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Survivability of discarded Norway lobster in the bottom trawl fishery of the Bay of Biscay

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Abstract :

In the context of the landing obligation set by the new Common Fisheries Policy (CFP), Norway lobster *Nephrops norvegicus* was identified as a species likely to have high survival rate when discarded in the bottom trawl fishery of the Bay of Biscay. Previous studies in this area reported a survival rate between 30% and 51%, but the experiments were done on a limited monitoring period and the seasonal variations were not investigated. This study was designed to obtain a reliable value for survival rate after a 14-day monitoring period in onshore tanks allowing considering delayed mortality. The study also tested the effect on the survival rate of using a discarding chute system, a sorting device that was made mandatory on the 1st of January 2017 for *Nephrops* trawlers in the Bay of Biscay. This device, which enables fishermen to discard undersized *Nephrops* back to the sea while sorting, led to an increased average survival rate (51.2%) compared with the standard sorting practice (36.9%). The impact of biological, environmental and fishing operation related variables on survival from the first day of captivity to the end of the monitoring period was examined using a generalized linear model. The results of the GLM indicate that injuries, season and duration of the air exposure, significantly influence the survival from the 1st day of captivity to the end of the monitoring period. The survival rate was higher for non-injured *Nephrops* as well as for *Nephrops* that have undergone short air exposure, in summer and autumn.

Highlights

► Survival of discarded *Nephrops* was monitored for 14 days in tanks. ► Injuries and air exposure reduced survival significantly. ► Survival was highest in summer and autumn. ► Use of a discarding chute system improved survival.

Keywords : *Nephrops norvegicus*, Sorting process, Captivity, Vitality, Season, Discard survival

1. Introduction

The new Common Fisheries Policy (CFP) brought into force the 1st of January 2014 gradually established a landing obligation to encourage the long-term reduction of discards. However, according to article 15 paragraph 4(b), exemptions to the landing obligation can be obtained for species in which "scientific evidence demonstrates high survival rates, taking into account the characteristics of the gear, of the fishing practices and of the ecosystem" (European Commission, 2013). In particular, Norway lobster *Nephrops norvegicus* was identified by the ICES Workshop on Methods for Estimating Discard Survival (WKMEDS) as a species susceptible of a high survival rate (ICES, 2015). Previous studies investigated the influence of biological parameters on *Nephrops* survival rate after discard and found that size, sex and physical injuries all had a significant influence (Campos et al., 2015; Méhault et al., 2016; Milligan et al., 2009; Valentinsson and Nilsson, 2015). Environmental parameters, such as air temperature (Giomi et al., 2008) and salinity (Harris and Ulmestrand, 2004), have also been shown to influence survival rate. Light, of the intensity level found at the sea surface, damages *Nephrops*' eyes, but no impact on their survival has been demonstrated (Chapman et al., 2000; Gaten et al., 2013). Variations in ability to recover and survive across the seasons are acknowledged (Albalat et al., 2010; Castro et al., 2003; Lund et al., 2009), but the causes of such differences remain unclear and probably involve biological and environmental factors such as moult status, size (Milligan et al., 2009) or air temperature. Finally, trawling characteristics such as catch composition, tow duration, speed, the type of selective device used on the fishing gears (Campos et al., 2015, Valentinsson and Nilsson, 2015) or handling practices on deck (Bergmann and Moor, 2001), for instance duration of air exposure (Méhault et al., 2016), also have a major effect on survival.

