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Published Version:
Haase S, McQueen K, Mion M, Andersson M, Hilvarsson A, Olesen HJ, et al. (2021). Short-term tagging mortality of Baltic cod (Gadus morhua). FISHERIES RESEARCH, 234, 1-7 [10.1016/j.fishres.2020.105804].

Availability:
This version is available at: https://hdl.handle.net/11585/780025 since: 2020-11-15

Published:
DOI: http://doi.org/10.1016/j.fishres.2020.105804

Short-term tagging mortality of Baltic cod (*Gadus morhua*)

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Abstract

Tagging-induced mortality experiments are an important component of mark-recapture studies, as they can be used to assess the appropriateness of the tagging methodology, and to improve the reliability of estimates of recapture rates used for calculations of mortality rates and population size. Here, short-term tagging mortality of Baltic cod was estimated through containment experiments in the southern Baltic Sea. Experimental cod were selected from trawl catches, and approximately half were tagged externally with T-bar tags and received an intraperitoneal injection of tetracycline-hydrochloride. The rest of the experimental cod formed the control group, and received neither tag nor injection. The tagged and control cod were mixed evenly within submersible cages, and held for 5-8 days. The experiments were conducted in different regions and during different months by different tagging teams. Overall mortality rate was 16% (n = 324), with the mortality rate of the tagged group 19%, and the mortality rate of the control group 13%. A general linear mixed model was fit to assess the effect of tagging, month, experiment duration, fish length and tagging site (i.e. the combined effect of region and tagging team) on mortality. Tagging had no effect on mortality, indicating that mortality can be attributed mainly to the capture and handling procedure. There was a significantly negative relationship between fish length (range: 20-55 cm) and mortality. Mortality did not differ between the months tested, but there was a significant effect of tagging site on mortality. Tagging-related mortality should be accounted for in analyses of data from mark-recapture studies of Baltic cod, and some variability in mortality between tagging sites can be expected.

Keywords: mark-recapture, T-bar, tetracycline-hydrochloride, Baltic Sea cod, post-release survival

Introduction

Mark-recapture studies can be an effective method of gaining information on the population size, total, natural and fishing mortality rates (Pine et al., 2003), individual growth rates (Fabens, 1965) and movement patterns (Hilborn, 1990) of fish within a stock. Short-term tagging mortality experiments are an important component of an effective mark-recapture study involving conventional tagging, to estimate the proportion of fish that die soon after release due to direct effects of the tagging process (e.g. stress of capture, handling and tagging) (Brattey and Cadigan, 2004). Given the ethical considerations associated with field research on live fish (Bennett et al., 2016), short-term mortality experiments can be used to ensure that the tagging method has minimal influence on the survival of the fish, and to determine the optimum gear type and season of tagging (Brattey and Cadigan, 2004). Estimation of short-term tagging mortality rates is also key to avoiding bias in estimates of population size and mortality rate calculated from recapture rate (Brownie and Robson, 1983).

Between 2016-2019, >25000 cod (*Gadus morhua*) in the southern Baltic Sea were tagged and released as part of the large-scale, international tagging project "TAgging BAltic COD" (TABACOD, Hüssy et al., 2020). Deteriorating body condition, decreasing relative abundance of large fish, and diminished spatial distribution range observed in the Eastern Baltic cod stock in recent years is a fisheries management concern (Eero et al., 2015). A lack of reliable age data has hindered the estimation of growth and mortality rates, which contributed to the suspension of the age-based analytical stock assessment in 2014 (Eero et al., 2015). The aims of the TABACOD tagging project were to gain new information on the growth, otolith formation and movements of the Eastern Baltic cod stock, and to estimate fishing and natural mortality rates independently from the stock assessment. The cod for the TABACOD tagging project were mainly caught by bottom trawl, injected with tetracycline-hydrochloride (an antibiotic which induces a permanent mark in fish otoliths) and tagged with external T-bar anchor tags (Hüssy et al., 2020).

