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3 **Survival of discarded plaice (*Pleuronectes platessa*) from**
4 **Norway lobster (*Nephrops norvegicus*) otter-trawl fishery**

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15
16 **Summary**

17 The introduction of landing obligations in the European Union common fisheries policy, has
18 increased the focus on discard survival. Since species with scientifically proven high survival
19 rates may be exempted from the landing obligations, the economic significance for the
20 fishing industry is large. Landing obligations include individuals below the minimum
21 conservation reference size (MCRS), which are not allowed to be sold for human
22 consumption. The Norway lobster (*Nephrops norvegicus*) fishery is a high value fishery, but
23 with a substantial amount of bycatch of plaice (*Pleuronectes platessa*) below the MCRS. In
24 the present study, observations were made on the short-term survival of plaice at or below
25 the MCRS, discarded from a small otter board trawler targeting *Nephrops* in Skagerrak
26 (ICES 3a). The average short-term survival of plaice was 15% at haul level, ranging from 0-
27 39%, after 10 days of captive observation. Survival significantly decreased with time on deck
28 and the retention of debris in the codend ($P < 0.0001$), while survival was not correlated to
29 size. Vitality assessments, using a combined reflex impairment and injury score, were tested
30 as predictor of survival and were significantly associated to survival ($P < 0.0001$) both for
31 individual fish and when grouped by hauls. Seabird predation behaviour was assessed and

it was estimated that seabirds predated or pursued 85% of discarded plaice below the MCRS.

Key words: Bycatch, Discard Ban, Discard survival, Injury Assessment, Landing obligation, Reflex action mortality predictor, RAMP, Vitality assessment

1 | Introduction

High discard rates are found in several European fisheries (Uhlmann et al., 2014). A central component of the reform of the European Union common fisheries policy (CFP) is a plan for gradual elimination of discards by landing obligations, where all individuals of certain commercial species are landed (Sardà et al., 2015; Uhlmann et al., 2014; Sigurðardóttir et al., 2015). However, individuals below a defined minimum conservation reference size (MCRS) have a low market value because they are not permitted sold for human consumption and in some cases they might even constitute an extra expense for the fishers (Condie et al., 2013).

The *Nephrops* (*Nephrops norvegicus*, Norway lobster) otter-trawl fishery is the most important commercial demersal fishery for human consumption in Kattegat and Skagerrak (Frandsen et al., 2009, 2010; Krag et al., 2008; Madsen et al., 2010; Feekings et al., 2012). It is also of high commercial importance in other European areas (Catchpole and Revill, 2007). To retain *Nephrops* the fishery uses relatively small mesh sizes. The mesh size in the codend is around 90 mm (inside mesh opening) in the Danish *Nephrops* fishery, which is smaller than the 120 mm used when targeting fish species for human consumption. Consequently, high bycatch and discard rates are often associated with European *Nephrops* fisheries (Bergmann et al., 2002; Catchpole et al., 2005; Catchpole and Revill, 2007, Uhlmann et al., 2014). In the Skagerrak and the adjacent Kattegat discards are reported to be larger than the landings in the crustacean fisheries (Uhlmann, 2014).

Plaice (*Pleuronectes platessa*) is an important commercial species that is often caught and discarded in *Nephrops* otter-trawl fisheries in Kattegat and Skagerrak (Feekings et al. 2012) and in otter-trawl fisheries in the North Sea (Madsen et al., 2013). The landing

obligation is therefore expected to have implications for the *Nephrops* fishery, typically having high discard rates.