The *Nephrops* catches are of particular importance in the North of the Bay of Biscay, where it accounted for 28% of the total landings in term of weight for the *Nephrops* bottom trawl *metier* in 2015 (Cornou et al., 2016). In 2012, 191 trawlers targeted *Nephrops* and generated more than €30 million in market value (Leblond et al., 2012). However, this mixed fishery has a historically high level of bycatch, composed of undersized *Nephrops* and other commercial species such as hake (Vogel et al., 2017). To improve the selectivity of this fishery, in 2008, the French national fishing committee made it mandatory to use one of the following selective devices: codend mesh size of 80 mm (instead of the 70 mm used up to 2008), flexible grid or bottom square mesh panel (JORF, 2008). In 2011, a square mesh cylinder was added to the list (JORF, 2011). In addition to these devices, the use of a 100 mm top square mesh panel for hake escapement has been mandatory since 2006 (European Commission, 2006). Furthermore, the minimum landing size was set at 9 cm (total length) to preserve the stock. Despite these improvements, discard rates remained high, accounting for about 30% in weight of all the *Nephrops* caught in 2015 (Cornou et al., 2016). The discarded *Nephrops* that survive can contribute to stock replenishment, making it particularly important to favour their survival. In this context, the European Commission incited initiatives that improve discarded *Nephrops* survival. The use of a discarding chute system was proposed by fishermen to decrease air exposure and injuries since these factors are known to be amongst the main drivers of *Nephrops* survival (Campos et al., 2015; Méhault et al., 2016; Ridgway et al., 2006a, 2006b; Wileman et al., 1999). This device is joined to the sorting table and makes it possible to discard individuals back to the sea throughout the on-board sorting process. This minimises the duration of air exposure as well as the possibility of being injured during the time spent on the deck, compared with the standard sorting practice that consisted in discarding *Nephrops* back to the sea at the end of the sorting process. The use of this sorting device became mandatory on the 1st of January 2017 (JORF 2016).

To measure survival rate, two methods were chosen for this study among the three identified by the Expert Working Group 13-16 (EWG13-16) of the Scientific, Technical and Economic Committee for Fisheries (STECF, 2013): vitality assessment and captive observation. Previous studies on discarded *Nephrops* survival in the Bay of Biscay that used a captive observation method in open water reported a survival rate between 30% and 51% (Gueguen and Charuau 1975; Méhault et al., 2016). However, these earlier studies were too short (3 days) to allow the asymptote of the survival rate to be reached, or to investigate variability between the different fishing seasons, or consider different sorting practices.

This study was designed to obtain a reliable value for survival rate, including its potential variations across seasons and different sorting practices. Individuals were sampled in three different seasons and two sorting practices were simulated: (1) the standard scenario, which consists of discarding the unwanted catch back into the sea at the end of the sorting process; and (2) the discarding chute system scenario, with individuals being discarded back to the sea during sorting. This study therefore investigated the influence of an environmental parameter (season), fishing operation characteristics (sorting practice, duration of air exposure, composition of the haul) and biological parameters (length, sex and injury) on *Nephrops* survival from the first day of captivity to the end of the monitoring period.

2. Materials and Methods

2.1. Sampling strategy and material

Sampling was conducted on the “Grande Vasière” *Nephrops* ground in the North of the Bay of Biscay (Fig. 1), in depths of 78−110 m, on board two commercial trawlers. The sampling was done in three different seasons, in April, June and September 2016 (hereafter named spring, summer and autumn, respectively). The hauls were conducted under regular commercial conditions: the duration was set at 3 hours, with a speed around 3.5 knots and both vessels were rigged with a twin bottom trawl equipped with a codend mesh size of 80 mm and a 100 mm top square mesh panel. On-board handling practices were kept as usual to obtain data representative of this fishery. The main characteristics of each fishing operation were recorded: the air temperature at the sorting time, the duration of air exposure, as well as the catch composition defined here by the ratio between the weight of *Nephrops* caught and the weight of the total catch.