Several studies have previously estimated short-term mortality rates of tagged Atlantic cod, for example in Newfoundland (Brattey and Cadigan, 2004) and the western Baltic Sea (Kock, 1975a, Stötera et al., 2019; Weltersbach and Strehlow, 2013). A variety of capture methods have been used in these studies, which can significantly influence the survival probability of cod (Weltersbach and Strehlow, 2013). Tagging procedure also varied between studies, with Brattey and Cadigan (2004) and Weltersbach and Strehlow (2013) applying T-bar anchor tags, Kock

(1975a) applying spaghetti and Carlin tags, and Stötera et al. (2019) using both T-bar anchor tags and intraperitoneal injection of tetracycline-hydrochloride and/or strontium chloride. The reported short-term mortality estimates also ranged widely, even within the Baltic Sea, from 0 % (Kock, 1975a) to 25.7 % (Weltersbach and Strehlow, 2013), probably due to the diversity of the capture and tagging methods used. Given the variability in estimates from previous studies, and with the potential for several variables (e.g. tagging procedure, capture gear, depth and temperature) to influence the mortality rates, it was considered valuable to conduct further short-term mortality experiments under the conditions specific to the recent tagging study of Eastern Baltic cod.

The aim of this study was to estimate the short-term mortality rates of cod trawled in the southern Baltic Sea and tagged with T-bar anchor tags and intraperitoneal injection of tetracycline-hydrochloride. Additionally, the influence of fish length, month of capture, experiment duration and the cumulative effects of capture region and tagging team specific procedural differences were investigated as possible factors contributing to the variability in short-term mortality rates.

Materials and Methods

Experimental design and data collection

The study design was adapted from containment studies (Pollock and Pine, 2007), similar to those conducted to estimate the short-term catch-and-release mortality associated with recreational angling for Baltic cod (Weltersbach and Strehlow, 2013) and short-term tagging mortality of Atlantic cod (Brattey and Cadigan, 2004). Cod were captured, handled, and tagged using the same methods as in the international tagging project “TABACOD” (Hüssy et al., 2020). The experiments were carried out by trained scientists and technicians coordinated by three different experimental coordinators, on-board three separate research vessels, thus forming three “tagging teams” (A, B and C). This approach was taken to reflect some of the variability in capture location, procedure and handling on-board of different vessels, which is unavoidable in an international tagging study.

Cod were caught in the Arkona and Bornholm Basin regions of the southern Baltic Sea (ICES subdivisions 24 and 25, REGULATION EC 218/2009), with bottom trawls (OTB TV3-520, OTB 300/60) of short duration (5-30 minutes). CTD casts performed close to the catch locations shortly before or after the trawls, for all experiments except experiment 7, provided information on the water temperature of the entire water column. Temperatures at surface and fishing depth are presented in Table 1. Immediately after catch, cod were transferred to a tank on board which was supplied with an inflow of fresh, surface seawater. Individuals without external signs of injury or illness (e.g. abrasions, bleeding, and barotrauma) were randomly selected from the catch and measured and weighed. The implementation of this selection procedure ensures that the estimates of mortality from these experiments reflect the mortality of cod selected for inclusion in the tagging project, but cannot provide insight into the general mortality rates of Baltic cod caught by trawl. Where possible, fish representing the full range of length classes available from the catch were selected. Total fish lengths included in the experiment ranged from 20 cm to 55 cm (Fig. 1). The length range of cod available from the catches is fairly typical for the size-truncated EBC stock, where catches in recent years have been dominated by fish <45 cm (ICES, 2020).

Cod selected for the tagged group were tagged with a T-bar anchor tag (Hallprint TBA) at the base of the first dorsal fin. They were then laid on their dorsal side and a solution of 10 mg/ml tetracycline was administered, using a syringe that was inserted at a shallow angle into the body cavity, approximately at the end of the pelvic fin tips. They received 100 mg tetracycline-hydrochloride per kg wet mass of cod (Stötera et al., 2019). Tagged cod were returned to a tank on board to check for immediate recovery from the tagging procedure, before they were transferred to the experimental cages. Individuals for the control group were handled in the same way, but received neither an injection nor a tag and thus had no individual mark. Handling of individual fish generally took 1-2 minutes, and time spent on-board between catch and transfer to the cages lasted about 1 hour.

