Abundance Trends of Glass Eels between 1978 and 1999 from Fisheries Data in the Gironde Basin, France

Laurent Beaulaton, Gérard Castelnaud

American Fisheries Society Symposium 58:257–274, 2009

Abundance Trends of Glass Eels between 1978 and 1999 from Fisheries Data in the Gironde Basin, France

Laurent Beaulaton[1,*] and Gérard Castelnaud
CEMAGREF, unité Ecosystèmes estuariens et poissons migrateurs amphihalins
50 avenue de Verdun, Cestas Cedex 33612 France

Abstract.—The glass eel is fished in the Gironde Basin, France, with large push nets, scoop nets, and the recently introduced small push net. This study uses fishery data to generate fisheries and abundance indicators for glass eels. Total catch, total effort, and catch per unit effort (CPUE) were calculated for the period 1978–1999 by classical statistical methods and by general linear models (GLM). Use of GLM enabled the correction of sampling variation and offered better trend estimation than classical CPUE. During the study period, the principal source of glass eel landings shifted from the scoop net fishery in the tidal river to the large push net fishery in the estuary. General linear model-based CPUEs for large push nets and for scoop nets showed that glass eel abundance declined by a factor of two to three at the beginning of the 1980s. Since 1985, abundance has stabilized at a low level and shows no sign of recovering. The abundance trend of glass eels in the Gironde Basin confirms the decline in glass eel populations observed elsewhere in Europe.

Introduction

The European eel *Anguilla anguilla* is an important cultural and economic resource. Eel fisheries are particularly intense in the rivers and lagoons of France, where all continental stages (glass, yellow, and silver) are targeted. Eel fisheries have the highest volume and cash value of any amphihaline species in France. Harvest in 1997, all developmental stages combined, was calculated at 700 t with a market price of 65 million euros (Castelnaud 2000). High prices paid for glass eels in recent years (>100 euro/kg) have further bolstered the species' economic value. For these reasons, the eel is much sought after.

Eel recruitment has been declining in Europe since about 1980 (Lobon-Cervia 1999; Dekker et al. 2003; ICES 2005). Recruitment indicators include fishery-dependent data (mostly glass eel landings) and fishery-independent data. Catch per unit effort (CPUE) is generally a better indicator of abundance than harvest data (Gascuel et al. 1995; but see Briand et al. 2003). However, CPUE series for glass eels are rare. The Gironde Basin in western France is the only European location where three different metiers are used to fish glass eels and where data that enable calculation of CPUE are recorded. Using data from CEMAGREF's GIRPECH database (Castelnaud et al. 2001), we estimated fisheries indicators over the period 1978–1999 for professional and nonprofessional fishermen by classical methods and by general linear models (GLM). We

[1]Corresponding author: laurent.beaulaton@onema.fr
[*]Current address: Office National de l'Eau et des Milieux Aquatiques, Direction Scientifique et Technique, Immeuble Le Péricentre, 16, avenue Louison Bobet, 94132 Fontenay-sous-Bois Cedex, France

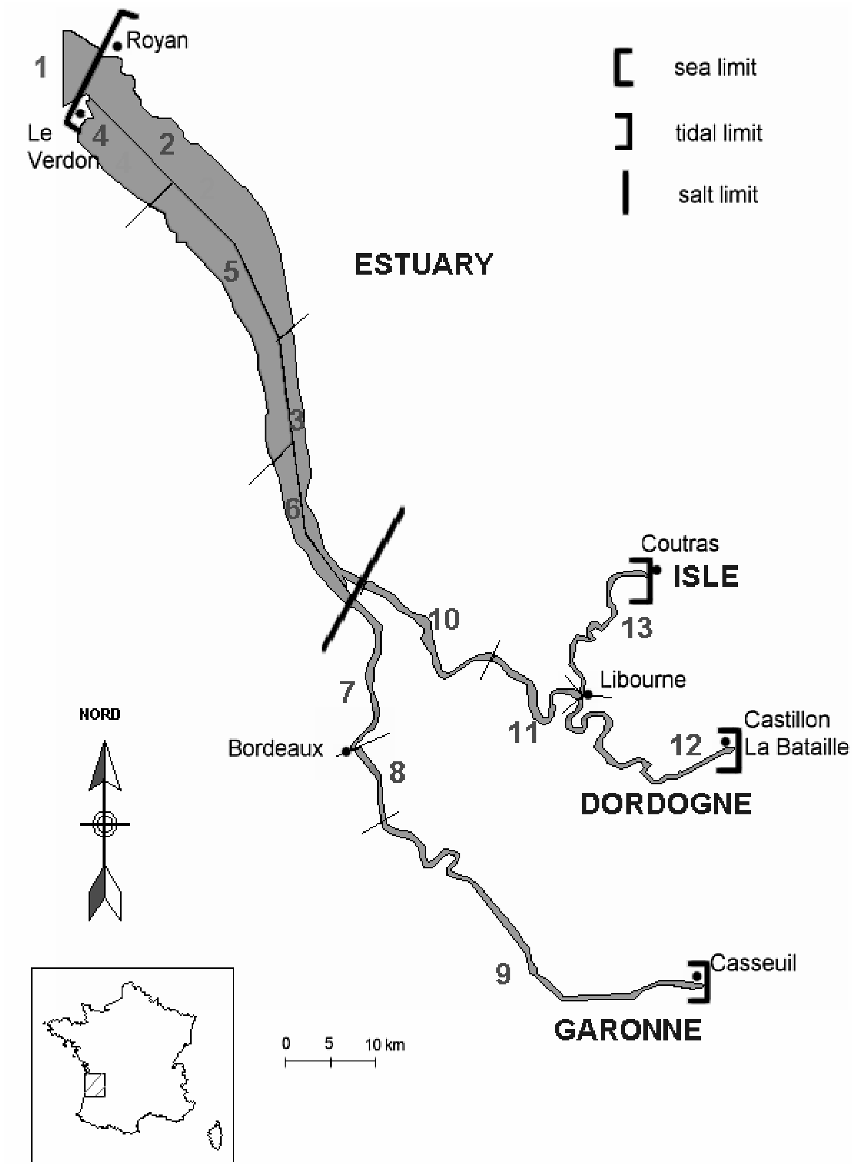


Figure 1. map of the Gironde basin and fishing zones (numbered).

then compared the ability of these two approaches to indicate trends in glass eel recruitment reliably.

Description of Glass Eel Fishing

Study Area

The Gironde Basin (Figure 1), as described by Castelnaud et al. (2001), is the lower part of the Garonne Basin, including the tidal part of the Dordogne and Garonne rivers and their common estuary. The basin stretches about 160 km inland from the Atlantic Ocean and is divided into 13 fishing zones, grouped into three compartments: the Estuary, made up of zones 2–6 (73 km); the Garonne, zones 7–9 (85 km); and the Dordogne, zones 10–13 (75 km). The Garonne and the Dordogne (which includes the lower Isle River) compartments are freshwater but tidal.

