Département RBE – Ressources Biologiques et Environnement
Unité STH - Sciences et Technologies Halieutiques
Laboratoire LTH - Technologie Halieutique, Lorient

L. Mérillet, D. Kopp, F. Morandeau, S. Méhault

Association du Grand Littoral Atlantique (AGLIA)

T. Rimaud, C. Piton

PDG/RBE/STH/LTBH/2017-002

January 2017

Assessment of the survival rate of unwanted catches of Norway lobster *Nephrops norvegicus* caught by bottom trawling in the Bay of Biscay

Final Report of the SURTINE Project: Assessment and Improvement of the *Nephrops* Survival in the Bay of Biscay

Contents

Acknowledgements

This study has been carried out in the framework of the SURTINE project, sponsored by AGLIA, with the financial support of the Ministry of the Environment, Energy and the Sea, of France Filière Pêche, of Ifremer and of the Brittany, Pays de la Loire and Nouvelle-Aquitaine Regional governments. We would like to thank the skippers and crews of the Côte d'Ambre and Men Gwen vessels for their hospitality and their collaboration in implementing the protocol. We would also like to thank SEM Lorient Keroman for premises available for experimentation.

1 Introduction

In the context of the reform of the Common Fishing Policy (CFP) undertaken by the European Union and implemented since 1st January 2014, the discarding of unwanted catches will gradually be forbidden. Article 15 of the CFP lays down a landing obligation for all species subject to European quotas and will come into force between 2015 and 2019 according to the species and the zones. The Regulation allows several exemptions including one for "species for which scientific proof shows high survival rates, due to the characteristics of the fishing gear, the fishing methods and the ecosystem" (EU Regulation No. 1380/2013). In particular, *Nephrops* were identified by the International Council for the Exploration of the Sea (ICES) as one of the species having the potential for a high survival rate (Workshop on Methods for Estimating Discard Survival - WKMEDS, ICES 2015).

In addition to the Total Allowable Catches (TAC) defined at European level, the *Nephrops* fishery in the Bay of Biscay is managed by a system of licenses, the national fishing licenses (ANP), the contingent of which is set at 232 ships. In recent years, approximately 200 licenses have been granted. The ships are between 9 and 20.8m in length with an average length of around 15m. The use of this license is conditional on different management measures including: (1) the use of a square mesh panel for hake, (2) a selective device for *Nephrops*, (3) a chute system allowing the rapid release of unwanted *Nephrops* catches and (4) a minimum landing size of 27mm (carapace length) which is greater than the European minimum size. 25 French ports are involved in this fishery. The ICES assessment estimates that the rate of exploitation is less than $F_{MSY\ Proxy}$ (ICES, 2016). In 2015, ICES assessed the quantity of *Nephrops* landed at 3659t (ICES, 2016). The majority of catches takes place between March and September. When the ships are engaged in *Nephrops* fishing, this constitutes the main component of their catches (54%) according to Cornou et al. (2015). The global discard rate varies according to the year but is approximately 50%. Discards are mainly made up of *Nephrops* and hake (more than 50% of the total quantity of discards). In 2014, 29.2% of *Nephrops* caught were discarded (Cornou et al. 2015).

A recent study of the survival of discarded *Nephrops* in this fishery found the average rate of survival between 42% and 60% (Méhault et al. 2016). The duration of this study (3 days) was not however considered to be sufficient by the Scientific, Technical and Economic Committee for Fisheries (STECF) to define a reliable mortality rate as its stabilisation over time could not be demonstrated. On the basis of these results, the European Commission granted a temporary exemption for the landing obligation of unwanted catches of *Nephrops* in ICES zones VIII and IX for 2016 (EU delegated regulation No. 2015/2439) and for 2017 (EU delegated regulation No. 2016/2374). A new request for an exemption may be considered providing new scientific and technical data relating to the survival of *Nephrops*.

Furthermore, in order to renew the exemption for 2017, the European Commission recommended that "the necessary measures to increase the survival of *Nephrops* be taken onboard the ships". In response to this recommendation, the professional fishermen in the Bay of Biscay have put forward a chute system implemented during the sorting process in order to reduce crushing and *Nephrops* time exposure to air. Equipping ships with these chute systems will become mandatory from 1st January 2017 under the terms of the Order of 27 May 2016 (MEEDE 2016).

This study is part of the SURTINE project, sponsored by the Association du Grand Littoral Atlantique (AGLIA) in scientific partnership with the Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER) in Lorient. In light of these new obligations and of the European Commission and WKMEDS' recommendations, this study proposes to reassess the survival rate of *Nephrops* discarded by the *Nephrops* fishery in the Bay of Biscay, based on monitoring data over a longer period than the previous studies in the area. The sampling protocol and the range of variables observed ensure that our study is representative of this fishery. Based on Valentinsson & Nilsson (2015), the study was carried out in captivity in onshore tanks to assess the vitality of the *Nephrops* on a daily basis until long-term stabilisation of the survival rate is reached (ICES 2015). For the first time, the sampling protocol made it possible to assess the survival rate for 2 different sorting methods: (1) standard method of releasing discards at the end of the sorting process and (2) removing the discards gradually during the sorting process using a chute system. The samples were taken at 3 periods of the 2016 fishing season (spring, summer and autumn) to ensure they were representative of the different conditions encountered.

2 Material and method

2.1 Material

2.1.1 At sea sampling

The sampling took place in Brittany, in the Grande Vasière mudflats area in the North of the Bay of Biscay, on board 2 trawlers registered in Lorient: The Côte d'Ambre (LO 422395/16.5m) for the spring and autumn campaigns, and the Men Gwen (LO 763742/18.5m) for the summer campaign. For each season, two sea trips were made: one to catch individuals that constitute the "control" sample and the other to catch individuals for the "test" sample. The catches were made by twin trawlers equipped with regulation selective fishing gear for hake (100mm square mesh panel) and for *Nephrops* (codend mesh size of 80mm). In each of the three sampling periods, 3 to 6 hauls were made (Figure 1).