An exemption for the landing obligation is described for species with scientific evidence of high survival rates (Article 15.4b of Regulation (EU) No 1380/2013). The short-term discard survival of plaice has been studied in demersal beam- and otter-trawling indicating a high degree of variability in estimated survival rates. The short-term survival of plaice in beam-trawling was estimated to vary between 2-24% (van Beek et al., 1990), 39-40% (Kaiser and Spencer, 1995), 27-57% (Revill et al., 2013), and 48-69% (Depestele et al., 2014), with tow duration varying between 60-120 minutes and observation periods of 3-5 days. In otter-trawls, van Beek et al. (1990), Millner et al. (1993) and Methling et al. (2017) and Morfin et al. (2017) estimated a short-term discard survival of plaice at haul level of 0-34%, 63-100% and 77-100%, respectively; and at seasonal level 45-67% (Morfin et al. (2017), with tow duration between 60-305 minutes and 4-10 days observation periods. None of these studies have examined the discard survival of plaice where *Nephrops* is the target species.

The main objective of the present study is to estimate the short-term survival of plaice caught in otter-trawls in a representative *Nephrops* fishery. The focus of this study was individuals below the minimum landing size (MLS) of 270 mm that corresponds to the minimum conservation reference sizes (MCRS, henceforth used), as specified in the CFP. Discard of plaice above MCRS is believed to be minimal since the fishery is not quota limited.

A further objective is to make a quantitative vitality assessment (ICES, 2014a, b), by examination of injuries and reflex impairment on caught individuals. This is to further explore the possibility of developing a methodology to predict short-term survival since this approach has shown potential in previous studies (Davis and Ottmar, 2006, Davis, 2007, 2010, Humborstad et al., 2009), including recent studies on plaice (Uhlmann et al., 2016; Methling et al., 2017).

Previous studies indicates that discards are an important food source for seabirds (Bicknell et al., 2013; Votier et al., 2013; Depestele et al., 2016) and the predation by seabirds might therefore add an additional unquantified contribution to overall discard survival. Consequently, a study was performed to examine the feeding behaviour of seabirds surrounding the vessel in response to discarding of plaice.

2 | Materials and methods

2.1 Sea trials

Sea trials were conducted from the Danish commercial fishing vessel “Tana” (RI286) in the South-Eastern part of Skagerrak (ICES Division IIIa) during June 2015. The vessel measured 11.7 m and was powered by a 125 kW diesel engine. The vessel fished with its own commercial *Nephrops* otter-board trawl in a single rig. The head line height of the trawl was around 1.2 m and the horizontal trawl opening around 10 m. The codend had 80 open meshes in circumference and was 30 meshes long. Codend netting was made of single polyethylene twine with a mesh size of 89.8 ± 2.6 mm (average (AVG) $\pm$ standard deviation (SD); N = 24), measured with an ICES mesh gauge (Fonteyne, 2007).

Sea trials were conducted following commercial seasonal practices for smaller vessels fishing at night and a 3 hours tow duration. The vessel departed from harbour in the evening and returned before noon the next day. On each fishing trip, 2-3 hauls were conducted in the same area resulting in 7 experimental and 2 control hauls (Table 1). Towing speed was maintained as constant as possible for all hauls with a speed of 2.3 ± 0.03 knots (AVG $\pm$ SD). The duration of all experimental tows was 180 minutes, except one haul, which lasted 160 minutes due to minor technical complications with the trawl. The duration of the 2 control tows was 15 minutes. Data loggers (from Star-Oddi) were attached to the codend to record salinity and temperature during 2 of the hauls.

At the end of the haul the trawl was lifted out of the water and the codend was emptied from a height of ~1 m into a fish pound (2x2 m) filled with sea water. Then the conveyor belt was started transporting the catch to a 0.5 m² sorting table. The catch was continuously emptied from the fish pound and sorted. Seawater was regularly filled into the fish pound to be able to move the catch towards the conveyor belt, which is commercial practice for this vessel.

2.2 Sampling procedure

Plaice collected for the experiment were sampled from the sorting table, one individual at a time. Plaice estimated by eye to be below MCRS were collected randomly by taking the

127 first and nearest arriving on the sorting table. From each haul approximately 20 individuals
128 were selected, which corresponds the general time period for commercial sorting of the
129 catch. They were all length measured and assessed individually for injuries and impairment
130 of reflexes. Plaice was tagged individually with a numbered t-bar tag placed near the caudal
131 peduncle on the side of the anal fin using a tagging gun (Mark II, Avery Dennison,
132 Massachusetts, USA).

