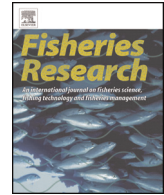




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# Short-term survival of discarded target fish and non-target invertebrate species in the “eurocutter” beam trawl fishery of the southern North Sea



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## ABSTRACT

Few studies have examined discard survival in beam trawl fisheries, especially in 4 m beam trawl fisheries using chain mats and limited haul durations. This so-called “eurocutter” fishery is carried out by beam trawlers with an engine power  $\leq 221$  kW and is allowed in the 6 to 12 nm zone in contrast to larger beam trawlers which operate solely outside of the 12 nm limit. Chain mat beam trawling was developed to prevent large boulders from entering the net, and is typically conducted at lower fishing speed than tickler chain beam trawling. This study obtained short-term survival estimates for this “eurocutter” fishery by monitoring post-capture mortality in tank-held organisms. Survival was high to very high ( $>75\%$ ) for benthic invertebrates, but not for fish. All examined whiting (*Merlangius merlangus*) and pouting (*Trisopterus* sp.) died. Only 14% of sole (*Solea solea*) survived to 91 h of observation, and 48% of plaice (*Pleuronectes platessa*) to 77 h. The survival probability was higher for cod (*Gadus morhua*) (66% to 88 h) and skates (*Rajidae*) (72% to 80 h). However, the mortality rate had not stabilized within the period of observation. Survival models were used to estimate the minimum duration of captivity required to properly evaluate short-term survival, and to investigate the role of physical injuries and other pertinent covariates (catch weight, fish length, fishing depth, salinity, sea surface temperature, air temperature and fishing trip) in determining fish discard survival. The results of this study indicate a high variability in discard survival amongst taxa and highlight that physical injuries when taken alone are a limited proxy for survival of 4 m beam trawl discards and that small fish specimens have a limited chance of surviving discarding.

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## 1. Introduction

The overall ecological impact of beam trawl fisheries is amongst the highest of different gear types (Suuronen et al., 2012). In addition to the well-documented effects on benthic habitats, discarding is also of particular concern. The UK beam trawler fleet discards approximately one third of the weight of their fish catch in the North Sea (Enever et al., 2009), while the German flatfish-directed beam trawler fleet discards between 56 and 72% of their total catch (Ulleweit et al., 2008). Despite a number of initiatives to reduce discards in beam trawl and other fisheries, the European Commission (EC) has deemed progress to be insufficient and has therefore proposed a ban on discards of commercial species (European Commission (EC), 2013). However, decision making concerning a ban is on-going and survival of fishery discards is a ponderous subject of debate (European Council (EC), 2013).

Information is required on the relative conservation benefits that might arise from accounting for all fishery catches as part of a ban in which all discards die, versus those arising from regulations that allow for discarding of certain species, with ensuing survival of some organisms.

In practice, considerable efforts are made to understand discard amounts, but relatively little is known about the survival of discarded organisms. Formal estimates of discard survival are difficult to obtain due to the complex logistics for survival studies (see review in Broadhurst et al., 2006). A number of those survival studies of discards in beam trawl fisheries were conducted mainly in the early 1990s. They focussed primarily on beam trawling with tickler chains and either very short ( $\leq 0.5$  h) or long hauls ( $\geq 2$  h) (Table 1). This study focuses on the “eurocutter” fishery with 4 m beam trawls and chain mats and with haul durations of approximately 1.5 h. Beam trawling with tickler chains is typically conducted at higher fishing speeds than with chain mats (Rijnsdorp et al., 2008). Also, in contrast to tickler chain beam trawling, chain mat trawling can be conducted in rocky fishing grounds as the chain configuration prevents boulders from entering and tearing up the

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**Table 1**

Summary of environmental, technical and biological data collected during six five-day fishing trips by RV “Belgica” in the southern North Sea.

Fishing trip	24–28 November 2008	1–5 December 2008	2–6 February 2009	30 March–3 April 2009	26–30 November 2009	30 November–4 December 2009
ICES rectangles fished	31F2, 33F1 and 34F1	32F1 and 33F1	31F1, 32F1, 33F1, 33F2	31F2	33F1	33F1
Depth fished (m)	14–35	25–33	28–50	10–13	15–32	28–33
Salinity (PSU)	33.8 (0.4)	34.0 (0.1)	35.0 (0.0)	35.0 (0.0)	34.9 (0.1)	34.2 (0.2)
Sea surface temperature (°C)	9.3 (0.8)	9.3 (0.4)	5.8 (0.4)	8.2 (0.1)	12.1 (0.1)	11.3 (0.1)
Air temperature (°C)	7.5 (0.9)	5.2 (1.0)	4.9 (0.5)	9.3 (0.6)	10.84 (0.37)	9.43 (0.54)
Commercial hauls						
Catch weight (kg)	40.0–414.5	67.2–197.0	70.9–200.6	64.5–251.9	70.9–200.6	64.5–153.0
Haul duration (min)	97.0 (9.7)	99.3 (8.9)	91.7 (4.1)	87.0 (6.1)	84.2 (16.9)	91.3 (3.5)
Number of hauls	5	7	6	9	7	5
Number of individuals:						
<i>Gadus morhua</i>	17	9	–	27	3	8
<i>Merlangius merlangus</i>	–	30	–	–	26	20
<i>Pleuronectes platessa</i>	–	5	24	47	9	12
Rajidae	–	34	38	–	39	44
<i>Solea solea</i>	42	48	52	24	48	56
<i>Trisopterus</i> sp.	–	31	–	–	13	5
Total length (cm)						
<i>Gadus morhua</i>	32–52	33–63	–	32–56	54–63	42–75
<i>Merlangius merlangus</i>	–	17–35	–	–	17–36	15–28
<i>Pleuronectes platessa</i>	–	20–27	17–29	15–31	17–29	18–32
Rajidae	–	10–43	14–46	–	8–53	7–47
<i>Solea solea</i>	13–35	16–31	17–31	19–33	15–28	15–28
<i>Trisopterus</i> sp.	–	13–30	–	–	15–28	16–29
“Reference” hauls						
Number of hauls	–	–	1	2	–	2
Number of individuals:						
<i>Pleuronectes platessa</i>	–	–	1	24	–	–
<i>Solea solea</i>	–	–	8	18	–	20
Total length (cm)						
<i>Pleuronectes platessa</i>	–	–	16	18–31	–	–
<i>Solea solea</i>	–	–	21–34	23–34	–	19–29
Commercial hauls						
<i>Asterias rubens</i>	103	40	75	–	–	–
<i>Ophiura</i> sp.	–	–	27	20	1	7
<i>Psammechinus miliaris</i>	59	60	–	–	–	–
<i>Cancer pagurus</i>	5	5	8	–	–	22
<i>Liocarcinus</i> sp.	18	–	29	21	–	5
<i>Pagurus bernhardus</i>	13	42	17	–	–	–
<i>Aphrodite aculeata</i>	–	–	25	–	15	–

net. Given that haul duration (Van Beek et al., 1990), catch composition and towing speed affect fishing induced stress, injuries and survival (Davis, 2002), differences in survival between trawls with tickler chains and chain mats are expected (e.g. Lindeboom and de Groot, 1998: 170). “Eurocutter” beam trawlers have an engine power  $\leq 221$  kW and have different fishing rights than larger vessels. They are allowed to fish in the 6 to 12 nm zone and in the plaice box (Beare et al., 2013), thus exhibiting different fishing patterns than larger vessels (Poos and Rijnsdorp, 2007). Differences in the environment in which fishing takes place (e.g. depth, salinity, temperature) may also influence discard survival. The Dutch and Belgian “eurocutter” fishery mainly takes place in the southern North Sea (Taal et al., 2010; Tessens and Velghe, 2009; Van Hal et al., 2010). Dutch “eurocutters” predominantly fish with tickler chain beam trawls during the summer period in the southeastern North Sea, whereas most of the Belgian beam trawl landings and discards originate from the winter period (Marchal, 2006; Tessens and Velghe, 2009; Depestele et al., 2011). Although the “eurocutter” fleet is small (10.7% and 19.6% of the Dutch resp. Belgian beam trawler fleet in 2009), the envisaged differences in discard survival between beam trawl fisheries could lead to different advice for the “small” and “large” beam trawler fleet in the framework of the discard ban, thereby motivating this study.

