Push net fisheries are responsible for injuries and post fishing mortalities in glass eel (*Anguilla anguilla*).

Cédric Briand, Brice Sauvaget, Laurent Beaulaton, Patrick Girard, Véronique Véron, Denis Fatin.

Abstract

Post fishing mortalities of glass eels have been monitored in 2007 in the Vilaine estuary. The mortality of glass eel varied from 2 to 82% (mean 42%) in the two days following the fishery. The mortality of samples collected by hand nets or from the trapping ladder was null. Alterations of the skin mucus were analyzed by the used of indigo carmin. The mortality was significantly correlated with body injuries, but not to other environmental factor. The presence of a large hurt on the body always led to the death of glass eel, and among dead glass eels, only 3.5 % might have died of factors outside fishing conditions. These results are discussed, along with results from other estuaries, in the view of transporting glass eel across Europe, with the objective of restoring the eel stock.

Introduction

Three main markets have driven the development of the glass eel fisheries on the Atlantic coast of Europe. The export originally done towards Northern and Eastern Europe for restocking and Mexico for human consumption has shifted in the seventies to an export towards Spain, and then progressively towards Japan then China. This shift has been accompanied by a very large increase in prices. The value of glass eel has been multiplied a hundred folds since the 1970's (BRIAND *et al.*, 2008). It has also been accompanied by a slight but continuous increase in effort, mostly related to changes in fishing practices, to compensate for the reduction of abundance, which is now only at 5% of its 1970's value (ICES, 2008 in prep.). In the 1960's, in most estuaries of the Atlantic coast, push net fisheries (i.e. nets propelled on each side of a boat) have replaced the more traditional hand net fisheries (ELIE et FONTENELLE, 1982; CASTELNAUD *et al.*, 1994; CASTELNAUD *et al.*, 2000). These push net fisheries sometimes fish at large speed, with the glass eel being pressed in the deepest part of the net. Apart from the increase in fishing effort, push nets fisheries have two side effects. Firstly, the level of by-catches affects the nursery function of the estuaries (GASCUEL, 1985; ROBIN, 1990; ANTUNES et WEBER, 1996; SOBRINO *et al.*, 2005; GISBERT et LÓPEZ, 2008). Secondly, the speed and tow duration conditions are known to induce injuries, which might result in mortalities occurring mostly in the days following the fishery, and a lesser quality for the glass eel later sold for aquaculture or restocking purpose. The glass eel are treated by fish dealers to ensure that dying glass eels are removed from the holding tanks, and frozen to be later sold in the Spanish food market. A European regulation (COMMISSION OF THE EUROPEAN COMMUNITIES, 2005) uses the transport of glass eel towards Europe, as one of the possible strategies to rebuild the stock. In this context, the question of glass eel mortalities due to fishing practices becomes more important. When calculating the net effect of transport on the whole stock survival, the mortality induced during glass eel fishery and transport has to be accounted for. The objective of this work is to present the results of an experimental monitoring of glass eel mortalities after the fishery. The mortality rate is analyzed in relation to the loss of mucus, which is put forward by a new technique: the use of Indigo Carmin. The monitoring of mortality rates also aims at identifying if additional factors linked with the environment (temperature, flow) or the use of a dredge in the estuary are responsible for the large waves of mortality observed once every two or three years by the fish dealers.

Material and method

Site and fishing conditions.

Since the construction of the Arzal dam, the Vilaine estuary has been reduced from an initial length of 50 kilometers to 12 kilometers. Close to the dam, the tide ranges 6 m. The mean flow from December to March, the main period for glass eel migration varies from 100 to 200 $m^3.s^{-1}$ (2001-2004). The salinity in the estuary ranges from 35 ppt to full freshwater conditions during springtime floods.

The glass eel fishery takes place in a area delimited by the dam at the upper end and by a bend marking the enlargement of the estuary 1 km downstream (Figure 1). The fishing effort is very high, 130 boats are licensed for Fishing in the Vilaine estuary. Glass eels are fished at night from 6 p.m. to 8 a.m. and from three hours before high tide to one hour after. They are caught from boats equipped with circular nets of 1.2 m diameter propelled on each side. The nets can be pushed at the surface, but they are often mounted on perches which allow the boats to fish at the bottom near the dam (8 m). The fishery was stopped by the 11th of March in 2007.

The estuary is dredged from October 15th till March 15th, for tidal coefficients larger than 70 and from one hour before high tide to six hours after. The dredge uses rotating brushes to deepen or maintain navigable channels in the estuary. The dredge operates by putting the mud into suspension and letting it be carried away with tide currents. It intervenes 4.1 km from the fishery.

Experimental analysis of the effect of Indigo Carmin

The analysis of skin erosion by carmin-indigo was detected during the screening of various dyes for marking recapture experiment. Some glass eels collected by the fishery had tails that were colored in blue, hinting that this dye could detect skin injuries. To analyze the effect of the dye, 20 healthy glass eels collected at the trapping ladder were wiped from their mucus, and placed in carmin-indigo 0.5 $g.l^{-1}$ during half an hour, and then checked for marks. The same analysis was done on a control sample of 20 glass eels.

Mortality and fishing condition monitoring

The glass eel samples were collected in the Vilaine estuary in 2007 by three methods.

(1) On board of one fishing boat from December to February. The boat, typical of the fishery, was 9 m long, 75 horse powered, and equipped with two circular nets of 1.2 m of diameter (BRIAND *et al.*, 2003). The boat's fish tank, full of estuarine water renewed with the boat's pump, was covered by a grid allowing to separate living glass eel from floating remains, by-catch, and dead or dying glass eels (GASCUEL, 1987, Elie, 1979 #267). At the end of the fishery, samples were collected from that tank, excluding thus a part of the mortality. To observe the fishing conditions and count the glass eel remaining on the grid of the fish tank, an observer was present on board on Monday nights. Some samples were also collected without on board monitoring on Tuesday nights.

(2) In March, additional samplings were done in the sluice with a hand net.

(3) Finally some samples are collected in the holding tank of the trapping ladder. The ladder is made of two ramps equipped with tuffs of synthetic fibers, wetted by a gentle flow (BRIAND *et al.*, 2002). At the end of the upper ramp, the glass eel fall into a holding tank. The content of the tank was sorted to separate glass eel from yellow eel, and the glass eel were counted and weighted several times a week.