133

134 *2.3 Monitoring experimental fish*

135

136 Assessments of reflex impairment (reflex action mortality predictor, RAMP) were performed
137 in a separate 35 L water-filled box. To reduce handling time, only 3 different reflex responses
138 were selected from a list of 6 previously tested on plaice (Methling et al., 2017). A score of
139 1 was given if a reflex was absent and a score of 0 if a reflex was present (see Table 2 for
140 descriptions of reflexes). We found that the chosen reflexes are relatively subjective and
141 easy to handle, particularly in poor weather conditions and at night time.

142 Physical injuries were evaluated according to the occurrence of damages described in
143 Table 3. Individuals scored 0 if the damage was absent, or 1 if the damage was present. To
144 take into account the severity of abrasions, bleeding and wounds, an individual assessed
145 with the most severe level of injury would also be scored in the lower tier. Therefore, an
146 individual with internal organ exposure would by definition also have a deep wound, and a
147 deep wound would also count as a superficial wound. An exception was protruding intestines
148 that is likely caused by physical pressure in the fish pound or squeezing while towing or
149 hauling the gear, but without occurrence of wounding and bleeding.

150 The time from being lifted out of water until placed in on-board tanks was recorded for
151 each individual. After the completion of vitality assessment tests and measures, the tagged
152 individual was placed in hard plastic transport container (85×65×25 cm), with drilled out
153 holes allowing for water exchange, that were placed in 300 L water tanks (91×72×66 cm)
154 installed on the deck (Figure 1) having room for two transport containers. A maximum of 40
155 plaice was held simultaneously in one on-board tank. The water in the 300 L tanks was
156 refreshed by a deck pump using surface water. Oxygen content was regularly checked using
157 a hand-held meter (Polaris, Oxyguard, Denmark).

158 In the two control hauls, the codend was emptied directly into a 90 L container with sea
159 water and 20 individuals were transferred directly into transport containers and placed in the
160 on-board 300 L tanks as non-treated controls. Additional 20 individuals were subjected to
161 vitality assessments using the same procedure as for the experimental individuals. All other
162 procedures for the control were the same as described for experimental hauls.

163 In the harbour the transport containers were moved into a large 1000 L insulated tank
164 (148×117×97 cm) with chilled (~10 °C) oxygenated seawater. Tanks were transported by
165 truck to holding facilities about 50 km from the landing harbour where plaice were moved to
166 two large observation tanks each with around 6000 L of filtered seawater with a constant
167 flow of ~2 L/min. Plaice were divided between the two tanks with one control group in each
168 tank. The temperature and oxygen saturation in the holding tanks was measured daily and
169 was (AVG ± SD) 16.3 ± 0.4 °C and 78.2 ± 3.4%, and 16.3 °C ± 0.4 and 81.9 ± 5.0% for tank
170 1 and 2 respectively.

171 When transferring plaice to the observation tanks, a screening for dead individuals was
172 performed. Assessment of mortality was based on the onset of rigor mortis and colour of the
173 gills. In case of doubt the individual was placed in a quarantine box in the holding tank. The
174 quarantine box was a 90 L plastic container with drilled out holes so that it was emerged just
175 below the surface to allow a free flow of oxygenated seawater. This enabled easy
176 observation and removal of dead individuals with minimal risk of disturbance and possible
177 infections to the remaining fish that mainly stayed at the bottom of the tanks.

178

179 *2.4 Seabird predation behaviour*

180

181 A total of 81 dead plaice were selected from the catch, with a total length (AVG ± SD) of 229
182 ± 34 mm (range: 150-299 mm). One by one plaice were slipped down the vessels chute
183 leading from the sorting table directly over the side of the ship. The behavioural response of
184 the seabirds was divided into 4 categories: "Attempting", when the seabirds pursued a fish,
185 but discontinued the effort (almost) immediately. "Eaten", when there was positive
186 confirmation that a seabird captured and succeeded to swallow a fish. "No reaction", in the
187 cases where no seabirds pursued a fish. "Unknown", when the seabirds pursued the fish
188 and captured it, but flew outside of the field of view, so the final outcome could not be

determined. The experiment was carried out in the morning during daylight at a cruising speed of approximately 1.5 knots.

