Caught on camera: Widespread direct evidence of illegal discards in coastal waters of the Western Baltic Sea

Philipp Rene Schubert (pschubert@geomar.de)
Helmholtz Centre for Ocean Research: Helmholtz-Zentrum fur Ozeanforschung Kiel
https://orcid.org/0000-0003-1838-7250
Rolf Karez
Landesamt für Umwelt Schleswig-Holstein
Thorsten B. H. Reusch
Helmholtz Centre for Ocean Research: Helmholtz-Zentrum fur Ozeanforschung Kiel

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Abstract

Most fish stocks in the European Union (EU) are still being overfished. One recent measure of the EU common fisheries policy to curb overfishing is the introduction of landing obligations that are meant to reduce discards, but the success of landing obligations is controversial, as discards still take place. In the German Western Baltic Sea , discards are currently estimated using ship observer data, but vessels <12 m are not sufficiently controlled. We here use an independent method and document widespread discard of undersized cod and flatfish in late summer 2018 using video transects. Discards along the coastline of the south-western Baltic Sea amount to an extrapolated 14.0 t of cod and 1.0 t of flatfish decomposing on the sea floor in 1-13 m depth in a subarea of Mecklenburg Bight that covers only 2.3% of ICES (International Council for the Exploration of the Sea) subdivisions 22-24, the habitat of Western Baltic cod. Compared to a similar video-mapping seven years earlier (in 2011), the amount of discard increased markedly, suggesting that the implementation of landing obligations in the time between the two mappings for under-sized catches has not resulted in a decrease but an increase of discards. We suggest that higher observed discards of cod in 2018 are also due to a high percentage of cod coming from the 2016-cohort of the Western Baltic cod stock which are just undersized but nevertheless caught by most passive net gear. Our data complement estimates based on ship observer data, while providing the first direct evidence of the fate of discards in the benthic marine habitat.

1 Introduction

Despite international measures to sustainably manage fisheries around the globe, many fish stocks are still being overfished (Pauly et al., 2005). The waters of the European Union are no exception, with 64% of all stocks subject to ongoing overfishing and 51% of stock sizes outside of safe biological limits (Froese et al., 2018; Fernandes et al., 2017). An important part of the overfishing problem is the discarding of unwanted species or *de jure* undersized fish. It is well established that even if thrown back, many die off shore (Cook et al., 2019), although survival rate varies depending on the fish species, fishing technique and the environmental conditions. Those dead fish will not count against quotas, resulting in an underreporting of the actual fishing mortality. The reason for catching unwanted species or undersized fish is caused by the use of wrong mesh size or fishing at the wrong time and/or place or depth. Consequently, to enhance the selectivity of catch methods, one of the key objectives of the 2013 Reform of the European Union (EU) Common Fisheries Policy (CFP) was to put an end to the discarding of most commercial species in European marine waters between 2015 and 2019 (EU, 2013). Specifically, the introduction of a landing obligation (LO) requires that all catches of stocks under catch limits and with a legal minimum conservation reference size (MCRS) are to be recorded and, where applicable, counted against quotas. Only very few exemptions are granted for protected species, for species with a high survivability, and for discards that cannot be easily reduced through selectivity and avoidance measures (Mortensen et al., 2017). Nevertheless, illegal discards are still a major issue in European fisheries (ICES, 2019a). This is because control and enforcement of the LO are not straightforward, as these illegal discards happen while at sea. Observations on small boats or controls in the harbour are often not feasible due to the high number of small boats and harbours and a lack of control personnel (Karp et al., 2019).

In the south-western Baltic Sea along the German coast of the federal state of Schleswig-Holstein (within ICES subdivision 22), gillnets and trap-nets are the prevalent fishing method and most fishers are part-time fishers (Meyer and Krumme, 2021). This gillnet fishery targets cod (*Gadus morhua*) and flatfish like plaice (*Pleuronectes platessa*) and flounder (*Platichthys flesus*; Funk et al., 2020) and is typically associated with high rates of incidental mortality among entangled and discarded fish (Portt et al., 2006; Cook et al., 2019). The LO in the Baltic entered into force for all vessels in 2015 (cod) and 2017 (plaice) and applies to two demersal species: cod and plaice, two pelagic species (Herring *Clupea harengus* and sprat *Sprattus sprattus*), and one diadromous species (salmon *Salmo salar*). Of these species, only cod and plaice cause relevant amounts of discards (Kraak et al., 2016). Reliable estimates, however, are challenging for the gillnet fishery due to low level of sampling only through observer data (ICES, 2021). In 2019, the International Council for the Exploration of the Sea (ICES) estimates that discard rate for Western Baltic cod in SD 22 is 1.4% for passive gears (ICES, 2019c), but also states that "reliable estimates of the potentially unallocated removals are not available for this fleet [of part-time fishers and vessels < 8 m in Germany]"(ICES, 2019c).

