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By-catch of juvenile flounder, *Platichthys flesus* L. 1758, in the glass-eel fishery of the Loire Estuary, France

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Abstract

By-catch of 0-group flounder, *Platichthys flesus* L. 1758, in the Loire glass-eel fishery was estimated for 1987 and 1988. Samples were taken throughout the estuary but the by-catch mainly occurred in the Central area. This pattern was observed in both surveys despite different hydrological conditions. The overall by-catch was 41 million animals for 1987 and 7 million for 1988. This difference was not only a consequence of a lowered fishing effort, it also suggests a difference in year-class strength. Because of the great variability of postlarval distribution the accuracy of the estimates was very poor and only orders of magnitude can be discussed.

Keywords : Flounder, *Platichthys flesus*, by-catch, juvenile, glass-eel, *Anguilla anguilla*, Loire, estuary.

Les prises accessoires de flets, Platichthys flesus *L.* 1758, *occasionnées par la pêche de la civelle en Loire, France.*

Résumé

L'analyse quantitative des destructions de flets, *Platichthys flesus* L. 1758, occasionnées par la pêche de civelles de Loire a été réalisée en 1987 et 1988. L'échantillonnage a concerné toute la pêcherie bien que les captures de flets soient surtout concentrées dans la partie centrale de l'estuaire. Cette répartition est observée en 1987 comme en 1988 dans un contexte hydrologique pourtant différent. L'estimation des captures totales représente 41 millions d'individus en 1987 et 7 millions en 1988. Cette différence n'est pas seulement due à la diminution de l'effort de pêche, elle indique aussi une différence d'abondance des classes d'âge de chaque année. A cause de la forte variabilité associée à la distribution des postlarves, la précision des résultats est faible et seuls les ordres de grandeurs pourront être comparés.

Mots-clés : Flet, *Platichthys flesus*, prises accessoires, juvénile, civelle, *Anguilla anguilla*, Loire, estuaire.

INTRODUCTION

In the Loire Estuary (northern Bay of Biscay, France), a general study of the effect of human activities on juvenile fish was carried out (Robin, 1988). The aim of the program was to compare fish mortality related to small mesh fisheries and to industrial water intake at the Cordemais Power Station. It focused on two estuarine species: smelt, *Osmerus eperlanus* L., and flounder, *Platichthys flesus* L. For these species, the main characteristics of Loire populations were described by Lardeux (1986) and Masson (1987).

Fishing for glass-eel (*Anguilla anguilla* L., postlarvae) takes place in the estuaries of the European

Atlantic coast from the Severn Estuary (UK) to Portugal. At this stage of its life cycle this species has a very high commercial value. The migration of glass-eel from the continental shelf to inland waters has been known for a long time (Schmidt, 1906; Gandolfi-Hornyold, 1936 and Elie, 1979). However, studies of the consequence of glass-eel fishing on estuarine communities are more recent (Gascuel *et al.*, 1983; Weber, 1987). In his survey of the by-catch of french glass-eel fisheries, Gascuel (1985) analysed some samples from the Loire. He observed that flounder larvae and juveniles entered the estuary in late winter and were caught by the end of the fishing season. Smelt larvae arrived later in this area and were not caught.

This study is the first assessment of the number of flounder killed by glass-eel fishing. On-board observations were carried out at the end of two fishing seasons (1987 and 1988), when flounders represent the bulk of the by-catch. They were combined with fishing effort and glass-eel production (data analysed by Guérault and Desaunay, IFREMER laboratory, Nantes, France).

METHODS

For both fishing seasons, 1987 and 1988, a sampling program was carried out in order to estimate the number of flounder caught during each year. However, the observations from the first season were used in 1988 to improve the sampling strategy (*i.e.* number and distribution of the samples).

Planning the sampling distribution in time and space was linked to the available data on fishing effort and glass-eel production. Elementary units for sampling and fishing effort were "one-night-at-sea" and for production of a kilogram of glass-eel.

Characteristics of the glass-eel fishery

In the Loire estuary, fishing for glass-eel takes place from St-Nazaire to Thouaré (66 km away from St-Nazaire, *fig.* 1). During the winter about 290 fishing boats fish with 2 tow-nets with a 1.2 m diameter and a 1.5 mm mesh at the cod-end. Engine power is limited to 100 horsepower. Fishing is done at night during the flood-tide. Flood tides are shorter in the upper reaches of the estuary and when the river is in spate.