2.5 Short-term survival

Including sea trials, the entire experimental period lasted 14 days, with an observation period of 10 days. This was expected to be sufficient time to observe any short-term fishing related mortality, as the majority of mortality during discard survival studies occurs within the first days (Wassenberg and Hill, 1993; Methling et al., 2017). The holding tanks were inspected for dead individuals and oxygen saturation recorded at 24 hour intervals during the observation period to reduce potentially stress.

A hand held telescopic fishing net was used to examine fish by a gentle nudge. An individual was identified as healthy if it avoided the net, while non-responding individuals and individuals lying blind side up were examined for *rigor mortis* and gill colouration. In the case of fully developed *rigor mortis* and grey gills the individual was assumed dead and removed from the tank. If either of these two signs were not present or clear, e.g. tissue still soft but grey coloured gills, they were transferred to the quarantine box

2.6 Modelling and statistical analysis

The survival probability across time was assessed by the Kaplan-Meier estimator (Kaplan and Meier, 1958), i.e. the accumulated product of the fractions of individuals at risk for each time interval between observed deaths:

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

where d_i is the number of deaths during the time interval $[t_i - 1; t_i]$ and n_i is the remaining individuals at risk at time t_i . A log-rank Mantel-Cox test was used to compare survival probabilities.

Vitality impairment scores were calculated by combining the RAMP test score and the injury assessment score (Uhlmann et al., 2016). Each individual, i , received a vitality impairment score (v_i) of 0 to 1 (0 = no impairment; 1 = full impairment) calculated from:

$$vi_i = \frac{RAMP_i + Injury_i}{vi_{max}} \quad (2)$$

where $RAMP_i$ and $Injury_i$ is the RAMP and injury score, respectively, and vi_{max} is the maximum possible impairment.

The correlation between vitality impairment score and mortality was tested using Spearman's rank order test, and the relationship fitted to a logistic regression model. Student's t-test was used to compare averages for normally distributed data with equal variance and Mann-Whitney U test to compare medians if those assumptions were not met. Statistical significance was accepted at $P \leq 0.05$.

3 | Results

3.1 Sea trials

Over the span of 10 sea days, 7 experimental hauls and 2 controls hauls were completed. As typically for *Nephrops* trawling, the codend contained large amounts of mud and clay, being the preferred sediment by *Nephrops* (Rice and Chapman, 1971). However, in 5 out of the 7 experimental hauls, the codend contained unusually large amount of debris consisting of mud and large pieces of peat (estimated weight: 50-70 kg). Hauls were hereafter labelled as either “dirty” or “clean”. The measured seabed temperature (AVG $\pm$ SD) was 12.6 ± 0.4 °C (range: 11.5-14.1) and average salinity was 31.6 ± 0.4 PSU (range: 30.8-33.0; N = 820). Deck temperature between 13 and 20 degrees, were recorded when sorting the catch, during the trials period.

3.2 Short-term discard survival

A total of 216 plaice were sampled during the 7 experimental and 2 control tows, kept under captive observation and short-term survival was recorded (Table 4).

Kaplan-Meier survival estimates for experimental and control hauls are shown in Figure 2A. The survival probability in the 7 experimental hauls ranged between 0-39% for individual

hauls and between 84-100% in the 2 control hauls. The survival probabilities (AVG $\pm$ SD) in the method control: 89% and untreated control: 100% (SD = 0.0), were not significantly different (Log-rank Mantel-Cox test: $\chi^2_{(4, N = 78)} = 6.8$; $P > 0.05$), but significantly higher than the average survival (15%) in the experimental hauls (Log-rank Mantel-Cox test: $\chi^2_{(1, N = 212)} = 132.5$; $P < 0.0001$).