Glass Eel Fishing

Glass eels are targeted in the study area by professional fishermen who are officially permitted to sell their catch, and by nonprofessional fishermen (recreational anglers and poachers), who lack authorization to sell. In the tidal river compartments (zones 7–13), professional and nonprofessional fishermen use scoop nets, and beginning January 1996, professionals use small push nets. In the estuary (zones 2–6), professionals use large push nets.

Fishing with Scoop Nets

The scoop net, called *tamis* in France, is the traditional device used for glass eel fishing. It is a large round or oval landing net that is deployed from a boat close to the river's edge by professional fishermen or on shore by nonprofessionals. Fishing typically starts at the beginning of the flood tide and finishes two hours after the beginning of the ebb tide. This fishery is carried out exclusively at night, using a lamp and by making slow movements with the net against the current to catch the eels (Rochard 1992; Girardin et al. 2004).

For professional fishermen, the maximum size permitted is 1.2 m diameter and 1.3 m deep. Maximum diameter and depth are 0.5 m for nonprofessionals. Mesh size varies but is usually 1.5 mm (Girardin et al. 2004). Fishing is allowed in the tidal river compartments from 15 November to 15 April for professionals and from 1 December to 15 April for nonprofessionals. The fishery is closed between 1800 hours on Saturdays and 0600 hours on Mondays.

Fishing with Large Push Nets

This method, called *pibalour* in France, consists of pushing two nets with rigid rectangular frames against the current. The frames are placed either at the front or at the sides of a boat. Regulations limit the number of frames to two, the surface area of nets to 7 m^2, boats to 10 gross registered metric tons, and engine power to 60 hp. There is no regulation on mesh size, and the fishermen use a mesh size of 2–4 mm at the opening of the net and 1–2 mm at the end (Rochard 1992). Fishing takes place mainly during flood tide. This technique is permitted in the estuary from 15 November to 31 March. In March, the fishery is closed between 1800 hours on Saturdays and 0600 hours on Mondays.

Fishing with Small Push Nets

This fishing technique, called *drossage* in France, is similar to the large push net. Two circular nets, 1.2 m in diameter, are mounted on the sides of the boat. The net must not be more than 1.3 m deep. Boats must be under 8 m in length, with maximum engine power of 100 hp but throttled back to 60 hp. The season runs from 15 November to 15 April and is closed between 1800 hours on Saturdays and 0600 hours on Mondays. The small push net fishery is permitted only in the tidal river compartments. It was first authorized in January 1996.

Monitoring the Fishery

Since 1977, CEMAGREF has monitored the glass eel fishery through a sample of cooperating professional fishermen (see Castelnaud et al. 2001). Composition of the sample fluctuates from one season to the next. We set up the "GIRPECH" database in 1994 to compile and verify historic fisheries data and as a repository for new data (Castelnaud et al. 2001). Catch data were collected yearly by visiting each fisherman individually. Data were recorded at the best precision available (by tide or by day) but sometimes the fishermen give us only aggregated data by 2-week periods, by month, or by season. The fishing zone was identified and data were classified into two levels of quality according to data reliability and whether effort data were included. Quality 1 represents data of the better quality. We recorded total number of active fishermen for each zone and each métier from information coming from administrative agencies, fishermen's organizations, and cooperating fishermen. This data gave us nominal effort and were used to scale up from our sample to the whole population. Cooperating fishermen represented 13% and 5%, respectively, of the whole population of large push net and scoop net fishermen in the 1980s and 22% and 20% in the 1990s. For small push nets, our sample represented 28% of the whole population of small push net fishermen.

The glass eel fishing season, which usually runs from November to April, will be referred to by the year of the second part of the season (e.g., the season from November 1998 to April 1999 is termed the 1999 season).

Analysis

Classical Method

As in Castelnaud et al. (2001), the classical theory of stratified sampling (Cochran 1977) was used to calculate total seasonal catch and effort for each métier. Mean catch and mean effective effort per zone (or group of zones) and per métier were calculated for each season using data of both quality levels from our sample of cooperating fishermen. Total catch and total effective effort were calculated for each zone (group of zones) and each métier by multiplying mean catch and effective effort by the nominal effort (total number of active fishermen) per zone and métier. Summed total catch and total effort per zone (group of zones) gave total catch and effort for the entire Gironde Basin, for each métier, and for the whole population of fishermen. All of these calculations were accompanied by the calculation of 95% confidence intervals. Catches are reported in metric tons, and the unit of effort is one day's fishing. The three métiers are treated separately in both classical and GLM (see below) analyses because there is no equivalence among units of effort. The stratification into "zone" was not used for a given season unless zone means differed (empty intersection of confidence intervals for the zones). Not all zone stratifications were investigated, since these data have been analyzed elsewhere (Girardin et al. 2004). We thus determined that:

For the large push net métier, only zone 3 had significant differences in catch and effort compared with other estuary zones; and

For the scoop net and the small push net métier, Garonne and the Dordogne compartment had significant differences in catch and effort.

Following Castelnaud et al. (1994), we assumed that nonprofessionals in the tidal river compartments had similar scoop net mean catches and mean efforts as professionals. Thus we used professional mean catches and effort and total number of active nonprofessionals to estimate total catches and effort of nonprofessionals.

We assumed that the system under study met the requirements of homogeneity and independence needed to consider that CPUE is proportional to abundance (Beverton and Holt 1957; Gulland 1969; Ricker 1975; Kleiber and Perrin 1991).

To calculate seasonal CPUEs for the three métiers, no other stratification was applied. We simply used a mean of the CPUE per cooperating fisherman, using only data of quality 1. The CPUE for a fisherman is defined as total catch divided by total effort for the season. We did not estimate CPUE for nonprofessional fishermen because we had no direct data from this category.

GLM method

Presentation of the Model

To maximize proportionality between CPUE and abundance, we used a GLM to correct distortions of catch and effort data from our nonrandom sample of cooperating fishermen.

The use of GLMs is common in fisheries science (examples in Castelnaud et al. 2001). The GLM procedure in SAS software (SAS 2000) was used to carry out this analysis.

GLMs are a generalization of traditional linear models and account for variation in observations (here, CPUE) by the addition of effects (McCullagh and Nelder 1989). We used a logarithmic transformation to give positive predicted values and to stabilize the variance (Legendre and Legendre 1979; Castelnaud et al. 2001). Before taking the logarithm, we added 1 to the CPUE (Dekker 1998; Castelnaud et al. 2001) to avoid the problem of zero catches, which would give nil CPUEs for which the logarithm could not be calculated. The constant of 1 was chosen so that only the positive part of the logarithmic function was used. We tested the normality of residuals (an assumption of the GLM procedure) with a Kolmogorov-Smirnov test using the capability procedure in SAS.

Presentation of the Effects

We tested different effects, as well as combinations of these effects. For brevity, we present only the model that was selected on the basis of biological and statistical significance. Other tested models gave similar results.