This study had three main objectives. The primary aim was to obtain estimates of the short-term survival of a wide range of discarded organisms in the “eurocutter” fishery. The fish species

selected in this study were those that constituted most of the discards in the fishery and represent a diversity of biological characteristics (e.g. Depestele et al., 2011; Silva et al., 2012; Uhlmann et al., 2011): two flatfish species, i.e. sole (*Solea solea*) and European plaice (*Pleuronectes platessa*), three roundfish species, i.e. whiting (*Merlangius merlangus*), pouting (*Trisopterus* sp., >90% *T. luscus*) and cod (*Gadus morhua*), and skates (*Rajidae*) for the elasmobranchs. The survival of benthic invertebrate species was also examined to investigate the effect of longer haul durations on survival, as the only “chain mat” study on their discard survival was conducted during 30 min hauls (Kaiser and Spencer, 1995). The selected invertebrates were common starfish (*Asterias rubens*), ophiurids (*Ophiura* sp.), edible crab (*Cancer pagurus*), hermit crab (*Pagurus bernhardus*), sea mouse (*Aphrodite aculeata*), green sea urchins (*Psammechinus miliaris*) and swimming crabs (*Liocarcinus* sp., of which >90% were *L. holsatus*).

The second aim of the study was to evaluate whether the degree of injury sustained by an organism can predict eventual discard survival in the “eurocutter” fishery. The relationship between injuries and discard survival has been found for invertebrates and fish in other fisheries (e.g. Enever et al., 2008; Benoît et al., 2010, 2012). The benefit of defining such relevant proxies for discard survival is that they represent a much more cost-effective manner of evaluating and accounting for the various factors that can affect discard survival (e.g., Benoît et al., 2010, 2012; Davis, 2010).

The third aim of the study was to better understand how discard impacts might be mitigated. While increased selectivity can reduce the catch of non-marketable organisms, reducing fishing impact on them (Broadhurst et al., 2006), certain modifications to fishing operations also have the potential to increase discard survival rates of the organisms for which catch is unavoidable in a particular fishery (e.g. Benoît et al., 2010; Enever et al., 2010). Consequently, understanding the technical, environmental and biological factors that affect discard survival is key to developing effective discard mortality mitigation measures. Main and interacting effects on survival are summarized in Davis (2002). Technical factors relate to capture stressors from different gear types and deployments (e.g. haul duration, catch handling, etc.). Environmental conditions can induce additional stress through changes in e.g. salinity, air and sea surface temperature (Harris and Ulmestrand, 2004; Uhlmann and Broadhurst, 2013). Of the biological factors, especially the size and physiology to withstand stress and injury are important.

## 2. Materials and methods

### 2.1. Discard survival experiments

Survival experiments were performed aboard the RV “Belgica” during a total of six five-day fishing trips in the southern North Sea (ICES subarea IVc, ICES statistical rectangles 31F1, 31F2, 32F1, 33F1, 33F2 and 34F1) (Table 1). This area was selected because of its importance for the Belgian beam trawler fleet (Depestele et al., 2011). Fishing was conducted on commercial fishing grounds, based on tracks provided by commercial fishermen. Two 4 m beam trawls were attached next to each other with an extra trawl head in the middle of the 8 m beam to allow catch comparison trials as part of another study (e.g. Fonteyne and Polet, 2002). Organisms were retrieved from one of the beam trawls equipped with a chain mat and an 80 mm diamond mesh codend. The net was made of polyethylene netting, single braided in the top panel and double braided in the lower panel. The cod-end was made of double braided polyethylene netting with a twine thickness of 4 mm. The mean duration ( $\pm$ S.E.) of experimental treatment hauls was  $92 \pm 12.0$  min with a speed of about 4 knots and the length of the fishing warps was about 2.5–3 times the depth, consistent with practices in the commercial “eurocutter” fishery. We performed 35 hauls to collect fish, and 25 to sample benthic invertebrates. Five hauls of limited duration (<20 min) and with minimal post-haul handling times of captured fish before being placed in holding tanks (<5 min) were conducted to serve as experimental controls. Sole and plaice were caught in sufficient numbers in these control hauls.

The organisms from experimental treatment hauls were deposited on deck, collected in boxes to be weighed, after which specimens were placed in holding tanks. Previous studies have shown that air exposure is one of the greatest contributors to discard mortality within and among species (Benoît et al., 2013 and references herein). In the commercial fisheries of the North Sea and the Western English Channel, the mean duration of air exposure ( $\pm$ S.E.), measured as the difference between the release of the catch on deck and the first and last organism being returned to the sea, varies between a minimum of 12 ( $\pm 5$ ) min and a maximum of

30 ( $\pm 8$ ) min. The mean duration of air exposure was 16 ( $\pm 4$ ) min in the experimental manipulations of this study. Fatally damaged specimens were registered but not held, while others were held in two types of plastic holding tanks. A maximum of 8 roundfish or skate individuals were kept in holding tanks of 175 L ( $70 \times 50 \times 50$  cm). Flatfish and invertebrates were held in 24 L tanks ( $60 \times 40 \times 11$  cm) as used in Van Beek et al. (1990). A maximum of 4 flatfish, 20 invertebrates or 6 edible crabs were retained per tank. A continuous flow of fresh, ambient sea surface water was provided. No feeding took place during the subsequent observation period.

Survival was monitored twice daily for a minimum duration of 60 h in the holding tanks, an artificial limit imposed by the trip durations. Fish mortality was based on common death signs, such as motionlessness during approximately 2 min of observation, non-response to physical stimuli, flaring of the gills (roundfish), curling of wings (skates), and rigor mortis. Invertebrates were considered dead in the absence of body movements, e.g. a live sea mouse curls its body by contracting longitudinal muscles upon touching (Kaiser and Spencer, 1995). Dead specimens were removed from the holding tanks.

