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Discarded *Nephrops* survival after trawling in the Bay of Biscay

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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 prone 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 2011 it compels the fishermen to adopt at least one of four selective devices (either a codend mesh size of 80mm, a flexible grid, a bottom square mesh panel, or a square mesh cylinder) (CNPMEM, 2011). 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 on 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 an effect on 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 that 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 under the experimental conditions, and the general implication of these results from a fishery management point of view.

2. Material and method

2.1. Survival rate

The *Nephrops* survival experiment was conducted by observers on board of seven commercial vessels at various time of the fishing season along the years 2009 and 2010 on the *Nephrops* grounds of the bay of Biscay. The survival rate of discarded *Nephrops* was calculated from the combination of the vitality state of individuals before being discarded and the chance of living animals to survive after re-immersion. Therefore, the methodology used was split in two main steps.

First, the vitality state (V) of *Nephrops* before being discarded was assessed. All along the sorting procedure of the catch on board, *Nephrops* let aside by the crew to be discarded were sampled in various part of the heap. The crew was asked to 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. The vitality state was assessed visually like it was done by Gueguen & Charueau in 1975 and by Morizur *et al*. in 1982. Though more detailed vitality state scales are available (Ridgway *et al*., 2006), the simple and easy option was chosen because of the necessity to get a compromise between the sample size and the time of treatment. Therefore, the vitality states were defined according to three categories: (1) Healthy (H): the *Nephrops* is able of 'flip-tail' and its body is tonic, (2) moribund (M): the *Nephrops* is alive (*eg*. move legs or antenna) but without body tonus (3) Dead (D): the *Nephrops* doesn't move at all and has no tonus. The proportions of individual of each vitality state were then computed for each haul.

Additionally, the cephalothoracic length, the sex and the number of pincers were also recorded for each individual.

Then, the proportion of individuals discarded alive and still alive after three days of re-immersion (S) was assessed. For that, once the codend was onboard and the crew started to sort the catch, a sample of about 100 living *Nephrops* (either healthy or moribund) to be discarded was taken. Their number of pincers and their sex were recorded. They were put individually in numbered perforated plastic tubes, which were themselves put in bags (figure 2a and 2b) to be re-immerged nearby the site where they were caught. 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 and the cephalothoracic length was recorded. For each haul *h*, the proportions of individuals healthy before re-immersion (*b*) that became either moribund ($H_{b,h} \rightarrow M_{a,h}$), dead ($H_{b,h} \rightarrow D_{a,h}$) or remained healthy ($H_{b,h} \rightarrow H_{a,h}$) after three days in the sea (*a*) were recorded, as well as the proportion of moribund individuals that became healthy ($M_{b,h} \rightarrow H_{a,h}$), dead ($M_{b,h} \rightarrow D_{a,h}$) or remained moribund ($M_{b,h} \rightarrow M_{a,h}$) were calculated.

The survival rate (SR) 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). Only individuals that were healthy after 3 days of re-immersion were considered for the survival rate estimate:

$$\overline{SR_{Obs.}}\ \frac{1}{Haul.S} * \frac{1}{Haul.V} * \left(\sum_{h=1}^{Haul.S} \frac{M_{b,h} \rightarrow H_{a,h}}{M_{b,h}} * \sum_{h=1}^{Haul.V} \frac{M_{b,h}}{M_{b,h} + H_{b,h} + D_{b,h}} + \sum_{h=1}^{Haul.S} \frac{H_{b,h} \rightarrow H_{a,h}}{H_{b,h}} * \sum_{h=1}^{Haul.V} \frac{H_{b,h}}{M_{b,h} + H_{b,h} + D_{b,h}} \right) \quad \{1\}$$

With

$SR_{Obs.}$ = observed discarded *Nephrops* survival rate

Haul.S = total number of hauls sampled for the Survival experiment

Haul.V = total number of hauls sampled for the Vitality experiment

h = individual haul

M = Moribund individuals

H = Healthy individuals

D = Dead individuals

b = before re-immersion

a = after 3 days re-immersion

In the same time, a control experiment was conducted in order to check the effect of the re-immersion conditions on the survival rate. For that, creels were used to catch control *Nephrops* with minimum stress. Creels were baited and soak for 2 days nearby the trawl fishing grounds. The control catch was composed of both *Nephrops norvegicus* (17 individuals) and *Munida rugosa* (138 individuals). Since the *Nephrops* sample was small, and considering that *Munida* and *Nephrops* are both decapods and live on the same grounds, they were both included in the control group. *Nephrops norvegicus* and *Munida rugosa* were put in experimental tubes and bags and re-immerged for three days the same way as the individuals discarded from trawling.