The same procedure was applied to each sample. Dead glass eels were counted and kept for analysis, while the living and dying glass eel, were placed in three replicate batches of about 50 glass eel. Each sample was kept in similar conditions in 7.5 liter aquaria filled with estuarine water of salinity varying from 1.5 to 7.5 ppt. The batches were then checked for mortality the next morning, some hours after the fishery and at regular interval during the two next days. The total mortality corresponds to the addition of in board mortality, initial mortality back from the fishery and mortality during monitoring.

Dead glass eels and the glass eels still alive at the end of the experiment were treated with Carmin Indigo (0.5 $g.l^{-1}$, 30 minutes). The location (dorsal, ventral, tail) and intensity of the mark was recorded. The scale for intensity of ventral and dorsal areas varied from 0 (no marks), 1 some marks, 2 marks covering large areas. For the tail, only the class 0 (absence and 2 (presence) was used as narrow range of the location studied prevented to judge for the intensity of marking.

Pigment stage monitoring and residency duration

Pigments stages were analyzed on freshly collected glass eel using ELIE *et al.* (1982). The duration of stages has been modeled according to pigmentation time which is a transformed value of daily temperature and salinities in the estuary (BRIAND *et al.*, 2005). Using this model, the cumulated pigmentation time was back calculated from the date of sample collection. We then used the gamma curves used to simulate stage transition against pigment time to calculate the date corresponding to the median of the distribution for each stage. For instance, the median of the gamma curve simulating the passage from V_B to VI_{A0} could have been calculated four days before the sampling date. So a stage VI_{A0} would “on average” have remained four days in the estuary. We then calculated the mean date of arrival which corresponds to the weighted mean using the proportion in each stage.

Statistical analysis

The low number of observations of the level of mortality did not enable a full testing of the effect of environmental variables or fishing conditions on the level of mortality. The mean value of environmental conditions was calculated according to the mean residency duration in estuary calculated from pigment stages. For instance it was averaged on three days if the mean residency was three days. The correlation was analyzed between cumulated mortality rates and temperature, tide, flow, number of hour of dredging, fishing speed, fishing duration, level of catch. The influence of the fishery was analyzed as the correlation between the percentage of injured glass eel and the total mortality.

Results

Experimental analysis of indigo-carmin

The glass eel wiped from their mucus presented various intensities of blue color on the skin and dyed quickly, while the untouched ones remain living and transparent (Figure 2).

Fishing conditions

Ten samples came from trips monitored on board, and two additional samples were gathered from other fishing nights where no observer was present. All samples were collected at regular interval from 05 December to the 22 February. For the fishing monitored on board, the catch per night varied from 0.3 to 3.4 kg (total 13.5 kg). The mean trait duration per trip was eleven to thirty minutes. The boat speed varied from 1.39 to 1.59 $m.s^{-1}$. The fishing depth was either at 0.5 m near the surface or down to 2.5 to 6.5 m.

Six samples have also been collected in the sluice from 5 March to 18 April, mostly after the fishing season which ended the 11th March. The net's speed was about three times lower than when towed from a boat and varied from 0.47 to 0.69 $m.s^{-1}$. The duration of a sampling trait was much shorter with hand net than with push net as it varied from 40 to 150 seconds. The catch varied from 60 g to 248g (total 1.173 kg).

Four samples have also been collected at the trapping ladder.

Pigmentation stages and residency

The pigment stages samples comprise mostly V_B and VI_{A0} stages at the beginning of the season and become more advanced as the fishery closes (Table 1). The mean residency calculated from the Briand et al., (2005) model varies from 3 days in December to 37 days (10 April). It is much lower during the fishing season (mean 5.2 days) than after (mean 15.3 days).

Mortality monitoring

Samples collected by the fishery

During the fishing period, the mortality recorded onboard had a mean value of 2% (min=0, max=6.7%, N=10). Back from the fishery, during the first sorting for dead glass eels, the mean initial mortality rate was 12% (min=0, max=36%, N=10). Combining the results of all replicates, the mean mortality after two days varied from 2 to 59% (mean 28%). The mortality lessened after the first day (Figure 4) and the hourly rate of mortality passed from 1.23% for the first 24 hours to 0.33% after one day and 0.08% after the second day. When we add to this value the initial mortality and the mortality recorded on board, the total morality varies from 2 to 82% (mean 42%).

Samples collected with hand nets and at the trapping ladder

The mortality after two days recorded from six samples fished with hand nets in the sluice is 0%. One glass eel dropped from the net has been unfortunately stepped on while emptying the net during the fishery.

The mortality after two days from four samples collected at the trapping ladder is 0% even though some have escaped the aquaria and spent the night on the table.

Analysis of skin erosion

A total of 2153 glass eels have been examined individually under the binocular, 1340 corresponding to glass collected by the fishery, 813 in the sluice.
Dorsal and Ventral injuries were dependent ($p<1$ e-16) i.e. they were often observed together on the same glass eels, as were body and tail marking ($p<1$ e-16). The dependence was also highly significant obtained when looking at dead glass eel and living glass eel separately (Figure 5). So the dorsal and ventral injuries were grouped as “body” injuries and analyzed for their relation to the tail injuries.

Among 1784 living glass eel, only 1 (0.05%) was heavily injured (mark=2) on the body, 120 (7%) had injuries at the tail, and 230 (13%) showed presence of a slight hurt on the body (mark=1).

Among 369 dead glass eels, there were a low proportion of glass eel dead without mark on the tail (6.7%, 25/369). Among those last, the proportion of dead glass eel without mark on the tail with large body injury (mark tail=0, body=2, 0.09%, 2/369) differed significantly from expected value indicating that glass eel injured on the body were almost always injured on the tail (Figure 6) . There was also a larger than expected proportion of glass eel that were dead without any external injury (mark tail=0 body =0, N=13, 3.5 % of dead glass eels, 0.7% of the total). For those few glass eel which stood apart, we can expect that the cause of mortality was different from skin erosion.

Statistical analysis

As the distribution of mortality differed from normality (Kolmogorov Smirnov, $p<0.01$), the correlation was analyzed using Spearman rho. The only significant correlation was found between total mortality and the % of injured glass eel (Spearman’s rho=0.76, p=0.04). The other correlation were not significant with the largest correlation being with the number of glass eel caught (rho=-0.52 p=0.12), the mean speed (rho=-0.41 p= 0.26) and the temperature (rho=-0.4, p=0.24). The other factors : tide, flow had correlations lower than 0.3. The mortality was not correlated with the number of hour of dredging (rho=0.27) and this conclusion wasn’t changed when using a constant duration of residency of 3 days instead of a calculation based on pigment stage structure.

