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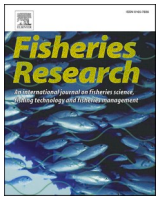

Short communication

Initial experiments to assess potential short-term discard survival of cod (*Gadus morhua*) in the Baltic Sea set-net fishery

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ABSTRACT

The European Union's landing obligation includes an exemption for species with documented high survival rates. This is highly relevant for the cod (Gadus morhua) stock in the Baltic Sea, being in a critical state. This study provides initial information on potential discard survival rates for cod (Gadus morhua) caught in trammel nets in the Baltic Sea. Catch-damage-index (CDI) and Reflex Action Mortality Predictor (RAMP) scores were used to assess fish condition immediately after capture and at the end of observation periods. A total of 61 cod were caught in eight different net fleets fished during three trials. Two cod died in the net and three cod died during the observation period from two to 10 days. The results indicate a potential in dedicating resources to cod discard survival studies.

1. Introduction

Cod (Gadus morhua) was the most important commercial demersal fish species in the Baltic Sea but is also of high importance in other areas in the North Atlantic Ocean. The two Baltic Sea cod stocks are in a critical state after low recruitment for many years (ICES, 2021a, b). There have been severe catch reductions in recent years (up to around 90 %) and the directed cod fishery have been closed. The landing obligation in the European Union's Common Fisheries Policy prohibits the discard of most commercial species but also includes an exemption for species with documented high survival rates (EU regulation, 1380/2013). Fish below MRCS (minimum conservation reference sizes) are not allowed to be sold for human consumption whereas exempt species that are discarded can recover and support the spawning stocks. Despite the landing obligation and decades use of selective fishing methods (Madsen et al., 2021) there are still catches of smaller cod below MRCS observed in the Baltic Sea (ICES, 2021a, b).

Discard survival studies have been conducted for many species and in many areas (Rihan et al., 2019). Several discard survival studies have been conducted in areas close to the Baltic Sea with a focus on plaice and towed fishing gears (Methling et al., 2017; Eskelund et al., 2019; Savina et al., 2019; Noack et al., 2019) and exemptions from the landing obligation granted. Knowledge on discard survival in set-net fisheries is limited with only one recent study from European fisheries (Ern et al., 2022). This study indicates a high discard survival of plaice caught by trammel nets in the Baltic Sea (Ern et al., 2022).

The importance of set-net fisheries (gill and trammel nets) is expected to increase because of lower environmental impacts relative to active bottom-towed fishing gears (Suuronen et al., 2012; Savina et al., 2018). For this reason, larger areas in the Danish territory of the Western Baltic Sea are under the process of closure for towed fishing gears while set-nets remain allowed. Trammel nets are the most frequently used fishing gear in Danish set-net fisheries followed by gillnets.

The documentation required for an exemption from the landing obligation is comprehensive (Rihan et al., 2019) and discard survival experiments can be both challenging (Breen and Catchpole, 2021) and resource demanding. There are many species that potentially could be relevant for discard survival studies. Although cod is of high importance for fisheries, the expectation is that cod are more sensitive to air exposure than flatfish that have skin oxygen uptake (Steffensen et al., 1981).

This study aims at collecting initial information on potential short-term discard survival for cod caught by trammel nets to assess the potential in devoting resources to more detailed studies. The experiments are conducted in the Baltic Sea where the cod stock is in a critical state. Our focus is on the widespread coastal fishery where the frequency of smaller cod is expected to be higher than in deeper water.

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Table 1
Stimulus and responses of reflexes, and description of injuries in Atlantic cod (*Gadus morhua*). For reflex impairment, individuals were scored 0 if the response was completed within five seconds of the stimulus, or 1 if the response was not completed within five seconds (*i.e.,* impaired). For injuries, individuals were scored 0 if damage was absent, or 1 if damage was present.

Reflex	Stimulus and responses
Righting	Righting itself when turned upside down under water
Evasion	Swims toward the bottom when released at the surface
Tail grab	Struggle or tries to escape when tail is held between two fingers
Floating	Floats in the surface water and is unable to dive
Injury	**Description**
Bruises (minor/medium/major)	Areas with discolouration or scale loss (<10 % / 10–50 % / >50 %)
Fin fraying	Shredding of the thin skin between the fin rays
Blood clots	Blood clots visible through the skin
Minor wounds (head/body)	Shallow cuts or punctured skin
Deep wounds (head/body)	Deep cuts or punctured skin, often with bleeding
Exposed intestines	Intestines visible through the anus
Net marks	String cuts from net contact