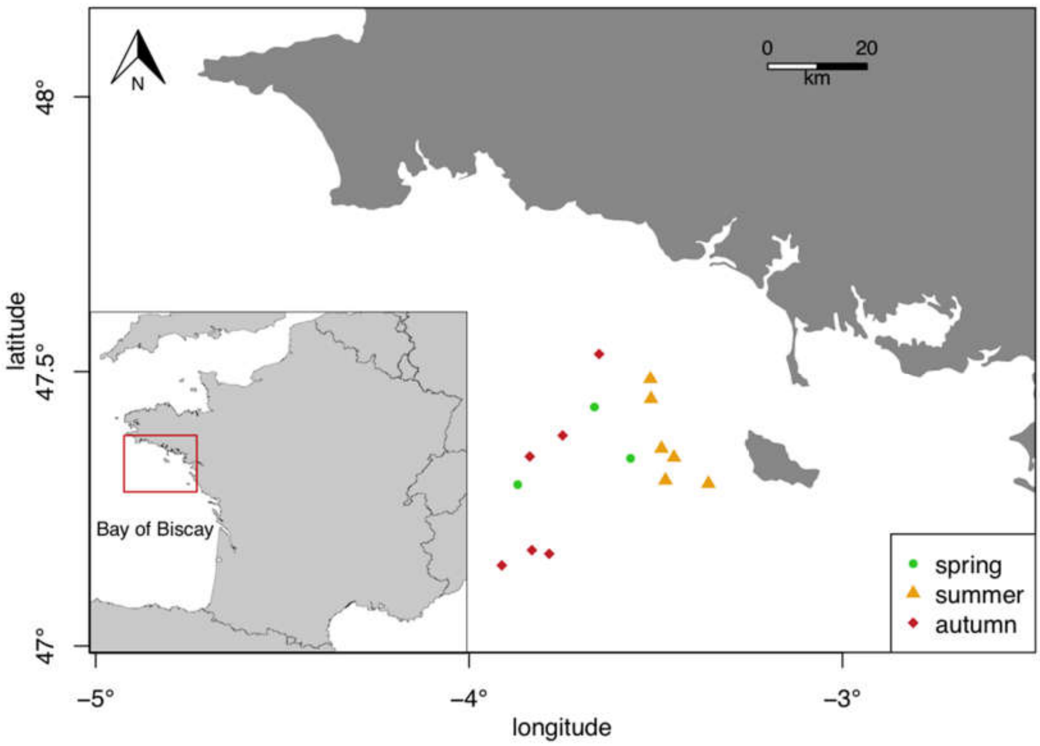

Figure 1: Position of the sampling sites at each season

2.1.2 Onboard and onshore tanks

In accordance with WKMEDS' recommendations, monitoring of *Nephrops*' mortality was carried out in captivity. Onshore tanks were preferred to the natural environment for logistic reasons (weather conditions, ship chartering costs) and protocol. The daily emersion of samples and their exposure on the deck for monitoring can cause stress and damage which could affect the survival rate (Castro et al. 2003, Campos et al. 2015). Moreover, re-immersion in the natural environment exposes the individuals held in trays to a higher number of attacks from amphipods than normally expected (Morizur et al. 1982).

In order to simulate the release of the *Nephrops* and to monitor their vitality state, it was decided to use water tanks, on board the ship during sampling, then on the shore for the following 14 days.

Onboard tanks

The tank onboard the ship is that normally used by the crew for the storage of live *Nephrops*. It operates in a closed circuit and is supplied with natural sea water drawn from the surface during navigation time. It is equipped with a bubbler system. It is made of stainless steel and contains approximately 2m^3 of water. The water is cooled to the temperature of the sea bottom, measured in advance using a probe fixed to the trawl (cf. 2.3.1).

Onshore tanks

The onshore tanks were located in closed premises in Lorient fishing port. The short distance between the onshore tanks and the landing point reduced transport time and air exposure to a few minutes. The seawater was taken from the Lorient harbour. It was supplied by the Port technical services, and was treated and checked monthly for food use. In order to avoid contamination and guarantee that the quality of the water does not cause *Nephrops* mortality, onshore tanks operated in a closed circuit and were equipped with a biological filter, a mechanical sand filter, a skimmer and an ultraviolet treatment (Figure 2). The trays of *Nephrops* were placed in 2 containers, closed with a cover, with a capacity of $0.7m^3$ each. The bubbler system guarantees the environment is oxygenated. The water temperature is kept at the temperature measured on the sea bottom during sampling.

The main physicochemical parameters of the water in the tanks (temperature, salinity and nitrite rate) are checked onboard and on the shore on a daily basis. The ammonium, phosphate and silicate rates, which also indicate the quality of the water (Valentinsson & Nilsson 2015), are measured twice a week during onshore monitoring.

The individuals were not fed during the 14 days of the study in the tanks, as per the previous studies on the survival of *Nephrops* in tanks (Ridgway et al. 2006; Valentinsson & Nilsson 2015).

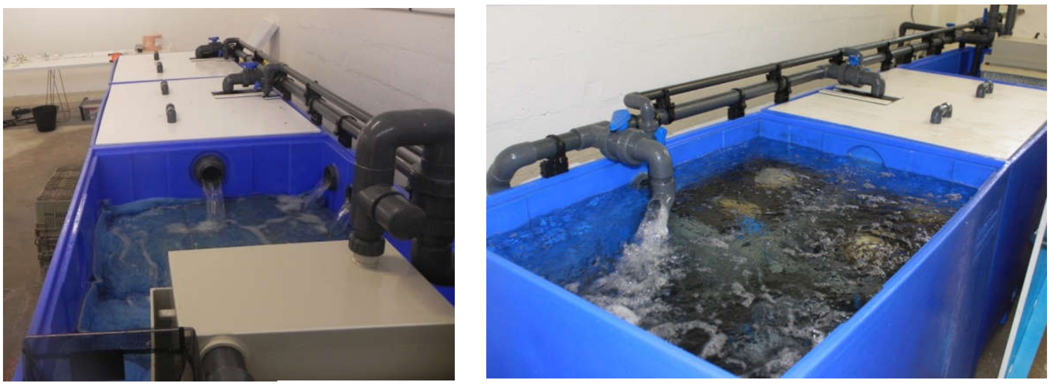

Figure 2: Onshore sample storage tanks

2.1.3 Cellular trays

In order to ensure individual monitoring of the vitality of the *Nephrops* taken from the 2 sorting scenarios, the individuals are placed in trays with individual cells (Figure 3). These trays are made up of 135 cells (35mm X 35mm X 200mm), each being identified by a code made up of a combination of a number and a letter (1-9, A-O). Perforations allow the water to circulate in the trays. The individual cells limit the risk of mortality due to cannibalism, sometimes observed in captivity conditions (Castro et al. 2003; Campos et al. 2015).