3.3 Clean and dirty hauls

When divided into “clean” and “dirty” hauls (Figure 2B), the average survival in “clean” hauls (no large debris or excessive amount of sediment) reached 37%, whereas in “dirty” hauls, average survival reached 5% at the end of the 10 days observation period. In one haul, where several large pieces of peat were retained in the codend, all individuals died within three days of observation. The difference in survival between “clean” and “dirty” hauls was significantly different (Log-rank Mantel-Cox test: $\chi^2_{(1, N = 133)} = 25.4$; $P < 0.0001$).

3.4 Time on deck and size

The total time spent on deck including handling (vitality assessment and tagging) affected survival, with a significant negative correlation between the number of days surviving and deck + handling time (Spearman's $\rho = -0.45$; $N = 113$; $P < 0.0001$). The deck + handling time (AVG $\pm$ SD) for surviving individuals: 21 $\pm$ 15 minutes (range: 0-49; $N=20$) was significantly lower than for dead individuals: 31 $\pm$ 17 minutes (range 4-69; $N = 113$) (Mann-Whitney $U = 745$; $n_1 = 113$; $n_2 = 20$; $P = 0.016$; two-tailed). Survival was not size dependent and there was no significant difference in total length (AVG $\pm$ SD) between surviving: 234 $\pm$ 31.8 mm ($N = 20$), and dead individuals: 229 $\pm$ 23.6 mm ($N = 113$), (Student's t-test: $P > 0.05$).

3.5 Vitality assessments

The most common injuries observed were scale loss and fin fraying, followed by bleeding and abrasion (Table 4). There were a few individuals with wounds, only very few individuals with deeper wounds and no individuals with internal organs exposed.

There was a significant correlation between vitality impairment and survival (Spearman's rank test: $\rho = 0.70$; $N = 172$; $P < 0.0001$), with vitality impairment ranging from 0% to 62% in surviving individuals and from 8% to 77% in individuals that died (Figure 3A). To predict survival based on vitality impairment, a logistic regression model was fitted to individual observations ($N = 172$) and showed a significant association between the probability of survival and vitality impairment score (F-test: $F = 109$; $P < 0.001$; $R^2 = 0.56$) (Figure 3A).

A significant correlation between vitality impairment score and average survival, grouped by hauls, was also found (Spearman's rank test: $\rho = 0.77$; $N = 53$; $P < 0.0001$) (Figure 3B). The logistic regression model fitted to the grouped observations ($N = 53$) showed a significant association between the probability of survival and vitality impairment score (F-test: $F = 48$; $P < 0.001$, $R^2 = 0.66$). Between the two regression models, the model based on grouped observations, was a slightly better predictor of survival with a larger degree explained by vitality impairment ($R^2 = 0.66$), than if based on individual observations ($R^2 = 0.56$).

3.6 Seabird predation behaviour

The seabirds observed in proximity to the vessel were mainly great black-backed gulls (*Larus marinus*) and European herring gulls (*Larus argentatus*). The reactions of seabirds to plaice of different sized slipped from the side of the vessel are summarized in Figure 4. All individuals < 198 mm were eaten. When size increased the seabirds were no longer able to swallow the plaice (the largest individual observed eaten was 240 mm), but either pursued and quickly discontinued or disappeared out of sight with the discarded fish. With individuals larger than 240 mm, seabirds often pursued a fish but discontinued the effort almost immediately. Below the MCRS (270 mm), 85% of plaice was eaten or pursued (attempt discontinued or unknown fate).