Experimental cod were placed in cages, which differed between the tagging teams. Team A used cages with dimensions 150 cm x 100 cm x 120 cm. Team B used cages with dimensions 120 cm x 80 cm x 100 cm. Team C used a round cage with diameter 150 cm and height 55 cm, and a square cage with dimensions 130 cm x 130 cm x 52 cm. Depending on the size of the individuals and the cage, 3-16 (mean = 7) cod were placed in each cage, with cod placed in cages with individuals of a similar size, to reduce the risk of cannibalism. Approximately equal numbers of control and treatment fish were placed in each cage. The cages were then lowered to the seafloor, at a depth similar to the capture depth. The duration of each experiment was 5-8 days (Table 1), dependent on weather conditions and practical constraints of research cruises.

In total, 415 cod caught between April and November 2017 were used for 9 containment experiments. A small subsample of cod (n = 24) were additionally surgically implanted with data storage tags (DSTs), as part of a qualitative investigation into the short-term survival and healing from this surgery. Another small subsample (n = 28) was treated for barotrauma by venting the gas-bladder with a hypodermic needle. These two groups were excluded from subsequent analysis as the sample sizes were too small for a quantitative analysis on the effects of these treatments on survival probability across the range of experimental conditions. Additionally, 23 cod escaped from the cages or were in cages that were lost and 16 cod were excluded because there was evidence that the cage was attacked by seals, which resulted in higher mortality. This resulted in 324 cod being included in this analysis (197, 80 and 47 handled by Tagging Team A, B and C, respectively). The tagging group and the control group included 168 and 156 individuals, respectively (Table 1).

Table 1: Overview of experimental set up, and overall mortality rate of cod for each experiment, sorted by date. Sample sizes and survival rates refer to cod included in the analysis. Water temperatures were measured with a CTD cast shortly before or after trawls.

Experiment Number	Deployment date	Tagging team	Number of cages	Fishing depth (m)	Surface water temperature (°C)	Water temperature at fishing depth (°C)	Number of tagged cod	Mean lengths (range) of tagged cod (cm)	Number of control cod	Mean lengths (range) of control cod (cm)	Experiment duration (days)	Mortality rate of tagged cod	Mortality rate of control cod
1	20.04.2017	A	11	21	6.6	6.0	24	40 (21-49)	27	37 (21-50)	7	0.17	0.07
2	11.05.2017	A	8	20	7.6	7.1	23	34 (20-49)	24	36 (25-47)	7	0.17	0.17
3	23.05.2017	B	4	43	10.5	6.0	24	32 (29-44)	24	32 (27-43)	5	0.13	0.0
4	01.06.2017	A	4	21	12.9	12.0	10	40 (29-49)	4	43 (38-47)	8	0.10	0.0
5	09.06.2017	A	4	34	13.4	11.8	12	36 (27-48)	9	35 (27-52)	6	0.17	0.22
6	15.06.2017	A	4	23-38	15.5	14.0	13	20 (26-35)	12	29 (25-35)	7	0.54	0.42
7	20.09.2017	C	5	53-60	-	-	26	32 (20-49)	21	33 (22-55)	5	0.27	0.29
8	07.11.2017	B	3	44	9.6	8.0	16	31 (26-43)	16	31 (27-36)	6	0.0	0.0
9	15.11.2017	A	4	20-23	9.4	9.4	20	39 (30-44)	19	38 (31-43)	5	0.2	0.05
Sum	20.4.-15.11.2017		42	20-60	6.6-15.5	6.0-14.0	168	35 (20-49)	156	34 (21-55)	5-8	0.19	0.13

The experiments were carried out during different months, with cod caught with bottom trawls from regions with different depths (Table 1). Team A trawled cod from depths ranging between 20-38 m (mean depth = 23.2 m) on the southern slopes of the Arkona Basin and deployed the experimental cages at a depth of 20m off the northern coast of the island of Rügen. Team B trawled cod from depths ranging between 43-44 m (mean depth = 43.4 m), and Team C trawled cod from depths ranging between 53-60 m (mean depth = 56.7 m). Team B and C both trawled and deployed their experimental cages at depths similar to capture on the northern and western slopes of the Bornholm Basin. The fishing areas and depths were within the regions commonly fished to collect cod for the TABACOD tagging project in the relatively shallow Arkona and Bornholm Basin regions of the southern Baltic (see Hüssy et al., 2020 for a map of TABACOD tagging locations).

