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Discarded *Nephrops* survival after trawling

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Discarded *Nephrops* survival after trawling

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1. Introduction

The *Nephrops* stock of the bay of Biscay is exclusively exploited by French fishermen. This stock, cohabiting with hake, is targeted by trawlers fleets which are subjected to more and more regulations to tend towards responsible and sustainable fishing practices. The European legislation imposes various technical measures to manage this resource, among which the minimum codend mesh size of 70mm and set the minimum landing size at 8.5cm (EU, 1998). Moreover, the French national fishing committee took more restrictive measures in order to reduce the discard rate and preserve the stock: it set the minimum landing size at 9cm (28mm of carapace length), and in 2007 it compels the fishermen to adopt at least one of three selective devices (either a codend mesh size of 80mm, a flexible grid or a bottom square mesh panel) (CNPMEM, 2007). However, despite these technical measures, the discard rates in this mixed fishery remains high, with an average of 55% of the catch discarded between 2003 and 2008 (Guérineau *et al*., 2010). At the same time, it is known that the caught and discarded *Nephrops* are able to survive (eg. Harris and Adrews, 2005; Castro *et al*., 2003), to grow and to reproduce, though the surface light damage their eyes and blind them (Chapman *et al*., 2000). The survival rate of *Nephrops* discarded from trawlers in the bay of Biscay was studied by Gueguen and Charueau in 1975. They conclude that 30% of discarded *Nephrops* can survive. This rate was adopted by the ICES and used in the stock assessment procedure up to now. However, the gears used evolved since the seventies: the codend mesh size went gradually from 55mm in 1975 to 70 or 80mm nowadays and *Nephrops* trawlers were rigged with a simple gear in 1975 whereas they are now rigged with twin gears. Furthermore, the article about the experiment conducted in the seventies shows that bias may have been introduced in the results due to the chosen protocol. Indeed, the *Nephrops* sampled to assess their survival rate were re-immerged at sea in cages where the density of individuals was high, which may have bias the results. The authors indicate that this methodology may have induced mortality and underestimated the survival rate. Besides, other *Nephrops* survival experiments have been conducted since then in Portugal and Scotland (Castro *et al*., 2003; Ulmestrand *et al*., 1998, Harris and Ulmestrand, 2004). Both authors re-immerged the *Nephrops* in cages with individual compartments. As many authors show (eg. Guéguen and Charuau, 1975), the survival rate depends on the time the individuals spend on the deck before being discarded, and according to fishermen observations, their capacity to survive also depends on the air temperature. This last parameter was not taken into account in previous studies. We believe all these reasons justify the need to update the survival rate of discarded *Nephrops* with an appropriate methodology that tends to minimise the bias in the results. This paper presents the methodology used on board of commercial vessels to re-assess the survival rate of discarded *Nephrops* in the bay of Biscay, the range of survival rates observed according to the parameters affecting significantly the survival rate, and the general implication of these results from a fishery management point of view.

2. Material and method

The *Nephrops* survival experiment was conducted by observers on board of several commercial vessels at various time of the fishing season along the years 2009 and 2010 on the *Nephrops* fishing grounds of the bay of Biscay. The methodology was split in too main steps. First, the vitality state of *Nephrops* before being discarded was assessed according to three categories: healthy, moribund or dead. Then, the survival rate after three days of re-immersion of individuals discarded healthy or moribund was assessed (survival of living individuals). The global survival rate of discarded *Nephrops* was calculated from the combination of these two components (Figure 1).