Tested effects were:

Season—for estimating interseasonal changes in abundance;

Tide month—for estimating within-season changes in abundance, based on the tidal calendar. See details below;

Tide—for estimation of changes in abundance within the tidal cycle. See details below;

Fisherman—to account for variation in fishing skill among fishermen;

Season × tide month interaction – to represent variation in seasonality.

The selected model is expressed as:

$$\ln (\text{CPUE} + 1) = \text{season} + \text{tide month} + \text{tide} + \text{fisherman} + \text{season} \times \text{tide month} + \text{error}$$

Detail of the Tide Month Effect

The French Marine Hydrographic and Oceanographic Service predicts tidal coefficients, which are the differences in height between high tide and low tide, on an arbitrary scale from 20 to 120. High coefficients correspond to a spring tide (mean 95) and low ones to a neap tide (mean 45). The tide-month effect was added to analyze intraseasonal changes. A tide half-month is the interval between two minimum tide coefficients (i.e., between two neap tides). A tide month is a succession of two tide half-months (Figure 2).

We used tidal rather than calendar months because glass eel movements are tidally influenced (Lowe 1950; Martin 1995; Jessop 2003). One tide month thus includes all the phases of the tide (spring tide, neap tide, etc.).

The number of days in a tide month varies between 27 and 30 (mean 28.5). Tide month 1 began with the first neap tide in October and ended before the official opening of the fishing season on 15 November. This ensured that the entire fishing season was covered. Since there were only 13 catch data points in tide month 1 during the study years, we did

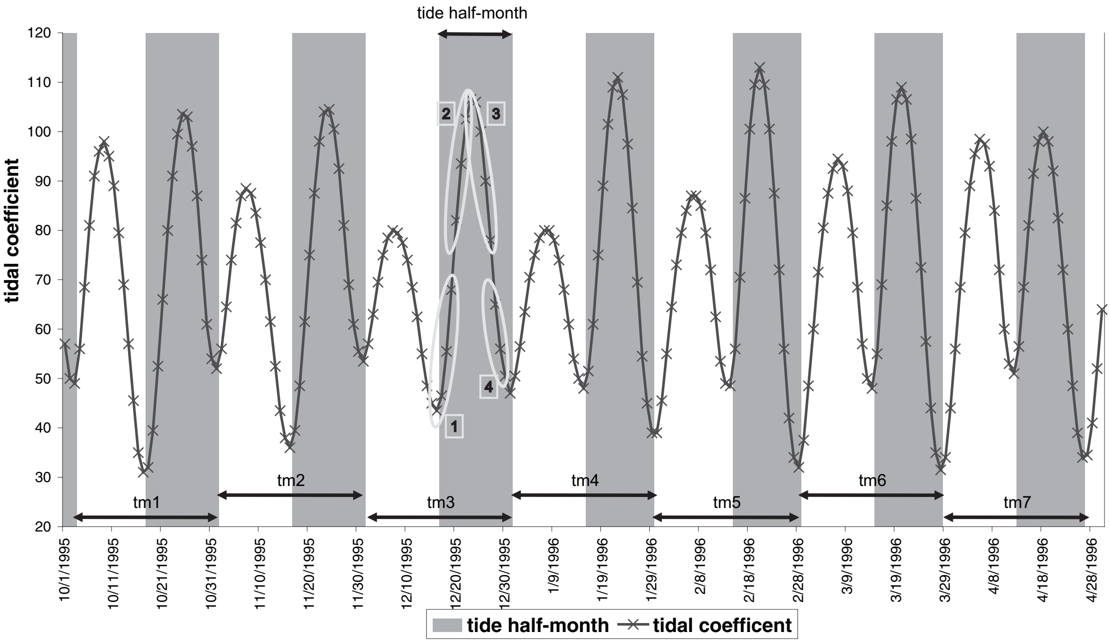


Figure 2. The 1996 glass eel fishing season, divided into tide half-months according to tide coefficients. One gray bar and one white bar form a tide month ("tm x": tide month x). The ovals group days by tide phase (see details of the tide effect in the text).

Table 1. Earliest, mean, and latest dates of the beginning of tide months.

	Date of beginning of tide month							
	1	2	3	4	5	6	7	End of 7
Earliest	2/10	28/10	23/11	27/12	23/01	25/02	25/03	22/04
Mean	5/10	3/11	3/12	2/01	1/02	2/03	31/03	27/04
Latest	12/10	10/11	11/12	10/01	9/02	10/03	8/04	30/04

not use data from this tide month.

Note that this type of division does not follow the civil calendar (Table 1). For example, the closing of the large push net fishing season (31 March) comes either at the end of tide month 6 or at the beginning of tide month 7, depending on the season.

Detail of the Tide Effect

The tide effect is based on a breakdown of a tide half-month into four parts (Figure 2).

1. First half of rising coefficients.
2. Second half of rising coefficients.
3. First half of falling coefficients.
4. Second half of falling coefficients.

Data Used

Only quality 1 data with effort specification per day or per tide (see Methods) were used in analyses. Since small push nets came into use only recently, GLM was applied only to the large push net and scoop net metiers. Catch per unit effort was calculated per day or per tide, per cooperating fisherman and per zone.

Relevance of the Model

The model was evaluated as follows:

The adjusted coefficient of determination indicated the strength of the model;

Fisher tests indicated the significance of the model and its effects; and

Kolmogorov-Smirnov tests evaluated the normality of residuals.

Estimating CPUE Per Season and Per Tide Month

Once we had evaluated the different effects, it was possible to calculate mean CPUE per season by adding the effects of a given season and the arithmetical means of the other effects. In the same way, to calculate mean CPUE per tide month, we added the effect of a given tide month to the arithmetical means of the other effects. The lsmeans procedure in SAS was used to carry out this function (SAS 2000).

Comparison of the Two Methods

In theory, all metiers in the fishery should give the same assessment of the abundance of stocks (Chadwick and O'Boyle 1990). In order to test this hypothesis, we regressed the large push net CPUE against the scoop net CPUE, as estimated using the classical method and by GLM. We used the SAS reg procedure (SAS 2000). The regression was expressed as large push net = $a \times$ scoop net + b, where the constant b was kept only if it was significant at the 5% level (student test). We used a student test to judge the significance of the model, and the coefficient of determination (R^2) was computed.

Using the same approach, we regressed CPUE calculated using the classical method against CPUE based on GLM for each métier to examine the effect of calculation method on the CPUE series.

Results

Classical Method: Estimate of Catch, Effort, and CPUE

Total catch by professionals using large push nets fluctuated between 14 and 50 mt from 1978 to 1999 (Table 2; Figure 3). Two effort phases were evident. From 1978–1988, about 40 nominal fishermen exerted about 2,500 effective days of effort annually; from 1989 to 1999, about 70 nominal fishermen exerted about 5,000 d annually (Table 3). The increase in effort corresponded with a sudden increase in the price of glass eels. CPUE fell by half between 1978 and 1984 (mean 15.5 kg/d) and between 1985 and 1999 (mean 7.7 kg/d). Since 1985, CPUEs have more or less stabilized around 6–7 kg/d.