From the juridical point of view, fishing in the estuary is overseen by two services (Affaires Maritimes and Ministère de l'Environnement) which divide the fishery into 3 parts with different regulations. This is summarized in *table* 1.

The end of the fishing season changes from year to year. Fishermen ask for extentions of the fishing period when they have not been able to fish within the usual time. Ordinary ends are April the 15th in the Marine part and March the 15th in the other parts.

In the assessment of glass-eel production, Guérault and Desaunay used the same 3 geographical divisions. The fishing season was also divided into fortnight periods. The whole fishery was then considered as a set of strata determined by time and space divisions. The size of each stratum depends on the production (or fishing effort) from one part of the estuary during a fortnight.

Since observations of the by-catch have to be combined with this data, the planning of on-board sampling must use the same time-and-space stratification. In *tables* 4-6 the strata are identified with a code of two letters and four figures (*e.g.* "MA0203" stands for the Marine part in the second fortnight of March.)

On-board sampling technique

All boats used the same fishing gear and sorting out technique. The catch was placed on a grid covering a fish-well. Only glass-eel crawled through it and then all the by-catch was collected and fixed in approximately 10% formalin. Fish were identified and counted in the laboratory. On-board observations were ordinary fishing trips: fishermen were free to choose their route and way of working. Thanks to the fishermen, scientists were accepted on board; they were allowed to watch but always were observers. Without an observer, the by-catch was returned to sea at the end of the fishing trip. Resistant fish like eel, "more-than-one-year old" grey mullet or flounder can survive but larvae and juvenile fish die.

Data processing

After each on-board observation, a set of parameters was recorded including the weight of glass-eel and the number of flounder caught per trip.

The aim of this work was to compute the overall number of flounder caught per year by the whole fishery. As this impact on young fish has to be compared with the effect of other human activities, it was necessary to compute confidence limits of the estimates. Given the estimate Y, the precision on Y is: $(t\sqrt{s^2(\bar{Y})})/\mathrm{Y}$. The Student "*t*" was used according to the number of samples or, in stratified sampling, using Satterthwaite's formula (in Cochran, 1977).

The notations and formulae used in the by-catch computation are given in *table* 2. They take into account the following problems.

Underestimation of the by-catch

In the first survey (1987), the fishing time and catch of glass-eel were significantly smaller in the trips studied than in the average fishery trip. This difference was not related to the fact that scientists were on-board but to the sampling frequency. With two samples per fornight in each area, we studied one