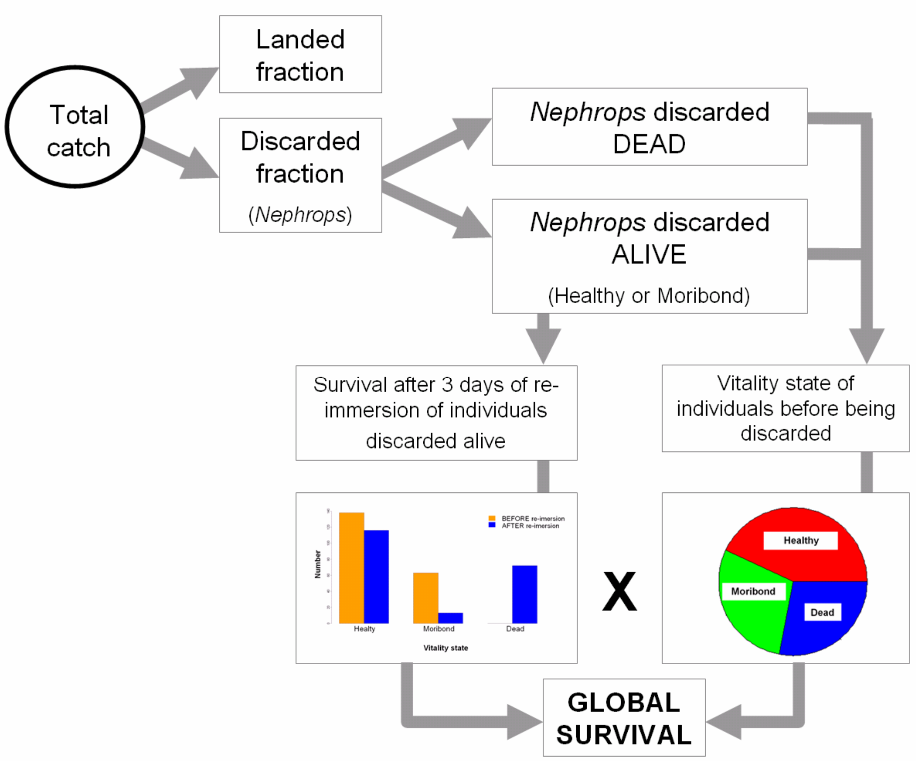


Figure 1. Procedure of estimation of global survival rate from the components: combination of vitality state before discard and survival of living individuals.

2.1. Assessment of vitality (V) state before discard

Along the sorting procedure of the catch on board, *Nephrops* let aside by the crew were taken in various part of the fraction to be discarded. The crew was asked not change its practices on board in order to get samples representative of commercial conditions. The duration of emersion, i.e. the time between the moment at which the codend arrived on board and the moment the vitality state was assessed was recorded for each sample. The air temperature, the total catch, the landed and discarded fractions weight were also recorded. Usually, two samples per haul were taken at distinct duration of emersion. The vitality state was assessed visually like it was done by Gueguen and Charueau in 1975 and by Morizur *et al*. in 1982. However, more detailed vitality state scales are available (Ridgway *et al*., 2006) but we chose the very simple and easy one because of the necessity to get a compromise between the sample size and the time of treatment. So, the vitality state was defined according to three categories: (1) healthy: the *Nephrops* is able of 'flip-tail' and its body is tonic, (2) moribund: the *Nephrops* is alive (*eg*. move legs or antenna) but without tonus (3) dead: the *Nephrops* doesn't move at all and has no tonus. The proportions of each vitality state were then computed for each sample, and the percentage of healthy, moribund and dead individuals in the samples were written respectively V_h, V_m and V_d. For each individual, the cephalothoracic or carapace length, the sex and the number of pincers were also recorded.

2.2. Assessment of survival (S) of *Nephrops* discarded alive after three days of re-immersion

Once the codend was onboard and the crew started to sort the catch, a sample of 100 living *Nephrops* (either healthy or moribund) to be discarded was taken. Their number of pincers and their sex were recorded. Then, they were put individually in numbered perforated plastic tubes, which were themselves put in bags to be re-immerged at proximity of the site where they were caught (Figure 2a and 2b). The time to process the samples by the observers was equivalent to the time to process the catch by the crew: the duration of emersion of the sample was representative of the duration of emersion of the Nephrops to be discarded on the deck of commercial vessels.

Figure 2a. Perforated plastic tube (25cm * Ø 5cm).

Figure 2b. Re-immersion bag containing 25 plastic tubes.

Each bag containing 25 *Nephrops* tubes was immerged for 3 days. Then, directly after hauling back on board, the vitality state of each individual was assessed in order to calculate the proportion of the three vitality states in the samples and their cephalothoracic length was recorded. In each sample, the proportions of individuals re-immerged healthy and that became either moribund ($S_{h,m}$), dead ($S_{h,d}$) or remained healthy ($S_{h,h}$) were recorded, as well as the proportion of moribund individuals that became healthy ($S_{m,h}$), dead ($S_{m,d}$) or remained moribund ($S_{m,m}$) were calculated.