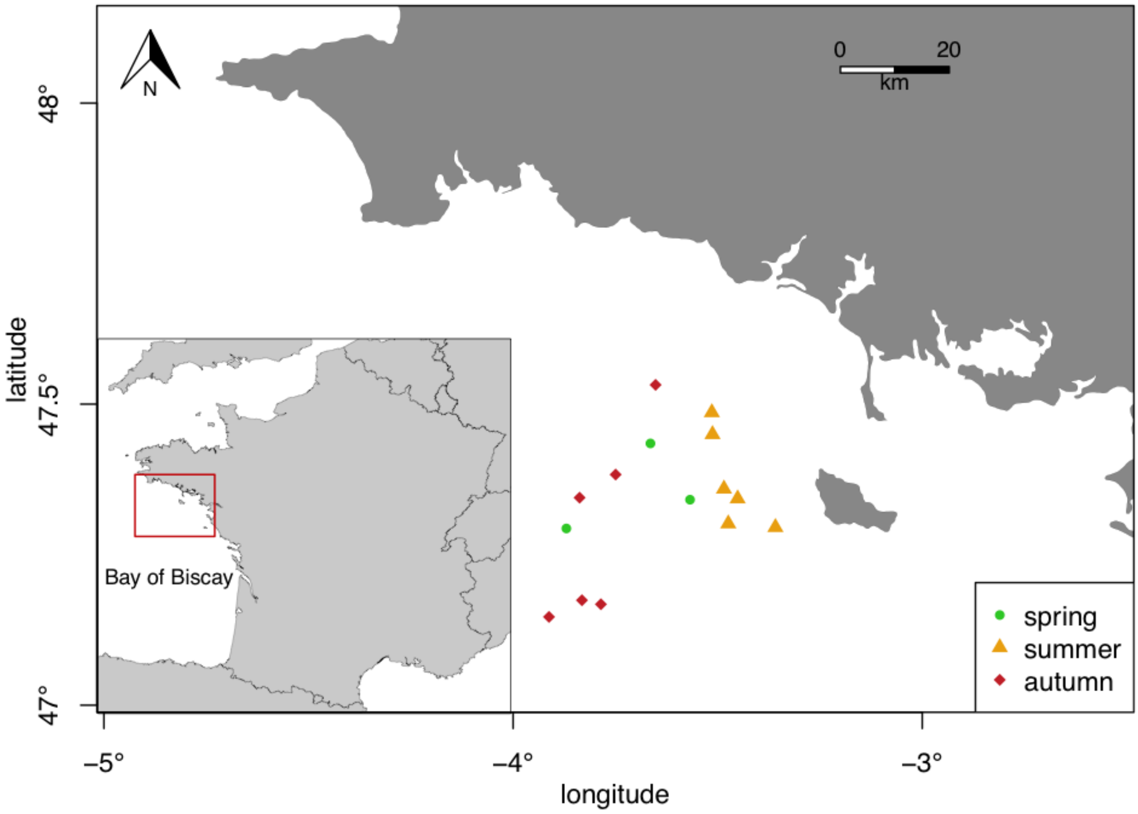

Figure 1:Map of the Bay of Biscay with sampling sites location at each season

2.1.1. Control group sampling

To disentangle the part of the mortality caused by the catch from any caused by captivity, control samplings were also made. Sampling of control individuals was conducted on separate fishing trips at each season, before the test group was sampled. Tow duration was set at 1 hour to prevent physical damage (Milligan et al., 2009). Living *Nephrops* were sampled among the undersized *Nephrops* and put in trays with individual cells (35 mm × 35 mm × 200 mm) (Fig. 2) in on-board tanks. Once landed, these *Nephrops* were kept in onshore tanks until stabilisation of mortality was observed. Then a set of individuals with a sex ratio of about 50:50 were selected and these were placed in the on-board tanks during the sampling of the test group and have undergone the same protocol as the test group sampling.

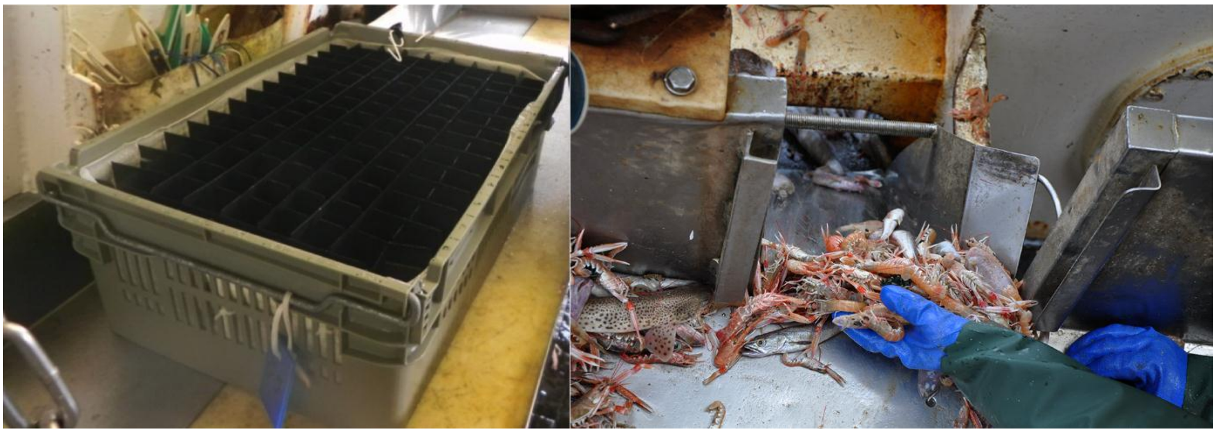

Figure 2:Tray with individual cells in which Nephrops were kept during the monitoring period (left panel) and example of discarding chute system onboard a commercial trawler (right panel). Credits: T.Rimaud and T.Evain.