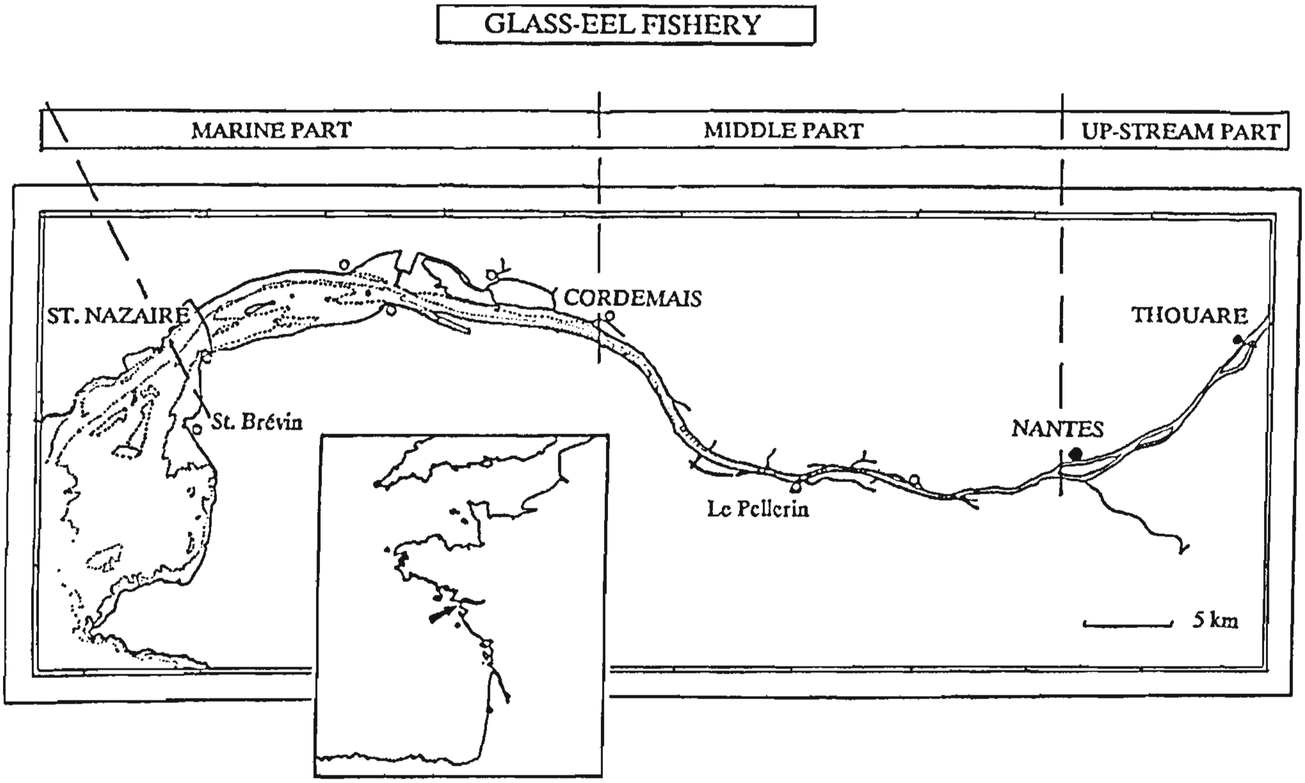

Figure 1. — The Loire Estuary and different parts of the fishing area.

Table 1. — Fishing seasons in the different parts of the estuary.

Area	Limits (and distances from the sea)			Fishing seasons
Marine	St-Nazaire	→	Cordemais	Dec. 15th 1986-May 1st 1987
	0	→	26 km	Dec. 15th 1987-April 15th 1988
Middle	Cordemais	→	Nantes	Dec. 15th 1986-April 15th 1987
	26	→	52 km	
Up-stream	Nantes	→	Thouaré	Dec. 15th 1987-April 15th 1988
	52	→	66 km	

trip in a spring tide and one in a neap tide. This did not correspond to the fishermen's activity: they go fishing more often in the spring tides when floods last longer and yields are better. This characteristic of the fishery was taken into account in the second survey. Nevertheless, for the first year we had to develop a calculation that would not underestimate the by-catch.

Instead of using the mean by-catch per fishing trip (combined with the number of trips in each stratum) we used an auxiliary variate in a ratio-estimate. The fishing time was correlated to the catch of glass-eel ($r^2=0.55$ with 22 degrees of freedom), so the production of one stratum could indicate the fishing time for all the boats. In this case, the studied trips gave a ratio estimate of the by-catch: the number of flounder caught per kilogram of glass-eel. For a given period, we assume that there is a positive relationship between fishing time (or catch of glass-eel) and catch of flounder. We could not check it because the relationship changes with the season's time (*i.e.* before versus after larvae entered the estuary).

The usual ratio estimate $R_1=\bar{y}/\bar{x}$ had a bias of order $1/n$. This was a problem in stratified sampling with very few samples per stratum. In order to realize the consequence of this bias on the final computation we computed the unbiased ratio-estimate (R_2) described by Hartley and Ross (1954). These authors do not provide an estimate of the variance for their ratio so we only give the variance of R^1 (according to

Table 2. – Notations and formulae used in computation of the by-catch.

The fishery is divided into a set of strata determined by time and space limits.

The suffix h denotes the stratum and i the fishing trip within the stratum.

y_{hi} = by-catch of the ith trip in the stratum h (number of flounder).

x_{hi} = catch of glass-eel of the ith trip in the stratum h (weight in kilogrammes).

n_h = number of studied trips in the stratum h.

$R_{1h} = \bar{y}_h / \bar{x}_h$ by-catch per kilogramme of glass-eel.

