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Survival of discarded *Nephrops norvegicus* after trawling in the Bay of Biscay

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Abstract :

The new Common Fisheries Policy may exempt some species from the landing obligation if a high survival rate can be demonstrated among discards. This study focuses on the survival capacity of *Nephrops norvegicus* discarded from trawlers of the Bay of Biscay (France). Three sea trials were conducted on board 3 commercial trawlers and 15 fishing operations were sampled. The vitality of *Nephrops* was classed into three categories (healthy, moribund or dead) before release at sea and samples of healthy and moribund individuals were kept in captivity on *Nephrops* grounds for three days. A Generalised Linear Model was used to examine the variability in the proportion of healthy *Nephrops* discarded, which was significantly influenced by tow duration, duration of air exposure and temperature, as well as individual length. By combining the results on vitality before release at sea with those on survival in captivity following re-immersion, resampled by bootstrapping, it was calculated that 51% [42–60%] of discarded *Nephrops* would survive after three days of re-immersion. We discuss the sources of variability in survival rate, as well as the implications of a potential exemption from the landing obligation for this species.

Keywords : Vitality, Captivity, South western waters, Bottom trawl, GLM

1. Introduction

The European Union recently modified its Common Fisheries Policy and brought into force the prohibition of discarding catches (European Commission, 2013). Nonetheless, article 15 paragraph 2(b) of the regulation mentions the possibility of exemption from the landing obligation for species for which "scientific evidence demonstrates high survival rates". Research has thus shown that not all the discarded individuals die and, depending on biological, environmental and technical parameters, their survival rate could be quite high (Revill, 2012). The biological factors potentially influencing animal survival include: species (Broadhurst et al., 2006), size (Davis and Olla, 2002 and Benoit et al., 2013) physical injuries

(Depestele et al., 2014) and physiological stress (Bergmann et al., 2001). Environmental factors such as temperature, depth and light conditions have also been found to influence an animal"s ability to recover after having been thrown back into the water (Davis and Olla, 2002 and Giomi et al., 2008). Finally, technical parameters such as catch size (Tenningen et al., 2012), handling practices on deck (Castro et al., 2003 and Macbeth et al., 2006), duration of air exposure (Davis, 2002, Broadhurst et al., 2006, Benoit et al., 2010, Benoit et al., 2012 and Benoit et al., 2013) and gear type (Neilson et al., 1989) are amongst those with the strongest effects on organism survival.

In this regard, it is necessary to develop approaches for survival experiments that will provide information about species potential for "high survival rate". Three methods were identified by the Expert Working Group 13–16 (EWG13-16) from the Scientific, Technical and Economic Committee for Fisheries (STECF, 2013), namely, captive observation (Revill et al., 2013 and Depestele et al., 2014), vitality and reflex assessments (Davis and Ottmar, 2006, Humborstad et al., 2009 and Davis, 2010) and tagging or biotelemetry experiments (Donaldson et al., 2008 and Yergey et al., 2012). These measures of animal survival are especially important as they could be used for stock assessments. Following the implementation of the landing obligation, any individuals that would otherwise have survived the discarding process would thereafter contribute to the overall fishing mortality of the stock. This has significant implications for stocks that include discards in their assessment: determination of discard survival will now influence the assessment process and the setting of total allowable catch (TAC). This is particularly true for stocks simply assumed to have no chance of survival after discarding (either because it is considered negligible or because accurate estimates are not available) or for the few species that already formally have a discard survival factor incorporated in the stock assessment process, such as *Nephrops*.