2. Materials and methods

Trials were conducted in the western Baltic Sea (ICES subdivisions 22) from a Danish gillnetter (named: Fuglen; vessel number: H 32; length 9.79 m) fishing commercially with trammel nets (nominal mesh size in inner/outer wall: 75/350 mm). The fishery is a typically mixed one, catching flatfish and round fish species (primarily cod). Nets were set overnight in fleets where 10 individual nets are connected hereafter referred as sets. As the nets were hauled back onto the vessel, netting and fish passed through a net hauler onto a sorting table where the whole fish catch was manually untangled by the fisher following commercial practice. Air exposure during handling was below one minute for all cod. Cod above MRCS are also embedded by the landing obligation and because of the severe catch reductions the proportion of cod above MRCS caught without sufficient quota has increased. All cod $\leq$ 45 cm total length (TL) were collected by scientists and assessed for reflex impairments using reflex action mortality predictor (RAMP) methodology (Davis, 2010) and injuries using the catch-damage-index (CDI) methodology (Table 1; Esaiassen et al., 2013; Ern et al., 2022). Cod were then tagged and moved to a 300-L holding tank with aerated seawater. The fish were brought ashore within three hrs of capture and haphazardly placed in livewells (described in Ern et al., 2022) within the harbour.

Seabed temperature and salinity at the fishing site were measured using a Star-Oddi DST CTD. Measurements were made using a sink on a line, a few minutes before the fishers began pulling the net aboard the vessel. Depth at the fishing site was taken from the vessels echo sounder. Fleets were set continuously during two fishing days (sets 5–6 and 6–8) and fishing conditions the same.

Fish were inspected individually at least four times per day. Observations started with two-day screening and was then increased to 7–10 days for the remaining trials (our animal experimental permission allows a maximum 10 days captivity). Individual fish were defined as dead if they exhibited a lack of visible operculum movement, loss of equilibrium, or were unresponsive to a gentle nudge on the caudal peduncle (defined by our animal experimental permission). At the end of the observation periods, RAMP and CDI assessments were conducted. After this, fish were euthanized in 2-phenoxyethanol, and sacrificed by spinal transection.

3. Results

Cod was collected from 8 sets, fished over 5 different days during 3 periods (Table 2). There is variation in fishing conditions for soaking time (19–23 h), depth (4.1–10.5 m), seabed and (3.3–9.6 °C) deck temperature (4.5–11.3 °C) and salinity (10–14 ppt).

All mortality took place in the first half day. Three cod out of 61 died within the first three hours of observations in livewells and two were dead in the net and not included in reflex and injury assessments. Survival over time with estimated confidence limits (95 %) is shown in Fig. 1 by using the Kaplan–Meier model (Breen and Catchpole, 2021). The strongest estimate, considering number observations and length of observation period, appears when including cod stored for seven days (excluding the first set only) where survival with 95 % confidence interval is 90 % (82–99 %; 7 sets; N = 51). For this estimate, the observation period without mortality is 6.5 days. The survival estimate is slightly higher (Fig. 1) if cod are store stored 2 days only (all 8 sets; N = 61), only sets with cod observed 8 days (5 sets; N = 43) or only sets with

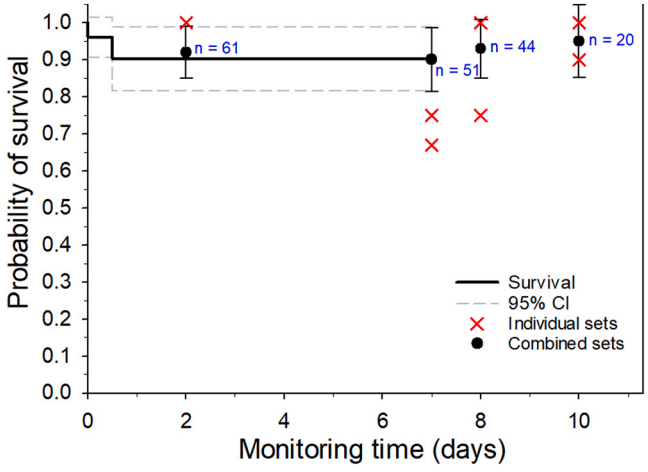

Fig. 1. Survival with 95 % confidence interval (CI) estimated from the Kaplan-Meier model. The estimates are made for 2 days monitoring, all cod monitored 7 days (confidence limits for full period), all cod monitored for 8 and 10 days. Red crosses indicate mortality over the full period for individual sets. All mortality took place the first half day.

Table 2
Summary of fishing conditions, observation duration, and mortality rate.