2.1.2. Test group sampling

Nephrops were randomly sampled among the discarded individuals following two different sorting processes: (1) to simulate the standard sorting scenario individuals were collected at the end of the sorting process and (2) to simulate the discarding chute system sorting scenario (Fig. 2), individuals were sampled every 10 minutes. Both sorting processes were implemented during each fishing operation. *Nephrops* were placed in the trays and immerged in the on-board tanks. When a sampled individual was found to be dead, the corresponding cell in the tray was left empty. Cephalothoracic length (mm), sex and presence of injuries (cuts on the tail, smashed *Nephrops*, broken rostrum, necrosis stains and holes in the carapace) were recorded at the death of the *Nephrops* or at the end of the monitoring period. Environmental variables and characteristics of the fishing operation were recorded at each haul (Table 1).

Table 1: Summary of the environmental and fishing operation related variables. For control individuals, the number in the column "Number of Nephrops sampled" is the one of Nephrops taken on board during the test sampling.

Season	**Fishing operation**	**Air temperature (°C)**	**Sorting scenario**	**Air exposure min and max (h:min)**	**Number of *Nephrops* sampled**
Spring		11.4	Control	00:58 to 01:13	131
	1	15.7	Standard	01:36 to 01:58	264
			Chute system	00:45 to 01:49	260
	2	16.2	Standard	01:15 to 01:34	267
			Chute system	00:27 to 01:10	264
	3	19.1	Standard	01:03	132
			Chute system	00:25 to 01:09	263
Summer		16.5	Control	00:30 to 02:02	255
	4	15.7	Standard	01:23	130
			Chute system	00:31 to 01:02	131
	5	16.2	Standard	01:05	131
			Chute system	00:13 to 00:43	131
	6	19.1	Standard	01:19	122
			Chute system	00:27 to 01:01	133
	7	19.9	Chute system	00:16 to 00:48	127
	8	19.2	Standard	01:13	125
			Standard	01:35	133
			Chute system	00:27 to 00:58	122
	9	20.1	Standard	01:03	129
			Chute system	00:16 to 00:48	129
Autumn		NA	Control	00:48 to 00:52	128
	10	20.6	Standard	01:15	132
			Chute system	00:30 to 01:00	131
	11	19.0	Standard	01:17	131
			Chute system	00:29 to 01:00	128
	12	18.9	Standard	01:17	130
			Chute system	00:27 to 00:56	129
	13	18.0	Standard	01:08	129
			Chute system	00:25 to 00:56	126
	14	19.5	Standard	01:12	131
			Chute system	00:31 to 00:58	130
	15	21.5	Chute system	00:29 to 00:57	130
Total					4934

2.1.3. Experimental set up

The on-board tanks on both sampling vessels were approximately 2 m^3 and were equipped with bubbler systems. The water flowing in was pumped close to the surface and cooled to reach the temperature measured on the seabed at the sampling sites location. The onshore holding facilities were located in the port of Lorient, so air exposure during the transit from the vessel to the onshore tanks only lasted a few minutes. In the onshore facilities, control and test trays were randomly distributed between two tanks of 0.7 m^3 each, whose temperature was set to the value recorded at the sampling sites. Salinity, temperature and nutrient concentrations were checked on a regular basis to ensure no variations could impair *Nephrops* survival. In addition, tanks were filled with pumped seawater that was bio-filtrated and recirculated during the experiment. They were equipped with a bubbler system and a cover to maintain *Nephrops* into the dark. *Nephrops* were not fed, based on their demonstrated ability to endure a monitoring period without food (Valentinsson and Nilsson, 2015) and the potential stress induced by an inadequate alimentation.