2.2. Statistical analysis

In order to identify the external parameters that affect significantly the vitality state of discarded *Nephrops*, the effect of 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. AIC method was used to fit the best model. The effect of sex and number of pincers on the vitality state was explored using analysis of variance and *t*-test.

The survival rate was also assessed by a boot strap method. The survival of *Nephrops* after 3 days of immersion was considered independent of the proportion of Healthy, Moribund and Dead individuals in the discarded fraction. The proportions of $H_b \rightarrow H_a$ and $M_b \rightarrow H_a$ were sampled with replacement among the hauls dedicated to the survival experiment. The proportion of M_b and H_b were sampled with replacement among the hauls dedicated to the assessment of the vitality state before discard. The bootstrap mean of the Survival Rate (SR) and its 95% confidence interval were computed from 1000 iterations of equation {1}.

3. Results

3.1. Summary of sampling sessions

7 Fishing trips were carried out on board of commercial vessels to assess the vitality state (V) before discard (figure 3a). 26 fishing operations were sampled. In order to cover a wide range of duration of emersion, some of them were sampled at the beginning and at the end of the crew sorting process. On average, samples consisted of 160 individuals. On the whole, 5637 *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 (table 1).

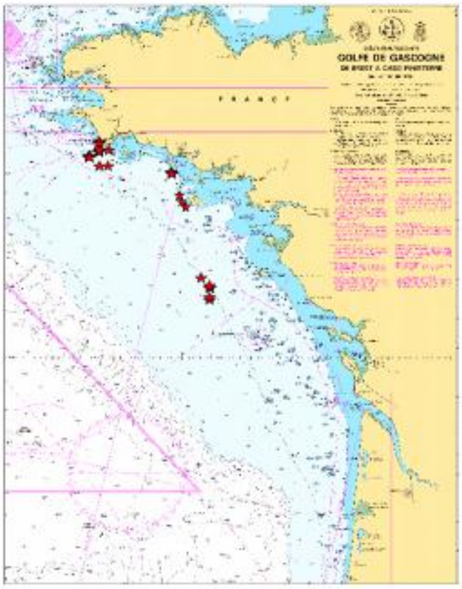

Figure 3a: Location of sampling stations to assess the vitality state (V) before discard

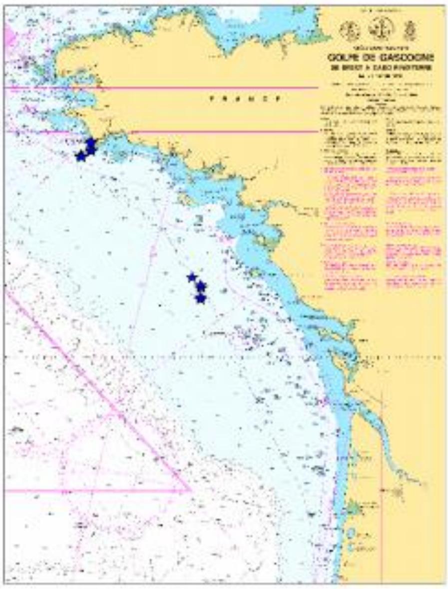

Figure 3b: Location of sampling stations to assess the survival (S) of *Nephrops* discarded alive after three days of re-immersion