In the same time, a control experiment was conducted in order to check the effect of these re-immersion conditions on the survival rate. For that, 'control' *Nephrops* were caught with creels and re-immerged immediately after the catch in the plastic tubes and bags.

2.3. Global survival rate (GS)

The global survival rate (GS) was obtained for each sample by combining the proportions obtained from the assessment of survival of *Nephrops* discarded alive after three days of re-immersion (S) and the assessment of vitality state before discard (V). We considered that an individual survived after re-immersion if it was healthy:

$GS = V_h*S_{h,h} + V_m*S_{m,h}$

2.4. Statistical analysis

In order to identify the external parameters that affect significantly the vitality state of discarded *Nephrops*, the effect of the individual size, the duration of emersion on the deck, the total catch volume, the tow duration, the air temperature on the deck were explored by fitting a General Linear Model (GLM) to the proportions of healthy individuals. The effect of sex and number of pincers on the vitality state was also explored using analysis of variance and *t*-test.

3. Results

3.1. Summary of sampling sessions

8 Fishing trips were carried out on board of 7 distinct commercial vessels to assess the vitality state (V) before discard (Figure 3a). 33 fishing operations were sampled. Since for some of them, two samples were taken, a total of 46 samples have been analysed. On average, samples consisted of 150 individuals. On the whole, 7030 *Nephrops* have been measured.

3 fishing trips were carried out on board of 2 distinct commercial boats (Figure 3b) to assess the survival of *Nephrops* discarded alive after three days of re-immersion (S). 15 fishing operations were sampled, i.e. 1557 *Nephrops* were re-immerged in plastic tubes and bags for three days.

Figure 3a. Location of sampling stations to assess the vitality state (V) before discard.

Figure 3b. Location of sampling stations to assess the survival (S) of *Nephrops* discarded alive after three days of re-immersion.

3.2. Control creels results

Creel control fishing was carried out during the two first sea trials dedicated to the assessment of the survival of *Nephrops* discarded alive after three days of re-immersion (S). For logistic and space reasons on board, it was not possible to do it during the third sea trial. The first sea trials only caught *Munida rugosa*. After re-immersion, 94% of them survived.

The creel control fishing of the second sea trials only caught 16 *Nephrops*, among which two of them died after 72hours of re-immersion in tubes.

3.3. Evolution of vitality state

For the 33 hauls sampled, external data have been collected. The observed temperature ranged between 10 and 23°C, the duration of emersion of the samples on the deck ranged from 12 minutes to 2 hours and 10 minutes, the air temperature observed ranged from 10 to 23°C and the tow duration ranged from 1 hour and 05 minutes to 1 hour and 55 minutes (Figure 4).

A General Linear Model (GLM) was fitted to the percentage of healthy individuals. It shows that the duration immersion ($p < 1.10^{-3}$) and the air temperature on the deck ($p < 1.10^{-3}$) had a highly significant effect on the proportion of healthy *Nephrops* before discard, though the deviance explained by the model is low (26%). The *Shapiro* test indicates the residuals of that model are normally distributed ($p = 0.44$). This model indicates that the shorter the duration of emersion on the deck and the lower the air temperature, the higher the percentage of healthy individuals in the fraction of the catch to be discarded.

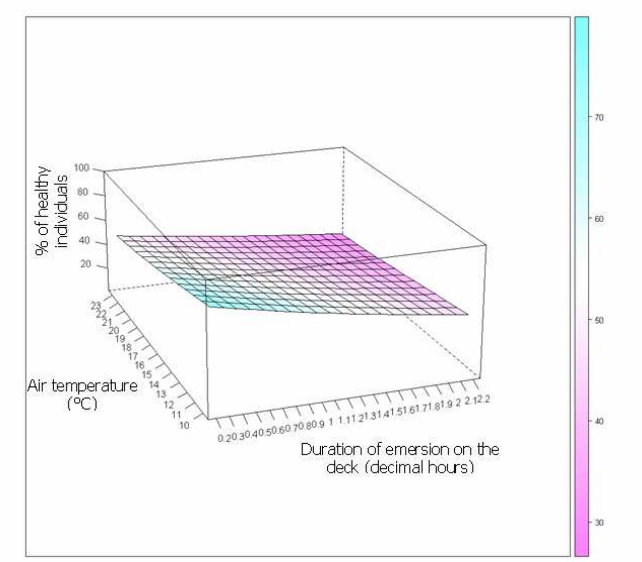


Figure 4. Predicted values for healthy individuals in relation to the air temperature and the time spend on the deck before re-immersion.