The average condition factor of experimental cod ($Fulton's\ K = \frac{weight\ (g)}{length\ (cm)^3} * 100$) varied only slightly between sites, with the average (± standard deviation) condition of cod of Team A 0.97 ± 0.14, of Team B 0.84 ± 0.11, and of Team C 0.94 ± 0.13. The condition of 10 cod of Tagging Team A could not be estimated, as weight measurements were not recorded.

Data analysis

Two-sample Kolmogorov-Smirnov test was used to investigate differences in length frequency distributions of the control and treatment group. Chi-squared tests were conducted to check whether the proportion of experimental cod in the tagged and control group differed significantly between tagging teams and tagging months. Mortality (number died/sample size) of tagged and control cod was calculated separately, and for all experimental cod combined.

A generalized linear mixed effect model (GLMER) with a random intercept a_i was used to analyse the fixed effect of the categorical variables month (*month*) and tagging treatment (*treatment*: tagged/control), and the continuous variables total fish length (*TL*) and experiment duration (*ED*) on the survival of individual j. As condition factor could not be calculated for every experimental cod, this variable was not included in the model, to avoid reduction of the sample size. Due to the binary response variable, we chose a model with logit-link function. Site *i* was included as a random effect, being a combination of fishing depth, tagging team, gear and vessel. This variable was included as a random effect, as we wanted to account for potential unavoidable variability introduced by conducting the experiments across different tagging sites and teams, but quantifying these differences was not part of our research question.

The full model was:

$$Y_{ij} \sim Bin(1, p_{ij})$$

$$logit(p_{ij}) = \alpha + \beta_1 x\ month_{ij} + \beta_2\ x\ TL_{ij} + \beta_3\ x\ ED_{ij} + \beta_4\ x\ treatment_{ij} + a_i$$

Y_{ij} is 0 if individual j at site i died and 1 otherwise. We assumed that the random intercept a_i is normally distributed with mean 0 and variance σ_a^2. The parameters α and β are the intercept and slopes of the fixed effects, respectively. Stepwise backwards elimination of the predicting variables based on Akaike information criterion (AIC, Akaike (1973)) was used for model selection. Models with lower AIC are considered to have a better fit, with a $\Delta AIC > 2$ considered to signify a significant difference between model fits. For models with $\Delta AIC < 2$, the model with fewer predicting variables was selected as the most appropriate (Burnham and Anderson, 2002). Fitted values and predictor variables versus residuals were visually checked for dependence and obvious non-linear patterns.

All statistical analyses were performed in R version 3.5.1 (R Development Core Team, 2008) and the lme4 package (Bates et al., 2012).

Results

There were no differences between the proportions of experimental cod distributed between the two treatments (tagged vs. control) within the three tagging teams (chi-square = 0.34, df = 2, p = 0.85, Table S1) or the five tagging months (chi-square = 1.96, df = 4, p = 0.74, Table S2). The length distributions of the control and tagged groups were not significantly different (Kolmogorov-Smirnov test: D = 0.09, p = 0.53), with the mean length for the tagged fish (35±7 cm) slightly larger than the control group (34±7 cm, Figure 1).