2.2. Vitality assessment

Vitality was assessed visually, based on the three vitality levels defined in Méhault et al. (2016), developed based on unstressed *Nephrops* reactions: (1) healthy: the *Nephrops* has some strength in its body, moves without stimulus and is able to do a 'tail-flip'; (2) moribund: the *Nephrops* moves slowly or only if stimulated, only its appendages move; (3) dead: the *Nephrops* does not move at all and shows no reaction to stimuli. The vitality state of each *Nephrops* was recorded on a daily basis over 14 days. Individuals that were not moving were gently stimulated with long curved tweezers and if they did not react, they were put into a water-filled tray with large cells for further examination. Dead individuals were removed from the trays.

2.3. Data analysis

2.3.1. Survival rate

Survival rate was calculated for each sampling scenario and for the controls, based on the proportion of *Nephrops* alive at the end of the captivity period. The survival rate was computed for each season and for the three seasons pooled together. The moribund *Nephrops* (0.7% of the total sampled individuals at the end of the experimentation) were counted as alive and a 95% confidence interval (CI) was calculated for each survival rate (mean ±1.96×SD.).

2.3.2. Kaplan-Meier plots

Over the captivity period, we recorded the day on which each *Nephrops* died and at the end of the experimentation, we recorded which individuals had survived. This kind of data is known as right-censored data, because death was not necessarily observed during the experimentation, and can be analysed by a Kaplan-Meier estimation. Kaplan-Meier estimator allows visualising the proportion of survival with time. Plots were realised for each of the three seasons and on the three seasons pooled together, with their corresponding 95% confidence interval. The difference between the curves of the two sorting scenarios was tested with a log-rank test. Analyses were conducted with the “survival” package, in R 3.3.1 (R Development Core Team, 2016).

2.3.3. Generalized linear model analysis

A generalized linear model (GLM) was used to investigate which environmental, biological or technical parameters influenced the survival rate of discarded *Nephrops*. We fitted the GLM with a binomial distribution and a logit link function to the survival from the 1st day of captivity to the end of experimentation. Live *Nephrops* were coded 0 and dead *Nephrops* coded 1. Explanatory variables included in the GLM were season, duration of air exposure, catch composition, presence of injuries, sex and length. The model can be expressed as shown in Eq. 1.

(1) $\text{logit}\,(P(Y_i = 1 \mid \mathrm{X_i})) = \beta_0 + \mathrm{X}_i \vec{\beta}$

With $P(Y_i = 1 \mid \mathrm{X_i})$ the probability for *Nephrops i* to be dead at day 14 knowing the design matrix of the covariates X_i; β_0 the intercept; $\vec{\beta}$ the vector of the coefficients

The best model was selected with a stepwise procedure based on the minimization of the Akaike Information Criterion (AIC). For the qualitative variables injury (coded as “Yes” or “No”) and season, the modality “No” of the variable injury and the modality “Autumn” of the variable season were taken as references in the summary output. Nagelkerke’s pseudo R^2 was used to quantify the variance explained by the model (Nagelkerke 1991).

3. Results

A total of 4934 *Nephrops* were sampled, with 1581, 1798 and 1555 individuals in spring, summer and autumn, respectively. This number includes the 131 control *Nephrops* sampled in spring, 255 in summer and 128 in autumn. Cephalothoracic length ranged from 15 to 33 mm (mean 24.3±2.7mm) with a mean length of 22.8±2.8 mm, 25.2±2.4 mm, and 24.3±2.4 mm in spring, summer and autumn, respectively (significant pairwise difference). The percentage of injured *Nephrops* was the highest in summer (26.6%) and the lowest in spring (11.2%) with a significant difference between these two seasons. The sex ratio was balanced at all seasons. Catch composition was significantly different between all seasons, with a higher value of catch composition index in spring (0.29±0.08) compared with autumn (0.12±0.03) and summer (0.11±0.06). For each of the two sorting scenarios, duration of the air exposure significantly varies between seasons, with a longer air exposure in spring (0.92±0.33 h for chute system; 1.41±0.31 h for standard) compared with summer (0.61±0.23 h for chute system; 1.30±0.16 h for standard) and autumn (0.71±0.18 h for chute system; 1.23±0.06 h for standard). Finally, air temperature was significantly different between all seasons, with a mean of 16.4±2.0°C in spring, 19.6±1.4°C in summer and 19.4±1.1°C in autumn.