For the *Nephrops* fishery in Bay of Biscay, the survival rate of discards from trawlers was studied by Gueguen and Charueau (1975) and by Morizur et al. (1982). These authors concluded that 30% of discarded *Nephrops* could survive, and this rate was later adopted by the International Council for the Exploration of the Sea (ICES) who have since used this figure in the stock assessment procedure. However, the gears used to fish this species have evolved since the 1970s: the codend mesh size has gradually increased from 55 mm in 1975–70 or 80 mm today and, while *Nephrops* trawlers were previously rigged with a single gear, they are now rigged with twin gears, leading to a reduction of the catch volume per codend. The French national fishing committee has also taken restrictive measures in order to reduce the discard rate and preserve the stock: the minimum landing size was set at 9 cm (28 mm cephalothoracic length) and, in 2007, the fishermen had to adopt at least one selective device from the following: a codend mesh size of 80 mm, a flexible grid, or a bottom square mesh panel (CNPMEM, 2010). In 2011, one more selective device, a square mesh cylinder, was added to the legislation. However, despite these technical measures, the discard rates in this mixed bottom trawl fishery remain high, with an average of 49% of the catch discarded in 2013 (Cornou et al., 2015).

The present paper reports a new evaluation of the survival rate of discarded *Nephrops* in the Bay of Biscay using two methods recommended by EWG13-16 (STECF, 2013): vitality assessment and captive observation of captured individuals.

We also aimed to determine if this survival rate was influenced by a biological factor (size), an environmental parameter (air temperature) and aspects related to the operational practices (tow duration and duration of air exposure).

2. Materials and methods

2.1. Sampling strategy

The survival experiment was conducted on the *Nephrops* grounds of the Bay of Biscay known as the "Grande Vasière" (Dubrulle et al., 2007), extending from 46°00 N to 47°50 N and 4°50 W–3°00W, on the continental shelf off the Atlantic coast of France at depths between 65 and 113 m (Fig. 1). Three commercial trawlers were used for sampling during the fishing season in July and October 2009 and in July 2010 (Table 1). All vessels were rigged with twin bottom trawls, which are commonly used to target *Nephrops* in this fishery (Macher et al., 2008). The hauls sampled were conducted under normal commercial conditions: the mean duration of the tows was 2.3 h (1.27–3.25), the towing speed ranged between 3 and 4 knots, the codend mesh size was 80 mm (CNPMEM, 2010) and the net extension was equipped with the compulsory square mesh panel (European Union, 1998). The crew was asked to keep onboard handling practices as usual in order to obtain samples representative of normal commercial fishing conditions.
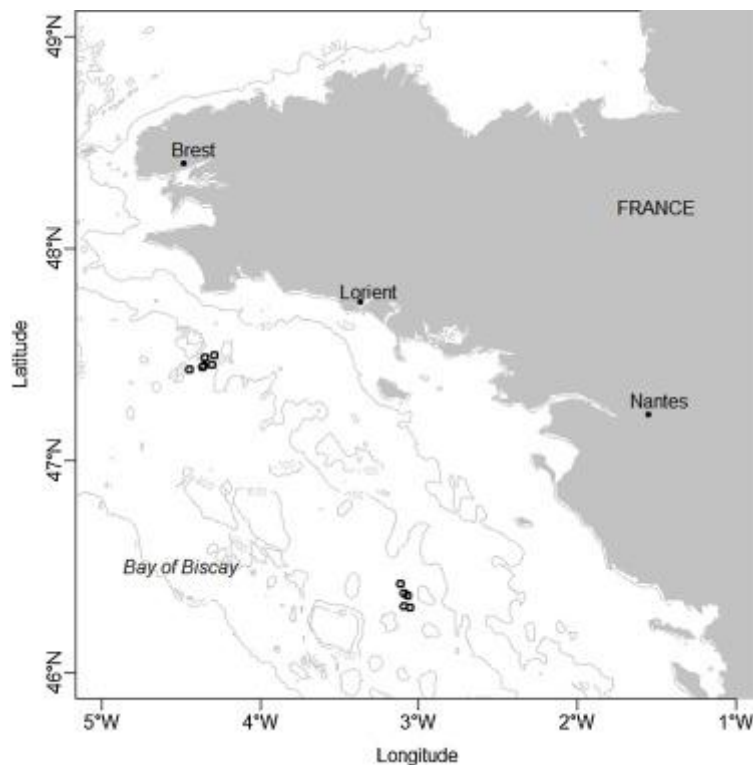

Fig. 1. Map of the study area in the Bay of Biscay presenting the location of sampling sites (black dots) and the 50 m, 100 m and 200 m iso-depth lines (grey lines).