Table 1 : summary of data collected for vitality (V) and survival(S) experiments

Vessel	Haul number	Number of *Nephrops* sampled for the survival experiment (S)	Number of *Nephrops* sampled for the vitality experiment (V)	Tow duration (decimal hours)	Duration of exondation on the deck (decimal hours)	Air temperature (°C)	Sex-ratio $\left(\frac{N_{Males}}{N_{Females}}\right)$
Vessel 1	1	NA	127	3.67	1.25	14	0.71
	1	NA	122	3.67	0.41	14	NA
	2	NA	114	3.75	1	16	0.59
	2	NA	117	3.75	0.33	16	NA
	3	NA	201	3.83	1.17	14	0.39
	3	NA	94	3.83	0.33	14	NA
	4	NA	117	4.92	1	11	0.35
Vessel 2	1	94	NA	NA	NA	NA	NA
	2	69	237	2.93	0.93	18	NA
	3	99	269	3.03	1.45	17	NA
	4	100	277	1.67	1	21	NA
	5	75	329	1.27	0.72	23	NA
Vessel 3	1	96	119	2.33	1.65	17	1.13
	2	100	190	2.1	0.82	20	0.7
	3	100	72	1.55	1.42	18	1.11
	4	100	81	2.02	1.12	15	0.73
	4	NA	106	2.02	0.83	15	NA
	5	99	79	1.93	1.33	16	1.13
	5	NA	91	1.93	1	16	NA
Vessel 4	1	NA	149	2.75	2.22	20	0.96
	2	NA	140	3.08	1.3	20	1.26
	3	NA	148	1.42	1.08	23	1.21
Vessel 5	1	NA	132	3.65	2.1	NA	0.83
	1	NA	154	3.65	0.97	NA	NA
	2	NA	149	3.77	1.05	NA	0.86
Vessel 6	1	NA	78	3.65	1.1	NA	0.51
	1	NA	78	3.65	0.6	NA	NA
	2	NA	37	2.4	0.52	NA	0.68
	2	NA	37	2.4	0.43	NA	NA
	3	NA	120	1.7	0.8	NA	0.53
	3	NA	91	1.7	0.47	NA	NA
	4	NA	140	1.1	1.93	NA	0.47
	4	NA	162	1.1	0.77	NA	NA
Vessel 7	1	140	256	3.25	1.08	22	1.03
	2	93	286	3.25	0.83	20	1.07
	3	98	334	2.75	0.67	20	0.48
	4	146	NA	NA	NA	NA	NA
	6	148	404	1.75	1.08	20	0.63

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. After re-immersion, 96% of *Munida* survived. Among the 17 *Nephrops* caught with creel, one died after 72hours of re-immersion in tubes (ie. 94% of control *Nephrops* survived).

3.3. Evolution of vitality state (V)

For the vitality experiment, the observed temperature ranged between 10 and 23°C, the duration of emersion of the samples on the deck ranged from 20 minutes to 2 hours and 13 minutes. The tow duration ranged from 1 hour and 05 minutes to 4 hour and 55 minutes.

The General Linear Model (GLM) fitted to the percentage of healthy individuals shows that the duration of immersion had a highly significant effect on the proportion of healthy *Nephrops* before discard ($p < 1.10^{-3}$), though the variability explained by the model is low (22%). The *Shapiro* test indicates the residuals of that model are normally distributed ($p = 0.34$). This model indicates that the shorter the duration of emersion on the deck, the higher the percentage of healthy individuals in the fraction of the catch to be discarded.

Under the conditions observed during our experiments in the discarded fraction, an average of 38.3% of *Nephrops* was healthy and 33.3% of *Nephrops* were moribund before being thrown overboard.

3.4. Evolution of survival (S) 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 2). We found that moribund individuals have a high capacity to recover (57% 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.

Table 2: Percentage of individuals either moribund or healthy before re-immersion that becomes dead, moribund of healthy after re-immersion.

		After re-immersion		
		Dead	Moribund	Healthy
Before re-immersion	Moribund	40%	3%	57%
	Healthy	19%	3%	78%

Among the vitality samples for which sex ratio was calculated, 32% show a sex-ratio inferior to 1, *i.e.*, in our study, the proportion of female is higher than the proportion of male in 38% of the cases (table 1). The *t*-test indicates that there is no significant difference in the capacity of male or female *Nephrops* to survive after re-immersion (p>0.05). The same test also indicates that the number of pincers does not affect significantly the capacity of *Nephrops* to survive after 3 days of re-immersion (p>0.05).

3.5. 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. Our observations show that the global survival rate ranges between 18 and 72%, with an average of 51.4%.

Without considering the environmental parameters, the bootstrap method indicates that the mean survival rate of discarded *Nephrops* under the observed conditions during our experiment is 50.6% with 95% confidence interval of 44.9% and 56.0% (figure 4).