$s^2(R_{1h})$ = estimated variance of R_{1h}

$$s^2(R_{1h}) = \frac{(1-f_h)}{n_h \bar{x}_h^2} \frac{\sum_{i=1}^{nh} (y_{hi} - R_{1h} x_{hi})^2}{(n_h - 1)}$$

R_{2h} = unbiased ratio estimate (Hartley and Ross, 1954).

$$R_{2h} = r_h + \frac{n_h (N_h - 1)}{(n_h - 1) N_h X_h} (\bar{y}_h - r_h \bar{x}_h)$$

where

$$r_h = \frac{1}{n_h} \sum_{i=1}^{n_h} \left(\frac{y_{hi}}{x_{hi}} \right)$$

X_h = glass-eel production of the stratum h.

N_h = number of fishing trips of the stratum h.

Y_{1h} = by-catch of flounder of the stratum h.

$$Y_{1h} = R_{1h} X_h$$

$$s^2(Y_{1h}) = s^2(R_{1h}) s^2(X_h) + x_h s^2(R_{1h}) + R_{1h} s^2(X_{1h})$$

Y = total by-catch of flounder.

$$Y = \sum (Y_{1h})$$

estimated variance of Y:

$$s^2(Y) = \sum (s^2(Y_{1h}))$$

Cochran, 1977) and confidence limits of the results calculated with R_1.

Stratum size

In both surveys, the stratum size (determined from the production of glass-eel in each stratum) was not known but estimated. Although this is not the usual case we consider that the bias due to errors in the stratum size was small. Cochran (1977) shows that the gain from stratification is preserved if sizes are estimated much more accurately than the variate itself. This was our case: productions (X_h) were estimated from large samples of commercial data, much more accurately than the by-catch per kg of glass-eel. However, errors in stratum size were taken into account in computation of the total by-catch variance per stratum ($Y_h = X_h R_{1h}$). Given X_h and R_{1h} two independent variates

$$s^2(Y_h) = s^2(X_h) s^2(R_{1h}) + X_h s^2(R_{1h}) + R_{1h} s^2(X_h).$$

Distribution of samples

In the first series of observations, 2 samples were taken from each stratum (*table* 3). Some preliminary observations were made in February but the complete survey of the whole fishing area was planned from March till the season's end (22 samples).

Because of other sampling programs being carried out as the same time it was not possible for us to markedly increase the number of "nights-at-sea". Nevertheless, we used the 1987 data to improve sampling distribution in the second survey. The optimal allocation of samples was computed so as to realize which of these parameters had the strongest influence on the total's variance:

- the size of the strata,
- the internal variability in each stratum.

In the optimum allocation, the number of samples per stratum was proportional to the product of the stratum's size and the variate's standard deviation:

$$n_h = N . \frac{N_h SD(R_{1h})}{\sum N_h SD(R_{1h})}$$

(with n_h = number of samples in stratum h; N = total number of samples; N_h = size of stratum h; $SD(R_{1h})$ = standard deviation of the ratio estimate R_1 for stratum h).

In all strata where the calculated n_h was less than 2 we chose 2 samples. The computation was done for a total of 30 samples.

This analysis was considered more as a guide for further sampling than a fixed data source. It underlines the high variability of the by-catch which seemed more important to take note of than the difference in sizes between the strata. *Table* 4 shows that 10 extra samples should be taken from the Middle area during the first fortnight of April (stratum MI0104). In practice this would not be possible but we tried to increase sample numbers as soon as flounder larvae were noticed. On the contrary, sampling was reduced before larvae arrived and in the up-stream area the whole month of March was considered as one stratum.

RESULTS

Year to year differences in the by-catch can depend on changes in fishing activity as well as changes in

Table 3. – Distribution of on-board observations in the two surveys (01 stands for the first fortnight of the month and 02 for the second).

Area	1987 February 01	February 02	March 01	March 02	April 01	April 02	Total
Marine	–	1	2	2	2	2	9
Middle	–	2	2	2	3	No	9
Up-stream	–	–	2	2	3	fishing	7

Area	1988 March 01	March 02	April 01	April 02	Total
Marine	2	3	3	End	8
Middle	2	2	5	of	9
Up-stream	1	2	2	fishing	5

Table 4. – Optimum allocation of 30 samples in the strata observed in 1987.