A General Linear Model (GLM) was fitted to the percentage of moribund individuals. It indicates that the duration immersion ($p < 1.10^{-3}$) and the air temperature on the deck ($p < 1.10^{-3}$) had a highly significant effect on the proportion of moribund *Nephrops* before discard, with 40% of the deviance explained by the model. The *Shapiro* test indicates the residuals of that model are normally distributed (p = 0.28). This model indicates that the longer the duration of emersion on the deck and the higher the air temperature, the higher the percentage of moribund individuals in the fraction of the catch to be discarded (Figure 5).

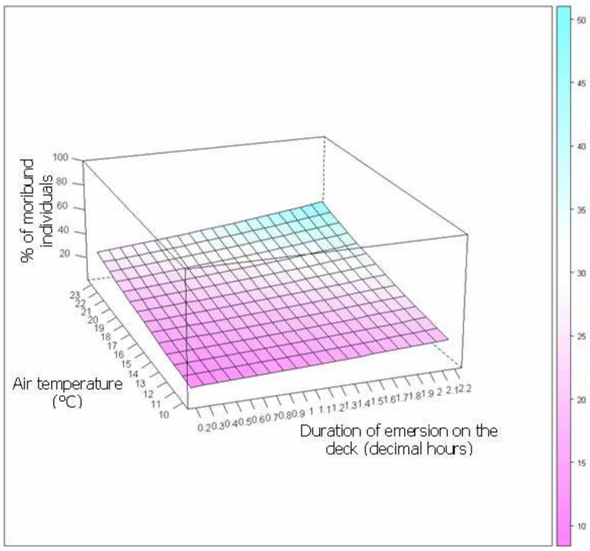


Figure 5. Predicted values for moribund individuals in relation to the air temperature and the time spend on the deck before re-immersion.

3.4. Evolution of survival rate of *Nephrops* discarded alive after re-immersion

The vitality state of each living individual was assessed before and after re-immersion and each of them was identified with a number. Therefore, the evolution of the vitality state after the catch and 3 days on the sea bottom could be quantified (Table 1). We found that moribund individuals have a high capacity to recover (62% of moribund become healthy) and healthy individual before re-immersion tend to remain healthy. Very few individuals, either healthy or moribund before re-immersion become moribund (3%). However, the variability around these means is high.

The proportion of healthy individuals after re-immersion was observed with respect to the sex of *Nephrops*. The results show that females are significantly more resistant than males (*t*.test, $p=4.10^{-6}$) (Figure 6).

Table 1. Percentage of individuals either moribund or healthy before re-immersion that becomes dead, moribund of healthy after re-immersion (with 95% confidence interval).

Before re-immersion \ After re-immersion	Dead	Moribund	Healthy
Moribund	**35%** ± 23%	**3%** ± 7%	**62%** ± 26%
Healthy	**21%** ± 21%	**3%** ± 6%	**76%**±25%

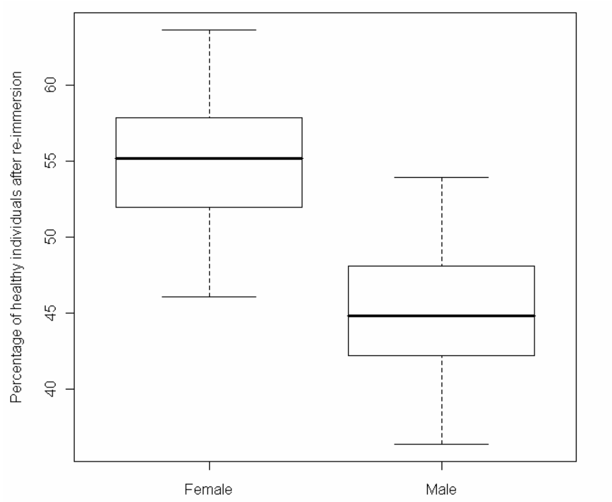


Figure 6. Percentage of healthy individuals according to their sex.