Table 1. Summary of data from vitality and survival experiments.

Sampling period	Fishing Operation number	Time of exposure to air (decimal hours)	Air temperature (°C)	Tow duration (decimal hours)	Number of *Nephrops* sampled for vitality	Number of *Nephrops* sampled for survival
	1	NA	NA	NA	0	94
	2	0.93	18	2.93	237	69
July 2009	3	1.45	17	3.03	269	99
	4	1.00	21	1.67	277	100
	5	0.72	23	1.27	329	75
	6	1.65	17	2.33	119	96
October 2009	7	0.82	20	2.10	190	100
	8	1.42	18	1.55	72	100
	9	1.12	15	2.02	81	100
	10	1.33	16	1.93	79	99
	11	1.08	22	3.25	256	140
	12	0.83	20	3.25	286	93
July 2010	13	0.67	20	2.75	334	98
	14	NA	NA	NA	0	146
	15	1.08	20	1.75	404	148

2.2. Survival rate

Survival rate estimation was made using two independent procedures: vitality assessments and field captive observations. Vitality assessments estimated survival as the proportion of individuals alive prior to discarding in a given sample. From field captive observations, survival rate was estimated as the proportion of individuals that survived a re-immersion phase, based on a sample of living individuals at the time of re-immersion. Both estimates were used to compute the overall survival rate of discarded *Nephrops*.

2.2.1. Vitality assessment

Thirteen fishing operations were carried out to assess the vitality state (V) of *Nephrops* before discard. Samples of *Nephrops* were taken randomly from the discard heap. Sample size ranged from 72 to 404 individuals (mean = 225), with 2933 *Nephrops* examined in total (Table 1). Cephalothoracic length was measured and vitality state was assessed visually (Gueguen and Charueau, 1975 and Castro et al., 2003). Vitality state was rated at three levels: (1) healthy (H): the *Nephrops* was able to do a „tail-flip" and its body is lively, (2) moribund (M): the *Nephrops* was alive (*e.g.* it moves its legs or antenna) but has no strength in its body (3) dead (D): the *Nephrops* did not move at all and has no strength. Although more detailed vitality state scales were available (*e.g.* Ridgway et al., 2006), this was considered the best compromise between sample size and sample treatment time. Proportions of healthy, moribund and dead individuals were calculated for each fishing operation.

2.2.2. Field captive observations

2.2.2.1. Experimental setup

Living *Nephrops* that were either healthy or moribund, were put into numbered plastic tubes (1 *Nephrops* per tube), which were themselves put in oyster farming bags to be re-immerged close to the site where they were caught. The tubes were made of perforated PVC with dimensions of 25 cm length and 5 cm diameter. They were closed by pieces of net at each extremity (Fig. 2). Each bag contained 25 *Nephrops* tubes, which were immerged for 3 days, in accordance with the methodology proposed by Gueguen and Charueau (1975) in the bay of Biscay.
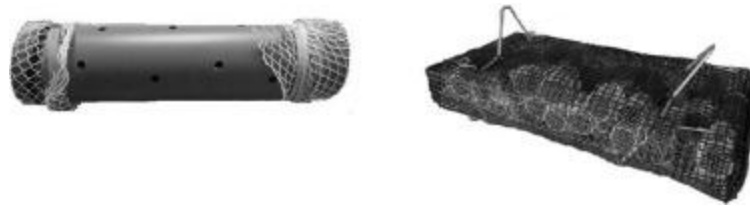

Fig. 2. Tubes (left side) and bags (right side) used for field captive observations. Tubes characteristics: Dimensions = 25 cm length × 5 cm diameter, number of holes = 15, holes diameter = 7 mm, stretch mesh size = 12 mm. Bags characteristics: Dimensions = 70 × 40 × 15 cm, square mesh size = 15 × 15 mm, number of tubes per bag = 25.