Explanatory factors for survival were recorded (Table 1). Haul-specific environmental characteristics (mean and range) were catch weight (137.6 kg, 40–414.5 kg), mean depth fished (30.3 m, 10–50 m), salinity (34.5 PSU, 33.3–35.0 PSU), SST (9.6 °C, 4.6–12.4 °C) and air temperature (7.9 °C, 3.6 °C–11.4 °C). Length and physical damage were considered important at the level of the individual. Invertebrates were not measured. Fish length was measured to the nearest cm. Physical injuries were assessed according to taxon-specific schemes. Benthic invertebrates were assessed following the scheme of Veale et al. (2001) (Table 2). Sea mouse (*Aphrodita aculeata*) was categorised as either undamaged or damaged (crushed). The physical injuries of fish species were evaluated by the Catch Damage Index (CDI), in order to avoid subjectivity of categorising fish by inspecting their condition and behaviour (e.g. Van Beek et al., 1990). CDI was originally developed to assess quality defects caused by fishing gears (Esaïassen et al., 2013), but was modified to evaluate relevant physical damage for fish survival (Table 3). The intention was to reduce subjectivity as much as possible by accounting for purely measurable physical damages as a predictor of survival.

### 2.2. Discard survival analysis

#### 2.2.1. Estimating empirical survival functions

The survival of a taxon was estimated as a function of time using the non-parametric Kaplan-Meier procedure (Kaplan and Meier, 1958). The Kaplan-Meier survival probability for each finite time interval  $i$  is defined as:

$$\hat{S}(t) = \prod t_i \leq t \left( \frac{n_i - d_i}{n_i} \right) \quad (1)$$

where  $\hat{S}(t)$  is the estimated survival probability at time  $t$ ,  $n_i$  is the number of individuals at risks of death during the finite time interval  $i$  and  $d_i$  is the number of deaths during  $i$ . This approach easily accommodates right-censored observations, which are organisms for which death was not observed because the study was terminated before they died.

**Table 2**  
Scores for damage inflicted on benthic invertebrates (modified from Veale et al., 2001).

Species	1	2	3	4
Starfish/Brittlestars	No visible damage	Arms missing	Worn and arms missing/minor disc damage	Major disc damage/crushed
Crabs	No visible damage	Legs missing/small carapace cracks	Major carapace cracks	Crushed
Hermit crabs	No visible damage	Edge of shell chipped	Shell cracked or punctured	Crushed
Urchins	No visible damage	<50% spine loss	>50% spine loss/minor cracks	Crushed

**Table 3**

Modified catch damage index (CDI) to evaluate physical injuries for fish after catching and handling operations (modified from [Esaïassen et al., 2013](#)). Bruises are scored separately for head, body and tail.

CDI	Description	Score
Gear related damages	No gear marks	0
	Gear marks such as incisions	1
Skin-abrasion	<10% scale loss	0
	Between ≤10% and <50% scale loss	1
	≥50% scale loss	2
Bruises (separate scoring for head, body and tail)	Non discoloration	0
	<50% discoloration on the area	1
	≥50% discoloration on the area	2
Pressure injuries	No compression detected	0
	<30% compression detected	1
	≥30% compression detected	2
Broken spine	No	0
	Yes	1
Fin and tail damage	No marks	0
	<30% visible marks	1
	≥30% visible marks	2
Max total score (CDI)		14

2.2.2. Predicting survival based on physical injuries

The ability of the CDI to predict fish survival was assessed intraspecific using the modelling approach developed by [Benoît et al. \(2012\)](#), in which a small number of parametric survival models with CDI (or analogous covariates) as a predictor were fit to the experimental data. The classes of the CDI were recoded into a binary “injury” variable, with all values below the overall mean CDI in one class and those above in the other. This resulted in sufficient observations to fit all models for both injury classes, and increased the discriminating association with survival, (e.g. [Enever et al., 2008](#)). Estimation of survival during captivity was based on the analysis of survival probability as a function of time, while accounting for right-censored data. The underlying distribution was a Weibull-type survival function, conditional on the injury class:

$$\hat{S}(t) = \exp[-(\alpha * t)^\gamma] \tag{2}$$

where  $\hat{S}(t)$  is the estimated survival probability and the scale and shape parameters of the Weibull distribution are given by  $\alpha$  and  $\gamma$ . The survival model [2] assumes that all individuals follow the same survival function, and that  $\hat{S}(t)$  is a continuous declining function of  $t$ . The homogeneity assumption is violated if only a portion of the captured fish is adversely affected by the capture and handling process, such as the most severely injured individuals. [Benoît et al. \(2012\)](#) accounted for inhomogeneity using a two component survival mixture model (SMM). The first component models the survival of individuals adversely affected by trawling (Eq. (2)), which are assumed to follow a common survival function while the second component accounts for the proportion of individuals that were not adversely affected, which are assumed to not be at risk of dying during the course of the captivity study (for more details and justification, see [Benoît et al., 2012](#)). The resulting survival mixture

model (SMM) is:

$$\hat{S}'(t) = \pi * \exp[-(\alpha * t)^\gamma] + (1 - \pi) \tag{3}$$

where  $\pi$  is the proportion of individuals that were adversely affected by the fishing event. When all individuals are adversely affected, i.e.  $\pi = 1$ , the equation equals Eq. (2). Covariates suspected of affecting the survival probability can be included in the definition of  $\alpha$  (i.e. covariates affect the rate of mortality over time) and/or  $\pi$  (i.e. covariates affect the probability that an individual is affected or not). Six models were defined by varying how covariates were incorporated into the parameters  $\alpha$  and  $\pi$  ([Table 4](#)). The relative evidence for each of these models was assessed using differences in Akaike’s Information Criterion corrected for small sample sizes,  $\Delta AICc$ . Models with  $\Delta AICc < 2$  were interpreted as having similar support in the data, while  $\Delta AICc$  values between 3 and 7 suggested less support for the competing model, and values  $> 10$  suggested the alternative model being unlikely ([Burnham and Anderson, 2002](#)). The fit of the SMM selected via  $\Delta AICc$  was assessed by comparing model predictions to the empirical Kaplan-Meier (KM) survival curves, which do not assume an underlying survival function. The SMM model selection was considered suitable if the selected models fitted well within the 95% confidence intervals of the KM curves. The difference in KM curves between injury classes was also tested by the formal rank test for right-censored survival data ([Harrington and Fleming, 1982](#)).

Effective discard mortality studies should possess two key features (e.g., [Davis 2010; Broadhurst et al., 2006](#)). The first is the use of proper control subjects to account for mortality induced by captivity, as was included in this study (see above). The second is to ensure that the duration of captivity is sufficiently long to cover potential delayed mortality of individuals resulting from the capture and handling. An advantage of the SMM approach is that the potential for delayed mortality can be assessed. Evidence for models W1 and W2 ([Table 4](#)) implies on-going mortality of individuals, while evidence for the remaining models (mixture models M1-M4) implies that survivorship in the samples will level off at  $\hat{S}'(t) \approx 1 - \pi$ . Furthermore, if there is evidence for the mixture models, the time at which survivorship is expected to level off (say when 99% of affected individuals have died),  $t_s$ , can be estimated as:

$$t_s = \frac{-\ln(0.001)(1/\gamma)}{\alpha} \tag{4}$$

As such, we calculated  $t_s$  for the species in our study to determine what the ideal duration of captivity would have been, assuming the model is correct. These values can then serve in planning future survival studies involving the captivity of these species.

In addition to the intraspecific survival models, CDI scores were compared interspecifically with a non-parametric Kruskal-Wallis test and post-hoc comparison by Mann-Whitney tests with false discovery rate (FDR) corrections ([Benjamini and Hochberg, 1995; García, 2004](#)).