The proportion of healthy individuals after re-immersion was observed with respect to the number of pincers of *Nephrops*. The results show that the rate of healthy individuals is significantly different if they have zero, one or two pincers: the individuals with two pincers have significantly higher chance to survive and remain healthy than if they have one or no pincer at all (ANOVA and Tukey HSD test, $p < 1.10^{-6}$) (Figure 7).

The proportion of healthy individuals after re-immersion was observed with respect to the *Nephrops* size. The analysis was conducted on the length interval for which 95% of the observations of the 15 samples were made, *i.e.* from 21 to 32mm of carapace length, in order to avoid the non representative observations in the tails of the length distribution. A simple linear model was fitted on these data. It indicates that, on that length range, the larger the individuals, the lower their chance to be healthy after three days of re-immersion ($p < 1.10^{-3}$, $R^2 = 0.89$) (Figure 8).

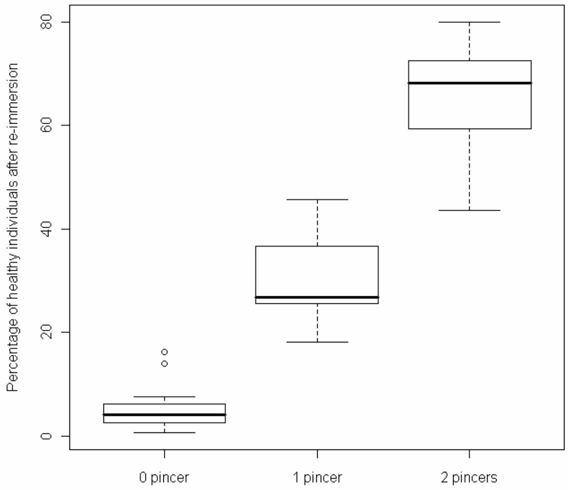


Figure 7. Percentage of healthy individuals according to their number of pincers.

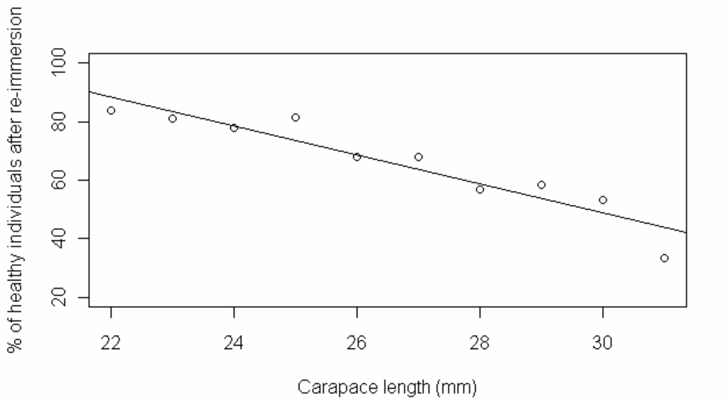


Figure 8. Percentage of healthy individuals according to their carapace length.

3.5. Global survival rate

The global survival rate is the combination of the proportion of living individuals before re-immersion and the survival rate of living individuals re-immerged. According to our model on the range of our observations, the global survival rate varies between 45 and 65% depending on the air temperature and the duration of emersion on the deck (Figure 9).

Examples of calculation of observed global survival rate are presented in Table 2. They show a high variability around the mean rates, and indicate that the global survival rate tend to decrease when the duration of emersion and air temperature increase.