2.2.2.2. Control group

Control experiments were conducted to test the effect of captivity on *Nephrops* survival. Creels were used to catch control *Nephrops* with minimum stress. They were baited and immerged for two days close to the trawl fishing grounds. The catch was composed of 17 individuals of *N. norvegicus* and 138 specimens of plated lobster (*Munida rugosa*) all of which were healthy. The control *Nephrops* sample was small. Considering that *M. rugosa* and *Nephrops* are both decapods, with similar order of magnitude of body length, living in the same habitat and presenting the capacity to resist to air exposure (Bergmann and Moore, 2001), *M. rugosa* was considered a suitable replacement for *Nephrops* in the control group. Individuals were put in experimental tubes and bags and re-immerged for three days. Control group mortality is provided as an indicator of uncertainty in test group survival rate, but is not included in the calculation.

2.2.2.3. Test group

Fifteen fishing operations were sampled and 1557 healthy and moribund *Nephrops* were re-immerged in plastic tubes and bags for three days (Table 1). For each of the fifteen hauls, a sample of about 100 living *Nephrops* to be discarded was taken randomly from the heap. The vitality of each sampled individual was assessed. The individuals were then put in tubes and bags for re-immersion. To keep time of air exposure representative of commercial fishing conditions, the *Nephrops* bags were put back on the sea floor after the crew finished processing the catch and had cleaned the deck of discards. Following the re-immersion period and directly after hauling the bags back on board, the vitality state of each individual was reassessed. For each haul, out of the individuals that had been healthy before re-immersion, the proportions that were now moribund, dead or that were still healthy after three days in

the sea were calculated, as were the proportions of moribund individuals that were later found to be healthy, dead or that remained moribund. The proportion of individuals still alive after re-immersion was recorded for each sample.

2.2.2.4. Survival rate: combination of vitality and field captive observations

Since dead animals were not re-immerged, the observations on captive *Nephrops* only provide the survival rate of either healthy or moribund individuals without accounting for mortality in the initially discarded population. To get the survival rate of a batch of discarded *Nephrops*, survival rates from captive observations have to be combined to the proportions of healthy, moribund or dead animals before discard, assessed in the vitality experiment.

The calculation of the survival rate was based on the assumption that the chance of an individual surviving after re-immersion only depends on its prior vitality state. The percentage of healthy individuals that remained healthy and the percentage of moribund individuals that became healthy from the field captive experiment were calculated for each haul. These indices were then multiplied by the proportion of healthy and moribund individuals in each sample of the vitality experiment (Eq. (1)). In order to avoid overestimation of survival rate, only individuals found to be healthy after re-immersion were considered alive, and individuals remaining moribund after re-immersion were considered as dead. Overall survival rate per haul was expressed as:

Equation (1)

$$SR = (M_b \rightarrow H_a)/M_b * M_b/(M_b + H_b + D_b) + (H_b \rightarrow H_a) * H_b/(M_b + H_b + D_b)$$

With

SR = discarded *Nephrops* survival rate per haul

M = number of moribund individuals

H = number of healthy individuals

D = number of dead individuals

b = before re-immersion

a = after three days of re-immersion

$\rightarrow$ = became

2.3. Statistical analysis

For each haul, a series of explanatory variables were collected that included a biological parameter (cephalothoracic length of *Nephrops*), an environmental parameter (ambient air temperature) and fishing operation parameters (tow duration and duration of air exposure).

A Generalised Linear Model (GLM) was used to describe the variability of the vitality before discard according to the explanatory variables. Binomially distributed errors and *logit* link were used to fit the GLM to the proportion of healthy individuals observed from the vitality assessment. The selection of the model was based on the AIC value (Akaike, 1974), and the distribution and homogeneity of the residuals were checked to validate the model.