For professionals using scoop nets, effort decreased at least 90% and catch decreased at least 99% between 1978 and 1981 and between 1996 and 1999 (Tables 2 and 3). For CPUE, there was a major drop between 1981 and 1982, followed by relative stability (1978–1981: 20.7 kg/d; 1982–1999: 4.7 kg/d). Scoop net catches prior to 1996 are similar to summed professional catches by small push nets and by scoop nets after 1996. Moreover, scoop net catches have dropped considerably since 1996. Thus the introduction of small push nets does not seem to have produced an overall increase in glass eel harvest in the tidal river compartments.

Total catches by all fishermen were high at the beginning of the study period, with a mean of 289.1 mt between 1978 and 1981 and a peak of 430 mt in 1980 (Table 2).

Table 2. Total catches (metric tons) and CPUE (kg/boat/day, by classic and GLM methods) by professional (PRO) and non-professional (non-PRO) fishermen in the Gironde basin between 1978 and 1999. x = stratification into zones was used for this season (see Methods).

Season	Large push net - PRO			Scoop net				Small push net		Total
	Landings	CPUE		PRO			Non-PRO	PRO		landings
	(t)	Classical	GLM	Landings	CPUE		Landings	Landings	CPUE	(t)
				(t)	Classical	GLM	(t)	(t)	Classical	
1978	26.7	12.8	10.3	83.3	16.5	6.8	107.8			217.8
1979	28.0	14.0	10.0	89.7	15.5	6.6	116.2			234.0
1980	45.8	25.4	17.8	167.3	27.1	9.0	217.1			430.2
1981	45.5	14.9	9.5	78.3 x	23.5	7.2	150.6			274.4
1982	49.6	10.9	8.4	36.6	6.3	4.6	36.5			122.8
1983	49.5	12.7	9.0	25.8	5.2	4.6	26.9			102.2
1984	30.5	17.6	9.6	26.0	5.5	5.4	26.0			82.6
1985	16.3	8.1	5.4	11.7	3.6	2.0	11.8			39.8
1986	26.3	8.8	5.6	13.6	5.4	6.1	14.4			54.3
1987	31.9	13.5	4.3	25.0	8.0	3.4	28.6			85.5
1988	25.4	9.3	4.7	6.7	4.6	3.1	6.7			38.9
1989	37.5	7.1	4.3	15.6 x	7.4	2.6	17.3			70.5
1990	28.6	5.6	3.7	8.6	3.0	1.2	9.0			46.2
1991	36.0	8.5	4.4	9.6 x	4.6	0.9	14.5			60.0
1992	17.0	4.5	2.6	8.0	4.3	1.7	12.8			37.8
1993	29.6 x	8.9	4.9	11.6	5.4	3.2	21.7			62.9
1994	34.6 x	9.2	5.3	6.5	4.2	2.3	12.4			53.5
1995	47.5	7.9	4.4	9.6	3.7	2.5	18.9			75.9
1996	21.4 x	4.7	3.4	1.5	2.3	1.6	4.2	2.2	1.8	29.4
1997	33.0 x	6.3	3.4	3.6	7.3	2.3	6.4	7.9 x	3.3	50.9
1998	14.1 x	3.8	2.7	0.4	0.7	1.2	1.0	1.7	1.4	17.2
1999	40.6	8.9	4.0	0.8	1.7	1.6	2.7	7.5 x	2.2	51.6

Catches halved after 1982 and then dropped below 100 t in 1984, with a mean for 1984–1999 of 53.6 t. Nonprofessionals made an important contribution to total catches, particularly in the 1980s. Catches by large push nets (professionals only) were fairly stable compared with the scoop net metiers.

For all metiers and categories of fishermen, confidence intervals are relatively wide until the end of the 1980s and narrower in the 1990s. This is due to the small number of cooperating fishermen during the first-decade period and high variability among fishermen.

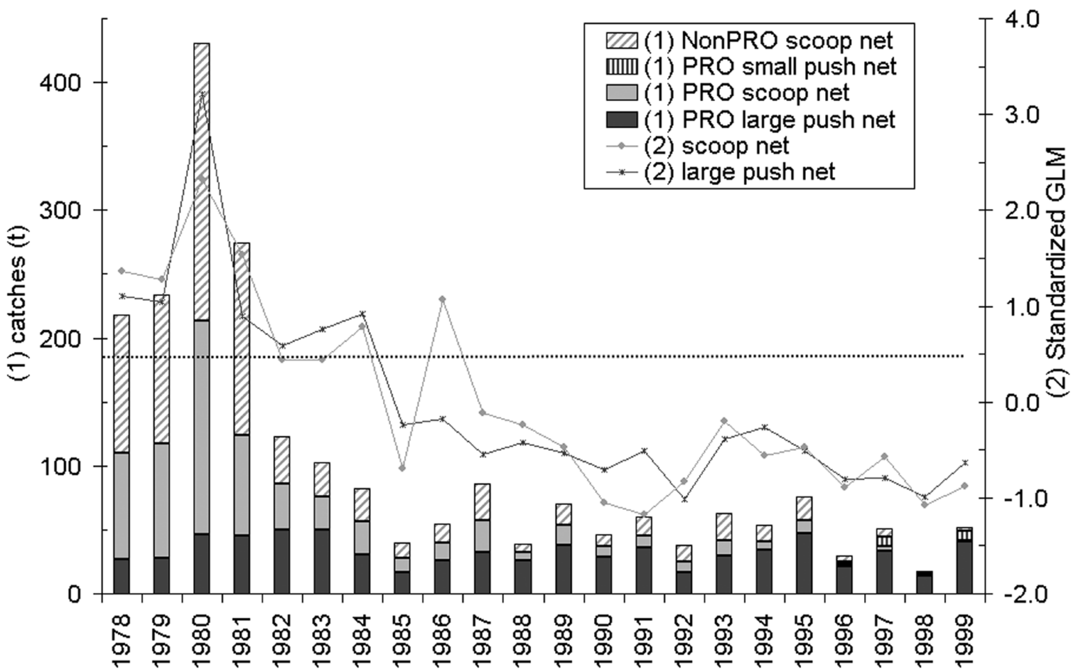


Figure 3. Total catches for the three metiers and standardized CPUE (from GLM) for the large push net and the scoop net métiers.

GLM Method: Estimate of the CPUE

Indicators of the appropriateness of the GLM model for large push nets and for scoop nets are presented in Table 4. The GLM has few degrees of freedom (1% for the large push net métier and 4% for the scoop net métier), thus being parsimonious (for a definition of parsimony, see Johnson and Omland 2004). The coefficients of determination (R^2 and adjusted R^2) for both métiers are about 45%. The model and the various effects are all highly significant, with P-values < 0.0001. However, the residuals are not normal.