In addition, the number of injured *Nephrops* was significantly different between sorting scenarios (Chi^2 test, $Chi^2 = 10.595$, p-value = 0.0011), with a higher number of injured individuals with the standard sorting scenario (20.7%) than with the discarding chute system (17.7%). Mean air exposure was significantly lower with the chute system scenario (0.75 h) compared with the standard one (1.34 h) (t-test, t = -74.1, p-value <0.0001). At the end of the on board sampling at day 0, *Nephrops* sorted with the discarding chute system showed a percentage of dead individuals two times lower than the ones sorted with the standard scenario as well as a higher percentage of healthy individuals (Table 2). The percentage of moribund individuals was similar between the two sorting scenarios (Table 2).

Table 2: Percentage of dead, moribund and healthy Nephrops at day 0, according to the sorting scenario.

	Vitality state at day 0 (% of total number of *Nephrops* in each sorting scenario)		
Sorting scenario	Dead	Moribund	Healthy
Standard	33.0	31.3	35.7
Discarding chute system	15.6	34.8	49.6

Examination of the survival rates for each season revealed that mortality stabilized after day 5 and that this stabilisation was not as marked in spring as in summer or autumn since the slopes of the survival curves between day 6 and day 14 were smaller in summer and autumn (Fig. 3, A, B, C). For each season, the two sorting scenarios were significantly different and the survival rate of the individuals sorted with the discarding chute system was always higher than the one of individuals sorted with the standard scenario. The difference between the two sorting scenarios was lower in spring (Chi^2 = 7.7, p-value = 0.006) than in summer (Chi^2 = 71.3, p-value <0.0001) and autumn (Chi^2 = 54.7, p-value <0.0001). Overall, for the three seasons pooled together (Fig. 3, D), the stabilisation of the survival rate was reached at day 5 and the survival rate was significantly different between the two sorting scenarios (Chi^2 = 116, p-value <0.0001). At all seasons, control *Nephrops* underwent a lower mortality than the test individuals did.