Figure 3: Cellular trays for keeping *Nephrops* in captivity

2.2 Sampling

2.2.1 "Control" sampling

The implementation of a "control" sample is designed to dissociate any possible effect of the experimental system during captivity from the effect of the fishing operation on *Nephrops*' vitality. Individuals which are destined to be discarded are taken from unwanted catches during short hauls (± 1 hour) which increases their chances of survival. They are then stored in the onboard tanks.

Back on shore, these *Nephrops* are kept in captivity and monitored daily until mortality stabilises. The day before the "test" sampling fishing trip, live individuals, in good physical condition (cf. 2.3.3), are selected, with a sex-ratio of approximately 50-50 to make up the "control" sample. The individuals making up a "control" tray are therefore taken from several hauls and are considered as no longer being affected by the stress of the catch. Part of this sample is then placed in the same experimental conditions as the *Nephrops* in the "test" samples, i.e. loaded into the on-board tanks during the "test" sampling.

2.2.2 "Test"

The "test" samples are taken from standardised hauls lasting 3 hours. This duration corresponds to the average haul time performed by professional fishing vessels when they are trawl fishing for *Nephrops*. Once on the deck, the catch is sorted by the crew according to their normal methods. For each haul, two sorting scenarios are used: (1) standard sorting with release at the end of the ("standard" sorting scenario) and (2) sorting simulating the use of a chute system where the *Nephrops* are released quickly ("chute system" scenario). The vitality status of each *Nephrops* is recorded on board before it is put into a tray (cf. 2.3.3).

For the spring campaign, the "test" sampling was performed in 3 hauls in 1 day. The summer and autumn campaigns were organised with 6 hauls spread over 2 days so as to highlight inter-haul variability.

"Standard scenario": Standard sorting practices with release at the end of sorting

A random sample of *Nephrops* is taken from the discards that fall into the baskets on the deck (all species). The sample is taken in a single operation without taking account of the physical state of the *Nephrops* or their vitality (cf.2.3.3). To ensure the random nature of the sample, it is composed of *Nephrops* taken from different baskets of discards.

"Chute system" scenario: Sorting method simulating the use of a chute system to release the *Nephrops* quickly

This scenario is designed to simulate the effect of the use of a discard chute during sorting, which makes it possible to limit the crushing of the *Nephrops* and also limit their duration of air exposure by releasing them gradually during sorting. A random sample of *Nephrops* is placed in a basket during the catch sorting process, without taking account of the physical state of the *Nephrops* or of their vitality. A sub-sample is taken every 10 minutes between the start of sorting (T0') and the sampling end time so as to simulate gradual discarding. This sub-sample is added to the trays in the tanks until they are full. The size of the sub-samples depends on the time between the arrival of the codend on the deck (T0) and the start of sorting (T0') and varies generally by between 30 and 35 individuals.

2.3 Measurements

2.3.1 Physicochemical parameters

An NKE probe positioned on the trawl headrope enables the measurement and recording of the temperature and salinity profiles in the sampling areas. A few days before the "test" sampling, the profiles are recorded in order to set the temperature of the water of the tanks on board and on the shore i.e. 11.0 ± 0.5°C in spring and 11.5 ± 0.5°C in summer and autumn. During the experimentation, the physicochemical parameters of the onshore tanks were stable: (1) salinity 31.5g/l and nitrite content less than 0.1 mg/L (daily measurements), (2) ammonium content less than 0.05mg/L, phosphate content greater than 1.8 mg/L and silicate content greater than 60.0mg/L (measurements made twice a week).

2.3.2 Environmental, technical and biological variables

Environmental and technical variables

The environment at the time of the catch and the characteristics of the fishing process can affect the *Nephrops*' survival rate. Several environmental variables were noted during the sampling process (air temperature, sea bottom temperature, depth, type of sediment and wave height), as well as variables related to the fishing process (volume and composition of the catches, haul duration, trawl speed, time catches are on the deck (T0), sorting start time (T0'), tank entry time (T_v)). In addition, the duration of air exposure is a key variable for survival (Harris & Ulmestrand 2004; Ridgway et al. 2006) and is calculated by the difference T_v-T0. Harris & Andrews (2005) reported that the catch composition can affect the *Nephrops*' vitality in the trawl. A "Catch index" variable (weight of marketable *Nephrops*/total weight of the catch) is created so as to take this factor into account.

The biological variables

The following anatomic characteristics are measured for each *Nephrops*, at the time of death or after the 14 days observation (for practical reasons): the sex, carapace length and presence/absence of injuries (carapace cut, punctured, stained, crushed or rostrum broken).

2.3.3 Vitality assessment

The vitality state of each *Nephrops* was noted for the first time when it was put into the tray on board. The live and dead individuals are kept and placed in the cellular trays. The dead individuals are listed and not re-immersed in a tank. A cell is then left empty. On the shore, the vitality state is recorded on a daily basis during the 14 days' monitoring period in the tanks according to the 3 vitality states described in Table 1 (Méhault et al. 2016). These criteria are based on the characteristics of individuals that have not undergone trawling. Every day, the trays are emerged and the vitality state of each *Nephrops* is noted. Individuals that do not move are stimulated with long curved tweezers and if no reaction is observed, they are moved into a water tank for closer inspection as recommended by Valentinsson & Nilsson (2015). Dead individuals are removed.

To reply in a clear manner to the main objective of this study which aimed at obtaining a survival rate of unwanted catches of *Nephrops* in the Bay of Biscay, only the "healthy" and "dead" statuses are considered in the statistical analysis. The number of "moribund" individuals on D14 (0.7% of the total number) is reallocated to the "healthy" class for the calculation of the survival rate on D14.