4 | Discussion

315

316 The overall short-term discard survival of the experiment was 15%, ranging from 0 to 39%
317 for individual tows. This is within previously examined discard survival proportions from
318 some beam and otter trawls studies (van Beek et al., 1990; Kaiser and Spencer, 1995; Revill
319 et al., 2013; Depestele et al., 2014). Towing durations was however shorter in those studies
320 (maximum 2 hours). The tow duration is thought to have an impact on the discard survival
321 (Broadhurst et al., 2006) since the catch weight will increase and the fish is expected to
322 suffer from stress and physical damages. Millner (1993) estimated a high discard survival
323 (63-93%), however the fishing depth was only 5-20 m, the tow duration only 120 minutes
324 and the experiment was done on fewer individuals. Furthermore, the survival curves
325 reported do not seem to reach a horizontal asymptote at the end of the observation period,
326 indicating that the survival might be underestimated. The higher discard survival rates (45-
327 67%) estimated in a recent study (Morfin et al., 2017), was from a more directed plaice
328 fishery (not *Nephrops*).

329 The vessel used in our experiment is in the lower size category for the *Nephrops* fishing
330 fleet, catches and towing times will often be higher for trawlers larger than the one used in
331 the present study, which might have negative consequences on survival probability. A recent
332 experiment conducted from the same vessel with the same towing duration but in a directed
333 plaice fishery during winter season, estimated an average discard survival of 89% (Methling
334 et al., 2017). The marked difference in survival between studies could be due to the
335 presence of the excessive amount of sediment and debris in the codend causing further
336 abrasion injuries together with the *Nephrops* shells, higher temperatures (air and water) in
337 the present study or a combination of both.

338 The high survival of the control group suggest that the experimental conditions were not
339 the primary source of mortality. There was difference in temperature between seabed and
340 holding tanks, but both temperatures are within the tolerance level of the plaice and should
341 not affect its general condition (Clarke and Johnston, 1999). However, several survivors
342 showed signs of irritation and beginning inflammation around the tag position in the post-
343 experiment examinations, which suggests that this tagging method could have a negative
344 effect on the condition of the fish.

345 Wassenberg and Hill (1993) suggest that the majority of mortality for plaice occurs within
346 the first 3 days. The mortality in the present experiment was highest in the first 4 days, but

347 the survival curve did not level off until day 6. A horizontal asymptote of survival was reached
348 after around 8 days, suggesting the observation period was sufficient to observe fishery
349 related short term survival, but longer observation period might be necessary to include
350 mortality caused by secondary factors, e.g. disease or starvation. A fasting plaice would not
351 die from starvation in the time period of the present experiment according to Fonds et al.
352 (1992).

353 The two “clean” tows without excessive sediment and debris had the lowest mortality.
354 The remaining tows often contained several large lumps of peat, each up to 50-70 kg that
355 might damage the catch in the codend during the tow. This was evident by a large degree
356 of abrasion and bleeding injuries in tows that retained peat.

357 Several studies have found a correlation between air exposure and discard survival of
358 plaice (van Beek et al., 1990; Ross and Hokenson, 1997; Humborstad et al., 2009; Benoit
359 et al, 2013; Methling et al., 2017). This study shows similar results with a negative correlation
360 between time on deck and survival. However, there is a large variance in the present
361 observations with some fish being on deck for almost 50 minutes surviving, whereas other
362 individuals died after 4 minutes on the deck.

363 The quality of the water in the fish pound might influence survival (illustrated by deck
364 time). Because of oxygen consumption by the catch, mud and relatively low oxygen
365 saturation (high temperatures) the oxygen level was likely rapidly declining creating a
366 hypoxic environment. However, flatfish are known for superior resilience to low oxygen and
367 air exposure in comparison with roundfish (Broadhurst et al., 2006), and plaice in particular
368 have possible cutaneous O₂ uptake (Steffensen et al, 1981). The combination of several
369 stressors might lead to possible cumulative lethal effects (Davis, 2002; Broadhurst et al.,
370 2006).

371 Previous studies have shown reflex impairment as a tool to predict stress and even
372 delayed mortality in different species of fish (Davis, 2007, 2010; Humborstad et al., 2009,
373 2016; Methling et al., 2017). Reflex impairment alone was not a strong indicator of delayed
374 mortality in this study. The uncoupling of reflex impairments from the delayed mortality
375 leaves the injuries as the best indicator, which could be useful as mortality predictor since
376 injury assessment can be done in the field without accessories opposed to most reflex
377 impairments. Consequently, using vitality impairment as a mortality predictor for plaice could
378 be plausible, as the results show a high mortality after medium accumulated impairment, i.e.