For the Western Baltic cod stock, the ICES reports that "discarding still takes place despite the fact that the landing obligation has been in place since 2015". The estimated number of discards for cod in the Western Baltic Sea (ICES subdivisions 22–24) is 157 tons in 2018 (approx. 4.2% of total landings), based on observer data (ICES, 2019a), while the corresponding number for plaice in subdivisions 21–23 in 2018 is 1,387 tons (approx. 40% of total landings; ICES, 2019b). Nevertheless, based on ICES data, reported landings below minimum size (BMS) are very low for cod and for plaice and are estimated to be only 24 t (cod, SDs 22–24) and 13 t (plaice, SDs 21–23) in 2018, respectively. This can be taken as further evidence that discarding still plays a significant role for these species (ICES, 2019a + b) as landings below BMS should be higher if all undersized fish caught were brought to port and counted against the respective quota. The main reasons behind discards are considered to be a) the catch being below the minimum landing size or b) to optimize total catch value, smaller individuals are discarded (high-grading; Feekings et al. 2012).

Here, we report on an unplanned but nevertheless significant underwater data set with direct discard observations that complements traditional estimates of occurring discards. We took advantage of a comprehensive video mapping effort of coastal habitat types along the Baltic coastline of the state of Schleswig-Holstein (Germany) by tow-camera in the years 2018 to 2020 and compared those recent videos with older mapping videos along the same transects from 2011. It is important to note that those two mapping campaigns from 2011 and 2018 to 2020 were not planned or designed to detect or study any fisheries related dead fish, but we rather took advantage of the incidental and numerous sightings of dead fish during the analysis of the more recent videos in the post-processing. We compared the two mapping campaigns to examine whether there has been a change in number of fish carcasses on the shallow seafloor between 2011 and 2018. The results were then used to discuss the effects of the implementation of the LO in 2015 and 2017 (for cod and for plaice in the Western Baltic Sea respectively). Our study complements observer-based data estimations and quantifies discard from data at the seafloor, i.e. where any deceased fish would ultimately end up.

2 Material And Methods

2.1 Study region

The study region is situated in the Baltic Sea, the largest brackish water body in the world, which is characterized by steep physical and chemical gradients, limited water exchange, low biodiversity and strong anthropogenic impacts (Reusch et al., 2018). The study region lies within the ICES subdivision 22 (Full ICES area code: 27.3.c.22). In late summer, oxygen deficiencies are a common occurrence in coastal areas due to seasonal wind driven upwelling and low oxygen levels in deeper waters (Carstensen and Conley, 2019). Oxygen data loggers in shallow waters along the coast are operated and maintained by a cooperation of GEOMAR and State Agency for Agriculture, Environment, and Rural Areas Schleswig-Holstein (LLUR). Data from the nearest logger in Neustadt (Holstein) were retrieved and checked for low oxygen events in the time between July 1st and October 5th of 2018 (data from Franz et al., 2019). Low oxygen levels were defined by values < 5 mg O2/l, critical for cod and plaice are levels around 2 mg O2/l (Tiews, 1970).

The mapping project of coastal habitats and fish abundance was run along the entire coastline of Schleswig-Holstein (SH), between the border to Denmark in the North and the border to the adjacent German federal state of Mecklenburg-Western Pomerania in the Southeast (total sea area ca. 3,680 km²). Mapping was conducted in the vicinity of the coastline in a depth zone between 1–13 m depth, comprising a total area of approx. 1,000 km². The depth zone was defined *a priori* to fit the original purpose of the mapping to identify and estimate the extent of coastal habitats along the coast.

2.2 Tow-camera mapping

Video mapping of coastal habitats was conducted in the summer seasons (between May and October) in the years 2018–2020, mapping of the further investigated Mecklenburg Bight subarea (MBS) was conducted between 5th of September and 5th of October in 2018 (31 days). Video transects for the mapping of coastal habitats were run parallel and perpendicular to the shore. Parallel transects (PTs) were carried out in a depth of ca. 4 m, while perpendicular or vertical transects (VTs) were run from ca. 13 m depth to ca. 1 m depth. Older video transects from 2011 had a maximum depth of only 10 m, why we had to restrict the comparison to the depth range of 1–10 m (see below). Video-transects covered a total distance of 580.1 km of seafloor (PTs: 354.0 km, VTs: 226.1 km). VTs were distributed over the length of the entire coast with a fixed distance between transects of ca. 2 km along most coasts and ranged in length between 140 and 6,160 m (n = 163, mean length = 1,387 m, SD = 987 m), depending on the slope of the coast.