Table 1: Description of the characteristics of each vitality state

Vitality state	Description
Healthy	strength in its body, moves without stimulus and is able to do a 'tail-flip'
Moribund	moves slowly or only if stimulated, only its appendages move
Dead	doesn't move at all and shows no reaction to stimuli

2.4 Analyses

2.4.1 Calculation of the survival rate

The number of dead individuals per tray is counted on a daily basis starting from the first sampling day. A cumulative survival rate (Eq. (1)) is calculated at the end of the study period and averaged by scenario and by season, and a global survival rate is calculated per scenario over the three seasons (Eq.(2)).

(1) $$\overline{TS_{sc,S}} = 1 - \sum_{S=1}^{Nb_S} \frac{M_{sc,S}}{N_{sc,S}}$$ (2) $$\overline{TS_{sc}} = 1 - \frac{1}{Nb_S} \sum_{S=1}^{Nb_S} \frac{M_{sc,S}}{N_{sc,S}}$$

With:

$\overline{TS_{sc,S}}$ = mean survival rate on D14, by sorting scenario (sc) and by season (S)

$M_{sc,S}$ = number of dead individuals from D0 to D14, by sorting scenario (sc) and by season (S)

$N_{sc,S}$ = total number of individuals sampled by sorting scenario (sc) and by season (S)

$\overline{TS_{sc}}$ = mean survival rate on D14, by sorting scenario (sc) over the three seasons

$Nb_{S.}$ = number of seasons

sc = "control", "standard", "chute system"

S= "spring", "summer", "autumn"

The standard deviation of each mean survival rate is calculated to reflect the inter-haul variability and a confidence interval at 95% is also calculated (mean ± 1.96 X standard deviation).

2.4.2 Calculation of the survival probabilities using the Kaplan-Meier estimator

The tank monitoring data provides information on the time of death of each individual, from the first day of monitoring to the end of the captivity period or on its survival at the end of this period. This form of data is said to be censured and can be analysed by a Kaplan-Meier estimation. The Kaplan-Meier estimator (Eq. (3)) allows to show the probability of survival over time. Its value varies between 0 and 1. This method is often used because of the low number of hypotheses that it requires (independent of the occurrence of the event or of the observation) and because it is non-parametric (non-normal distribution of the survival probability). It is based on the individual survival times (Stevenson 2007, Goel et al. 2010). Calculations and graphic outputs have been made under R (3.3.1) with the "survival" package.

(3) $$\hat{S}(t) = \prod_{t_j \le t} \frac{r_j - d_j}{r_j}$$, where $0 \le t \le t^+$

With $\hat{S}(t)$ = estimator of the maximum plausibility that an individual has a life span greater than time t

d_j = number of dead individuals at time t_j

r_j = number of living individuals at time t_j

t_j = observation time t^+= end of monitoring time $j \in [0;14]$

This model is used on the data taken from each campaign and from the 3 campaigns grouped together. The 95% confidence interval of the Kaplan-Meier estimator is calculated from the mean and the standard deviations relating to the data considered (mean ± 1.96 X standard deviation).

2.4.3 Study of the variables affecting the survival rate using a generalised linear model (GLM)

In order to study the effect of the environmental, technical and individual variables on the *Nephrops* vitality state from D1 up to the end of the monitoring in the tanks (D14), a binomial GLM with a logit link function was used. The season, type of protocol, catch composition, air temperature, presence of injuries, size and sex have been included in the model. The type of protocol and duration of air exposure are correlated in this study. For this reason, this last variable has not been included in the generalised linear model.

The best model is then selected in accordance with AIC using a *stepwise procedure* (stepAIC function of the MASS package). The analysis was carried out under R (3.3.1).

3 Results

3.1 Sampling parameters

3.1.1 At sea sample parameters

A total of 1581 individuals were sampled during the spring campaign, 1798 in the summer campaign and 1555 in the autumn campaign. A total of 4934 *Nephrops* were thus monitored during the 3 seasons in this study. The details of the data relating to the "control" and "test" samples are summarised in Tables 2 and 3.

The protocol selected for the "standard" scenario planned to standardise the duration between the arrival of the trawl codend on the deck (T0) and the release of discards by the crew at 60 minutes, a time representative of the average exposure of unwanted catches of *Nephrops*. However, the standardisation of the duration of air exposure could not always be achieved for practical reasons (table 3).

Table 2: Summary of "control" sampling data

Vessel Season (date)	Haul duration min - max (h:min)	Seabed temp. (°C)	Air temp. (°C)	Air exposure min - max (h:min)	Captivity before « test » sampling (d)	Number of tray	Number of *Nephrops* sampled
Côte d'Ambre Spring (08/04/2016)	00:58 01:13	11,0	11,4	00:41 01:10	13	1	131
Côte d'Ambre Summer (15/06/2016)	00:30 02:02	11,4	16,5	00:15 00:51	13 to 14	2	255
Côte d'Ambre Autumn (16/09/2016)	00:48 00:52	11,6	NA	00:41 01:40	7	1	128
	Total Number of « control »						514