379 several recognizable injuries. It is, however, not without challenges to assess injuries on
380 plaice as its natural camouflage can show resemblance to abrasions while some internal
381 injuries might not be visible immediately.

382 The seabird predation experiment indicated that the majority of plaice below MCRS were
383 eaten or taken by the seabirds (gulls). In a previous study it was estimated that about 60%
384 of the discarded material (Catchpole et al., 2006) was taken by seabirds. The predation by
385 seabirds adds an additional unquantified contribution to discard mortality and thus might
386 also have a potential influence on the seabird population. The present study, however, had
387 a limited number of observations and there might be other influential factors on seabird
388 predation like vessel speed, discards composition and practice a light level that should be
389 assessed. Consequently our estimate was not an average estimate for this fishery, but an
390 indication that sea gulls potentially are capable of consuming a considerable proportion of
391 dead discarded plaice below a given size. Since sea gulls don't dive but pick up discarded
392 plaice in the air or immediately when they hit the sea surface, it is likely, that alive plaice
393 would also be taken. However this needs further investigations. A discard ban on plaice,
394 might consequently also affect sea bird communities.

395 The low short-term survival estimated in the present study suggest that plaice caught in
396 *Nephrops* fisheries might not be an obvious candidate for exception to the landing obligation.
397 Additional experiments would be of importance. Particularly from larger vessels, other areas
398 and with lower deck temperatures.

399

400

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408

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523 **Table 1** Overview of conducted hauls. Date for start of sea trials, average (Avg.) size and numbers of
 524 experimental fish. Depth at start and end of the tow. Control fish are taken from haul 5 and 7.

Haul	Date	Duration (min)	Depth (m)	Size (mm)		Numbers	
				Avg.	Range	Sample	Dead
1	29/6-2015	160	33-53	243	193-270	18	17 ¹
2	29/6-2015	180	28-33	236	180-273	18	11
3	1/7-2015	180	33-36	233	183-278	20	18 ²
4	1/7-2015	180	29-33	224	183-266	20	13
5	1/7-2015	16	30-31	217	156-266	20 + 20	3 + 0
6	2/7-2015	180	30-39	228	179-289	20	18
7	2/7-2015	15	33-33	216	164-256	20 + 20	1 + 0
8	3/7-2015	180	27-43	232	198-269	20	20
9	3/7-2015	180	31-35	228	188-265	20	16

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 526 ¹ A single individual disappeared during storing.
 527 ² Two individuals disappeared during storing.

Table 2 Description of the 3 reflex action mortality predictors. The overall potential score is between 0 and 3, with each individual was scored 1 if the specific response was absent (impairment) or 0 when the action was completed as described.

RAMP	Stimulus action	Response
Righting	The plaice is kept on the palm of the hand on its back at the surface and then released	Actively righting itself underwater
Evasion	The plaice is held by two hands at the water surface and is gently released	Fish swims actively away (to the bottom)
Tail grab	The tail of the plaice is held between two fingers	Actively struggles and swims away

532 **Table 3** Description of the injuries assessed. Individuals scored 0 if the damage was absent, or 1 if the damage
533 was present.

Injury	Description
Scale loss	Visible loss of scales from anywhere on the body
Fin fraying	Shredding of the thin skin between the anal, dorsal and/or caudal fin
Abrasion minor <30%	Bruises and discoloration on the pigmented upwards facing side <30%
Abrasion major >30%	Bruises and discoloration on the pigmented upwards facing side >30%
Bleeding minor <30%	Spots or patches of visible internal bleeding on the ventral side down <30%
Bleeding major >30%	Spots or patches of visible internal bleeding on the ventral side down >30%
Wounding	A superficial cut or puncture of the skin
Deep wounding	A deep cut or puncture of the skin, often with bleeding
Internal organ exposure	A sufficiently large wound causing the organs to be exposed
Protruding intestine	Intestines being visible through the anus and/or mouth

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535 **Table 4** Injury and RAMP scores for individual hauls and combined injury and reflex impairment score with
 536 standard deviation.