The survival rate was computed from Eq. (1) for the 13 hauls for which both the vitality estimates before discard and survival of *Nephrops* discarded alive had been recorded (Table 1). Mean survival rate was computed from bootstrap resampling with replacement and 1000 iterations, and 95% confidence intervals were calculated after verifying that the data met the distributional assumptions.

All analyses were conducted with R 3.0.2 software (R Development Core Team).

3. Results

The cephalothoracic length of the sampled *Nephrops* ranged from 10 to 50 mm (from 5 to 15 cm total length), with mean length of 26.7 mm (±7.5 SD.). From the vitality assessments, 40% (±21 SD.) of the *Nephrops* were found healthy before being discarded, 32% (±12 SD.) were moribund and 28% (±15 SD.) were dead. The GLM fitted to the observed percentages of healthy individuals among the discards, showed that all explanatory variables included in the model, had a significant effect on this proportion (all *p*-values < 0.05). Thus air temperature, tow duration, duration of air exposure and the cephalothoracic length all had negative effects on the vitality of discarded *Nephrops* (Table 2).

Table 2. Summary of variables, estimates, standard errors, Z and *p*-values of the model used to analyse the proportion of healthy *N. norvegicus* to be discarded.

		After three days re-immersion		
		Dead	**Moribund**	**Healthy**
Before re-immersion	Moribund	35.6 (11.8)	2.7 (3.4)	61.7 (13.4)
	Healthy	20.8 (10.8)	2.9 (2.8)	76.2 (12.6)

Field captive observations of the creel-caught control group showed that the current captivity conditions only incurred a very low mortality as only 1 *Nephrops* (6%) and 6 *Munida* (4%) were observed dead after three days of re-immersion. In the test group, observations of the vitality state of *Nephrops* before and after re-immersion showed that healthy individuals tended to remain healthy and moribund individuals had a high capacity for recovery. Although a higher rate of mortality was observed among moribund individuals than healthy ones, very few *N. norvegicus* assessed either healthy or moribund before re-immersion were assessed as moribund after re-immersion (Table 3).

Table 3. Summary of variables, estimates, standard errors, Z and *p*-values of the model used to analyse the proportion of healthy *N. norvegicus* to be discarded.

Variable	Estimate	SE	Z	p
Time to air exposure	−0.46	0.20	−2.25	0.03
Cephalothoracic length	−0.06	0.01	−4.54	<0.0001
Tow duration	−0.46	0.06	−7.17	<0.0001
Air temperature	−0.26	0.03	−8.90	<0.0001

The survival rates obtained by combining the proportions of living individuals before re-immersion and the proportions able to survive the re-immersion period in captivity (Eq. (1)) for 13 hauls ranged from 18 to 72%, and were normally distributed. The bootstrap re-sampling indicated that the mean survival rate of discarded *Nephrops* in the current study was 51% [42–60%].

4. Discussion

Fisheries discards are estimated to be about 7 million tons per year worldwide (Kelleher, 2005) and the North East Atlantic fisheries are identified in second position of worldwide discards in commercial fisheries (Alverson et al., 1994). Although several tools have proved to significantly reduce discards (Revill et al., 2006, Valentinsson and Ulmestrand, 2008 and Frandsen et al., 2009), the discard rate in the *Nephrops* trawl fishery remains high (Cornou et al., 2013 and Cornou et al., 2015) and the landing obligation to be brought into force by the reform of the European Common Fisheries Policy (CFP) implies that discarding *Nephrops,* a species under quota in the Bay of Biscay, will soon be prohibited. However, because there is the mention of potential exemptions for species for which "scientific evidence demonstrates high survival rates", *N. norvegicus* could be one of these exemptions as it shows a survival potential of 51% after discard in the Bay of Biscay. This survival rate is either higher or in the same range as those observed by most other authors in European seas. In the same fishery, Gueguen and Charueau (1975) found that 17% of discarded animals were healthy and 41% moribund after 1 h of air exposure and three days of re-immersion. From these observations, the average of 30% survival was agreed by ICES for stock assessment. Wileman et al. (1999) found a survival rate of 31% in the North West of Scotland, Castro et al. (2003) found 23–60% in the South of Portugal and Harris and Andrews (2005) found 31% on the West coast of Scotland. The protocols differed between these different studies, which could have led to differences in the final estimates of survival. Guegen and Charuau (1975) re-immerged discarded *Nephrops* in cages in which the density ranged from 30 to 140 individuals per batch. Morizur et al. (1982), who used the same method in the Bay of Biscay, pointed out that a high density in the cages may have increased the mortality rate induced by the experiment (*Nephrops* are more vulnerable to amphipods if stored at high density, and individuals may become aggressive and damage each other).