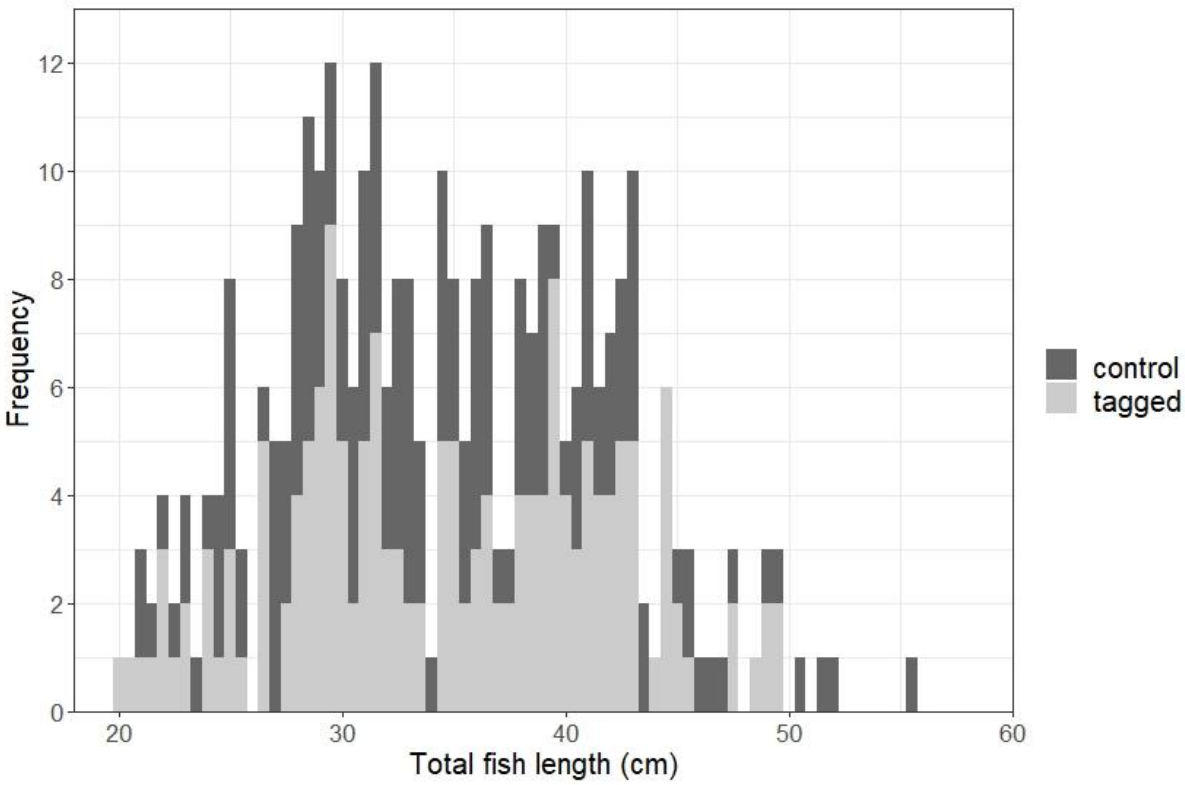

Figure 1: Cumulative length distribution of cod from the control group (black) and tagged with T-bars and injected with tetracycline-hydrochloride (grey).

The proportion of cod that died from the control and tagged groups combined was 0.16 (s.e. ± 0.02). Mortality rate of the control group was 0.13 (s.e. ± 0.03) and of the tagged group 0.19 (s.e. ± 0.03). Two (0.08) of the DST-tagged cod and 9 (0.32) of the cod treated for barotrauma died during the experiment.

Factors influencing mortality

The full model estimated β_1, the effect of month, as 0.06 (95% CI: -1.12-1.24) for May, 0.70 (95% CI: -0.38-1.77) for June, 0.88 (95% CI: -1.41-3.16) for September, and -0.45 (95% CI: -2.02-1.12) for November relative to April, respectively. β_2, the effect of total fish length, was estimated as -0.09 (95% CI: -0.14-0.04), β_3, the effect of experiment duration, as -0.16 (95% CI: -0.73-0.42), β_4, the effect of treatment, as 0.50 (95% CI: -0.15-1.15) for a tagged fish relative to an untagged fish, and α, the intercept as 1.49 (95% CI: -2.89-5.86). According to the binomial GLMER with tagging site as a random effect, including fish length as a fixed effect, provided the best fit to the data ($AIC_{full\ model}$ = 268.06; $AIC_{final\ model}$ = 263.49, Table 2). None of the other variables (treatment, month, experiment duration) significantly improved model fit. The probability of being dead at the end of the experiments decreased with increasing fish length

(Figure 2), with the predicted probability of mortality decreasing from 0.35 (95% CI: 0.42-0.14) for a 20 cm cod, to 0.02 (95% CI: 0.05-0.0) for a 55 cm cod. The estimated among-site variance σ_a^2 was 0.91 indicating rather large variation in mortality between sites.

Table 2: AIC values, degrees of freedom (df) and deviance used to select the best-fitting GLMER. The final model is marked in bold.

