia J. and Iglesias T.** (2008) Long-term numerical changes and regulation in a river stock of European eel *Anguilla anguilla*. *Freshwater Biology* 53, 1832–1844.
- McCleave J.D.** (2001) Simulation of the impact of dams and fishing weirs on reproductive potential of silver-phase American eels in the Kennebec River basin, Maine. *North American Journal of Fisheries Management* 21, 592–605.
- McCleave J.D., Brickley P.J., O'Brien K.M., Kistner D.A., Wong M.W., Gallagher M. and Watson S.M.** (1998) Do leptocephali of the European eel swim to reach continental waters? Status of the question. *Journal of the Marine Biological Association of the United Kingdom* 78, 285–306.
- Moriarty C.** (1996) The decline in catches of European elver 1980–1992. *Archives of Polish Fisheries* 4, 245–248.
- Moriarty C. and Dekker W.** (1997) Management of the European eel. *Fisheries Bulletin* 15, 110.
- Potter I.C., Bird D.J., Claridge P.N., Clarke K.R., Hyndes G.A. and Newton L.C.** (2001) Fish fauna of the Severn Estuary. Are there long-term changes in abundance and species composition and are the

recruitment patterns of the main marine species correlated? *Journal of Experimental Marine Biology and Ecology* 258, 15–37.

Robinet T.T. and Feunteun E.E. (2002) Sublethal effects of exposure to chemical compounds: a cause for the decline in Atlantic eels? *Ecotoxicology* 11, 265–277.

Tesch F.W. (2003) *The eel*. Oxford: Blackwell Publishing, 408 pp.

Turnpenny A.W.H. (1981) An analysis of mesh sizes required for screening fishes at water intakes. *Estuaries* 4, 363–368.

White E.M. (1994) *A study of the exploitation, migration and management of elvers and juvenile eel (Anguilla anguilla L.) in the Rivers Severn and Avon*. PhD thesis. London, University of Westminster, 186 pp.

White E.M. and Knights B. (1994) *Elver and eel migration and stocks in the Rivers Severn and Avon*. Bristol: National Rivers Authority NRA R & D Project Record: 256/13/ST, 141 pp.

White E.M. and Knights B. (1997a) Dynamics of upstream migration of the European eel, *Anguilla anguilla* (L.), in the Rivers Severn and Avon, England, with special reference to the effects of man-made barriers. *Fisheries Management and Ecology* 4, 311–324.

and

White E.M. and Knights B. (1997b) Environmental factors affecting migration of the European eel in the Rivers Severn and Avon, England. *Journal of Fish Biology* 50, 1104–1116.

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