To address this issue, Wileman et al. (1999) and Castro et al. (2003) re-immerged all the *Nephrops* in their studies in holding pens with individual compartments, sampled randomly regardless of their vitality state (*i.e.* including animals that did not show any signs of life). In the same way, our method was based on individual re-immersion, but only used animals that appeared to be alive, which had been randomly sampled among moribund or healthy individuals. The combination of an assessment of surviving individuals after re-immersion and vitality before discard is an alternative way to estimate survival rate of a fishing operation, permitting larger sample sizes for both vitality and survival observations.

The GLM fitted to the proportion of healthy individuals before discard indicates that the larger the individuals, the lower their probability of being healthy. The samples observed contained individuals larger than the commercial size, discarded mainly because of their moulting status, which makes them less commercially valuable. Morizur et al. (1982) indicated that this biological state may influence their capacity to withstand the fishing operation and catch handling. Length of air exposure, temperature and tow duration also had a significant effect on the survival of discarded *Nephrops*. Higher survival rates have generally been observed with lower air temperature (Giomi et al., 2008) but our experiment focused on the period of highest fishing activity for this seasonal *métier, i.e.* summertime.

The ranges of parameters observed during our experiment are representative of the practices of the French *Nephrops* fleet in the Bay of Biscay (*e.g.* catch handling or sorting practices). However, conditions such as the time of captivity or protection from predation in the water column may have affected the results. Several authors found that mortality may occur after 3 days of captivity (Castro et al., 2003 and Wileman et al., 1999). In the current study, 3% of *Nephrops* remained moribund at the end of this period of time, indicating that these individuals may have needed more than 3 days to either recover or die. In order to not over estimate survival, individuals found moribund at the end of the observation period were considered as dead. The mortality in the control group being low (4–6%), the uncertainty in the survival estimate due to captive conditions was meant to be low as well.

Even though our experiments were carried out on three different vessels to cover a wide range of crew experience, as the level of physical injuries suffered by discarded individuals may vary from one vessel to another. Depending on crew sorting practices and the layout of the deck, *Nephrops* may be more or less trampled and damaged during the sorting process. To optimize their chances of survival, the use of a sorting table and evacuation gutter on board would be a suitable option to minimize the duration of air exposure and physical damage. Such infrastructure would be beneficial for the stock since Chapman et al. (2000) demonstrated that *Nephrops* that survive after being thrown back to the sea continue to grow and reproduce.

In the Bay of Biscay, discarded *Nephrops* accounted for between 852 and 2044 tons in 2013 (Cornou et al., 2015). Efforts continue to improve gear selectivity and these are worthwhile since survival of escapees is usually higher than that of discards (Wileman et al., 1999; Guegen and Charuau, 1975). Efforts to improve gear selectivity to reduce discards are worthwhile since survival of escapees is usually higher than that of discards (Wileman et al., 1999; Guegen and Charuau, 1975).

Improving catch handling on board would give the best chance of survival of discards and contribute to the re-integration of a considerable number of animals into the population, whereas the landing obligation proposed under the new Common Fishery Policy would increase the fishing mortality and generate an equivalent loss for the stock biomass.

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