Evidence for possible relationships between survival and the damage index for invertebrates was tested using the Somers’ D statistic. This is a non-parametric asymmetric, rank biserial

**Table 4**

Assumption for the parameters  $\alpha$  and  $\pi$  in Eq. (3), to define the six competing models for the analysis of the fish survival probability.  $X$  is a matrix of the injury classes, with  $\beta$ ,  $\beta_1$  and  $\beta_2$  being the vectors of parameters for each injury class. The entry “constant” indicated that  $\alpha$  and/or  $\pi$  were estimated by model fitting (developed by [Benoît et al., 2012](#)).

Model	$\alpha$	$\pi$	Interpretation
Weibull 1 (W1)	Constant	1	Common survival function for all fish
Weibull 2 (W2)	$\exp(X'\beta)$	1	Common survival function for each injury class (Eq. 2)
Mixture 1 (M1)	Constant	Constant	Common survival function for a fixed proportion of affected individuals
Mixture 2 (M2)	$\exp(X'\beta)$	Constant	Common survival function within each injury class for a fixed proportion of affected individuals
Mixture 3 (M3)	Constant	$[1 + \exp(X'\beta_1)]^{-1}$	Common survival function for affected individuals, with the proportion affected dependent on injury class
Mixture 4 (M4)	$\exp(X'\beta_1)$	$[1 + \exp(X'\beta_2)]^{-1}$	Common survival function within each vitality class, where the proportion of affected individuals also depends on injury class

correlation coefficient, which can handle ties (Somers, 1962). The causal association between the ordinal damage scores and death (treated as a binary variable) was estimated and was reported as the confidence intervals (CI) around the Harrell's C-index, which parameterizes Somers' D to a probability scale from 0 to 1 (Harrell et al., 1982). In contrast to the case for fish, this approach was chosen because an absence of individuals in particular damage categories and particular properties of the data, such as most or all mortality occurring prior to holding for certain species, would have required a more complex application of the "fish" models. Instead a more simple analysis was used to determine the role of injuries on survivorship and an examination of survivorship at contrasting short and long holding durations was used to summarize the evidence for delayed mortality.

### 2.2.3. Factors potentially affecting fish discard survival

The potential contribution of catch weight, fish length, CDI, fishing depth, salinity, SST, air temperature and fishing trip to survival variability was investigated if more than 20 hauls were available, which restricted the analysis to sole ( $N=32$ ) and skates ( $N=22$ ). The discretized physical injury classes were re-examined, both as a single factor and in interaction with weight or length, which were considered to be the potentially strongest of possible interactions. Collinear explanatory variables were removed from the analysis according to a variance inflating factor (VIF) of two, to enable the detection of weak ecological signals (Zuur et al., 2010). We used a mixed-effects Cox proportional hazards model (Therneau and Grambsch, 2000) of the form:

$$\hat{h}(t) = h_0(t)\exp(X'\beta + Z'b) \quad (5)$$

where hazard function  $\hat{h}(t)$  is the probability of mortality at time  $t$ , conditional on survival until time  $t$ . In the model,  $\hat{h}(t)$  is conditional on a set of predictor covariates  $X'$  (catch weight, depth, length, injury class, fishing trip and SST in the case of sole) and a Gaussian haul-specific random effect  $Z'$ . The Cox model is a semi-parametric method in which hazards are estimated from the ranks of mortality times (Cox and Oakes, 1984). As defined above, the model deals with proportional hazards, in that the hazard for an individual at time  $t$  is a fixed proportion of the hazard of any other individual that depends on their state with respect to the covariates and the covariate parameter values. Parameters were estimated by partial maximum likelihood (Ripatti and Palmgren, 2000). In contrast to

the SMMs, the Cox model does not assume any particular baseline function  $h_0$ . While the absence of a parametric hazard function prevents a direct mechanistic interpretation of survival patterns such as provided by the SMMs, it provides a very flexible model in which to test for the effects of covariates without having to worry about the appropriateness of a particular parametric form. Cox regression was exclusively used for determining the potential influence of factors on survival. Model selection was based on the  $\Delta AICc$ .

## 3. Results

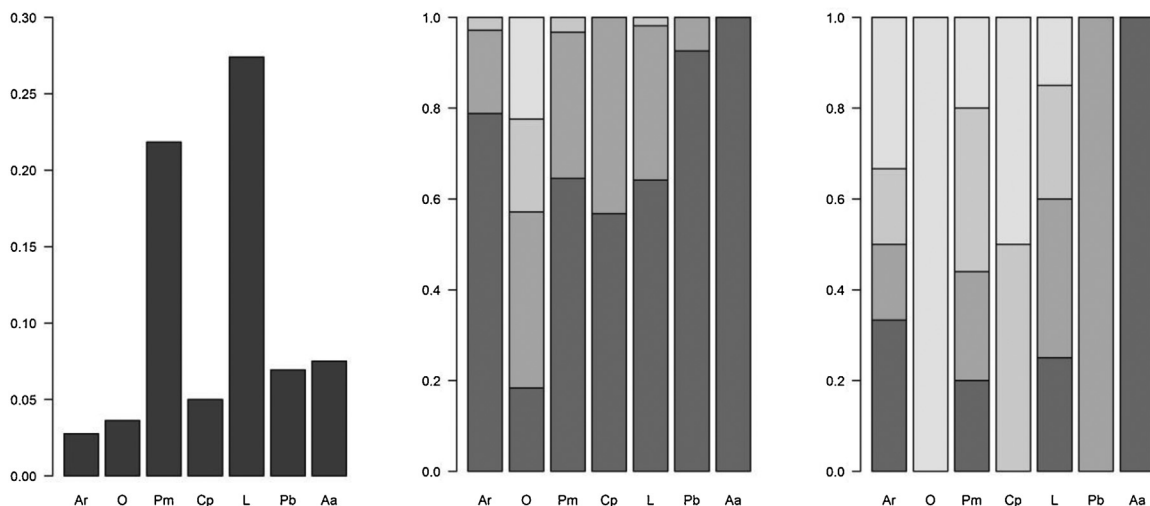
### 3.1. Discard survival

The survival probability during the first part of the observation period was high for all invertebrate species (>90%), except for swimming crabs (Fig. 1, Table 5). The survival of swimming crabs was 78% during the first 24 h. Approximately half of all individuals were monitored for at least 60 h. The Kaplan-Meier survival estimates for these longer observation periods did not decrease considerably for most of the species, except for green sea urchins. The survival of the latter was 75% after 72 h observation period.

The survival probability of the six examined fish taxa was much lower (Table 6). All whiting (*Merlangius merlangus*) and pouting (*Trisopterus* sp.) died within 24 h. Only 14% of sole (*Solea solea*) survived to 91 h of observation, while 48% of plaice (*Pleuronectes platessa*) survived to 77 h. In contrast, the survival probability was higher for cod (*Gadus morhua*) (66% to 88 h) and skates (*Rajidae*) (72% to 80 h). The Kaplan-Meier survival estimates of short hauls (<20 min) was 100% for plaice (25 individuals) and 96% for sole (46 individuals).