Discussion

The monitoring shows that glass eel fished too long and at a too high speed die of mucus loss. This is clearly indicated by the following arguments (1) It is shown using Indigo Carmin that 97% of the dead glass eels have skin injury problems. The presence of large surfaces where the mucus has been removed on the body is almost always fatal, as indeed we only found one glass eel (0.05%) having survived with large injuries on the body. (2) The only factor significantly correlated with mortality rate is the level of skin injury. (3) Samples collected with hand nets or at the trapping ladder do not die. Moreover, some glass eel collected at the trapping ladder escaped from the aquaria, but didn't die even if they spent the night out of water on the table.

The mucus forms an epithelial barrier responsible for osmotic integrity, and healthy glass eels are perfectly adapted to cope with salinity variations (BIRRELL *et al.*, 2000; WILSON *et al.*, 2004; CREAN *et al.*, 2007). When injured, the mucus coating loose transparency

(BOCQUÉNÉ et MIOSSEC, 1986), the glass eel become atonic, and their inflated body reflects a massive water influx to the body. In general, for fisheries, the abrasive qualities of netting materials suggest that fish may sustain severe injuries during the tow, especially in the cod end where individuals are exhausted and crowded together (SUURONEN, 2005). This might especially be true for glass eels as the nylon nets used to catch glass eel are very abrasive. In addition to this abrasion, at the landing, glass eels are wiped of a part of their mucus before calculating their weight, as they are expensive material. Given the high concentration of boats near the dam, with a number close to a hundred when the fishery is at its bulk, it is also possible that some glass eel are hurt by the engine screws.

The loss of mucus, and injuries at the tail, add to the stress of towing and handling. The general stress increases oxygen consumption, and alters the osmotic ability through a cortisol release (MCCORMICK, 2001). This factor therefore adds to alteration the mucus coating which is an important factor in both gas exchange and osmotic integrity (TESCH, 2003).

For this reason the fish traders keep their glass eel in a hyper osmotic environment with large oxygen supply shortly after the fishery, and some fishermen fill their tanks with salt water.

Our monitoring also clearly shows that mortality is linked with injury at the tail, as about three quarter of the fishes injured at the tail die in the two days after fishing, and less than 1/15 of dead fishes aren't injured at the tail. In the extremity of the tail, a vascular system of ventricles and valves assists the blood circulation over the full length of the body (TESCH, 2003). Glass eel get caught (photo) at the outer opening of the net where the mesh size is generally 1.8mm to 2 mm. This kind of meshing sometimes leads to the rupture of the spine (LEROUX et GUIGUES, 2002). Many glass eel get their tail meshed in the deepest part of the net where the mesh size is 1.3 mm. This kind of injury, while considered as reversible (Monein Langle, 1985) takes a large toll on the total mortality.

The injuries also are cause for potential outbreak of diseases in weakened glass eel. One of the two samples analyzed for disease during a mortality peaks returned positive with an infection of *Salmonella putrefaciens, Shewanella putrefaciens and Aeromonas sobria.* These opportunistic bacteria, present in the aquatic environment, become pathogenic especially in presence of fishes weakened by external stressor such as the fishery. They might explain the highest mortality found in February in one of the samples. Disease causation is complex (VERTHAAK et JOL, 1996) and many factors interact to produce a spatial or temporal trend. The fishing causes an increase in stress, direct injury and abrasion of the mucus protective layer, which might contribute to the occurrence of a wave of infection in the fish trader tanks. A similar strong positive correlation between skin ulcers and the viral skin disease lymphocystis and the fishing activity was found in the Dutch Wadden Sea (VERTHAAK et JOL, 1996). The authors speculated that flounders, usually caught as a bycatch and discarded after fishery suffered wounds and damage of the protective mucous layer, and were subsequently more vulnerable to infectious pathogens.

Flooding periods are usually reported by fishermen and fish dealers as factors causing an increase in mortality. This was not apparent in this study as no factor external to the fishery could be statistically related to the level of mortality. Particularly, no relationship was found with the intensity of dredging, which is reduced in volume, and does not induce chemical contamination in mussels near the dredging site (IFREMER, 2007). Still, as most of the variation in mortality rate remains unexplained, a combination of factors from the environment such as increased silt loads, release of potential irritants by the dredge, low temperature might also contribute to weaken the mucus coat and diminish the overall resistance of glass eels.

Putting the glass eel in aquaria of estuarine water without extra care and oxygenation would stand as a poor practice for the fish dealers. So the results obtained there are probably not representative of the glass eel processing chain, which have lower mortality rates. Nonetheless, they might well represent the outcome of glass eel transport when directly putting back glass eel after fishing with tow nets.

It should also be noticed that these results should not be regarded as representative of the whole Atlantic glass eel fishery. Mortalities may vary from one estuary to the next as catch conditions, net shapes and dimensions, boat speed, fishing depth and haul duration also vary. However an analysis of the results available in other estuaries, show that the mortalities observed in the Vilaine are probably comparable to those observed in the other push net fisheries using 1m20 diameter nets, which form a large part of the French glass eel catch.

Fish dealers report that mortalities are the largest in the Vilaine (30 to 40%). Mortalities recorded in the Loire would be around the level 15% to 20%. A monitoring performed in the Loire in 2002 reports large fishing speed, between 1.16 to 3.4 $m.s^{-1}$ (mean 2.26 $m.s^{-1}$) when compared to those measured in the Vilaine (1.4 $m.s^{-1}$). Mortality rates two days after fishing varied from 18 % à 78 %. The mortality rates increase during the first 36 h then stabilized. The results showed a clear correlation between mortality and fishing speed and a speed lower than 5 knots was recommended by the authors. A correlation between fishing duration and mortality rate was also identified on 7 samples. The fishing duration for a haul was 8 to 25 minutes according to the boat with a mean duration of 13 minutes. For a same boat, an increase in mortality rate from 20 % to 40-70 % was observed as the fishing duration was increased from 5 to 25 minutes (LEROUX et GUIGUES, 2002).