Fixed effects included	df	AIC	deviance
month, treatment, length, experiment duration	9	268.1	250.1
month, treatment, length	8	266.3	250.3
treatment, length	4	262.8	254.8
length	**3**	**263.5**	**257.5**
intercept only	2	281.9	277.9

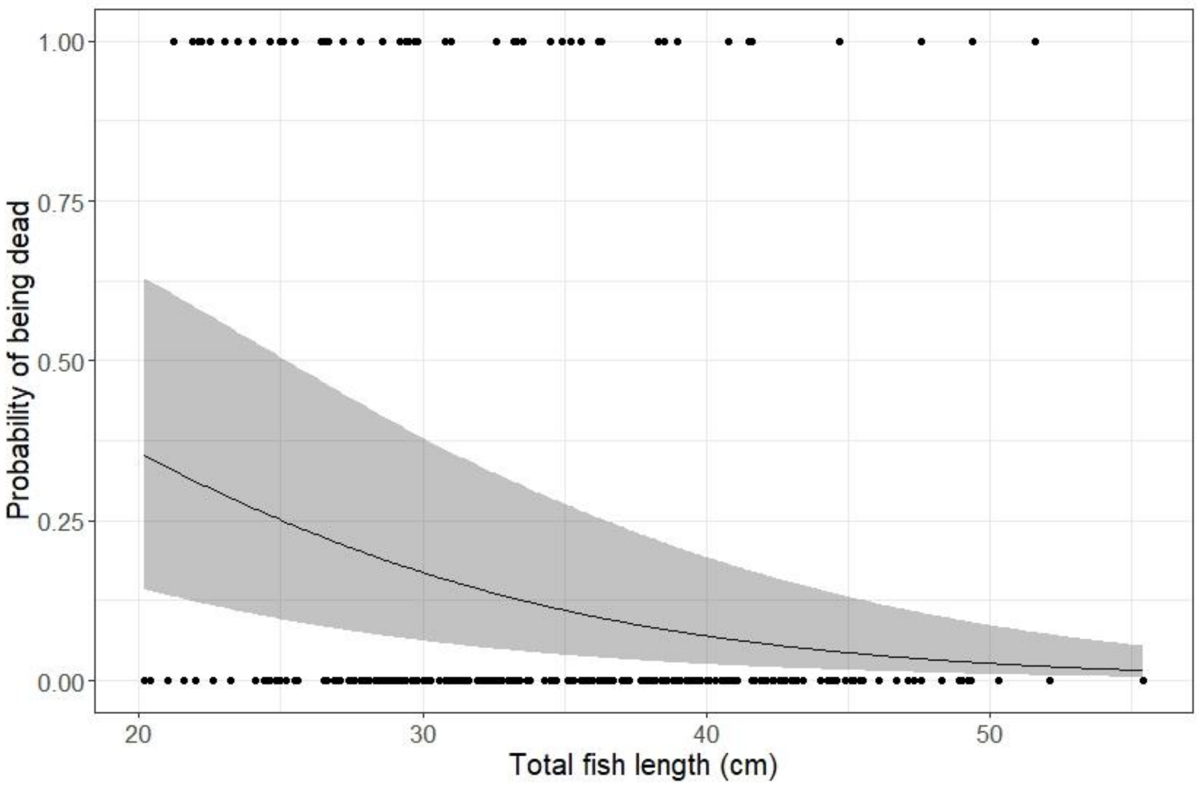

Figure 2: Mortality rate of experimental cod relative to total fish length (grey area indicating the 95% confidence intervals, black circles represent individual fish).

Discussion

Tagging with T-bar tags and injection with tetracycline-hydrochloride had no effect on mortality of Baltic cod selected from trawls as suitable for inclusion in a tagging study. However, the overall mortality of cod in these experiments, which can likely be attributed to the catch and handling procedure, was non-negligible and should be considered during analysis of data from the tagging project. The short-term (5-8 days) mortality rates of the tagged group of cod (excluding control fish) was 19.0%, which is between the reported short-term (10 days) mortality rates of tagged cod caught by pots (14.5%) and angling (25.7%) in a previous study on mortality rates of tagged Western Baltic cod (Weltersbach and Strehlow, 2013). Mortality rates of cod in the tagged group of the present study were higher than the short-term (1, 40 or 47 days) mortality rates reported for cod from the western Baltic Sea, captured in pound nets, and tagged with T-bar tags and the same concentrations of tetracycline as used here (4.0%, Stötera et al., 2019, and 5.0%, Krumme et al., 2020), and higher than the short-term (15-27 days) mortality of cod caught by trawl or gillnet from the western Baltic Sea in autumn and tagged with Carlin or spaghetti tags, which was negligible (Kock, 1975a). Overall short-term

(5-10 days) mortality of tagged cod captured by various gears (hand-lines, Japanese cod traps, otter trawl, line trawls) off the coast of Newfoundland was also lower (11.8%, Brattey and Cadigan, 2004) than mortality rates estimated in this study. This variability in short-term tagging mortality rates between studies highlights the importance of estimating mortality rates that correspond to the project-specific tagging and handling procedure, gear type and area.