### 3.2. Survival with respect to physical injuries

There was a strong and statistically significant ( $P < 0.0001$ ) association between the number of dead organisms and the physical injuries for hermit crabs ( $C=0.96$ ;  $CI=[0.95, 0.97]$ ), ophiurids ( $C=0.89$ ;  $CI=[0.87, 0.90]$ ) and green sea urchins ( $C=0.81$ ;  $CI=[0.79, 0.83]$ ) (Fig. 1). The association was less strong for common starfish ( $C=0.78$ ;  $CI=[0.75, 0.81]$ ;  $P < 0.05$ ) and swimming crabs ( $C=0.76$ ;  $CI=[0.73, 0.79]$ ). Furthermore, the only two dead edible crabs were respectively classified within damage



**Fig. 1.** The percentage of dead organisms at the end of the observation period (left), and the relationship between the physical injuries for surviving (middle) and dead (right) organisms. The physical injury classes (Table 1) are distinguished using grey shading, from dark grey for less severe physical injuries (class 1) to light grey for the most severe injuries (class 4). Aa: Aphrodita aculeata, Ar: Asterias rubens, Cp: Cancer pagurus, L: Liocarcinus sp., O: *Ophiura* sp., Pb: *Pagurus bernhardus*, and Pm: *Psammechinus miliaris*.

**Table 5**

Kaplan–Meier survival estimates with standard errors (S.E.) for benthic invertebrates during a short and long observation period. The number of investigated individual, *N*, and number of dead organisms, *N* (dead), are indicated for each time interval.

Species	<i>N</i>	Time (h)	<i>N</i> (dead)	Percent survival (%)
<i>Asterias rubens</i>	218	17	3	99 (1)
	107	65	6	97 (1)
<i>Ophiura</i> sp.	51	22	2	96 (3)
	24	60	2	96 (3)
<i>Psammechinus miliaris</i>	119	38	3	98 (2)
	83	72	23	80 (5)
<i>Cancer pagurus</i>	39	32	2	95 (4)
	20	84	2	95 (4)
<i>Liocarcinus</i> sp.	73	24	16	78 (6)
	53	67	18	75 (7)
<i>Pagurus bernhardus</i>	72	53	3	96 (3)
	43	72	4	94 (3)
<i>Aphrodita aculeata</i>	40	34	2	92 (5)
	25	69	3	92 (5)

classes 3 and 4. There were no physical injuries detected for sea mouse.

The mean CDI of all fish taxa ( $\pm$ SD) was 2.94 ( $\pm$ 1.78), being highest for cod (3.74) and lowest for skates (2.57). The variability of the CDI was highest for plaice (SD=1.99), cod (1.98) and skates (1.96), while physical injuries varied less for sole (1.67), whiting (1.20) and pouting (1.15) (Table 7). A Kruskal Wallis test revealed significant interspecific differences ( $\chi^2(5) = 19.7, P < 0.01$ ). Post-hoc tests showed that CDI scores of cod differed significantly from those of skates ( $P < 0.01, r = 0.26$ ), whiting ( $P < 0.01, r = 27.3$ ), sole ( $P < 0.05, r = 15.2$ ) and plaice ( $P < 0.1, r = 16.8$ ). CDI scores of skates were different from sole ( $P < 0.1, r = 11.1$ ) and pouting ( $P < 0.1, r = 15.7$ ). The model selection for skates and plaice highlighted a difference in survival between different injury classes as differences

**Table 6**

Kaplan–Meier survival estimates with standard errors (S.E.) for six fish species held in holding tanks after commercial hauls (1.5 h) with a chain mat beam trawl. Survival of plaice and sole was also tested for short hauls, which served as a control subjects for the experiments. The number of investigated individuals, *N*, and number of dead organisms, *N* (dead), are indicated for each time interval.

	<i>N</i>	Time (h)	<i>N</i> (dead)	Percent survival (%)
Commercial hauls				
<i>Rajidae</i>	141	65	34	77 (5)
	108	80	40	72 (6)
<i>Gadus morhua</i>	64	34	18	72 (8)
	45	88	21	66 (9)
<i>Merlangius merlangus</i> <i>Trisopterus</i> sp.	76	21	76	0 (-)
	49	16	49	0 (-)
<i>Pleuronectes platessa</i>	97	57	30	69 (7)
	88	77	41	48 (15)
<i>Solea solea</i>	246	64	186	29 (10)
	208	91	202	14 (25)
“Reference” hauls				
<i>Pleuronectes platessa</i>	25	63	0	100 (-)
	12	87	0	100 (-)
<i>Solea solea</i>	46	52	2	96 (3)
	29	63	2	96 (3)

**Table 7**

Frequency of the CDI scores across the observed fish species.

Species	Catch damage index										
	0	1	2	3	4	5	6	7	8	9	10
<i>Rajidae</i>	22	28	25	32	17	13	5	1	3	-	1
<i>Gadus morhua</i>	-	5	14	15	10	6	5	4	1	2	-
<i>Merlangius merlangus</i>	2	15	14	26	14	3	-	-	-	-	-
<i>Trisopterus</i> sp.	-	3	16	13	11	6	-	-	-	-	-
<i>Pleuronectes platessa</i>	9	17	18	14	17	10	8	3	-	1	-
<i>Solea solea</i>	15	41	68	48	42	40	8	5	1	-	-

in AICc were high ( $>10$ ) for models in which survival probability was unrelated to injury (models W1 and M1) (Table 8). The “best” model for plaice and skate was a simple Weibull model with survival rate as a function of physical injuries (model W2). However,  $\Delta$ AICc were small for models M3 and M4, indicating some evidence for mixture models in which the mixture weight  $\pi$  was a function of injury. KM curves for both species matched well with the predicted survival functions, e.g. W2 and M3 models for skates and W2 model for plaice (Fig. 2). A formal rank test for right-censored survival data confirmed a significant difference in survival probability between injury classes for both plaice ( $\chi^2_{(1, N=96)} = 20.7, P < 0.0001$ ) and skates ( $\chi^2_{(1, N=147)} = 26.9, P < 0.0001$ ). The model selection procedure for cod was less clear cut, with support for several of the competing models. Although the mean CDI of cod was highest amongst taxa, and had a high degree of variation, there was evidence for models with (W2 and M3) and without (W1) an effect of injury on survival. The KM curves of both injury classes showed a high degree of overlap (Fig. 2), and a statistical difference was not detected ( $\chi^2_{(1, N=61)} = 1.2, P = 0.28$ ). For sole, M4 was selected as the most likely model, although there was also evidence for model M3 (Table 8; Fig. 2). Though this provided some support for the relationship between physical injuries and survival of sole,  $\Delta$ AICc values indicated that other models excluding this relationship were not improbable. The SMM curves and the KM confidence intervals visualized the poor discriminative power of physical injuries to predict differences in survival probability (Fig. 2). Indeed, no statistical difference was detected between the survival of different injury classes ( $\chi^2_{(1, N=260)} = 0.1, P = 0.82$ ).

The time at which survivorship is expected to level off,  $t_s$ , was estimated from the M3 models. The predicted ideal duration of captivity required to observe all experimental mortality was approximately 5 days for sole ( $t_s = 4.7$ ; CI = [3.6, 5.9]), 9 days for skates ( $t_s = 8.7$ ; CI = [5.1, 12.3]) and plaice ( $t_s = 8.9$ ; CI = [4.8, 13.1]) and 21 days for cod ( $t_s = 21.1$ ; CI = [0, 61.2]).