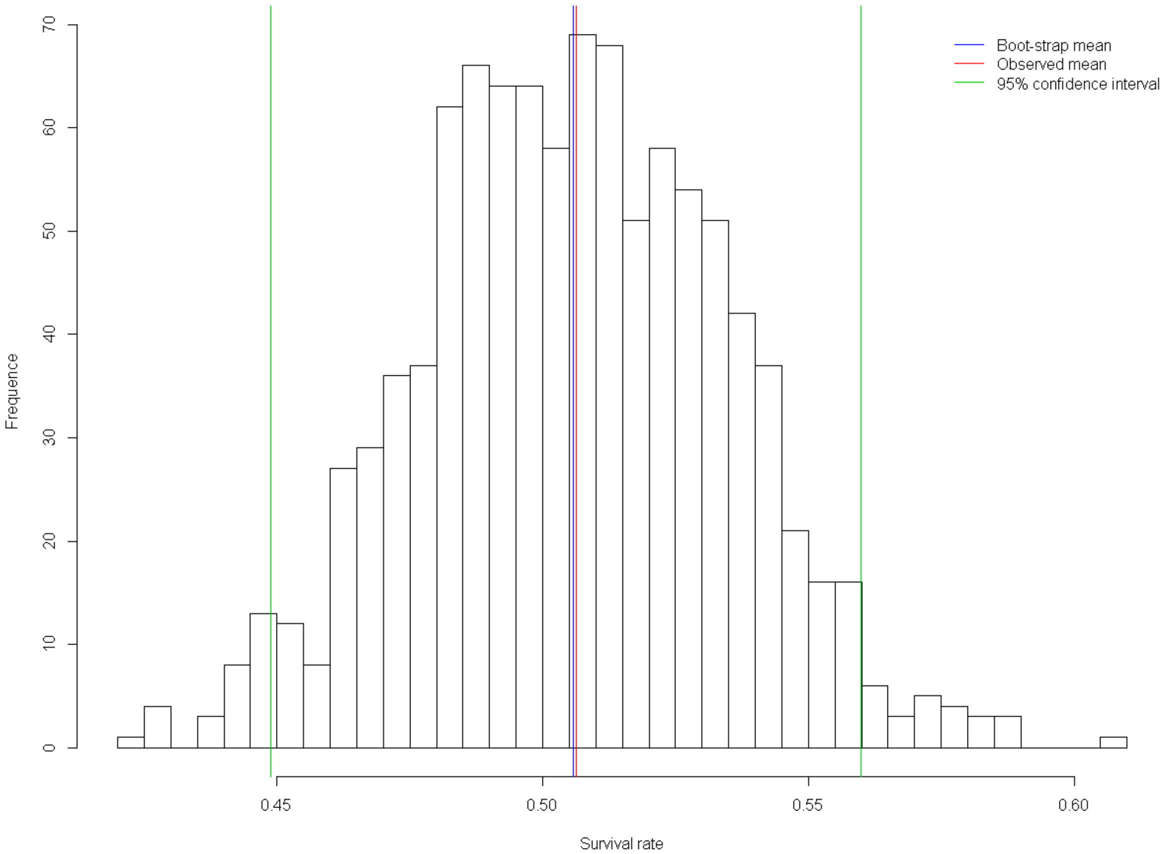

Figure 4: Bootstrap sampling of survival rate of discarded *Nephrops*

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 demonstrated 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 factor such as the duration of the emersion on the deck affects significantly their vitality state before discard, and consequently, their survival rate. Since the duration of emersion of the catch on the deck varies from one haul to another, from one vessel to another, it remains very delicate to get one single value of survival rate, which have to be interpreted with caution. Our study tend to show range of survival rates generally higher than the ones 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 indicates that the high density in cages may have increased the mortality rate induced by the experiment (*Nephrops* are more vulnerable to amphipods if stored at high density, and the individuals may be aggressive and damage each other). After one hour of emersion and three days of re-immersion in cages, Gueguen & 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, though we don't know in which proportions they counter balance each other.

Our study did not show that the air temperature or the catch volume in the codend had any significant effect on the survival rate, but we suspect these variables could have an effect in cases of wider range of observations. 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. 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 (Meillat, pers. com.) 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 (EU, 1998) from which fish such as young hake and horse mackerel escape. 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 (or discarded fraction) in the seventies were between 11 and 22mm of carapace length (Guéguen & Charuau, 1975), whereas in 2009 and 2010 the mean discarded size observed in our samples 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. Our study shows variability around 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 5). Being aware of that, 'evacuation gutter' (figure 6) to discard the *Nephrops* at sea all along the sorting process was investigated, 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 5 : example of sorting the catch involving a risk of trampling and damaging the *Nephrops* to be discarded.

Figure 6 : sorting gutter to discard the con-commercial catch all along the sorting process on board

The gears used having evolved between the seventies and the time of our study, and the protocol used being *a priori* improved, it seems necessary to reconsider the survival rate of discarded *Nephrops* since the non-wanted animals that survive return to the stock biomass. Our study clearly indicates that discarded *Nephrops* has a relatively high potential to survive after having been thrown back at sea. However, it remains difficult to define an exact proportion of survival due to the large range of factors that may affect it.

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