In the present study, there was no significant difference between the short-term mortality rates of tagged and control cod. These results agree with those of Brattey and Cadigan (2004), who found no difference in mortality rates between a control group of untagged cod and cod tagged with T-bar tags. The results differ slightly to those of Stötera et al. (2019), where injection with tetracycline-hydrochloride had a positive effect on survival rates of tagged cod, relative to a control group injected with a saline solution. In Stötera et al. (2019), experimental cod were reported to have visible injuries caused by cormorant (*Phalacrocorax carbo*) attacks and net abrasions from time spent in the cod-end of pound nets, and it was postulated that tetracycline may have effectively suppressed bacterial infections in injured cod. In the present study, cod had no external injuries and our control group received neither a tag nor an injection. This lack of previous injuries, additional handling and puncture wounds may counteract the relative advantage the treatment group gained through receiving a dose of antibiotics. Our findings indicate that the capture and handling procedures were responsible for the short-term mortality observed, implying that the additional stress of the tagging and injection procedures is negligible in terms of survival of tagged Baltic cod.

Although tagging had no effect on the mortality of Baltic cod, the best fitting GLMER indicated that the probability of mortality was not constant across all experimental fish. It is difficult to unambiguously explain the variation in mortality rates of experimental cod, due to the pre-selection of cod for the experiments. In tagging studies, only fish without visible external damage should be selected for tagging (Brattey and Cadigan, 2004), and the selection of apparently undamaged, healthy-looking fish for our experiments therefore allowed us to assess the mortality of cod included in the tagging study. However, the selection process may have introduced some bias, and this should be considered during interpretation of the results.

Fish length had a significantly negative effect on short-term mortality of experimental cod (tagged and control), within the length range used for our study (20-55 cm). This finding is in contrast to the results of previous experiments of short-term mortality of tagged cod, which found no relationship between cod length and mortality rates (Brattey and Cadigan, 2004).

However, the length range of experimental cod in the Brattey and Cadigan (2004) study was 41-115 cm, which therefore does not include smaller fish which may be particularly vulnerable to the catch and handling procedures.

Although not directly comparable with the survival of cod selected for our mortality experiments, some previous studies indicate that mortality from trawling can be related to fish size in certain gadoid species.

Experiments on the survival of escaped haddock (*Melanogrammus aeglefinus*) (range: 12-61 cm) and whiting (*Merlangius merlangus*) (range: 17-35 cm) from trawl gears have indicated that mortality is higher for smaller individuals (Sangster et al., 1996, Ingólfsson et al., 2007). Poorer swimming ability causing exhaustion-related stress and injury during trawling has been proposed as a potential mechanism explaining the inverse relationship between size and mortality of haddock escaping from towed fishing gear (Ingólfsson et al., 2007). However, in the same study, the mortality of cod (range: 22-94 cm) and saithe (*Pollachius virens*) (range: 26-68 cm) that escaped from trawls was negligible (Ingólfsson et al., 2007). Stressors associated with trawling may have contributed to the higher mortality of smaller cod in our short-term tagging mortality experiment, but further research would be required to confirm this finding.

In the present study, there was significant variation in mortality rates between tagging sites. The tagging site variable combines the effects of region, including depth of capture, and tagging team, which represents research vessel specific equipment, personnel and procedures. These potentially interacting effects can unfortunately not be disentangled in this study. It has been demonstrated previously that depth of capture can influence survival of cod captured by hook and line (Ferter et al., 2015; Milliken et al., 2009). Barotrauma related injuries from rapid decompression increase with increasing capture depths, though high barotrauma recovery and survival rates for cod able to descend back to depth after a capture event have been reported (Ferter et al., 2015). Variability in the skill level and experience of the individuals carrying out the tagging in the different teams is also likely to contribute to variation in tagging mortality (Dicken et al., 2009; Hoyle et al., 2015). Additional sources of variability which may have influenced the mortality rates between experiments, but which were not addressed in our study, include trawl duration and catch size. Targeted experiments would need to be carried out to address the effects of these additional variables on cod survival. Although we cannot assess the relative importance of all these effects on mortality of the experimental cod, including these sources of variability more realistically reflects the conditions associated with the large-scale, international tagging study.