	Experimental hauls							Control hauls	
	1	2	5	4	6	8	9	5	7
<i>Injury</i>									
Scale loss	0.83	0.33	0.75	0.85	0.95	0.95	0.80	0.60	0.50
Fin fraying	0.72	0.72	0.60	0.60	0.75	0.65	0.75	0.15	0.40
Abrasion (minor)	0.56	0.39	0.20	0.70	0.25	0.40	0.70	0.60	0.65
Abrasion (major)	0.39	0.11	0.80	0.30	0.75	0.60	0.45	0.05	0.10
Bleeding (minor)	0.28	0.39	0.40	0.55	0.45	0.35	0.55	0.65	0.75
Bleeding (major)	0.56	0.61	0.35	0.20	0.50	0.55	0.35	0.05	0.05
Wounding	0.28	0.11	0.05	0.15	0.05	0.10	0.15	0.10	0.20
Deep wounding	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Internal organ exposed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Protruding intestine	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.00	0.00
<i>RAMP</i>									
Righting	0.22	0.67	0.20	0.60	0.20	0.35	0.50	0.95	1.00
Evasion	0.06	0.22	0.10	0.40	0.15	0.10	0.15	0.95	0.95
Tail grab	0.11	0.44	0.15	0.55	0.15	0.25	0.25	0.95	1.00
<i>Impairment score</i>	0.58±0.13	0.4±0.13	0.53±0.11	0.41±0.17	0.57±0.10	0.55±0.09	0.52±0.19	0.19±0.14	0.22±0.09

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541 **Figure 1** A) On board holding tanks (300 L) with water supply. B) Transport box with tagged plaice submerged
542 in holding tank.

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545 **Figure 2** Short-term mean survival probability with 95% confidence intervals after 240 hours of (A) the study
546 total with experiment (●, N=133), control method (■, N=39) and untreated control (▲, N=40) or (B) divided
547 between potential contamination of the catch with "dirty" (○, N=95) and "clean" (□, N=38) tows. In (A) the
individual tows are illustrated in the background with a grey dashed line.

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550 **Figure 3** Vitality impairment (proportion) to predict (A) mortality (absent/present) in individual plaice or (B)
551 mortality proportion when treating the different tows as separate inputs. The observations, individuals and tow
552 dependent relationships, are added as ● in (A) and (B), respectively. Note that several points overlap in both
figures.

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555 **Figure 4** Seabird predation behaviour on discarded plaice. Behavioural categories provided (see section 2.4)
556 and total length of the plaice. The box plot indicates 10th (1st horizontal line), 25th (start of grey box), 75th (end
557 of grey box) and 90th (last horizontal line) percentiles. The filled line inside the box is the median and the
558 dashed the average total length. The numbers in parenthesis indicates number of observations for each
behavioural category.

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562 **Figure 1** A) On board holding tanks (300 L) with water supply. B) Transport box with tagged plaice submerged
563 in holding tank.

Figure 2 Short-term mean survival probability with 95% confidence intervals after 240 hours of (A) the study total with experiment (●, N=133), control method (■, N=39) and untreated control (▲, N=40) or (B) divided between potential contamination of the catch with "dirty" (○, N=95) and "clean" tows (□, N=38). In (A) the individual tows are illustrated in the background with a grey dashed line.

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591 proportion when treating the different tows as separate inputs. The observations, individuals and tow dependent
592 relationships, are added as • in (A) and (B), respectively. Note that several points overlap in both figures.

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Figure 3 Seabird predation behavior on discarded plaice. Behavioral categories provided (see section 2.4) and total length of the plaice. The box plot indicates 10th (1st horizontal line), 25th (start of grey box), 75th (end of grey box) and 90th (last horizontal line) percentiles. The filled line inside the box is the median and the dashed the average total length. The numbers in parenthesis indicates number of observations for each behavioral category.