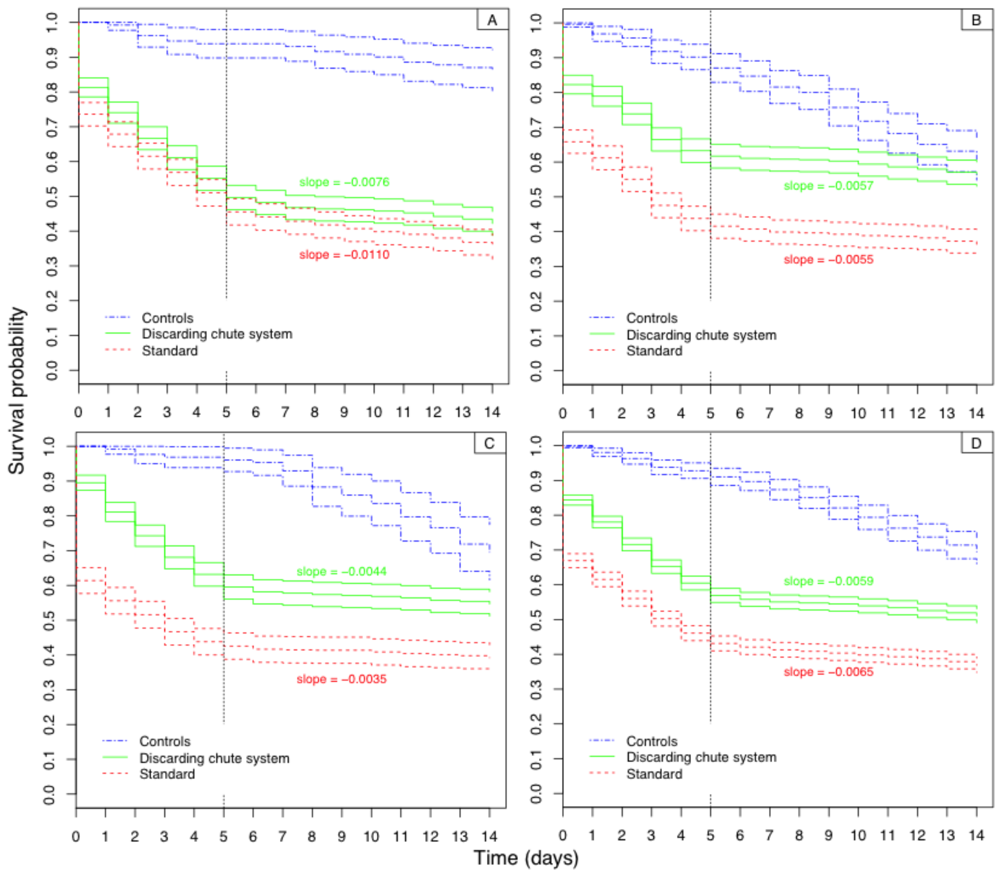

Figure 3:Kaplan-Meier estimation plots: survival probability as a function of time for spring (A), summer (B), autumn (C) and the three seasons pooled together (D). For each scenario, the survival curve is framed by a 95% confidence interval. The slope of the survival curve between days 5 and 14 for the 2 sorting scenarios is indicated beside each curve.

At the end of the 14 days monitoring period, for all seasons pooled together, the individuals sorted with the discarding chute system showed a survival rate of 51.2% [30.9; 71.5 %] while individuals sorted with the standard scenario had a lower survival rate of 36.9% [20.9; 52.9 %] (Table 3). Survival rate was slightly lower in spring, especially for the discarding chute system scenarios. Controls showed a survival rate of 86.3% in spring, 61.8% in summer and 69.5% in autumn.

Table 3: Survival rates (%) and their 95% confidence intervals [in square brackets] at the end of the monitoring period for the two sorting scenarios and control

Season	Standard scenario	Discarding chute scenario	Control
Spring	35.4 [15.3; 55.5]	42.3 [26.6; 57.9]	86.3
Summer	36.4 [30.3; 42.5]	56.5 [49.3; 63.7]	61.8
Autumn	39.2 [17.5; 60.9]	54.9 [31.5; 78.3]	69.5
Global	36.9 [20.9;52.9]	51.2 [30.9; 71.5]	69.3 [45.7; 93.0]

The results of the GLM indicate that the variables injury, season and duration of the air exposure, significantly influence the survival from the 1st day of captivity to the end of the monitoring period (Table 4). Presence of injuries and long air exposure reduce survival rate. Survival is highest in summer, then in autumn and lower in spring.

Table 4: Chi2 statistics and p-value indicate the significance of the variables in the best model. For each modality, the slope and standard deviation give the sign of the relation with survival at day 14. A positive slope indicates a positive relationship between the covariate and the survival which value 1 means death.

Variable	**Slope**	**Standard deviation**	**Chi^2 stat**	**p**	**Significance**
Injury			147.46	$< 2.2.e^{-16}$	***
injuryYes	1.24	0.11			
Duration air exposure	0.33	0.10	11.83	$5.85.e^{-4}$	***
Season			48.88	$2.44.e^{-11}$	***
seasonSUMMER	-0.12	0.09			
seasonSPRING	0.52	0.09			
Cephalothoracic length	0.02	0.01	2.12	0.15	NS

4. Discussion

In the context of sustainable management of marine resources, it is particularly important to limit non-target catches and favour the survival of discards. Our experiment offers new data on the survival rate of *Nephrops* discarded by trawlers in the Bay of Biscay. The result of 36.9% survival for the standard catch handling process for all seasons pooled together is in line with studies in other European *Nephrops* fisheries that used a similar method and monitoring period: 55% in Sweden (Valentinsson and Nilsson, 2015) and 62% in the UK (Armstrong et al., 2016). Moreover, to be consistent with *Nephrops* fishery evolution, we tested the use of a discarding chute system, which limits the duration of the air exposure as well as the possibility for the *Nephrops* of being injured on the deck. We demonstrated a significantly shorter air exposure and smaller number of injured *Nephrops* with the discarding chute scenario and our results highlighted the efficiency of this device since it led to a survival rate of 51.2% compared with the 36.9% for standard sorting practices.