Stratum	Stratum size N_h	Standard deviation SD (R_{1h})	N_hSD (R_{1h})	Number of samples n_h
MA0103	1 239	0.07	90.7	2
MI0103	1 548	0.50	780.7	2
UP0103	790	0.00	0	2
MA0203	1 365	17.43	23 790.2	2
MI0203	1 095	10.41	11 395.4	2
UP0203	863	3.22	2 776.9	2
MA0104	568	695.65	395 131.2	2
MI0104	583	4 833.58	2 817 977.5	12
UP0104	241	159.72	38 491.5	2
MA0204	376	166.39	62 563.9	2
			3 352 998	30

the abundance of fish. The hydrological conditions in the estuary are the background to many of these changes and so they must be taken into account. As far as sampling strategy is concerned, the conditions of the first survey are only worth using in the following one if the two seasons look the same.

Hydrological conditions

Variations in river flow and water temperature (at the Cordemais Power Station) are shown in *figure* 2. January 1987 was so cold that ice blocks drifted all through the estuary. After this cold period, prolongations of the fishing season were conceded throughout the fishery. The next winter was not cold but the river was in spate so much that fishing in the upper reaches of the estuary was reduced. Cold temperatures of continental waters may not interfere with flounder reproduction, which takes place off the coast at 30-50 m depths. For the March-April period temperature regimes were very similar in both years. In late winter, the migration of the larvae towards coastal and fresh waters can be reduced by river flooding.

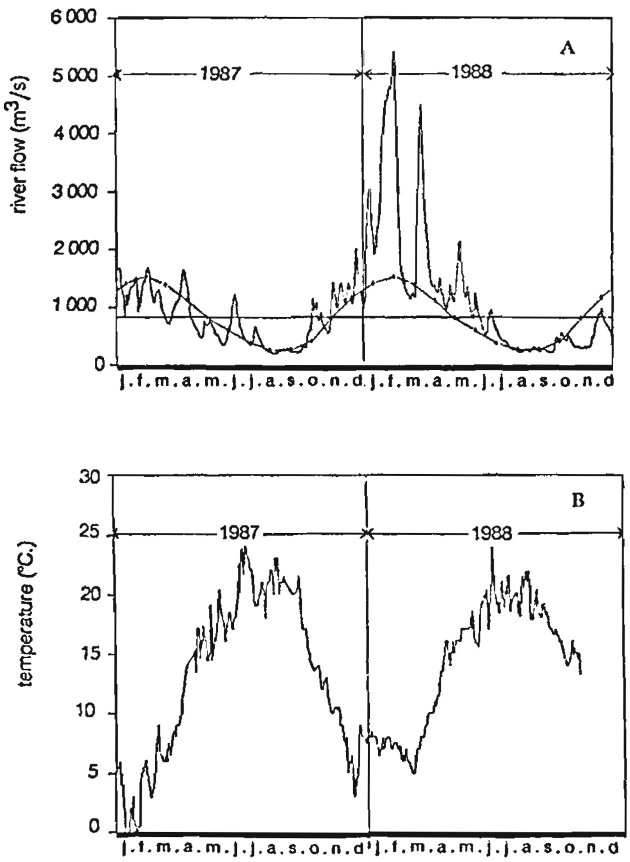

Figure 2. – Hydrological conditions during the 1987-1988 period: A = river flow, B = water temperature.

First year study (1987)

Fishing activity in the last part of the 1986-1987 fishing season and the corresponding by-catch of flounder is presented in *table* 5. From March until the end of the season, the fishing activity is very high: the glass-eel catch represented 70% of the total production. Nevertheless, fishing effort and yield

Table 5. — Fishing activity and flounder by-catch in 1987 (see *table* 2 for notations and formulae).