Table 3: Summary of "Test" sampling data

Vessel Season (date)	Fishing op.	Average depth (m)	Seabed temp. (°C)	Air temp. (°C)	Sorting scenario	Air exposure min - max (h:min)	Numb. of tray	Numb. of *Nephrops* sampled	Catch index
Côte d'Ambre Spring (21/04)	T1	87	11,0	15,7	Standard Chute system	01:36 to 01:58 00:45 to 01:49	2 2	264 260	0,35
	T2	101	11,0	16,2	Standard Chute system	01:15 to 01:34 00:27 to 01:10	2 2	267 264	0,11
	T3	92	11,0	19,1	Standard Chute system	01:03 00:25 to 01:09	1 2	132 263	0,19
Men Gwen Summer (29/06 30/06)	T11	83	11,3	15,7	Standard Chute system	01:23 00:31 to 01:02	1 1	130 131	0,20
	T12	84	11,3	16,2	Standard Chute system	01:05 00:13 to 00:43	1 1	131 131	0,08
	T13	85	11,4	19,1	Standard Chute system	01:19 00:27 to 01:01	1 1	122 133	0,06
	T14	78	11,3	19,9	Chute system	00:16 to 00:48	1	127	0,13
	T15	80	11,3	19,2	Standard Standard Chute system	01:13 01:35 00:27 to 00:58	1 1 1	125 133 122	0,17
	T16	82	11,4	20,1	Standard Chute system	01:03 00:16 to 00:48	1 1	129 129	0,04
Côte d'Ambre Autumn (22/09 23/09)	T21	85	11,5	20,6	Standard Chute system	01:15 00:30 to 01:00	1 1	132 131	0,07
	T22	100	11,5	19,0	Standard Chute system	01:17 00:29 to 01:00	1 1	131 128	0,16
	T23	110	11,5	18,9	Standard Chute system	01:17 00:27 to 00:56	1 1	130 129	0,14
	T24	110	11,5	18,0	Standard Chute system	01:08 00:25 to 00:56	1 1	129 126	0,12
	T25	105	11,5	19,5	Standard Chute system	01:12 00:31 to 00:58	1 1	131 130	0,13
	T26	110	11,5	21,5	Chute system	00:29 to 00:57	1	130	0,14
						Total Number of « test »		4420	

3.1.2 Biological parameters of *Nephrops* in the test samples

The size of the "test" individuals sampled varied from 15 to 33mm (mean of 24.3 ± 2.7mm) (Figure 4). Table 4 recapitulates the biological parameters of the "test" samples for the sex, size and injury variables in each season.

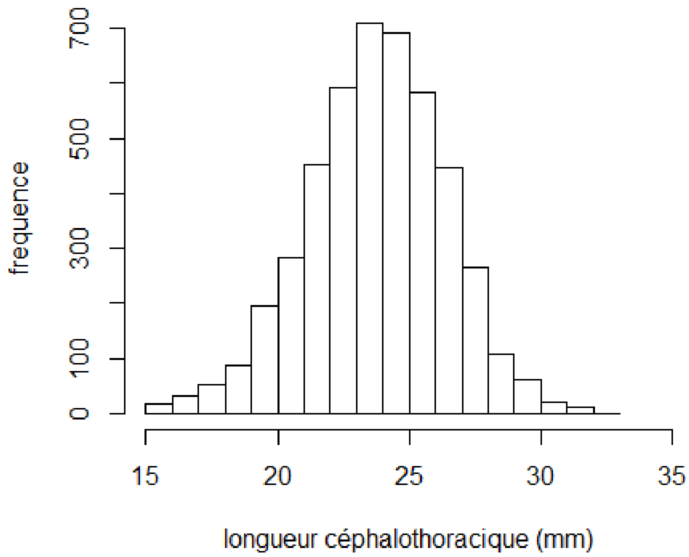

Figure 4: Histogram of the carapace length of the "test" *Nephrops*

Table 4: Summary of the biological parameters of the "test" sampling data

Vessel Season (date)	Sex (F female M male)	Mean length (CL mm) ± Standard deviation	Number of injured *Nephrops*
Côte d'Ambre Spring (21/04/2016)	594 F 609 M	22,6 ± 2,8	138
Men Gwenn Summer (29/06/2016)	815 F 728 M	25,3 ± 2,3	410
Côte d'Ambre Autumn (22/09/2016)	533 F 894 M	24,4 ± 2,4	220

3.2 Comparison of the three campaigns

Generally speaking, during the 3 campaigns, the survival of the "test" samples during the monitoring in the tanks follows the same evolution:

(1) Stabilisation of the survival probability of the "test" samples is observed from the fifth day after a constant reduction from D0. This stabilisation is particularly marked in the summer and autumn campaigns.

(2) A difference in mortality between the "standard" and " chute system" samples is observed from D0 and is maintained up to the end of the monitoring in the tanks. This difference is very small in spring but significant in summer and in autumn.

The results of the spring campaign, while remaining in the same order of magnitude, is slightly different from the summer and autumn campaigns which are similar (Table 5, Figure 5). The Kaplan-Meier curves show that the individuals in the "chute system" scenario have a higher probability of survival than that of the "standard" scenario, in each of the three seasons (Figure 5). Moreover, the survival probabilities are significantly different between the "standard" and the "chute system" scenarios in the summer and autumn campaigns, while in the spring campaign this difference is not significant.

The mortality of the "control" individuals in spring is relatively low and corresponds to the values observed in other studies (Méhault et al. 2016; Armstrong et al. 2016). On the contrary, the survival rate of "control" individuals is lower during the summer and autumn campaigns (Table 5).