The negative relationship between survival rate and injuries, already mentioned in previous studies (Albalat et al. 2016; Campos et al., 2015; Ridgway et al., 2006b; Wileman et al., 1999), is confirmed here and can be explained by a loss of haemolymph (Harris and Andrews 2005). Similarly, long air exposure is known to decrease survival (Harris and Andrews 2005; Méhault et al., 2016; Ridgway et al., 2006a), possible via dehydration and a reduction in the immune function (Harris and Andrews 2005; Ridgway et al., 2006a). Survival rate is significantly different between seasons and the highest rates occur in summer and autumn. This could be linked to the slightly higher duration of air exposure endured in spring or to the annual moulting period between February and May (Field et al., 1992), with a peak in April–May in our study. At this stage, it has been shown that decapods suffer more severe damage due to softness of their exoskeletons (Milligan et al., 2009; Ridgway et al., 2006b) and even suffer greater mortality (Wassenberg and Hill 1989). However, one should take with caution the higher mortality in spring demonstrated in the results of the GLM. Indeed, *Nephrops* suffered a lower mortality at day 0 in spring compared with summer and autumn but had then a sharper decrease of the survival rate (Fig. 3). This delayed mortality contributed to wider the difference between slopes of the modality “spring” and “summer” (“autumn” taken as a reference) of the season qualitative variable (Table 4). Overall, the GLM model explains a small part of the total variance (Nagelkerke’s pseudo $R^2 = 0.08$) so that the variance at the individual level may prevail over the variance explained by the explanatory variables of the GLM.

Because of experimental conditions, under- or over-estimation of survival rates may occur. First, in a study based on onshore monitoring, it is impossible to account for the predation pressure on *Nephrops*, or their ability to survive in their natural environment (burrowing, escaping predators, etc.) (Castro et al., 2003; STECF 2015). According to Albalat et al. (2016) who placed underwater camera to observe the behaviour of discarded *Nephrops,* the healthy individuals are able to stand, move and actively avoid predators by repeated tail-flips within a few minutes after their return to the bottom. The higher percentage at day 0 of healthy individuals in *Nephrops* sorted with the chute system compared with the standard scenario confirms the efficiency of such a device to enhance the survival of *Nephrops* in real fishing conditions. Mortality might also have been overestimated due to additional stress from the condition of captivity: starvation, restriction of movement and impossibility of burrowing behaviour (Castro et al., 2003), or the manipulation for daily vitality assessment as well as the stress induced by the transportation from the on-board to the onshore tanks. In addition, the sampling protocol also decreased the beneficence that the discarding chute system would have in real fishing condition due to the air exposure undergone by sampled *Nephrops* every time new individuals had to be added to the tray.

Finally, control *Nephrops* were caught and kept in a tank until stabilisation of survival prior to the test experiment, and endured between 21 and 31 days of starvation. The 69.3% survival rate obtained using trawl-caught control *Nephrops* is lower than the rate obtained in other studies that used creel-caught controls (Armstrong et al., 2016; Campos et al., 2015; Valentinsson and Nilsson 2015). This difference in survival could be explained by a difference in cephalothoracic length and in duration of the captivity period. Indeed, creel caught *Nephrops* are larger than the trawl-caught ones (Campos et al., 2015) and suffer very little stress from being caught (Ridgway et al., 2006b), so they do not have to handle an additional captivity period to reach a stabilisation of the survival. In this study, trawl-caught controls were preferred for consistency in size classes of individuals. Since no effect of cephalothoracic length on the survival at the end of the experimentation have been demonstrated, the 69.3% survival rate obtained and the absence of survival rate stabilisation observed for the controls most likely originates in the duration of the starvation period. Test individuals that spent only 14 days in captivity do not seem to suffer the same absence of stabilisation of mortality as controls since their survival rate shows a clear stabilisation. For this reason, the mortality suffered by control individuals is distinguished from the one underwent by test *Nephrops* and does not cast doubt on the survival rates obtained with the test individuals.

The longer monitoring period (14 days) compared with previous studies conducted in the same area (3 days for Gueguen and Charuau 1975 and Méhault et al., 2016) allowed us to reach the asymptote of survival rate for the test *Nephrops*. This made it possible to ensure that delayed mortality was taken into account and strengthen the reliability of our results. We provided an accurate survival rate estimate, which is the prerequisite to apply for an exemption from the discard ban and to propose mitigations measures. Despite our study demonstrates the capacity of *Nephrops* to survive after discard, little is known about *Nephrops'* ability to actually avoid predation and find a new burrow when discarded back to the seabed. An underwater video record, such as the methodology used in Albalat et al. (2016), could provide some insight for the *Nephrops* fishery of the Bay of Biscay.

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