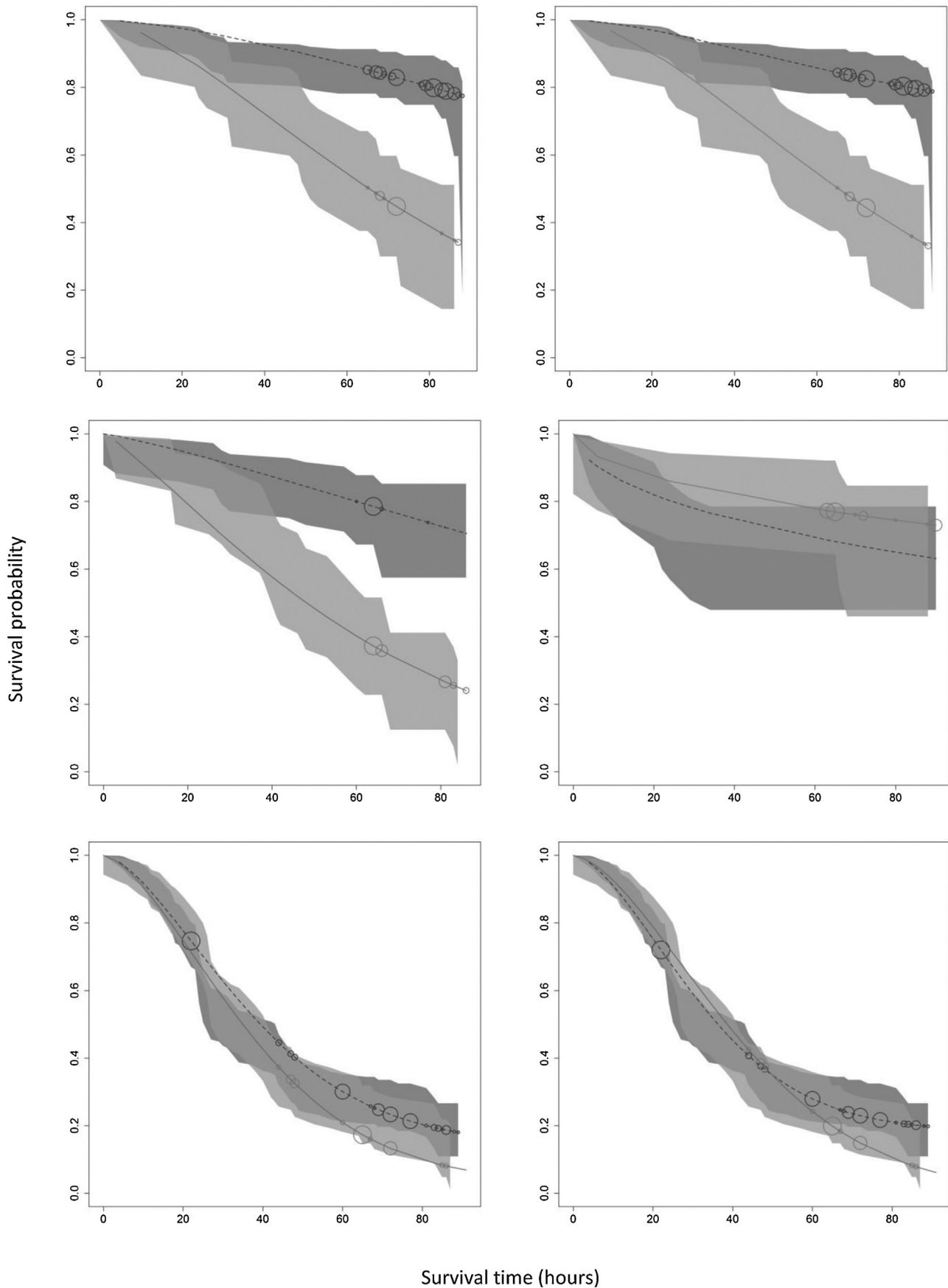
3.3. Factors potentially affecting discard survival

The contribution of catch weight, fish length, physical injuries, salinity, SST, air temperature and fishing trip was examined for the short-term survival probability of sole and skates. VIFs were  $<2$  for depth, SST, catch weight, length, CDI and fishing trip, which were selected for the modelling procedure for sole. Salinity and air

**Table 8**

Selection of survival mixture models based on  $\Delta$ AICc values. See Table 3 for the definition of each of the six competing models. The “best” models have zero  $\Delta$ AICc values, indicated in bold.

Species	Candidate models					
	W1	W2	M1	M2	M3	M4
<i>Rajidae</i>	19.9	<b>0</b>	58.4	60.4	1.3	3.4
<i>Gadus morhua</i>	<b>0</b>	1.5	3.4	3.8	1.9	5.3
<i>Pleuronectes platessa</i>	18	<b>0</b>	16.7	24	3	4.1
<i>Solea solea</i>	6.1	7.4	8	8.7	2.4	<b>0</b>



**Fig. 2.** Survival probability of skates (upper left: W2, upper right: M3), plaice (middle left: W2), cod (middle right: W2), and sole (lower left: M3, lower right: M4) in relation to time (h) in the holding tanks. Individuals with limited physical injuries are indicated in dark grey, except for cod. Lines are the fits from the survival mixed models, while shaded areas are point-wise 95% confidence intervals from the Kaplan–Meier survival analysis. The magnitude of right-censored individuals is indicated by the size of the circles along the fits.

**Table 9**  
Factors affecting fish survival: parameter estimates with standard errors (S.E.) and p-values for the final mixed effects Cox models for sole and skates.

	Exp (estimate)	S.E.	p-value
<i>Rajidae</i>			
Injury class	9.049	0.373	<0.001
Length	0.891	0.023	<0.001
<i>Solea solea</i>			
Catch weight	1.006	0.003	0.020
Depth	1.028	0.014	0.048
Injury class	1.467	0.179	0.033
Length	0.936	0.024	0.005

temperature correlated significantly ( $P < 0.0001$ ) with fishing trip (Respective Pearson  $r^2 = 0.89$ ;  $0.55$ ). The “best” model for sole (lowest AICc) retained catch weight, depth, injury class, length, fishing trip and the interaction between injuries and weight. This model explained 20.7% of the overall variability, including two variables that were insignificant ( $P = 0.051$  for depth;  $P = 0.052$  for the interaction). The next “best” model was more parsimonious, explained 17.8% and retained only significant variables: catch weight, depth, length and physical injuries. Table 9 summarises the results for the latter model. A higher catch weight, a greater depth and more injuries decreased the survival probability significantly ( $P < 0.05$ ). Larger individuals had significantly better survival probabilities ( $P = 0.005$ ). In contrast, 69.0% of the variability in survival probability of skates was explained by a model that included length and physical injuries. Depth, catch weight, length, CDI and fishing trip were selected for the candidate models ( $VIF < 2$ ). Salinity correlated significantly with fishing trip (Pearson  $r^2 = 0.97$ ,  $P < 0.0001$ ), depth was correlated to SST (Pearson  $r^2 = -0.73$ ,  $P < 0.0001$ ) and air temperature (Pearson  $r^2 = -0.48$ ,  $P < 0.0001$ ). Length and injuries were selected with a strong preference in eight candidate models ( $\Delta AICc > 20$  for the other models). Those models contained catch weight, fishing trip or the interaction of length and injury class, a combination of those or none of them. As was the case for sole, the inclusion of additional variables did not always coincide with adding significant factor or increasing explanatory power of model variability considerably ( $< 6\%$ ). Therefore the most parsimonious model was reported, i.e. with length and injuries (Table 9). Survival probability was significantly higher for larger individuals and less injured skates ( $P < 0.0001$ ). The length and injury effect was higher for skates than for sole (Table 9). The hourly hazard of death decreased with length by a factor 0.936 for soles and 0.891 for skates. In other words, the hourly survival chances of skates during the observation period increased by 10.9% with length, while with 6.4% for sole. Hourly survival probabilities decreased with increasing CDI scores by almost a tenfold more for skates than for soles.