Stratum	Fishing trips N_h	Class-eel catch (kg) X_h	$s^2 (X_h)$	Studied trips n_h	Flounder catch per kg of glass-eel			By-catch per stratum		
					R_{1h}	R_{2h}	$s^2 (R_{1h})$	Y_{1h}	Y_{2h}	$s^2 (Y_{1h})$
MA0103	1 239	14 096	7.81×10^5	2	0.38	0.31	1×10^{-2}	5 344	4 383	2.9×10^5
MI0103	1 548	17 090	1.07×10^6	2	1.02	1.30	3×10^{-1}	17 507	22 251	9.0×10^7
UP0103	790	8 313	2.08×10^5	2	0	0	0	0	0	0
MA0203	1 365	12 272	9.82×10^5	2	27.49	31.36	3.16×10^2	337 312	384 862	4.9×10^{10}
MI0203	1 095	10 030	6.42×10^5	2	29.75	38.72	1.2×10^2	298 439	388 332	1.3×10^{10}
UP0203	863	8 453	2.17×10^5	2	7.21	5.34	1	60 940	45 114	8.4×10^7
MA0104	568	4 165	1.50×10^5	2	2 261	2 325	5.02×10^5	9 416 283	9 683 066	9.6×10^{12}
MI0104	583	3 100	6.37×10^4	3	9 508	11 710	1.52×10^7	29 475 728	36 299 577	1.5×10^{14}
UP0104	241	1 381	1.85×10^4	3	221	222	2.55×10^4	305 118	305 894	5.0×10^{10}
MA0204	376	3 485	4.28×10^5	2	209	202	2.79×10^4	727 425	704 128	3.7×10^{11}
	8 668	82 385						40 644 096	47 837 606	2.45×10^{14}

Precision (X) = 5.2%.

Overall catch of flounder = Y_1 = 40 644 096.

Degrees of freedom = 3.
Student t = 3.18.
Precision (Y_1) = 99.8%.

decreased before the end of the prolongations. The best yields probably occurred in March, and off-season observations showed that glass-eel were very scarce in May.

Some "more-than-one-year-old" flounders were caught at the beginning of March, but the by-catch increased numerically when the "0-group" juveniles entered the estuary (*i.e.*: by the third week in March). From then on, a few larvae were observed in the upstream part of the estuary, although the bulk of the by-catch came from the Middle area (stratum Mi0104: Middle part during the first fortnight of April). During the second fortnight of April the number of flounder caught in the Marine part decreased, which suggests that the arrival of the 1987 year-class was coming to an end.

The overall by-catch of flounder amounted to 47 million animals. Compared with other species (Guérault *et al.*, 1989) flounder represent 84% of the entire by-catch. This assessment is only an order of magnitude since the precision of Y is very bad (104%). This is not surprising if one considers that 75% of the flounder were caught in the same stratum (Mi0104); three samples from this stratum could not possibly be enough.

The two ratio estimates yield rather similar results. The bias of R_1 due to small samples does not seem to be a problem. Furthermore, ratio estimates have a smaller variance than the mean per unit.

Second year study (1988, *table* 6)

In 1988, fishing effort in the last part of the season was lower than in 1987 (5 307 nights at sea instead of 8 668). Results of the study period also represented a smaller part of the annual catch of glass-eel (only 26%). The best yields were observed earlier in the season, in February, and there was no extention of the fishing season in the Marine part of the fishery.

In 1988, "0-group" flounder entered the estuary only during the beginning of April. The high by-catch period lasted only a fortnight and the Middle part of the estuary was again the area where most flounder were caught (96%). Total by-catch of flounder amounted to 6.8 million animals. This estimation is still quite inaccurate (precision = 112%). In spite of this, it seems that the order of magnitude of the by-catch was substantially lower than in 1987. In 1988, the difference in glass-eel catch between the studied trips and all the fishery trips was no longer significant. The problem of underestimating the by-catch was reduced and the mean per unit (by-catch per fishing trip) combined with fishing effort yields 5.3 million flounder. Nevertheless, the variance of this estimate is twice as high as what it is with the ratio-estimate (Y_1).

Length and age characteristics of the flounder

In both surveys, some flounder were observed before the arrival of the "0-group" juveniles: 19 were measured in 1987 and 6 in 1988. Their size ranged from 7 to 20 cm which suggests that they were not more than 1 or 2 years old. At this time of the year most of the adults are still on the spawning grounds, off the estuary. Some of them may have come back since the beginning of April (Masson, 1987) but they are not caught by the glass-eel tow nets.

Since the end of March 1987 and since the beginning of April 1988, the number of "born-in-the-year" juveniles represent more than 99% of the flounder. Length frequencies of juveniles caught in the Marine part of the estuary are shown in *figure* 3. Metamorphosis occurs at lengths between 7 and 12 mm (Russel,

Table 6. – Fishing activity and flounder by-catch in 1988 (see *table* 2 for notations and formulae).