So as the fishing speed reported there are larger than in the Vilaine, and as the Loire glass eel fishery also uses poles, it is possible that the lower mortality rate in the Loire account for the large part of poached glass eels entering the circuit there.
South from the Loire, in the Vendée, fishing conditions are close to those in the Vilaine, with mostly a fishery concentrated at the bottom of dams, but mortalities are only of an order 5 to 10 % due to the use of fishing gears with a very long net end (LEROUX et GUIGUES, 2002).
In some smaller estuaries such as the Aulne in Britany, the fishermen keep the glass eel in cages in the saline part of the estuary for several days before selling them. This practice allows them to better negotiate the price. While their net are similar to those used in the Vilaine, the mortality is claimed to be much lower (5 to 10 %). Interestingly, we can directly compare these claims with the results from a similar experiment in the Aulne estuary from 1999 to 2001 (Briand and Veron, 2001). The boats speed was slightly higher than in the Vilaine (from 1.2 $m.s^{-1}$ to 2.3 $m.s^{-1}$) but with shorter tow duration. The mean total mortality rate 36 % (min 0.5% max 100 %) comparable with that obtained in the Vilaine. The mortality also varied according to the position in the estuary, with larger mortality rates 49.6% (sd 30.9) in the downstream part of the estuary than in the upstream area at the tide reversal and accumulation area 23.4 (sd 21.5). The mortality was negatively correlated with the CPUE, indicating that dying glass eel were less fit for tidal stream transport, and this explains the large mortality (100 %) recorded in the downstream part of the estuary. The glass eels swimming at the surface were already losing their transparency and becoming white.

The mortalities in the Adour river (south of France) would also be of the magnitude of some percents, and mortalities around 30% are considered exceptional (Prouzet pers. com.). The mortality would also be different for Pibalour, large nets used in the Gironde and Charente estuaries, but is not accounted to our knowledge in the literature.

In Ireland, some experiments resulting from the catch of glass eels at trapping ladders or using tela nets results in 0% mortality (CREAN *et al.*, 2007).

To conclude, if the glass eel were to be transported throughout Europe, the mortality rate of the order of 20 to 40 % induced by glass eel push net fisheries would probably not be compatible with the level of survival require restoring the eel stock in the long term. A large change in fishing practice would have to occur, ensuring shorter hauls, with a lower speed, to use glass eel fishing and transport from the Atlantic as a means to restore the stock.

Acknowledgements

Frederic Lefranc, professional fisherman for providing glass eels and his very welcome company during fishing trips. This study was financed by the Institution d'Aménagement de la Vilaine, Agence de l'eau Loire Bretagne and the Bretagne region.

References

ANTUNES C. and WEBER M., 1996. The glass eel fishery and the by-catch in the Rio Minho after one decade (1981-1982 and 1991-1992). Archives of Polish Fisheries, 4, 131-139.

BIRRELL L., CRAMB G. and HAZON N., 2000. Osmoregulation during the development of glass eels and elvers. J Fish Biol, 56, 1450-1459.

BOCQUÉNÉ G. and MIOSSEC L., 1986. Toxicité aiguë et effets sublétaux, après une courte exposition de différents nonylphénols polyéthoxylés sur la civelle. Revue des Travaux de l'Institut des Pêches Maritimes, 48, 77-84.

BRIAND C., FATIN D. and LEGAULT A., 2002. Role of odour on the efficiency of an eel, *Anguilla anguilla*, ladder and trap. Environ Biol Fish, 65, 473-477.

BRIAND C., FATIN D., FEUNTEUN E. and FONTENELLE G., 2003. Estuarine and fluvial recruitment of European glass eel in a fished Atlantic estuary. Fish. Man. Ecol., 10, 377-384.

BRIAND C., FATIN D., CICCOTTI E. and LAMBERT P., 2005. A stage-structured model to predict the effect of temperature and salinity on glass eel *Anguilla anguilla* pigmentation development. J Fish Biol, 67, 995-1009.

BRIAND C., BONHOMMEAU S., BEAULATON L. and CASTELNAUD G., 2008. An appraisal of historical glass eel fisheries and markets: landings, trade routes and future prospect for management. In The Institute of Fisheries Management Annual Conference 2007 (ed C. Moriarty), Wesport, Ireland.

CASTELNAUD G., LOSTE C. and CHAMPION L., 2000. La pêche commerciale dans les eaux intérieures françaises à l'aube du XXIème siècle : bilan et perspectives. In Symposium CECPI on fisheries and society, pp. 1-24, Budapest.

CASTELNAUD G., GUÉRAULT D., DÉSAUNAY Y. and ELIE P., 1994. Production et abondance de la civelle en France au début des années 90. Bulletin Français de la Pêche et de la Pisciculture, 335, 263-288.

COMMISSION OF THE EUROPEAN COMMUNITIES, 2005. Proposal for a Council regulation establishing measures for the recovery of the stock of European Eel., Rep. No. 472 final - 2005/0201 (CNS).

CREAN S. R., DICK J. T. A., EVANS D. W., ROSELL R. S. and ELWOOD R. W., 2007. Survival of juvenile European eels (*Anguilla anguilla*), transferred among salinities, and developmental shifts in their salinity preference. J Zool, 266, 11-14.
ELIE P., 1979. Contribution à l'étude des montées de civelles d'Anguilla anguilla L. (poisson téléostéen anguilliforme) dans l'estuaire de la Loire : pêche, écologie, écophysiologie et élevage. Thèse de 3-ème cycle, Université de Rennes, Rennes.
ELIE P. and FONTENELLE G., 1982. La pêche de la civelle *Anguilla anguilla* en France (Nécessité d'une gestion de cette ressource). In Colloque International des entretiens écologiques de Dijon, pp. 112-124.
ELIE P., LECOMTE-FINIGER R., CANTRELLE I. and CHARLON N., 1982. Définition des limites des différents stades pigmentaires durant la phase civelle d'*Anguilla anguilla* L. Vie Milieu, 32, 149-157.
FRIENDLY M., 1992. Mosaic Displays for Loglinear Models. In ASA, Proceedings of the Statistical Graphics Section pp. 61-68, Boston.
GASCUEL D., 1985. Contribution à l'étude écologique des estuaires du littoral atlantique français : la faune accompagnatrice de la civelle. Thèse de Docteur-Ingénieur, Université de Rennes I, Rennes.
GASCUEL D., 1987. La civelle d'anguille dans l'estuaire de la Sèvre Niortaise : biologie, écologie, exploitation, rapport global. Publications Département Halieutique, Ecole Nationale Supérieure Agronomique, Rennes.
GISBERT E. and LÓPEZ M. A., 2008. Impact of glass eel fishery on by-catch fish species: a quantitative assessment In Fish and Diadromy in Europe (eds S. Dufour, E. Prévost, E. Rochard and P. Williot), Vol. 602. Hydrobiologia
ICES, 2008 in prep. Report of the ICES/EIFAC Working Group on Eels, Leuven, Belgique.
IFREMER, 2007. Dragage des ports de l'Estuaire de la Vilaine. Résultats du suivi de la qualité environnementale du milieu., La Trinité sur Mer.
LEROUX S. and GUIGUES T., 2002. Etude des facteurs et pratiques influençant la qualité de la civelle en Loire. Syndicat mixte pour le développement de l'aquaculture et de la pêche en pays de Loire/ Association Agrée départementale des pêcheurs professionnels Maritimes et Fluviaux en eau douce de Loire Atlantique, Nantes.
MCCORMICK S. D., 2001. Endocrine Control of Osmoregulation in Teleost Fish. Amer Zool, 41, 781-794.
MEYER D., ZEILEIS A. and HORNIK K., 2006. The strucplot framework: Visualizing multi-way contingency tables with vcd. Journal of Statistical Software, 17, 1-48.
ROBIN J. P., 1990. By-catch of juvenile flounder, Platichthys flesus L. 1758, in the glass-eel fishery of the Loire Estuary, France. Aquat Living Resour, 3 75-83
SOBRINO I., BALDO F., GARCIA-GONZALEZ D., CUESTA J. A., SILVA-GARCIA A., FERNANDEZ-DELGADO C., ARIAS A. M., RODRIGEZ A. and DRAKE P., 2005. The effect of estuarines fisheries on juvenile fish observed within the Gadalquivir estuary (SW Spain). Fish Res, 76, 229-242.
SUURONEN P., 2005. Mortality of fish escaping trawl gears, Rome.
TESCH F. W., 2003. The eel (ed J. E. Thorpe), pp. 407. Blackwell Publishing, London.
VERTHAAK A. D. and JOL J. G., 1996. Disease of flounder Platichthys flesus in Dutch coastal and estuarine waters, with particular reference to environmental stress factors. I Epizootiologu of gross lesions. Diseases of Aquatic Organisms, 26, 81-97.
WILSON J. M., ANTUNES C., BOUÇA P. D. and J. C., 2004. Osmoregulatory plasticity of the glass eel of Anguilla anguilla: freshwater entry and changes in branchial ion-transport protein expression. Canadian Journal of Fisheries and Aquatic Sciences, 61, 432-442.