Sets nº	Fishing date	Depth (m)	Soaking time (hrs)	Deck temperature (°C)	Seabed temperature (°C)	Seabed salinity (ppt)	Total length (cm)	Nº of cod	Observation duration (days)	Mortality (nº)
1	26.11.17	5.5	20	5.0	6.0	14	27–36	10	2	0
2	17.01.18	6.0	23	4.5	3.3	13	30–37	4	7	1
3	18.01.18	10.5	24	6.0	3.8	13	32–36	3	7	1*
4	06.11.18	4.7	20	11.1	9.5	11	32–40	10	10	0
5	06.11.18	4.7	20	11.1	9.5	11	29–39	10	10	1*
6	09.11.18	4.1	19	11.3	9.6	10	35–40	8	8	2
7	09.11.18	4.1	19	11.3	9.6	10	32–41	11	8	0
8	09.11.18	4.1	19	11.3	9.6	10	38–41	5	8	0

* Dead in net.

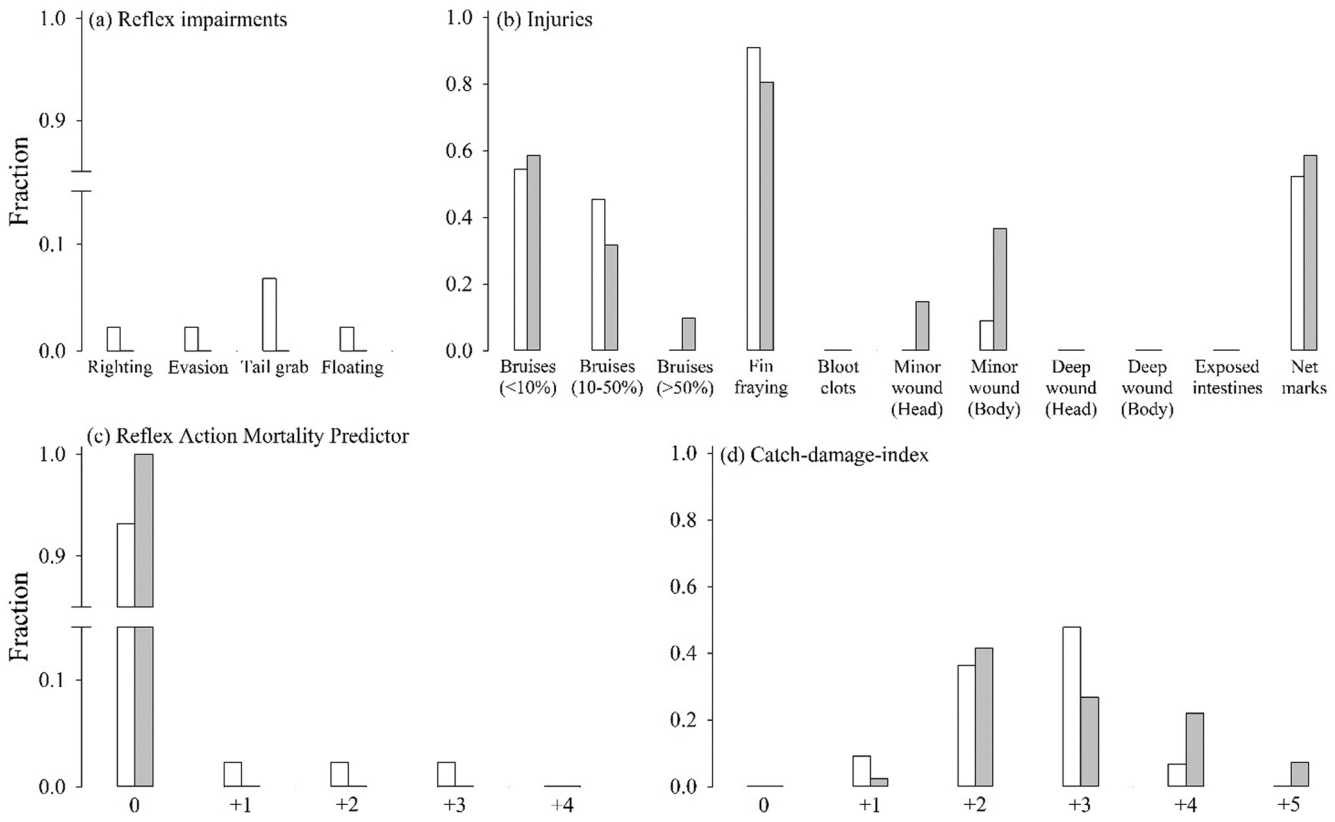

Fig. 2. Fraction exhibiting (a) impaired reflex responses, and (b) injuries immediately after capture (white) and at the end of the observation periods (grey), together with the distribution of (c) reflex action mortality predictor (RAMP) and (d) catch-damage-index (CDI) scores after capture (white) and after observation (grey).

cod observed 10 days (2 sets; N = 20).