Stratum	Fishing trips N_h	Glass-eel catch (kg) X_h	$s^2(X_h)$	Studied trips n_h	Flounder catch per kg of glass-eel			By-catch per stratum		
					R_{1h}	R_{2h}	$s^2(R_{1h})$	Y_{1h}	Y_{2h}	$s^2(Y_{1h})$
MA0103	1665	15790	1.52×10^6	2	0.05	0.01	0	770	160	1.5×10^6
MI0103	980	5745	1.55×10^5	2	0	0	0	0	0	0
UP1203	692	5566	3.59×10^4	3	0.06	0.06	0	334	334	8.5×10^4
MA0203	648	3425	8.91×10^4	3	0.42	0.44	0.1	1442	1509	1.6×10^6
MI0203	517	4327	7.39×10^4	2	0	0	0	0	0	0
MA0104	197	898	2.10×10^4	3	197	198	1.2×10^3	177477	178040	1.8×10^9
MI0104	358	1469	2.18×10^4	5	4539	4481	3.9×10^6	6667689	6583238	9.1×10^{12}
UP0104	250	1026	7.74×10^3	2	0	0	0	0	0	0
	5307	38246						6847535	6763117	9.1×10^{12}

Precision (X) = 7.3%.

Overall catch of flounder = Y_1 = 6847535.

Degrees of freedom = 5.
Student t = 2.5.
Precision (Y_1) = 110%.

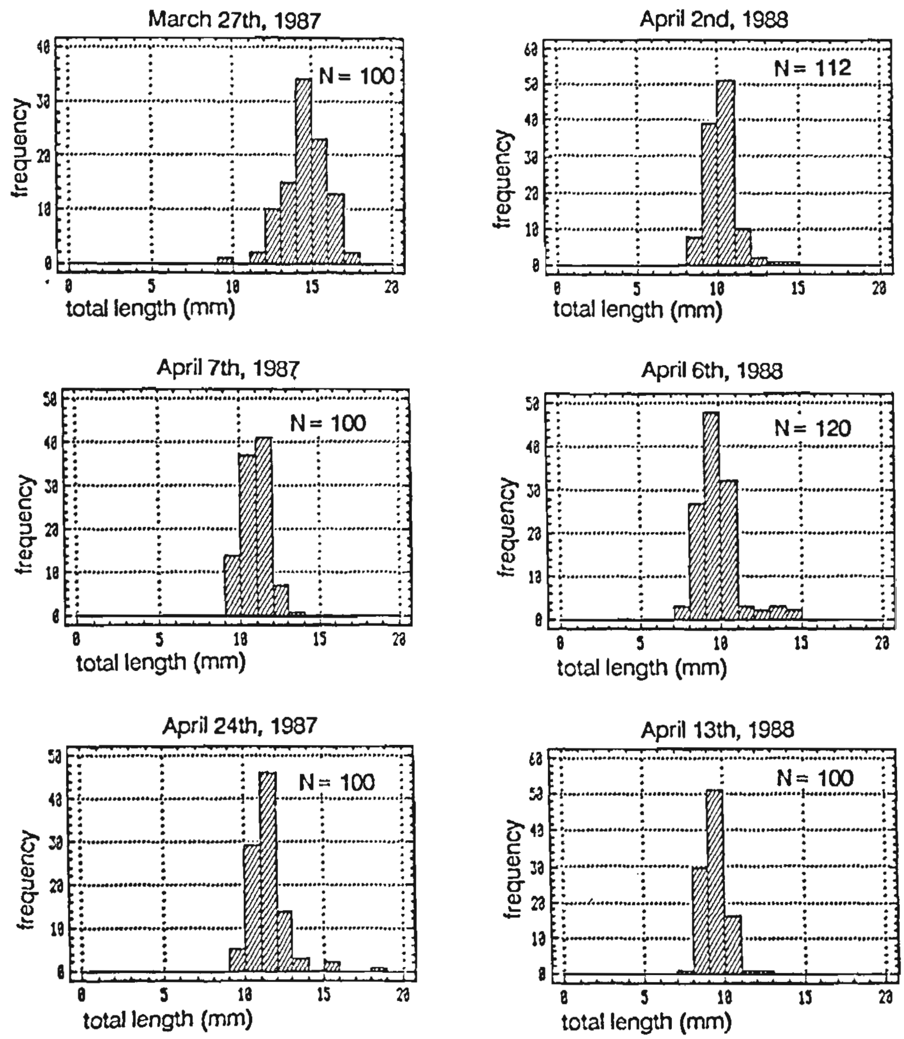

Figure 3. – Length frequencies for the "0-group" flounder caught in the Marine part of the fishery.