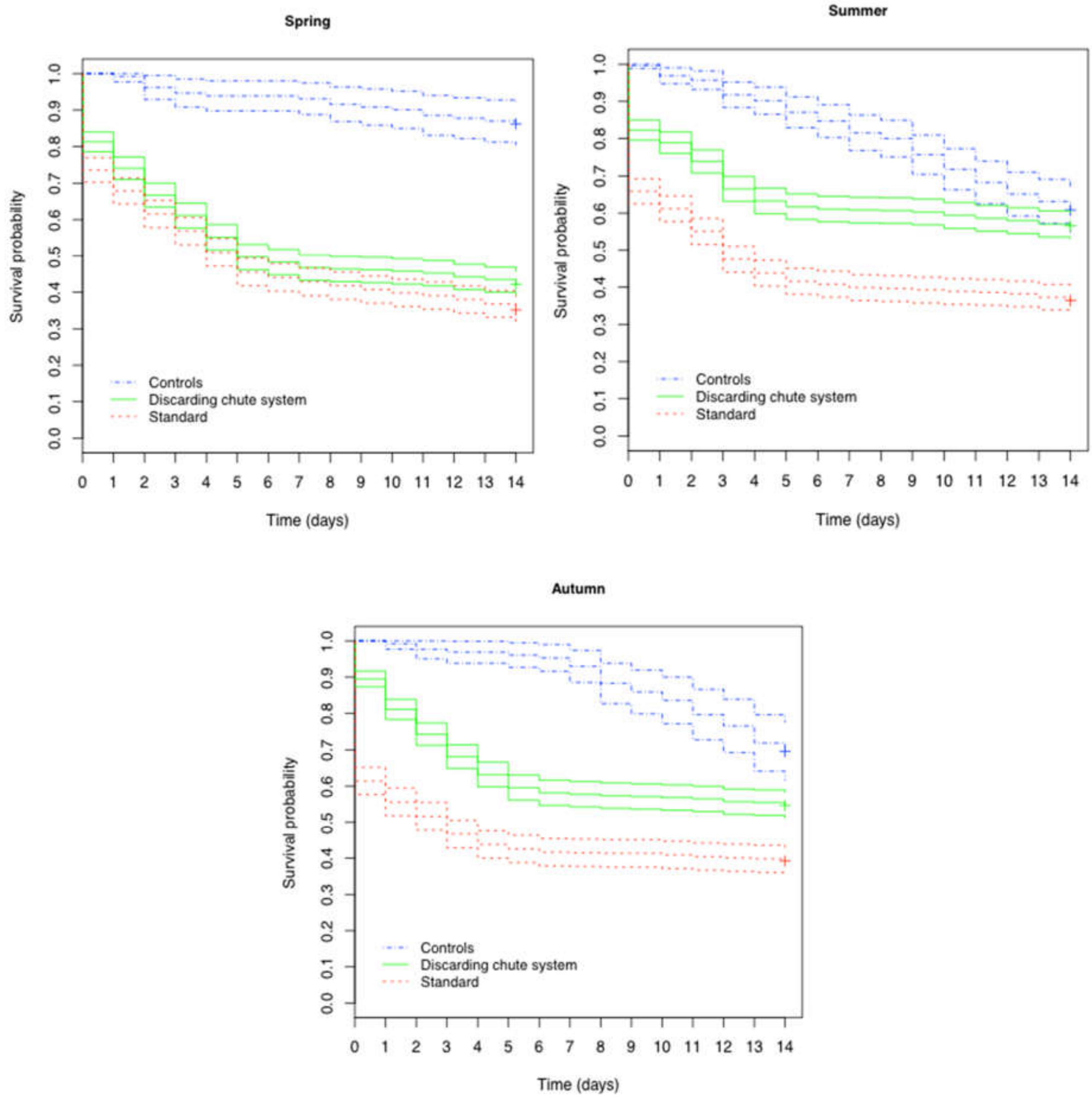

Figure 5: Estimation of the probability of survival during the monitoring in tanks in the spring, summer and autumn campaigns

Table 5: Summary of the survival rates and probabilities on D14 observed at the end of the monitoring in tanks with confidence intervals

	Survival rate			Probabilities of survival (Kaplan Meier)		
	Standard	Chute system	Control	Standard	Chute system	Control
Spring	35,4% [15,3 ;55,5]	42,3% [26,6 ;57,9]	86,3%	0,35 [0,33 ;0,37]	0,42 [0,40 ;0,44]	0,87 [0,83 ;0,89]
Summer	36,4% [30,3 ;42,5]	56,5% [49,2 ;63,7]	61,8% [58,8 ;64,8]	0,36 [0,35 ;0,38]	0,57 [0,55 ;0,58]	0,61 [0,58 ;0,64]
Autumn	39,2% [17,5 ;60,9]	54,9% [31,5 ;78,3]	69,5%	0,39 [0,37 ;0,41]	0,55 [0,53 ;0,56]	0,70 [0,66 ;0,74]

3.3 Global study

The trends observed in each season are verified in the three campaigns grouped together. At the end of the study in tanks, the survival rate of individuals in the "standard" scenario is lower than that of individuals in the "chute system" scenario (Table 6).

The probabilities of survival in the "chute system" and "standard" scenarios are significantly different from D0 and subsequently change in a parallel manner (Figure 6). A clear stabilisation is visible from D5 (slope of -0.0065 ± 0.0021 for the "standard" scenario and of -0.0059 ± 0.0021 for the " chute system" scenario"). The probability of survival of the "control" individuals decreases almost constantly over time. The standard deviations of the two scenarios are not related to those of the "control" sample.

Table 6: Summary of the global survival rate and probabilitie on D14 observed at the end of the monitoring in tanks with confidence intervals

	Survival rate			Probabilities of survival (Kaplan Meier)		
	Standard	Chute system	Control	Standard	Chute system	Control
Global	36,9% [20,9 ;52,9]	51,2% [30,9 ;71,5]	69,3% [45,7 ;93,0]	0,37 [0,36 ;0,38]	0,51 [0,50 ;0,52]	0,70 [0,67 ;0,72]

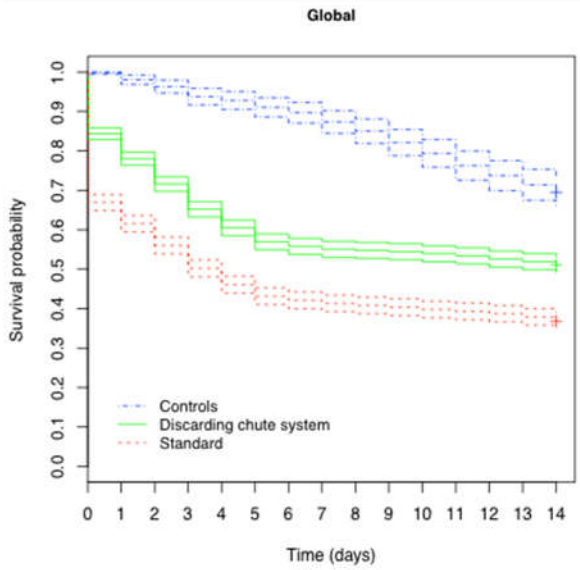

Figure 6: Estimation of the probability of survival during the monitoring in tanks for the three campaigns

The results of the generalised linear model show that the variables which explain vitality status of the *Nephrops* in tanks from D1 to D14 are the presence of injuries, the season and the type of protocol. The other variables tested were not significant. The number of dead individuals on D14 is higher in injured individuals and in those that were sorted by the "standard" protocol. The number of dead individuals was higher in spring than in autumn and lower in summer (Table 7). In the statistical analysis, autumn was taken as a reference point, the values for spring and summer therefore indicate a difference according to autumn. However, the variance explained by the model is low, ~ 10%, indicating that individual variability is driving *Nephrops* survival capacity from D1.