For both métiers, we observed high CPUEs at the beginning of the study period (1978–1984 mean: 10.6 kg/d for the large push net métier and 6.3 kg/d for the scoop net metier; Table 2 and Figure 3). Since 1985, CPUEs have decreased by factors of 2–3 and have fluctuated around a low level (1985–1999 mean: 4.2 kg/d for the large push net metier and 2.4 kg/d for the scoop net metier). The scoop net CPUE calculated by GLM showed a peak in 1986 that did not appear in the scoop net CPUE calculated by the classical method or in the large push net CPUEs. The GLM method requires more accurate data than the classical method; as a consequence, the data from only one fisherman, who appears to be particularly efficient, was used in 1986. Thus this peak probably corresponds to a sampling problem rather than a true peak in CPUE. Also, we note peaks in classical CPUEs in 1987 for the large push net and the scoop net metiers, but none in GLM-based CPUEs (Table 2). One particularly efficient large push net fisherman was added to the sample in this season. If we recalculate CPUE for 1987 by the classical method with this fisherman excluded, the peak disappears and the curve looks much like that obtained by GLM. For the scoop net métier, if we consider only the two fishermen (whose performance was only average) common to seasons 1986,

Table 3. Estimated nominal (number of active fishermen) and effective (number of days) fishing effort on glass eels by professional (PRO) and non-professional (non-PRO) fishermen in the Gironde basin between 1978 and 1999. x = stratification into zones was used for this season (see Methods).

Season	Large push net - PRO		Scoop net			Small push net - PRO		Total
			PRO		Non-PRO			
	Nominal fishermen	Effective days	Nominal fishermen	Effective days	Nominal fishermen	Nominal fishermen	Effective days	nominal fishermen
1978	41	1558	285	5919	369			695
1979	41	2132	285	5680	369			695
1980	41	3116	285	6918	370			696
1981	41	2798	285	6477	370			696
1982	41	3311	265	6161	264			570
1983	40	3760	226	6683	235			501
1984	40	2960	194	4882	194			428
1985	40	1710	192	3328	194			426
1986	40	2467	189	2961	200			429
1987	40	2280	157	3585	180			377
1988	40	2538	160	1728	160			360
1989	65	5128	122	2760	127			314
1990	66	5102	117	3089	123			306
1991	67	4909	93	3298	135			295
1992	66	4563	85	2696	135			286
1993	64	4296	76	2275	142			282
1994	64	4518	76	2064	144			284
1995	73	5783	72	2750	142			287
1996	66	4838 x	48	853	130	42	1293	286
1997	75	6122	64	818	116	65	3058 x	320
1998	76	5238	44	537	104	58	1255	282
1999	74	4688 x	25	450	87	74	3399	260

Table 4. GLM model parameters for large push net and scoop net CPUE

	Degrees of freedom		R^2	R^2 adjusted	Significance (F test)		Normality of residuals
	Model	total			Model	Effects	Kolmogorov-Smirnov test
Large push net	145	14783	45.3%	44.8%	<0.0001	all <0.0001	<0.01
Scoop net	138	3237	45.5%	43.1%	<0.0001	all <0.0001	<0.01

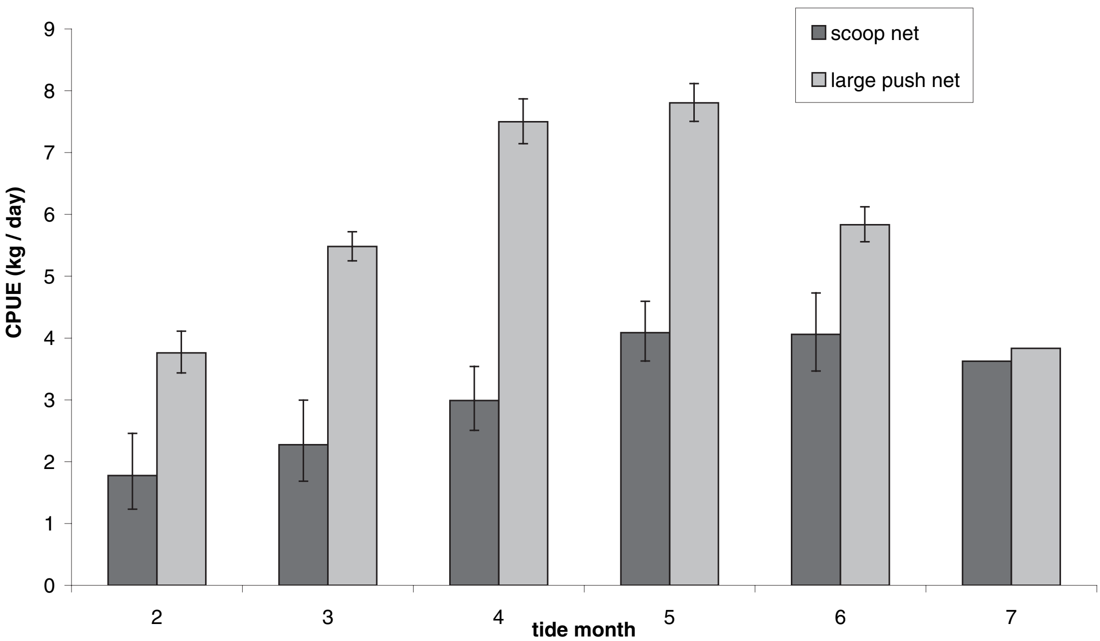


Figure 4. CPUE per tide month for the large push net and scoop net métier. Vertical bars represent confidence intervals.

1987, and 1988, then the 1987 season does not present a peak either.

Catch per unit effort per tide month for the large push net and the scoop net métiers followed a Gaussian curve (Figure 4). Large push net CPUE peaked in mid-season (period 4/5, end January/beginning February). Scoop net CPUE peaked near the end of the season (period 5/6 or end February/beginning March).

The GLM for both large push nets and scoop nets indicated that CPUE was strongest during Phase 3 (first half of falling coefficient; see Methods), followed by Phases 2 and 4. CPUE was lowest in Phase 1. The variation of predicted CPUE due to tide effect is less important than the variation due to other effects.

Comparison of the Classical Method and the GLM method

Regression analysis revealed significant relations between scoop net and large push net CPUEs using both methods (Table 5 and Figure 5). The R^2 for the GLM CPUEs (81%

Table 5. Characteristics of regressions relating large push net CPUE to scoop net CPUE using classical and GLM methods.

	Equation for the model	Significance (P>F)	R²	Adjusted R²	P Y-intercept
method	Large push net = 0.5605 x sccop net + 5.9305	<0.0001	60.85%	58.90%	<0.0001
GLM	Large push net = 1.4029 x sccop net + 1.1704	<0.0001	80.52%	79.55%	0.0908
GLM	Large push net = 1.6361 x sccop net	<0.0001	94.61%	94.35%	/

with *y*-intercept) was stronger than the R^2 for the classical CPUEs (61% with *y*-intercept). Moreover, the presence of a *y*-intercept in the classical regression indicates a bias in the relation between CPUEs of both métiers calculated using by this method. The CPUEs for the two métiers thus seem to demonstrate the same trend, which reflects abundance.