Tables

	V_B	VI_{A0}	VI_{A1}	VI_{A2}	VI_{A3}+
05/12/2006 01:12	97.6	2.4			
12/12/2006 06:05	97.6	1.2	1.2		
08/01/2007 18:00	96.9	3.1			
23/01/2007 04:17	80.0	12.0	8.0		
06/02/2007 03:40	85.9	9.4	4.7		
20/02/2007 03:18	79.6	13.0	7.4		
05/03/2007 02:15	85.7	10.2	4.1		
21/03/2007 02:53	36.5	34.6	25.0	3.8	
26/03/2007 22:42	49.2	33.3	14.3	3.2	
03/04/2007 02:47	29.4	32.4	32.4	4.4	1.5
10/04/2007 21:16	1.7	1.7	46.6	20.7	29.3
11/04/2007 22:16	23.0	29.5	41.0	4.9	1.6
18/04/2007 02:53	33.9	35.5	16.1	4.8	9.7

Table 1. Time of collection and pigment stage structure in the Vilaine estuary, VIA_3+ correspond to VIA_3 + VIA_4.

Figures

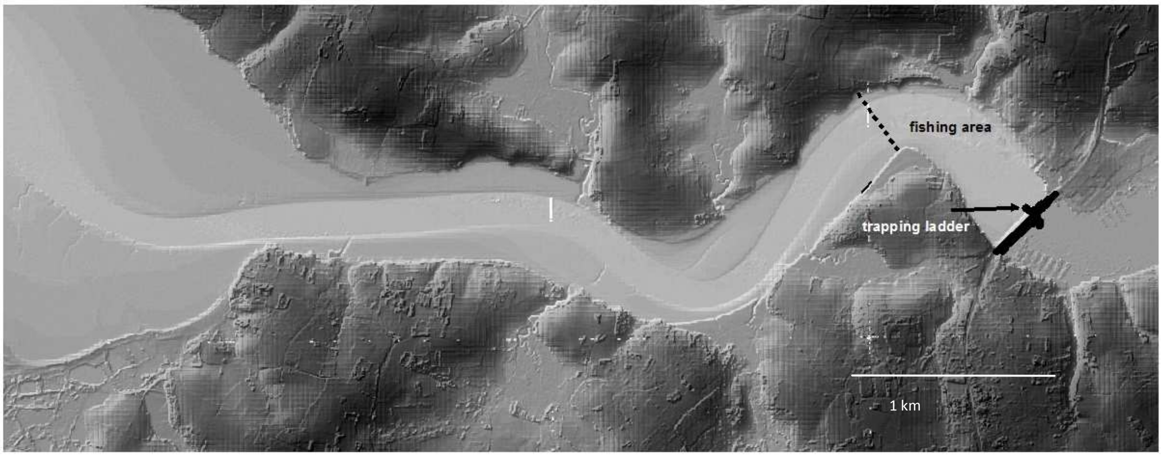

Figure 1.- Map of the Vilaine estuary showing the position of the fishing area and of the trapping ladder altitude relative to the shade of grey.