Table 7: Summary of the estimations, standard deviations, Z-statistics and p-values of the significant variables of the generalised linear model explaining the proportion of alive *Nephrops* at the end of the study in tanks

Variable	Slope	Standard deviation	Z statistic	p-value
Injury Yes	1,25	0,11	11,89	$<2{,}20.10^{-16}$
Season SUMMER	-0,18	0,10	-1,91	0,059
Season SPRING	0,75	0,13	5,94	$2{,}95.10^{-9}$
Sorting scenario Standard	0,26	0,08	3 ,41	$6{,}41.10^{-4}$

4 Discussion

The observations realized in this study were made in fishing conditions corresponding to those usually experienced by the fishermen (seasonality, gear, handling and catch sorting time) and the individuals were sampled in a random manner. The range of variation of parameters considered in this study is therefore representative of the *Nephrops* fishery in the Bay of Biscay. The survival rates obtained are consistent with the results of previous studies in this area. Méhault et al. (2016) observed a survival rate of 42.0% to 60.0% and Gueguen and Charuau (1975) found rates varying from 32.0% to 48.0%. Studies carried out in other fisheries in similar experimental conditions (monitoring in tanks without feeding) report survival rates of the same order of magnitude: between 27.3% and 43.0% (Ridgway et al. 2006), or even slightly higher, between 59% and 75% (Valentinsson & Nilsson 2015).

Concerning the "control" samples, it should be noted that non negligible mortality was observed as well as an absence of stabilisation of survival. This mortality of the "control" samples therefore limits the possibility of differentiating mortality caused by the catch process from mortality caused by captivity. For all campaigns, the probability of survival of the "control" individuals decreased progressively from D0 to D14 and reached an average of 69.3% [45.7; 93.0]. Other studies of *Nephrops*' survival, carried out in different experimental conditions with creel caught "control" individuals, reported a higher survival rate for the "control" individuals: from 70% to 98% (Campos et al. 2015) and between 95% and 98% (Valentinsson & Nilsson 2015). However, a Danish study carried out with the same protocol than our reported a similar survival rate of 73% [50.0; 90.0] (Bruun Nielsen 2015). In this study, the causes of mortality of the control individuals are not determined but are probably due to metabolic weakening of the *Nephrops* not fed for more than 21 days.

However, it seems that the "test" and "standard" samples are not subject to such mortality, as clear stabilisation appears from D5. The mortality observed in the "control" samples may however reflect a proportion of the mortality observed in the "test" samples. The survival rates and probabilities of the "test" samples presented in the "Results" section may, therefore, be under estimated to an extent that is difficult to quantify. Other factors may also lead to an over-estimation or under-estimation of the survival rate. Thus, the protocol in tanks may lead to an overestimation of the survival rate because different events normally occuring in the natural environment have not been taken into account (predation, capacity to find a habitat, a burrow, etc.). On the other hand, survival may have been underestimated due to the stress arising from the *Nephrops* being kept in captivity in individual cells, making it impossible to move or burrow (Castro et al. 2003), the conditions of captivity or the fact that the *Nephrops* are not fed.

Finally, the difference between the two sorting scenarios is potentially higher as, on the one hand, performing the simulation of the " chute system" scenario on board minimises the reduction of the duration of air exposure. A sub sample was taken every 10 minutes and putting the *Nephrops* in cells made it necessary to take the tray out from the tanks in order to transfer the individuals. This may lead to additional stress compared to that observed in real conditions and minimise the positive action of the chute system on *Nephrops* survival. On the other hand, in the "standard" scenario the effect of crushing by the crew is minimised because the whole catch must be put into baskets although unwanted catches are usually left on the deck until they are released.

Concerning our results, as was noted by Castro et al. (2003), Ridgway et al. (2006) and Benoît et al. (2010), the largest number of dead individuals in a day in the "test" samples was observed during the first days following the sampling. For the three campaigns in our study, the survival rate stabilised starting on D5. We consider that the mortality observed up to the start of stabilisation (D5) can be attributed to a great extent to the stress resulting from fishing.

Our results show a difference in mortality between the "standard" scenario and the "chute system" scenario, observed at the time of sampling on board. It was probably caused by the stress due to the duration of air exposure for a longer period and to the potential damage suffered by individuals during sorting in the "standard" scenario (Méhault et al. 2016). This deviation, higher from D0 in the summer and autumn campaigns than in the spring campaign, was maintained up to the end of the monitoring in each case.

The generalised linear model constructed to study the different variables affecting the survival rate of discarded *Nephrops* from D1 to D14 explains relatively low variance. However, the main explanatory variables (presence of injuries, season and type of protocol) are consistent with the literature on the subject. The highest mortality observed in injured individuals was also noted in other studies (Campos et al. 2015; Valentinsson & Nilsson 2015; Armstrong et al. 2016) and may be attributed to the loss of a large volume of haemolymph

(Harris & Andrews 2005). Different studies on the survival rate of *Nephrops* have, moreover, demonstrated a negative link with exposure time on the deck (Harris & Ulmestrand 2004; Ridgway et al. 2006; Milligan et al. 2009, Méhault et al. 2016) due in particular to dehydration (Harris & Andrews 2005) and a detrimental effect on the immune system (Ridgway et al. 2006).

5 Conclusion

This study has allowed to assess a survival rate interval of unwanted catches of *Nephrops* in the *Nephrops* fishery from the Bay of Biscay. This study was carried out at 3 different periods of the fishing season, in standardised fishing conditions. It is therefore representative of the *Nephrops* fishery in the Bay of Biscay. The survival rates calculated are 36.9% [20.9; 52.9] for individuals sorted with the "standard" scenario and 51.2% [30.9; 71.5] for individuals sorted with the "chute system" scenario. These results confirm the high survival potential of discarded *Nephrops* and support the conclusions of previous studies in the area. Moreover, our results show that the use of a chute system allowing direct release of unwanted *Nephrops* catches gradually during the sorting process significantly improves the survival rate of *Nephrops*.