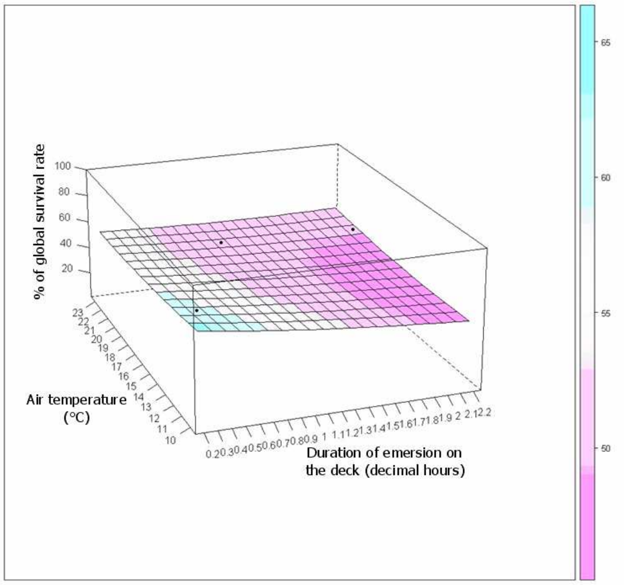
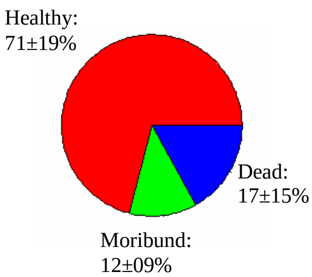
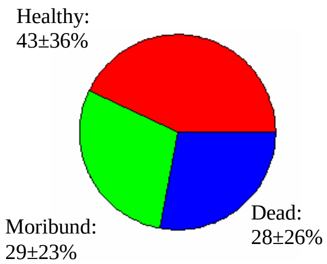
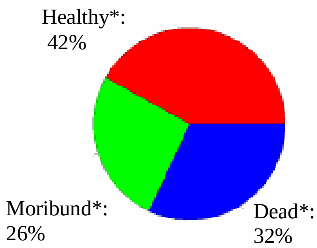


Figure 9. Evolution of the global survival rate of discarded *Nephrops* according to the air temperature and the duration of emersion on the deck. The 3 black points correspond to examples of observations detailed below (Table 2).

Table 2. Process of calculation of global survival rate from observations.

	Example 1	Example 2	Example 3*
Survival rate of living individuals after 3 days of re-immersion (S)	76 ± 25% 3 ± 6% 21 ± 21%	of healthy individuals	remain healthy become moribund die
	62 ± 26% 3 ± 7% 35 ± 23%	of moribund individuals	become healthy remain moribund die
Mean	00 : 20	01 : 05	2 : 10
Mean air	12°C	20°C	20°C
Number of	8	18	1
Proportion of vitality state before being discarded (V)			
		Global Survival rate (GS)	
Healthy	20% < 61% < 100%	00% < 51% < 100%	48%*
Moribund	00% < 03% < 08%	00% < 02% < 08%	2%*
Dead	00% < 36% < 76%	00% < 47% < 100%	50%*

** No variability shown because only one haul sampled under the conditions of air temperature and emersion duration of example 3.*

4. Discussion

Though efforts of selectivity in the *Nephrops* trawl fishery have been made, the discard rate remains high (Guerineau *et al*., 2010). However, it is now proved that discarded *Nephrops* have a capacity to survive after a period of emersion, even if the natural day light damages their eyes (Chapman *et al*., 2000). Our experiment shows that external factors such as the air temperature and the duration of the emersion on the deck affect significantly their vitality state on the deck before discard, and consequently, the global survival rate of discarded *Nephrops*. Since the air temperature fluctuates along the fishing season and the duration of emersion of the catch on the deck varies from one haul to another, it was impossible to get one single value of global survival rate. However, our study shows that on the range of air temperature and duration of emersion observed, the global survival rate varies from 45 to 65%. This interval is generally higher than the survival rate observed by other authors in other European seas (eg: 31% by Ulmestrand *et al*. (1998) in North West of Scotland 23 to 60% by Castro *et al*. (2003) in the South of Portugal, and 31% by Harris and Andrews (2005) on the West coast of Scotland). It is however important to note that these authors highlight the effect of the season on survival rates, and that none of them used exactly similar protocols.