+{ajouter map of France showing estuaries}

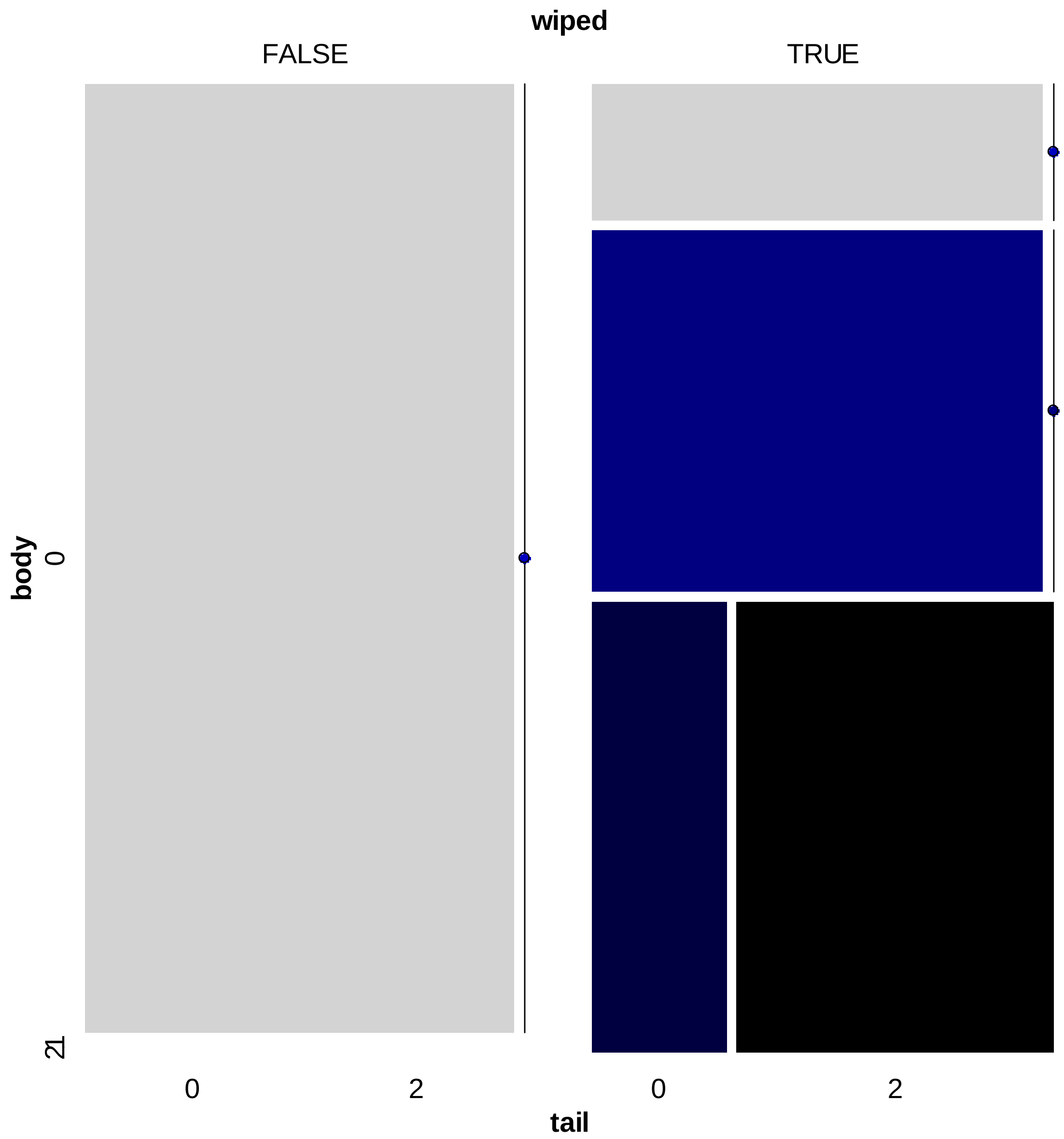

Figure 2. Experimental wiping of the mucus of 40 glass eels, and test of a marking with Carmin Indigo. The blue color is relative to the intensity of color on body and tail, TRUE glass eel wiped from their mucus, FALSE control. 0 = no mark, 1 = presence of a mark, 2 = marking visible on large areas. Using mosaic plot from vcd package in R (MEYER *et al.*, 2006).

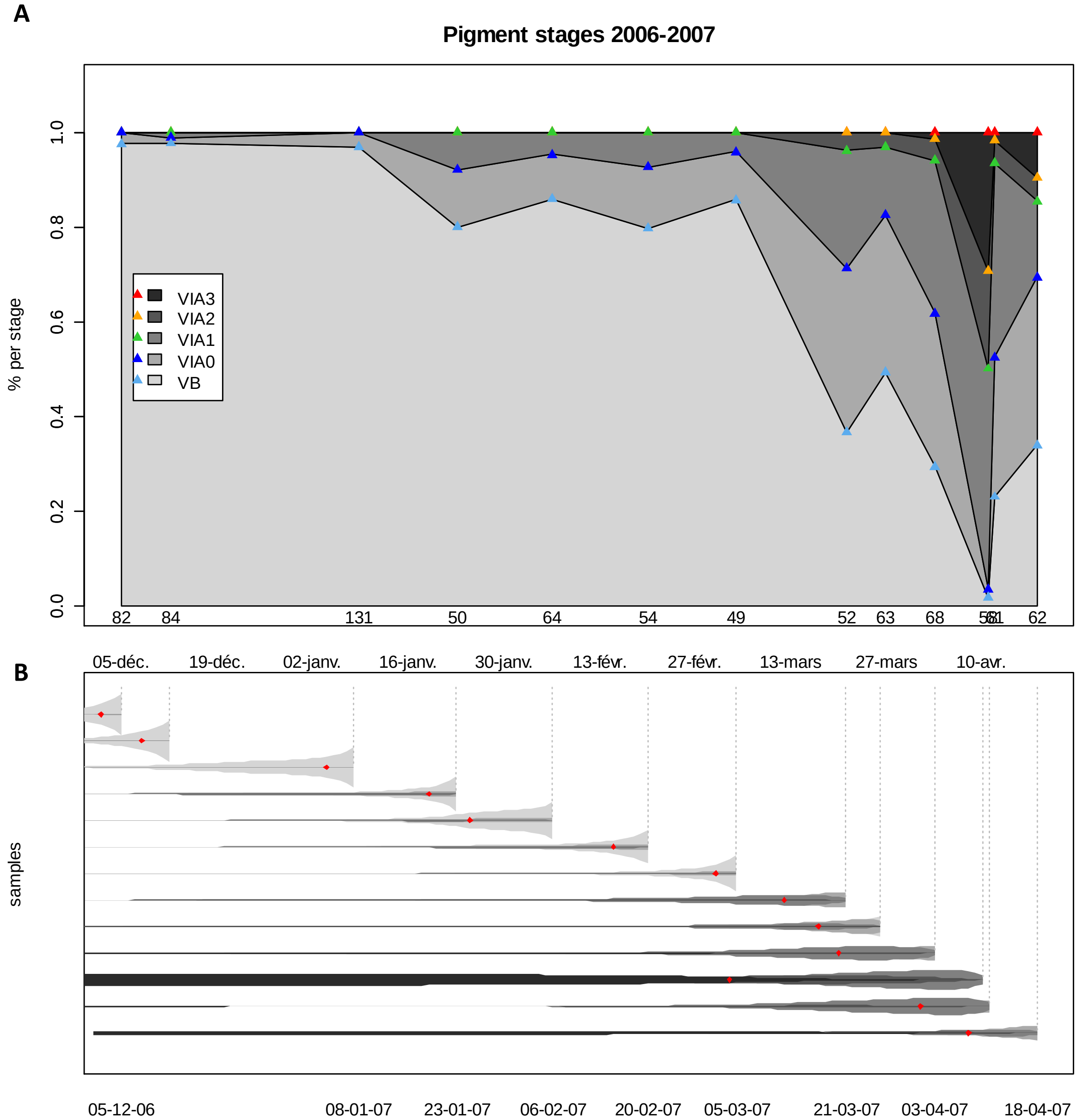

Figure 3.- A/ Cumulative proportions of pigment stages collected in the estuary during the fishing period, the number of glass eel in each sample is indicated at the date of collection under the graph. B/ Analysis of the probable arrival time in estuary according to the gamma repartition fitted by Briand et al. (2005). The color corresponds to each stage, the green lozenge to the mean date of arrival calculated by the model, the curves correspond the value of the gamma curves according to the cumulated value of pigment time between the date considered and the date of sample collection.