References

Armstrong, F., Randall, P., Santos, A. R., Jones, P., Firmin, C., Doran, S., Randall, P., Catchpole, T., Santos, A. R. (2016). Assessing the survival of discarded *Nephrops* in the English NE *Nephrops* selective trawl fishery (CEFAS report).

Benoît, H. P., Hurlbut, T., Chassé, J. (2010). Assessing the factors influencing discard mortality of demersal fishes using a semi-quantitative indicator of survival potential. *Fisheries Research*, 106(3), 436–447.

Bruun Nielsen, A. (2015). Discard survival of Norway lobster (*Nephrops norvegicus*). National Institute of Aquatic Resources (DTU Aqua), Hirtshals, Denmark.

Campos, A., Fonseca, P., Pilar-Fonseca, T., Leocádio, A. M., Castro, M. (2015). Survival of trawl-caught Norway lobster (*Nephrops norvegicus*) after capture and release-Potential effect of codend mesh type on survival. *Fisheries Research*, 172, 415–422.

Castro, M., Araújo, A., Monteiro, P., Madeira, A. M., Silvert, W. (2003). The efficacy of releasing caught *Nephrops* as a management measure. *Fisheries Research*, 65(1–3), 475–484.

Commission Européenne. Règlement délégué (UE) 2015/2439 de la commission du 12 octobre 2015 établissant un plan de rejets pour certaines pêcheries démersales dans les eaux occidentales australes, Journal officiel de l'Union européenne (2015). http://eur-lex.europa.eu/legal-content/FR/TXT/PDF/?uri=CELEX:32015R2439&from=FR

Commission Européenne. Règlement délégué (UE) 2016/2374 de la commission du 12 octobre 2016 établissant un plan de rejets pour certaines pêcheries démersales dans les eaux occidentales australes, Journal officiel de l'Union européenne. http://eur-lex.europa.eu/legal-content/FR/TXT/PDF/?uri=OJ:L:2016:352:FULL&from=FR

Cornou, A.-S., Diméet, J., Tétard, A., Gaudou, O., Quinio-Scavinner, M., Fauconnet, L., Rochet, M.-J. (2015). Observation à bord des navires de pêche professionnelle - Bilan de l'échantillonnage 2013. IFREMER.

Goel, M. K., Khanna, P., Kishore, J. (2010). Understanding survival analysis: Kaplan-Meier estimate. *International Journal of Ayurveda Research*, 1(4), 274–8.

Gueguen, J. & Charueau, A. (1975). Essai de détermination du taux de survie des langoustines hors taille rejetées lors des opérations de pêche commerciale. ICES CM 1975/K, 12.

Harris, R. R., & Andrews, M. B. (2005). Physiological changes in the Norway lobster *Nephrops norvegicus* escaping and discarded from commercial trawls on the West Coast of Scotland: 1. Body fluid volumes and haemolymph composition after capture and during recovery. *Journal of Experimental Marine Biology and Ecology*, 320(2), 179–193.

Harris, R. R., & Ulmestrand, M. (2004). Discarding Norway lobster (*Nephrops norvegicus*) through low salinity layers - Mortality and damage seen in simulation experiments. *ICES Journal of Marine Science*, 61(1), 127–139.

ICES. 2015. Report of the Workshop on Methods for Estimating Discard Survival 3 (WKMEDS 3), 20-24 April 2015, London, UK. ICES CM 2015\ACOM:39. 47 pp.

ICES.2016. Advice on fishing opportunities, catch, and effort Bay of Biscay and the Iberian Coast Ecoregion. Norway lobster (*Nephrops norvegicus*) in divisions 8.a–b, FUs 23–24 (Bay of Biscay North and Central) ICES Advice 2016, Book 7. 7pp.

Méhault, S., Morandeau, F., Kopp, D. (2016). Survival of discarded *Nephrops norvegicus* after trawling in the Bay of Biscay. *Fisheries Research*, *183*, 396–400.

Milligan, R. J., Albalat, a., Atkinson, R. J. a, Neil, D. M. (2009). The effects of trawling on the physical condition of the Norway lobster *Nephrops norvegicus* in relation to seasonal cycles in the Clyde Sea area. *ICES Journal of Marine Science*, 66(3), 488–494.

Ministère de l'Environnement, de l'Energie et de la Mer (2016) Arrêté n° DEVM1607912A Arrêté du 27 mai 2016 fixant les modalités de gestion des régimes d'autorisations européennes et nationales de pêche contingentées pour l'exercice de la pêche professionnelle en zone FAO 27. https://www.legifrance.gouv.fr/eli/arrete/2016/5/27/DEVM1607912A/jo/texte

Morizur, Y., Charuau, A., Rivoalen, J-J. (1982). Survie des langoustines (*Nephrops norvegicus*) s'échappant d'un cul de chalut. Council Meeting, 1982, of the International Council for the Exploration of the Sea, (Copenhagen (Denmark)), (11 Oct 1982). Available at: http://archimer.ifremer.fr/doc/00000/2339/

Parlement Européen et Conseil de l'Union Européenne. Règlement (UE) n° 1380/2013 du Parlement Européen et du Conseil du 11 décembre 2013, L 354/22 (2013). Journal officiel de l'Union européenne. http://eur-lex.europa.eu/legal-content/FR/TXT/PDF/?uri=CELEX:32013R1380&from=FR

Ridgway, I. D., Taylor, a. C., Atkinson, R. J. a, Chang, E. S., Neil, D. M. (2006). Impact of capture method and trawl duration on the health status of the Norway lobster, *Nephrops norvegicus*. *Journal of Experimental Marine Biology and Ecology*, 339(2), 135–147.

Stevenson, M., (2007). An Introduction to Survival Analysis. EpiCentre, IVABS, Massey University. p.31.

Valentinsson, D., Nilsson, H. C. (2015). Effects of gear and season on discard survivability in three Swedish fisheries for Norway lobster (*Nephrops norvegicus*). https://www.slu.se/globalassets/ew/org/inst/aqua/externwebb/radgivning/radgivning-om-fiskemojligheter-och-kvoter/*Nephrops*-discard-survival_2_v2.pdf