Results of CDI and RAMP assessments are presented in Fig. 2. More than 90 % of the cod responded successfully on all reflexes immediately after capture and 100 % when ending the observation period. In terms of injuries, fin fraying and net marks occurred frequently. The proportion with major bruises and wounds was low after capture but with increase by the end of observation period.

4. Discussion

Cod were exposed to variation in experimental conditions through the study. The results indicated a high short-term survival, and the RAMP score indicated no signs of weakening at the end of the observation period. Generally, mortality is expected to be highest in the first days (Breen and Catchpole, 2021; Madsen et al., 2022). Experimental guidelines do not specify a specific observation period duration but recommend that monitoring is continued until there is a period without or low mortality and the survival curve approaches an asymptote (Breen and Catchpole, 2021). In practice this is very often not the case (Madsen et al., 2022). Including seven days of monitoring (n = 51, 7 sets), our observation period without mortality is high compared to seven wintertime discard survival studies on plaice. Some studies of these studies have the number of surviving fish (which defines confidence limits) in the same order of magnitude (Madsen et al., 2022).

Bruises, fin fraying, and net marks were observed, likely stemming from entanglement in netting and being passed through a net hauler and manually untangled on deck. Although this appears to be non-fatal for short-term survival, there could be a long-term effect. Minor head and body wounds sustained by several cod during observation periods may stem from agonistic behaviour attacks or collisions with the sides of the livewells.

Our methodology for handling and storing fish seems to function well without any indications of experimentally induced mortality which was also experienced in a previously study (Ern et al., 2022). RAMP and CDI monitoring, before and after captative monitoring, functions as a control indicating potential method-induced mortality, where particularly cod with high vitality is not expected to reduce scores. Survival estimates related to the landing obligation exemptions are conservative in case of any additional method-induced mortality. Exemptions have been granted on discard survival estimates down to 46 % (Noack et al., 2019), and hence well below our estimate and lower 95 % confidence limits. Nevertheless, the use of control fish can be of importance for future experiments, particularly if the survival rate is lowered.

Air exposure is of importance for survival (Methling et al., 2017; Noack et al., 2019). However, handling is generally fast on set-net vessels, compared to towed fishing gears and was below one minute in this study and 14 s in the study by Ern et al. (2022), whereas it can exceed one hour in trawl fisheries (Methling et al., 2017; Noack et al., 2019). Longer soaking time could potentially lower survival. Soaking time in this study is believed to be above average. Generally, fishers avoid long soaking because of substantially reduced catch quality if fish dies in the net and reduced catching efficiency because of catches of crabs and seaweed.

Funk et al. (2020) studied changes in cod distribution in the western Baltic Sea by obtaining information on temporal depth and habitat use of cod from catch information from commercial gillnet fishers. Most catches were on shallower water than 20. Cod use deeper areas as summer approaches and when there is increasing temperature stratification in the water column and in the beginning of the year. The results also suggest potential size-related differences in depth use of cod with smaller cod in shallower water.

Being physoclistous, depth is a relevant parameter (decompression) since swim bladder rupture can be deleterious for survival (Midling et al., 2012), that otherwise will float resulting in low survival if left untreated (Humborstad et al., 2016). Experiments with acoustic transmitters indicated that cod could recover quickly if caught on lower

depths than 20 m in recreational fisheries (Ferter et al., 2015). The maximum depth in our study is 10.5 m where a single cod out of three was observed dead in the net and hence not suffering from decompression. Because of recently severe cod catch restrictions in the Baltic Sea, the set-net fishery will be more coastal targeting flatfish species. When targeting cod in other areas at deeper water than 20 m, the effect of decompression on survival must be considered.

It is important to consider the seasonal effect in further studies since survival likely decreases at higher temperatures. Because of temperature gradients in the Baltic Sea during summertime thermal shock might also contribute to lower survival.

Ethical statement

Experiments were approved by The Danish Animal Experiments Inspectorate (Permit Number: 2017–15–0201–01297).

CRediT authorship contribution statement

Rasmus Ern: Conceptualization, Writing – review & editing, Data curation, Formal analysis, Investigation, Methodology, Visualization. **Niels Madsen:** Conceptualization, Writing – original draft, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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