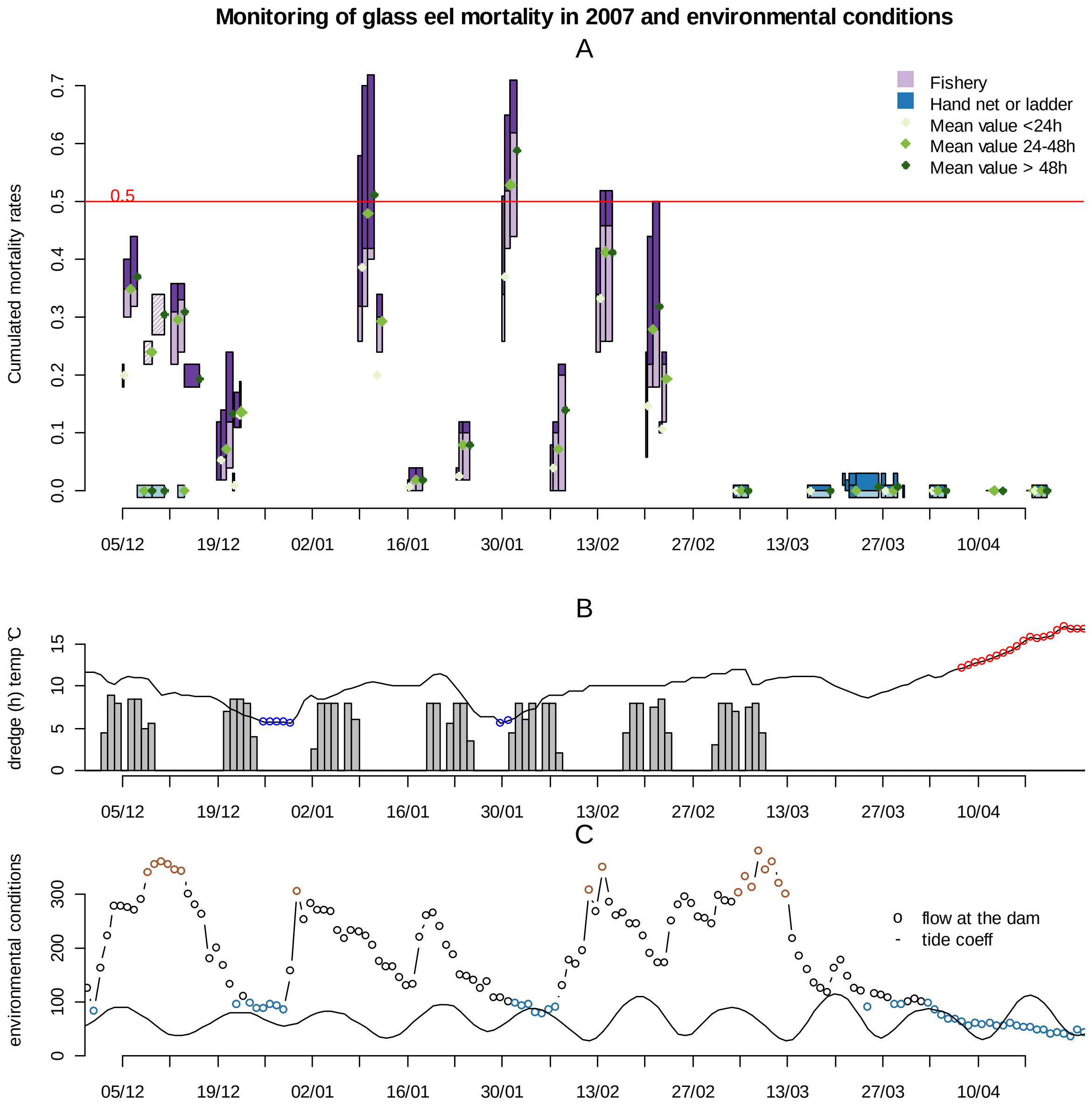

Figure 4.- Monitoring of glass eel mortality in 2007.

A. **The boxes represent the value of the lowest, middle and largest mortality among the triplicates except when only two samples were collected (shaded boxes). Purple represent samples collected by the fishery, blue samples collected by hand net or in the trapping ladder. The width of the boxes is relative to the time between controls for mortality. The lozenges represent the mean values calculated for different times intervals after the fishery**

B. **Daily activity of the dredge and estuarine water temperatures. Low temperatures <6°C in blue and large temperatures >12°C in red.**

C. **Variation of the flow at the dam, flooding period > 300 $m^3.s^{-1}$ in red, low flow (<100 $m^3.s^{-1}$) in blue.**