The fact that there is a stronger and unbiased relationship between scoop net CPUE and large push net CPUE with GLM suggests that the GLM method is more efficient at indicating glass eel abundance trends.

Regression analysis revealed significant relations between CPUE calculated using the classical method and GLM for both métiers (Table 6 and Figure 6). The R^2 for large push net CPUEs (86% with *y*-intercept) was stronger than the R^2 for the scoop net CPUEs (72% with *y*-intercept). Moreover, the presence of a *y*-intercept in the scoop net CPUE regression indicates a bias in the relation between CPUEs of both methods calculated for this metier. The relation between CPUEs calculated using both methods appears to be stronger for large push nets than for scoop nets.

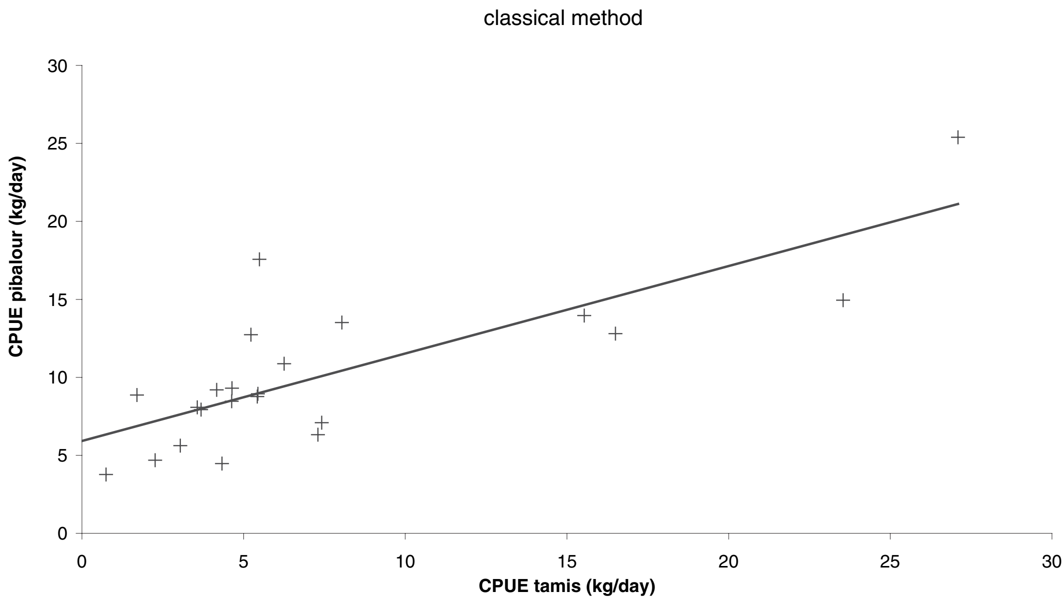
Discussion

All estimates were made with data supplied by a nonrandom sample of cooperating fishermen, whose composition varied among seasons. Major variations in catch and effort can be observed among fishermen. Consequently the estimate depends to a great extent on the sample of cooperating fishermen, which has to be representative, and on the quality of their data, which must be accurate. We note that for stratification by zone, CEMAGREF attempted to recruit during each season and for each zone the maximum number of fishermen disposed to cooperate and to report data of good quality.

Classical Method

Catch and effort estimates highlight a major shift in the Gironde fishery. In the early 1980s, the scoop net fishery in the tidal river compartment was the main source of landings. As the scoop net fishery rapidly decreased, the large push net fishery in the estuary became the principal fishery. This change was mainly due to a drastic decrease in the number of scoop net fishermen and their landings (decrease >90%) in the tidal river compartment while the number of large push nets doubled and their landings in the estuary remained stable.

Catch and effort indicators allow us to place CPUEs (calculated from samples) in their contexts (entire fisheries) and prevent misinterpretation of CPUE due, for example, to a short-term change in effort. We found a decrease in abundance, given the relative uni-



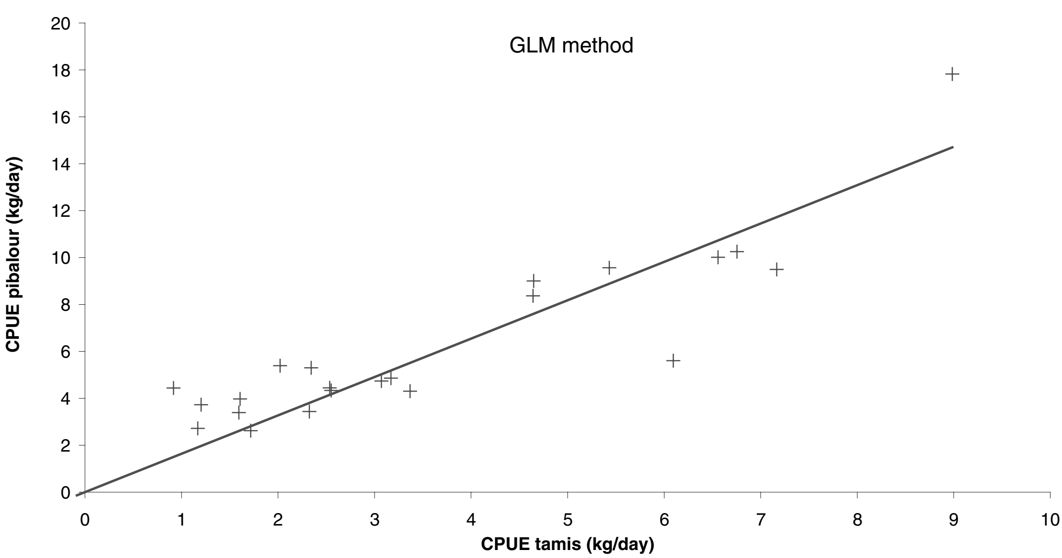


Figure 5. Regression between the scoop net CPUE and large push net CPUE calculated using the classical method (top) and GLM method (bottom)

Table 6. Characteristics of regressions relating CPUE using classical method to CPUE using GLM for large push net and scoop net.