1976), and many fish entering the estuary are still at this stage of development. The first juveniles reaching the estuary seem to be larger, born earlier, than those coming later. This migration phenomenon is the reason why mean length in the samples does not increase.

Length distributions bring interesting information about year-to-year differences in early-life stages. Flounder larvae arrived later in 1988 than in 1987. The postlarvae of the 1988 cohort were also smaller in size than those of 1987. This suggests that spawning occurred later in 1988 than in 1987.

DISCUSSION

The evidence of a considerable by-catch of juvenile fish at the end of the glass-eel fishing season had already been observed by Gascuel (1985). In the past, the River Board used this argument, concerning the loss of young fish to bring the fishing season to a close. Masson (1986) observed the upstream migration of flounder in the Loire estuarine marches. Postlarvae swim near the surface and along the banks during the flood tide. Such behavior makes them very vulnerable to glass-eel fishing. However, this study is the first quantitative assessment of the effect of glass-eel fishing on flounder (the main by-catch species).

Flounder juveniles were observed, in 1987, in all parts of the fishery. Nevertheless, by-catch in the "upstream" part is small and more than 75% of the impact is in the Middle zone. The concentration of flounder postlarvae in this area is consistent, with the observations of Dando and Beverton (1988) on the narrow zonation of fish postlarvae. They describe very small areas, determined by bottom salinity, with high postlarvae density which can explain the great variability of the by-catch, even within this part of the estuary. We have no data about which parameter can explain the concentration of postlarvae in this part of the estuary (salinity or food availability). However, this pattern is typical of pelagic postlarvae: a few months later, juveniles have their nursery grounds on the mudflats in the Marine part of the estuary.

The overall by-catch of flounder was higher in 1987 than in 1988 (41 versus 7 million animals). This difference is likely to be more related to changes in the flounder recruitment than to the reduction of fishing effort. ("Recruitment" is used here in the meaning of "abundance at the age at which the fish enter the glass-eel fishery".) The "0-group" juveniles were more abundant in the estuary after a cold and dry winter than when the river was in spate. Nevertheless, larval migration may not have been over at the end of the 1988 fishing season: length frequencies suggest that spawning took place later in 1988 than in 1987.

The purpose of this study was to compute estimates of the by-catch which will have to be compared with other mortalities. Unfortunately, the variances of the estimates are very high and this analysis can only be developed within an order of magnitude of the results. A reason for this lack of accuracy is that there were not enough samples taken from the Middle area during the first fortnight of April. The optimal allocation showed that it would be a problem. Nevertheless, a more intensive sampling program had to be shared between the two impacts that were being studied at that time: the glass-eel fishery and the effect of the Cordemais Power Station intake.

With the data gathered here we did find some indications about changes in recruitment or year-class strength. We can ask if the glass-eel by-catch provides a recruitement index which is easy to handle. The overall by-catch was not suitable because it depends on the total fishing effort. Mean catch per fishing trip or per hour seems better although great variations of fishing effort can influence the catchability. Once again, the lack of accuracy of the estimates is the problem. A more intensive sampling of the Middle area is required; it may be considered to be too much work for a species of low commercial value like the flounder.

CONCLUSION

The first attempt to estimate the by-catch of flounder for the entire fishery developed sampling programs throughout the estuary. At the end of the fishing seasons between 41 and 7 million postlarvae were killed but the variability of the by-catch was so high that estimates can only be considered as orders of magnitude. However, the difference between the two surveys showed that flounder recruitment might have been lower in 1988. The flounder by-catch in the glass-eel fishery may provide information on year-class strength for this species. In order to improve the accuracy of the results we suggest to focus sampling on the "middle area" where 75 and 96% of the postlarvae were caught.

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