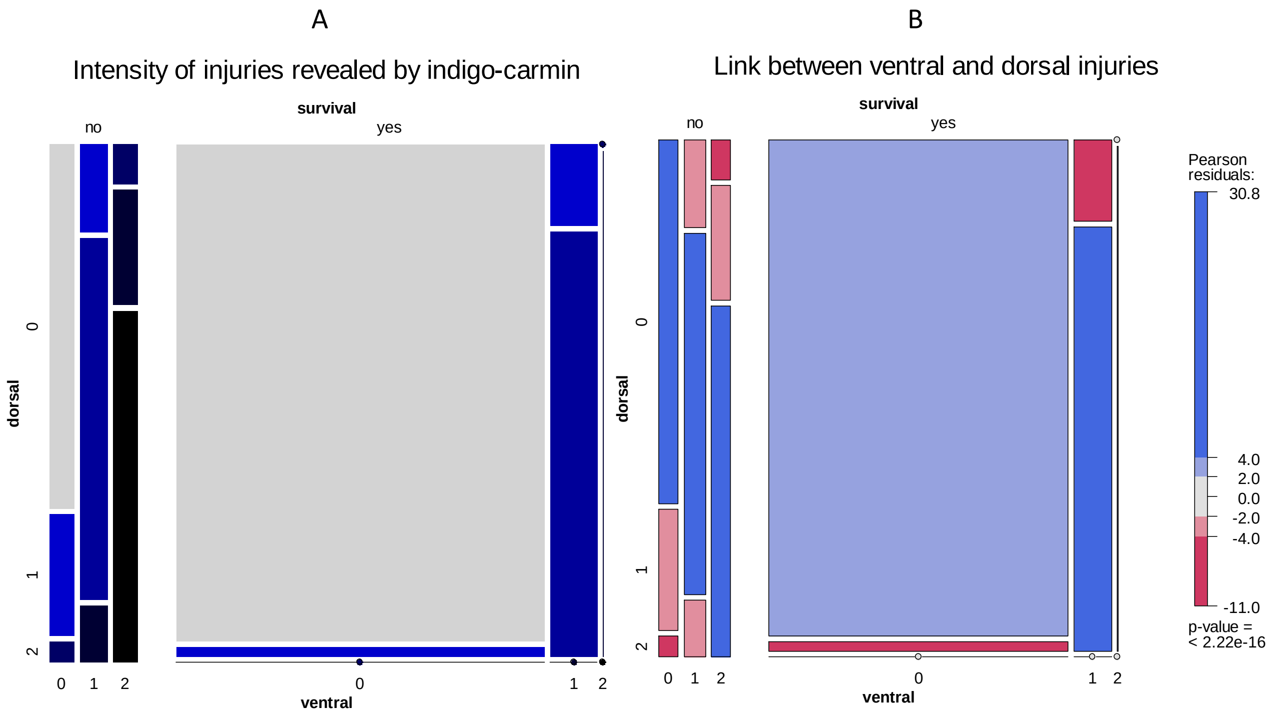

Figure 5.- Mosaic plots showing the dependence between dorsal and ventral injuries. The two graphs correspond to 2153 glass eel separated according to survival (vertical split into two groups) and to the detection of injuries on the body in the dorsal (horizontal split) and ventral area (vertical split). The area of each tile is proportional to numbers. A. The color corresponds to the intensity of injury. B. Same graph, but the colors correspond to values of standardized Pearson deviation from independence. Given the assumption of independence in the factors (normal distribution), the light blue and red color roughly correspond to p < .05 the darker shade to p < .0001 (FRIENDLY, 1992) R software(vcd package).

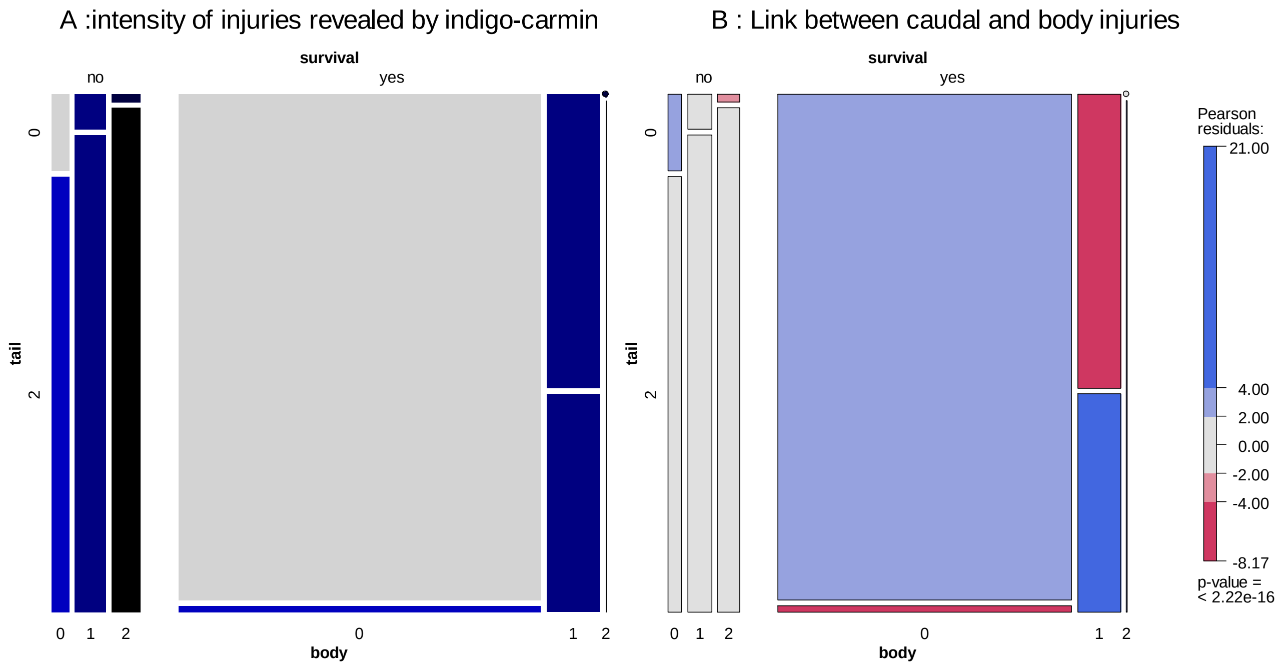

Figure 6.- Mosaic plot showing the dependence between caudal and body injuries. The graphs corresponds to 2153 glass eel separated according to survival (vertical split into two groups) and to the detection of injuries on the body (horizontal split) and tail area (vertical split).

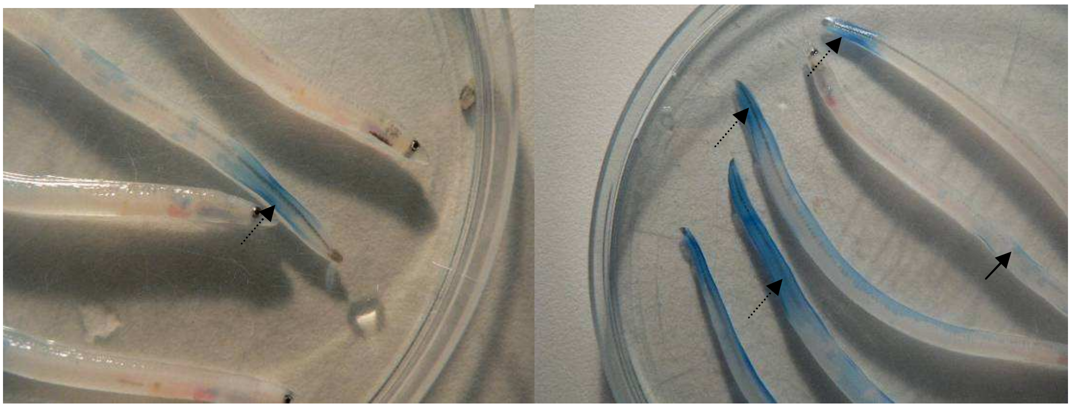

Photo 1 : Result of analyses of glass eel with carmin indigo. (full arrow, mark =1, dotted arrow, mark =2).