## 4. Discussion

### 4.1. Discard survival estimates from tank-based experiments

The survival of discarded invertebrates in the 4 m beam trawl fishery with chain mats (Table 5, Fig. 1, this study) followed the general observed pattern in previous studies (Table A1). All short-term survival estimates for Asteroidea and Gastropoda were consistently very high ( $> 85\%$ ), which is in agreement with other bottom trawling studies (e.g. Bergmann and Moore, 2001). A great deal of variation was observed in discard survival between species of Crustacea (14–93%) and Bivalvia (10–98%) (e.g. *Liocarcinus* sp. and *Cancer pagurus*, this study). Species-specificity is expected to be due to differences in biological traits (fragility, flexibility, physiology, etc.). Hard-bodied species without limbs (e.g. whelks) seem to have a better short-term survival rate than species with fragile

externalities (e.g. swimming crabs) (Kaiser and Spencer, 1995). This is supposedly why physical injuries show such a good association with invertebrate discard survival (this study) and why catch composition and weight help when predicting survival (Bergmann et al., 2001a). In addition, survival of invertebrate discards also depends on species-specific differences in secondary responses, e.g. tissue damage results in marked physiological stress responses. As an example, *Liocarcinus* sp. and *Cancer pagurus* both induce a rapid rise in glucose and lactate to autotomize limbs (Bergmann et al., 2001b; Patterson et al., 2007). Differences in secondary responses between both species can be speculated to contribute in the observed differences in survival probability of this study, by analogy with marked differences in autotomy reflex after trawling for *Liocarcinus depurator* and galatheids (Bergmann and Moore, 2001). Further, high within species variability has been reported, e.g. survival rate of brown shrimp (*Crangon crangon*) can vary between 30% and 80% in different environments (Gamito and Cabral, 2003; Lancaster and Frid, 2002). Other plausible contributors to the observed differences are thus technical and environmental conditions, such as temperature shock (Raicevich et al., 2011), salinity (Harris and Ulmestrand, 2004), etc. While physical injuries of benthic invertebrates were clearly associated with survival probabilities in this study, causal relationships could not be established and would require a more complex application of the “fish” models, which could not be performed due to limitations in the collected invertebrate data (Table 1).

Discard survival for fish was generally lower than that of invertebrates, though there are generally differences amongst fish taxa. For example, in a cross-species study, Benoît et al. (2013) found that Rajiformes generally have a higher survival potential than Pleuronectiformes, followed by Gadiformes. While Benoît et al. (2013) used a proxy for survival (time-to-mortality), their findings on elasmobranchs are confirmed by estimates from tank-based experiments for various bottom otter trawl fisheries (Enever et al., 2008; Laptikhovskiy, 2004; Benoît et al., 2012; Mandelman et al., 2013). This study provides the first estimates for beam trawl fisheries, confirming a relatively high skate survival rate ( $> 70\%$ ), which is relatively close to the estimate by Enever et al. (2008) for the UK otter trawl fishery (59.1%). The Pleuronectiformes in this study, sole and plaice, had a survival rate of 48.2% and 13.9% at 77 h and 91 h post capture respectively. These values compare favourably with those obtained from studies involving tickler chain beam trawls for sole and with chain mat beam trawling for plaice. Our estimates are considerably higher than those of plaice survival in tickler chain beam trawling and lower for sole in chain mat beam trawling in the western English Channel (Table A1). Discrepancies in results between studies may stem in part from a lack of fully quantifying post-capture mortality. Unless studies are terminated only once mortality of held fish has stabilized, discard mortality is likely to be underestimated to varying degrees. This may be the case for plaice, for which mortality had yet to stabilize when both our study and that of van Beek et al. (1990) were terminated. Due to their low number, individuals of dab (*Limanda limanda*) and lemon sole (*Microstomus kitt*) were not analysed in detail here, but also indicate that these Pleuronectiformes suffer high discard mortalities. From the 15 individuals of dab, 6 were dead after 60 h observation with 7 individuals censored. Only 3 out of 25 lemon soles were alive after a 60 h observation period. Surprisingly, the expected low survival rates for Gadiformes (Lindeboom and de Groot, 1998) were not fully confirmed. Indeed, whiting and pouting did not survive a short observation period, but the survival probability for cod was considerably higher than expected (65.9% at 88 h). The limited fishing depth for catching the cod individuals may be a plausible explanation. All individuals were caught at depths between 10 and 33 m, which is expected to result in higher cod survival due to less barotrauma during capture



compared to capture at a greater depth (Pálsson et al., 2003; van der Kooij et al., 2007).

The discard estimates clearly demonstrate different survival probabilities between taxa, but the absolute survival probabilities should be interpreted with caution. Benoît et al. (2012) explained that a multitude of conditions determine post-release survival (e.g. fishing depth, temperatures, handling practices, etc.) and that deriving estimates that are relevant to a fishery requires integration of the relevant conditions experienced by fish captured and discarded in that fishery. While the conditions experienced by the fish in our study were consistent with the types of condition present in the fishery, it is unlikely that they properly represented the distribution of conditions experienced by discarded fish in the fishery. Furthermore, the predictions of survival probability are based on a short term study in non-natural conditions and are likely overestimated since mortality due to post-release infection and predation risk was not quantified. Increased predation risk can be due to impaired swimming abilities (e.g., due to distended swim bladders) or due to post-traumatic behaviour, which can last for weeks beyond the period of observation. This was for instance observed *in situ* (North Sea) from data-storage tags in trawl captured cod, for which natural pre-capture vertical movements were only re-established after 10 days of being returned to the sea (Neat et al., 2009). Survival estimates from tank experiments should therefore be used as a step into a broader framework of understanding mortalities from discarding.

This study and others have highlighted the need to fully quantify capture and handling mortality by ensuring there is no delayed mortality in the study (i.e., that mortality has levelled off before the study is terminated). The SMM used here and in Benoît et al. (2012) have the advantage of essentially testing whether mortality has stabilized and allowing investigators to estimate the time at which this occurs. Some authors have suggested that survival curves generally level off within 4 days (Wassenberg and Hill, 1993), which is also suggested as the minimal period of inhibition of a species' normal activity (Neat et al., 2009). These findings were confirmed by the time of levelling off for sole at approximately 5 days. However, the survival only stabilized over a time of approximately 9 days for skates and plaice, and 21 days for cod. Evidence for ongoing mortality beyond a study's duration was also found in the study of Benoît et al. (2012) for witch flounder and for 9 out of 29 cases in the authors' review of several long-term discard and escape mortality studies. The long observation period for cod was however in contrast to the results of Benoît et al. (2012), where an ideal duration of captivity of 2 days was suggested. The reason for the long observation period in this study is due to 3 cod individuals that died late in the period of captivity (>60 h). When those individuals were artificially excluded from analysis, an ideal of duration of captivity was 1.9 days ( $t_s = 1.9$ ; CI = [1.2, 2.8]). Our study hence confirms the rapid mortality for cod, but also provided support for the potential of a delayed mortality.