Our study did not reveal a significant influence of month of capture on mortality rates. This is contrary to previous short-term tagging mortality experiments which demonstrated that mortality was highest for cod kept in enclosures during summer or autumn, when water temperatures in the enclosures were warmer or fluctuated more (Brattey and Cadigan, 2004). A previous cod tagging study in the western Baltic Sea reported higher mortality rates in summer, which were attributed to the stress associated with bringing cod from below the thermocline to the surface (Kock, 1975a), and recapture rates of tagged Baltic cod have previously been reported to be lowest for cod tagged during summer (Netzel 1976). Higher mortality rates of cod captured by longline during the summer have also been reported, presumably due to the rapid changes in temperatures experienced while being hauled from cold bottom waters to surface waters that can be up to 10°C warmer (Milliken et al., 2009).

The lack of a significant influence of month on mortality of experimental cod in our study could be related to the observation that most experimental fish apparently would not have experienced large changes in temperature during catch, regardless of month. The Baltic Sea is stratified, with the seasonal thermocline beginning to form in May, and breaking down again in autumn (Snoeijs-Leijonmalm and Andrén, 2017). In 2017, the seasonal thermocline was at depths between 20-30m (Naumann et al., 2018). The fishing depths of Team A were therefore close to the thermocline depth, which is reflected in the similarities between temperatures recorded at the surface and at fishing depth for experiments carried out by this team (Table 1). The largest differences in temperature during Team A's experiments were recorded in June, though temperatures at fishing depth were still only 0.9-1.6°C colder than at the surface (Table 1). The temperature differences between surface and fishing depth were larger during the experiments of Team B, which were conducted at greater depths. In May, while the thermocline was present, the temperature at the surface was 3.5°C warmer than at fishing depth (experiment 3, Table 1), whereas in November, the temperature difference between surface and fishing depth was only 1.6°C (experiment 8, Table 1). Although no temperature data is available for experiment 7, it is expected that the seasonal thermocline would still be present in September, and as Team C fished at depths deeper than the thermocline, experimental cod would have crossed the thermocline during catch. Although not significant, the lowest survival rates recorded in this study were for cod captured in June and September (Table 1), during which experimental fish experienced the warmest temperatures or were likely hauled across the thermocline during catch.

The summer period also coincides with spawning time of Eastern Baltic cod (Köster et al., 2017; Wieland et al., 2000). Spawning-related exhaustion or physiological stress may also contribute to reduced survival of Baltic cod captured during this time, as was observed in experiments focusing on the short-term survival of trawled Western Baltic cod in on-board tanks (Kock, 1975b). As we released surviving cod at the end of the experiment, we were however unable to determine the sex and maturity of all experimental cod, and can therefore only speculate that this may have influenced survival. Nevertheless, given the current understanding of cod physiology, carrying out tagging studies in winter months, i.e. quarter 4 and quarter 1, when temperatures and solar radiation are low, the water column is more mixed, and eastern Baltic cod are not spawning, should increase the likelihood of survival.

In conclusion, these experiments indicate that the capture of Baltic cod by trawl and tagging-associated handling result in short-term mortality that should be accounted for in estimates of tag-recapture rates. Although mortality rates were higher for smaller individuals, it is generally important to cover a wide size-range in tagging studies, so that results are representative of as much of the stock as possible. Furthermore, although the inclusion of several tagging teams and sites complicated the interpretation of results, experiments including such sources of variation produce results which more realistically reflect the variable mortality associated with a large, international tagging study that is conducted by different tagging teams in different regions.

Acknowledgements

This study was funded by BalticSea2020 (http://balticsea2020.org) through the project "*Tagging Baltic Cod*" (TABACOD). Thanks go to all staff involved in conducting the experiments. We would like to thank Axel Temming for valuable feedback on the manuscript. We thank the two anonymous reviewers for their constructive comments. The experiments were conducted under the animal test permissions AZ 7221.3.1-029/15 and 016-15-0201-0092.

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