Metier	Equation for the model	Significance ($P>F$)	R^2	Adjusted R^2	P Y-intercept
large push net	GLM = 0.6735 x class.− 0.5796	<0.0001	86%	85%	0.4072
large push net	GLM = 0.6270 x class.	<0.0001	97%	96%	/
scoop net	GLM = 0.2842 x class. −1.4898	<0.0001	72%	71%	0.0013

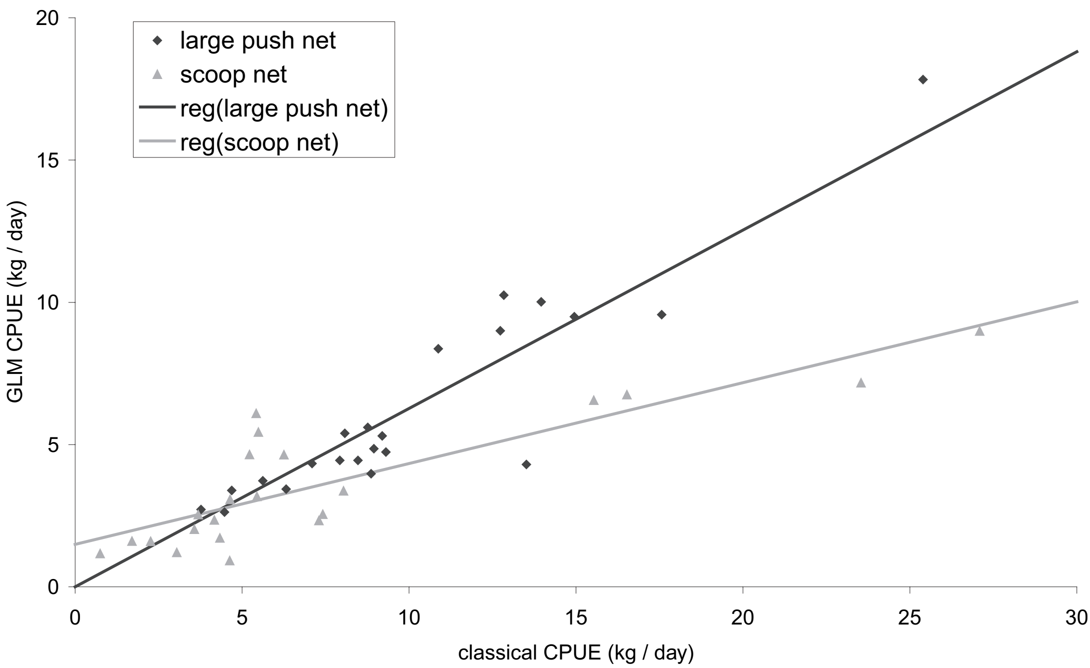


Figure 6. Regression between CPUE calculated using the classical method and CPUE calculated using GLM method for large push net and the scoop net.

formity of large push net catches, while effort increased, and a similar marked drop in scoop net catches while effort decreased, but more slowly than catch. The fisheries indicators of the different métiers thus lead us to conclude a drop in glass eel abundance over the past 20 years.

The introduction of the small push net métier in the tidal river compartments in 1996 did not enable professional fishermen to increase their CPUE or even to maintain their total landings (scoop net + small push net) in the tidal river compartment. The same observation was made on the Adour Basin after the introduction of small push nets there in 1995 (Prouzet et al. 2000).

Rough estimates of catch and effective effort by nonprofessionals show that this category had a high level of fishing pressure at least during the 1980s. The marked decrease in their catches after 1995 is associated with the emergence of the small push net métier. According to fishermen, small push nets tend to disperse the glass eels, making them less accessible to scoop nets. This mainly affects nonprofessional scoop net fishermen because professional scoop net fishermen didn't fish in these zones before the introduction of the small push net. Another explanation may come from the way nonprofessional catches are estimated with the mean catches of professionals with the scoop net métier. In fact, more and more professional fishermen are abandoning scoop nets in favor of small push nets. Those who fish with scoop nets often do so as a complement to the small push net métier and not as an entirely separate métier, as was the case before 1996.

GLM Method

The adjusted coefficients of determination (around 45%) remain acceptable, since they fall within the limits stated by Goni et al. (1999). Compared with reports they quote, our study contains a relatively large quantity of data, especially for the large push net metier (>14,000 data points).

The model respects Sparre's "good" model criteria (1985, in Brêthes 1990). Indeed, it was suitable for both major metiers because it is relatively simple, the parameters are easy to interpret, and it uses already existing data.

The residuals in the GLM model are not normal, mainly because of extreme values. However, linear models are fairly robust in the face of deviations from the normality assumption (SAS 2000), especially when the residuals reveal an absence of plurimodality (Castelnaud et al. 2001). Moreover, the model and effects are highly significant.

Our main reason for using the GLM method was to correct for fluctuations in the sample of cooperating fishermen, a difficulty also encountered in an earlier study on migration of spawning allice shad *Alosa alosa* (Castelnaud et al. 2001) The GLM approach is relatively efficient for this exercise. For example, the peak in 1987, caused by data from one fisherman, disappears with the GLM method. General linear models also have limitations. It requires catch per day or per tide, to permit analysis of tide effects. In the 1986 season, only a single scoop net fisherman provided data that met this criterion. If, in 1986, this single fisherman had had larger catches than his average for other seasons, he would have artificially swelled the CPUE for that season. The fisherman effect assigns a constant productivity to each fisherman from one season to another, which, in reality, is inexact. Variations exist for all the cooperating fishermen and for all seasons (acquired experience, new equipment, etc.), but when the sample size is large, these epiphenomena are averaged out.

A relaxation of data-acceptance criteria would permit the use of a larger amount of data. If the tide effect was set aside and the tide month effect was replaced by calendar month, then landings and effort by calendar month, which are recorded, could be used at the expense of a less detailed analysis of factors influencing CPUE.

Gascuel et al. (1995) showed that in the case of symmetrical or asymmetrical intra-seasonal CPUE curves, and in contrast to plateau curves, which represent an equilibrium between catch and the arrival of the glass eels, the use of CPUE as an abundance index is valid. The curves showing the tide month effect (Figure 4) are symmetrical for the large push net metier and asymmetrical for the scoop net metier. This supports the validity of glass eel CPUE in the Gironde as an abundance index.

Comparison of the Classical Method and the GLM Method

There is a strong linear relationship between CPUE for the two major métiers. The relation is better and more unbiased with the GLM-based CPUE than with the classical CPUE, which demonstrates the advantage of the GLM approach. Fishing with large push nets does not therefore appear to distort to any great extent the glass eel abundance signal that is transmitted to the scoop net fishery upstream. Two perhaps complementary hypotheses can be put forward: first, large push net effort is relatively constant throughout and between seasons; and second, this type of fishing takes too few glass eels to modify the glass eel abundance signal.

The relation between CPUE calculated by the classical method and the GLM method is better and less biased for large push nets than for scoop nets. This indicates that GLM makes fewer corrections for large push net data than for scoop net data. Our sample of fishermen using large push nets thus seems to be less subject to fluctuation than those using scoop nets.

We conclude that the most reliable and meaningful abundance series in the Gironde Basin is the large push net CPUE calculated using GLM.

Glass Eel Abundance Trends in the Gironde Basin

The glass eel abundance trend in the Gironde Basin reported herein corresponds to the decline in eel populations observed elsewhere in France (Guerault and Desaunay 1989; Castelnaud et al. 1994; Prouzet et al. 2000) and across Europe (ICES 2003; Dekker 1998, 2000; Dekker et al. 2003). All note a sharp drop at the beginning of the 1980s. The particular feature of our study is that the trend is confirmed by two métiers in the same river basin.

Conclusion

We demonstrate that estimates of catch, effort, and CPUE for two métiers (large push net, scoop net) converged to indicate a major drop in glass eel abundance. Catches with large push nets remained relatively stable while effort doubled and, in the same period, catches and effort with scoop nets decreased considerably. This induced a major shift from a scoop net-dominated fishery to a large push net-dominated fishery.