The factors discussed above are likely to contribute to an underestimation of discard mortality, however experimental holding of fish can also contribute to mortality via stress and unsuitable holding conditions, leading to overestimation (Portz et al., 2006). While proper experimental controls were not available for our study, the short hauls with minimal air exposure (<5 min) indicate that the tank induced mortality was minimal or nil.

#### 4.2. Other lessons from tank-based experiments

Tank-based experiments are also useful for determining the potential of mitigation options for reducing discard mortality. Tank-based experiments can highlight the prospects of focusing on biological, environmental or gear measures applied within a specific fishery. Van Beek et al. (1990) provided a first tank-based

evaluation of the main factors contributing to discard mortality in beam trawl fisheries. Haul duration and handling were detected as important technical drivers. These factors were therefore kept constant in this study, enabling the investigation of other technical factors, notably catch weight. Technical and biological factors were of primary interest, because gear modifications can potentially increase survival probabilities without changes in profitability, e.g. through selectivity changes or reduction in catch weight (e.g. Revill and Jennings, 2005; Enever et al., 2010). Fishing trips were conducted during winter to early spring to reduce temperature variability between trips. As water layers in the southern North Sea are typically tidally mixed (i.e. no thermocline), little to no differences were expected in temperature and salinity between the sea surface and bottom (Holligan et al., 1989). Other environmental conditions (e.g. salinity, depth) were not controlled for, as selection of fishing grounds was based on the advice of local fishermen. Also, the spawning condition of the fish was not sampled, as skates probably spawn during the summer months (Walker et al., 1997), and soles in mid-April in the Thames estuary and the Belgian coast (Fincham et al., 2013). Depth, SST, air temperature and salinity were monitored and included in the modelling procedure, because they varied considerably between fishing trips (Table 1). Fishing trip was also included to account for unidentified environmental and/or biological factors.

Statistically significant drivers of sole survival were catch weight, fish length, depth and injuries, but their explanatory power was limited, especially for depth. The overall explanatory power of the sole model was low (<20%); however total variability in the sole survivorship function was also low, as indicated by the limited variability of sole survival within and between injury classes in Fig. 2. This is in concordance to other discard survival studies, which could not detect any significant factors associated with sole survival other than length and injuries (Van Beek et al., 1990; Revill et al., 2013). In contrast, water temperature and condition of the fish have been indicated as significant drivers for plaice survival in beam trawl fisheries (Van Beek et al., 1990; Revill et al., 2013). This is also in contrast to skates' survival in this study, which varied considerably (Fig. 2), and was significantly driven by their length and injuries, explaining 69.0% of the model variability. In contrast to Enever et al. (2008; 2010), catch weight was not selected for skates. Catch weight increases compression in the codend, which could affect fish condition. The mean codend weight ( $\pm$ S.E.) in this study was 133.6 ( $\pm$ 39.1) kg for hauls in which skates could be retrieved, whereas Enever et al. (2008; 2010) reported mean weights up to 253 ( $\pm$ 30) kg, suggesting that there might be somewhat of a threshold for this effect (>200 kg). Mandelman and Farrington (2007) support this hypothesis for another elasmobranch, *Squalus acanthias*, where especially catch weights > 200 kg yielded rapid elevations in short-term mortality. The significance of a threshold catch weight for survival is however speculative, as survival inevitably also depends on interacting effects with catch composition and behaviour of the codend in the water column. This nevertheless points out that flatfish are more susceptible to suffocation in the codend. This could be due to an increased risk of pressure on the operculum, as suggested by Davis (2002) when comparing flatfish and roundfish. The investigated factors highlight that especially length is key to improved discard survival across fish species (Benoît et al., 2013). This implies a reinforcement of the existing need for increased size selectivity not only for discard reduction, but also for increased discard survival.

The number of potential factors affecting survival and the number of species examined was modest in this study due to constraints in our capacity to hold organisms for observation. Using quantified proxies for survival instead of full survival studies can ease this constraint (e.g. Benoît et al., 2013; Davis, 2010). Physical injuries are easily quantified for both invertebrates and fish and

constitute one such proxy that was found to be effective for invertebrates, plaice and skates. However they were not a useful mortality proxy for sole and cod. Physical injuries can be assessed in an objective way by either presence or absence or by evaluating what percentage of the body had bruises, among others (Table 2, 3). The CDI was constructed to this end on the basis of multiple physical injuries since these can have a high explanatory power in predicting discard survival (Pálsson et al., 2003). Each of the different CDI classes had equal weight in the total CDI score. The class “broken spine” can be classified as a lethal damage by itself and might have higher weight. However, we were not able to test this as there were no broken spines except for two isolated cases (cod and pouting). Here we have attempted to limit the subjectivity in determining a survival proxy by establishing quantitative rules for the CDI, thereby avoiding the need to address subjectivity post-hoc during analysis (e.g. Benoît et al., 2010). While physical injuries are quick and easy to measure and do not further complicate the already complex experimental designs, they do not fully predict survival as visible injuries are unrelated to reflex impairment, which is also a strong independent predictor (Davis and Ottmara, 2006; Stoner, 2012). Injury-based proxies that also incorporated the notion of fish “liveliness” were hence more effective in predicting post-capture mortality of sole (Van Beek et al., 1990). An index based on reflexes, Reflex Action Mortality Predictor (RAMP), also indicated a good relationship with the mortality of cod (Humborstad et al., 2009). Accounting for invisible, internal damage is hence indispensable for the development of a good proxy. Assessing liveliness though can be subjected to observer subjectivity (Benoît et al., 2010), and constructing the RAMP can only be through assay validation and fish stressor experiments under laboratory conditions (Davis, 2010; Humborstad et al., 2009). These additional constraints are an essential part of the complex, experimental design to study biological, environmental and gear-related factors of variability in discard survival. Yet, another proxy was recently developed, i.e. the time-to-mortality (TM) when a fish is exposed to air. This proxy indirectly includes both external and internal injuries. It provides an index of survival potential that is comparable to that obtained from more involved holding studies, and can also be used to investigate the role of factors believed to affect discard mortality (Benoît et al., 2013).

The constraints outlined above stress that interpretation of survival estimates from tank-based experiments should preferably be relative across taxa, and/or across other drivers, rather than absolute. A primary merit of tank-based experiments is hence identification of focal drivers for survival and consequent development of mitigating measures. They cannot be readily used in stock assessments, for instance. This would require an additional validation step, which could for instance be achieved with tagging experiments (Yergey et al., 2012). Fisheries managers should be aware of the constraints of this and similar studies when considering measures such as a discard ban. Decisions on whether to impose a fishing ban based on the survival potential of particular discards need to acknowledge the lack of certainty of the estimates and need to be based on studies that have followed the best practices discussed here and by others (e.g., Davis 2010).

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.fishres.2014.01.018>.

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