Our results are also higher than those obtained by Gueguen and Charuau in 1975 in the *Nephrops* fishery of the bay of Biscay. Indeed, they found that after 1 hour of emersion and three days of re-imersion, 16.5% of discarded animals were healthy and 40.8% moribund. From these observations, the average of 30% was agreed and used for the *Nephrops* stock assessment procedure. However, it is important to note the difference of protocol and gear used in 1975 and in 2009-2010. First of all, Gueguen and Charuau re-immerged discarded *Nephrops* in cages in which the density reached 30 to 140 individuals per batch. Morizur *et al*., who used the same methodology in 1982 in the bay of Biscay recognised that the high density in cages may increase the mortality rate induced by the experiment (*Nephrops* are much more vulnerable to amphipods, and the individuals may be aggressive and damage each other). After one hour of emersion and three days of re-immersion in cages, Gueguen and Charuau found a high proportion of moribund individuals (41.8%), whereas we only found 3% (±6%) after re-immersion. This suggests that high densities of individuals in captivity may have an effect on the vitality state of *Nephrops*. For these reasons, and inspired from Ulmestrand *et al*. (1998) and Castro *et al*. (2003), we decided to individualise the *Nephrops* in tubes during the re-immersion phase. We also checked the effect of that methodology with a control sample caught with creel (*i.e*. non stressed or non damaged animals). Although we observed a bit of mortality after having re-immerged creel caught *Nephrops* in tubes for three days, we did not take it into account in the data analysis since on the other hand we did not consider either the predation mortality avoided with the tubes. Our experimental methodology induced biases that tend to both underestimate and overestimate the survival rate that cancel each other, though we don't know in which proportions.

Although our study did not show that the catch volume in the codend had any significant effect on the survival rate in the range of our observations, it may be contradicted if the differences of catch volume are larger than the one observed. Indeed, it is likely that the larger the catch volume in the codend, the more compressed are the individuals and the higher the risk of physical damages (eg. loss of pincers). The trawl gear evolutions suggest that the mean catch volume in *Nephrops* trawl codend decrease between 1975 and 2009-2010. Indeed, before the nineties' in the bay of Biscay, simple trawls were used in the French *Nephrops* fishery, whereas since then, twin trawls with shorter footrope are being used. Furthermore, the vertical opening of twin trawls is about 30% less than the one of single trawl (M. Meillat, pers. comm.) which may lower catch of fish. The increase of mesh size from 55mm in the seventies to 70 or 80mm nowadays may also helps to reduce the catch volume in the codend, though the hanging ratio and the twine material (more rigid) tend to limit the efficiency of larger mesh size. Also, all *Nephrops* trawls are now equipped with a top square mesh panel from which fish such as young hake and horse mackerel escape (EU, 1998). This selective device also contributes to reduce the catch volume in the codend. Finally, in the nineties', fishermen adopted drop-out panels, which allows avoiding rocks to enter in the codend and prevent them to damage *Nephrops*.

The undersized individuals (=discarded fraction) in the seventies were between 11 and 22mm of carapace length (Guéguen and Charuau, 1975), whereas in 2009 and 2010 the mean discarded size observed was 27mm. Only 24% of the non commercial individuals caught were smaller or equal to 22mm. The numbers at length of discarded and landed fractions of the catches were obviously different in the seventies and in 2009-2010. We showed that individual length has a significant effect on survival capacity, with larger non commercial individuals having better chance to survive. This observation does not fit with our conclusions since we would expect better survival rate with smaller individuals such as the ones studied in Gueguen and Charuau experiment. However in any case, these results show that the survival rate changes according to the length distribution of the discarded fraction, and so the need to up-date it.

Our study also shows high variability around the mean survival rates, which can partly be explained by the process of the catch on board by the crew. Indeed, most of the time, the *Nephrops* to be discarded remain on the deck while the crew finishes sorting the catch. Depending on the crew habits and the sea state, they may be more or less trampled (eg. when the sea is rough, discarded *Nephrops* slide back rapidly to the sea after having being sorted, and if not, it can happen that crews let the *Nephrops* for a while on the deck with more or less chance to be damaged (Figure 10)). Being aware of that, the fisherman community is investigating the way to install 'evacuation gutter' (Figure 11) to discard the *Nephrops* at sea all along the sorting process, and that way, reducing considerably the emersion time and the risk of damages, and therefore, potentially increase the survival rate. However, such a device is not adaptable to all type of boat and should be thought independently for each individual case.

Figure 10. Traditional way of sorting the catch involving a risk of trampling and damaging the Nephrops to be discarded.

Figure 11. Sorting gutter to discard the con-commercial catch all along the sorting process on board.

As a conclusion, no single value of global survival rate of discarded *Nephrops* could be defined, but a range between 45 and 65%, higher than the 30% currently used in the stock assessment procedure. The gears used having considerably evolved between the seventies and the time of our study, and the protocol used being *a priori* improved, it seems necessary to reconsider the global survival rate of discarded *Nephrops* used in the assessment procedure since the discarded animals that survive return to the stock biomass.

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