The GLM models were clearly suited to calculating CPUE: they enabled us to correct sampling variations and produced estimates that agreed with classical CPUEs. Abundance decreased two- to threefold between 1980 and 1985 in both métiers and then fluctuated with no consistent trend until 1999. The GLM approach requires catch data with effort recorded per day or per tide and in sufficient quantities to permit inclusion of effects such as tides.

This study confirms that, after a considerable drop in the 1980s, glass eel abundance is now in a period of stagnation at a low level, with no signs of an upturn. The eel population needs a global restoration plan as stated by the EIFAC/ICES working group on eels. Since the glass eel fishery contributes to eel mortality, our findings imply that current regulations should be strictly applied (i.e., illegal fishing should be suppressed) while new restrictions are necessary for all categories of fishermen (e.g., season, size of gear, closed zones).

Acknowledgments

We thank Pierre Dumont and Guy Verreault for their support and Yves Le Gat, Eric Rochard, Paul Gonthier, and Patrick Lambert for their help and advice.

References

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Her Majesty's Stationery Office, London.

Brêthes, J. C. 1990. Le processsus d'évaluation des stocks. Pages 17–30 *in* J. C. Brêthes, and R. N. O'Boyle, editors. Méthodes d'évaluation des stocks halieutiques. Centre International d'Exploitation des Océans, Québec.

Briand, C., D. Fatin, G. Fontenelle, and E. Feunteun. 2003. Estuarine and fluvial recruitment of European glass eel in an Atlantic exploited estuary. Fisheries Management and Ecology 10:377–384.

Castelnaud, G. 2000. Localisation de la pêche, effectifs de pêcheurs et production des espèces amphihalines dans les fleuves français. Bulletin Français de la Pêche et de la Pisciculture 357/358:439–460.

Castelnaud, G., D. Guerault, Y. Desaunay, and P. Élie. 1994. Production et abondance de la civelle en France au début des années 90. Bulletin Français de la Pêche et de la Pisciculture 335:263–287.

Castelnaud, G., E. Rochard, and Y. Le Gat. 2001. Analyse de la tendance de l'abondance de l'alose *Alosa alosa* en Gironde à partir de l'estimation d'indicateurs halieutiques sur la période 1977–1998. Bulletin Français de la Pêche et de la Pisciculture 362/363:989–1015.

Chadwick, M., and R. N. O'Boyle. 1990. L'analyse des données de capture et d'effort. Pages 77–101 *in* J. C. Brêthes and R. N. O'Boyle, editors. Méthodes d'évaluation des stocks halieutiques. Centre International d'Exploitation des Océans, Québec.

Cochran, W. G. 1977. Sampling techniques, 3rd edition, Wiley, New York.

Dekker, W. 1998. Long-term trends in the glass eels immigrating at Den Oever, the Netherlands. Bulletin Français de la Pêche et de la Pisciculture 349:199–214.

Dekker, W. 2000. The fractal geometry of the European eel stock. ICES Journal of Marine Science 57:109–121.

Dekker, W., J. M. Casselman, D. K. Cairns, K. Tsukamoto, D. J. Jellyman, and H. Lickers. 2003. Worldwide decline of eel resources necessitates immediate action. Fisheries 28(12):28–30.

Gascuel, D., E. Feunteun, and G. Fontenelle. 1995. Seasonal dynamics of estuarine migration in glass eels (*Anguilla anguilla*). Aquatic Living Resources 8:123–133.

Girardin, M., G. Castelnaud, and L. Beaulaton. 2004. Surveillance halieutique de l'estuaire de la Gironde - suivi des captures 2002 - étude de la faune circulante 2003. Rapport pour EDF CNPE du Blayais, étude n°91, CEMAGREF groupement de Bordeaux, Cestas, France.

Goni, R., F. Alvarez, and S. Adlerstein. 1999. Application of generalized linear modeling to catch rate analysis of Western Mediterranean fisheries: the Castellon trawl fleet as a case study. Fisheries Research 42:291–302.

Guerault, D., and Y. Desaunay. 1989. Evolution de l'abondance de la civelle (*Anguilla anguilla*) dans les estuaires de la Loire et de la Vilaine (France) 1977–1988. Pages 1–8 and annexes in EIFAC Working Party on Eel, 1989, Porto, Portugal.

Gulland, J. A. 1969. Manuel d'évaluation des stocks d'animaux aquatiques. Première partie—analyse des populations. FAO, Manuel FAO de science halieutique no 4, Rome.

ICES (International Council for the Exploration of the Sea). 2003. Report of the ICES/EIFAC Working Group on Eels. ICES CM 2003/ACFM:06, Copenhagen.

ICES. 2005. Report of the ICES/EIFAC Working Group on Eels. ICES CM 2005/I:01, Copenhagen.

Jessop, B. M. 2003. Annual variability in the effects of water temperature, discharge, and tidal stage on the migration of American eel elvers from estuary to river. Pages 3–16 *in* D. A. Dixon, editor. Biology, management, and protection of catadromous eels. American Fisheries Society, Symposium 33, Bethesda, Maryland.

Johnson, J. B., and K. S. Omland. 2004. Model selection in ecology and evolution. Trends in Ecology and Evolution 19:101–108.

Kleiber, P., and C. Perrin. 1991. Catch-per-effort and stock status in the U.S. North Pacific albacore fishery: reappraisal of both. Fishery Bulletin 89:379–385.

Legendre, L., and P. Legendre. 1979. Ecologie numérique: Tome 1: le traitement multiple des données écologiques. Masson, Collection d'écologie no 12, Paris.

Lobon-Cervia, J. 1999. The decline of eel *Anguilla anguilla* (L.) in a river catchment of northern Spain 1986–1997. Further evidence for a critical status of eel in Iberian waters. Archiv Fur Hydrobiologie 144:245–253.

Lowe, R. H. 1950. Factors influencing the runs of elvers in the river Bann, Northern Ireland. Journal du Conseil International pour l'Exploration de la Mer 17:299–315.

Martin, M. H. 1995. The effects of temperature, river flow, and tidal cycles on the onset of glass eel and elver migration into fresh water in the American eel. Journal of Fish Biology 46:891–902.

McCullagh, P., and J. A. Nelder. 1989. Generalized linear models. Chapman and Hall, London.

Prouzet, P., F. Sanchez, M. N. De Casamajor, N. Bru, and R. Drouilhet. 2000. Impact de la pratique du tamis poussé en zone maritime de l'Adour sur l'abondance des civelles et sur leur pêche. IFREMER, St-Pée sur Nivelle, France.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin, no. 191.

Rochard, E. 1992. Mise au point d'une méthode de suivi de l'abondance des amphihalins dans le système fluvio-estuarien de la Gironde, application à l'étude écobiologique de l'esturgeon *Acipenser sturio.* Thèse de doctorat, Université de Rennes, France.

SAS. 2000. SAS OnlineDoc, Version 8. SAS Institute Inc.