Habitats were mapped continuously along video transects with an underwater tow-camera. The tow-camera consisted of an action camera (GoPro 3 + black) in a water proof housing with the following settings: video resolution: 1920x1080 pixels; 50 frames per second; Protune; field of view: medium; screen resolution: 16:9. Two laser beams with a constant distance of 24 cm enabled a size estimation of observed features. The tow-camera was deployed from a boat (< 8 m), travelling at idle speed (ca. 4–6 km h^{-1}). The actual width of the field of view depended on height of the camera above the seafloor (0.8–2.5 m) and varied between 1.8 and 4 m. The video signal was recorded internally on a SD-card and sent on board digitally via the tow cable for real-time control of the video. Depth, position, and time were provided by a combined GPS receiver and echo sounder (Humminbird 899ci). The GPS receiver was installed on the boat and recorded data at least every 2 seconds into a NMEA 0183-file (National Marine Electronics Association).

Older video data from a similar mapping in 2011 in the MBS were also re-analysed for dead fish observations in the course of this study. The method of this former mapping is described in detail in Schubert et al. (2015), but in short, transect location of PTs and TVs and video analysis were nearly identical. Differences existed in video quality (512 × 582 pixels, 25 frames per second), maximum depth of transects (max. 10 m), and exact time of the mapping (July-August 2011). The difference in vertical transect lengths was taken into account for the comparison with the newer transects (Table 1). It is important to further note that video quality of the older videos was sufficient to clearly detect dead fish, as smaller fauna and flora were also easily recognizable (e.g. periwinkles, blue mussels, sea stars) and a dead cod was visible in the old video material.

Videos were evaluated continuously in a second step by examination of the video on a computer screen and automatically combined with the NMEA data using a specifically designed computer program (unpublished program: *GAZER*, by W. Hukriede and P.R. Schubert), which produced a protocol file for further analyses. Spatio-temporal resolution for single observations was thus linked to velocity of the boat and frequency of GPS measurements, resulting in map distances between single observations of 0.8–3 m. Due to the large amount of video data, five different observers were assigned to this task. Intercalibration showed that individual observers did not differ significantly in their interpretation of coastal habitats and fish observations (data shown in Table I in Appendix).

2.3 Observation and measurements of fish carcasses

Single dead fish observations were assessed from video transects as an extra category ("dead fish"). During the assessment, only dead specimen of commercially exploited fish species (cod, flatfish) were observed. Screenshots were taken from all observed dead fish (example screenshots in appendix and in Supplementary Material). We conducted a size estimation of dead fish from all video screenshots that were of sufficient quality, meaning that the carcass has to be located near the centre of the screen, and with light conditions where both lasers were clearly visible against the seafloor. Size estimation was accurately possible in 12 cod and 3 flatfish and was performed by five individual observers independently. Due to orientation of the carcass, under water visibility, and measuring differences between observers, we calculated the mean of all observers and the standard deviation for each measured fish. Mean lengths standard deviation of > 3.5 cm were not included in further analyses. Most fish not measurable were of similar size as the measured subsample, as could be roughly estimated from other marine life of known size visible in the videos. Fig. VII in the appendix shows an example of a measurable cod (estimated length: 32.7 cm), Fig. V shows an example of a cod that could not be measured due to missing laser points.

2.4 Extrapolation of discards for Mecklenburg Bight subarea (MBS)

Most dead fish were observed in the MBS of the study region. Therefore, an extrapolation for dead fish within this subarea was calculated based on dead fish numbers and actually observed area of seafloor during the mapping. The actually observed area of seafloor (= 0.6 km²) was calculated as the lengths of all transects (PT and VT) in MBS (150.0 km) multiplied by an estimate of the width of the field of view assuming relatively clear water and high visibility for the area (i.e. 4 m). Note that this assumption is conservative with respect to our scientific objective, which is estimating the minimal number of decaying fish owing to discard on the seafloor. The areal extent of the MBS between 1 and 13 m depth was computed using ArcGIS (Vers. 10.6.). This depth zone in the MBS calculates to 238.74 km². We assume, that perpendicular transects are randomly distributed with respect to the probability to find dead fish as fishing by gillnets takes place along the whole coast and transects were evenly spaced. Additionally, the carcasses could be swept to other areas by currents and wave action and become more evenly distributed within the coastal region. The parallel transects ran in a depth of ca. 4 m and thus rather reduce the probability to find dead fish, as the typical depth of gillnets is around 7–11 m (pers. obs.). But without quantitative data about exact locations and depths of gillnets (which do not exist), it is not possible to estimate the bias inflicted to the extrapolation by the distribution and depth range of our transects, thus we can only extrapolate the observed numbers by the factor $\frac{238.74}{0.6} = 397.9$to obtain a rough estimate for dead fish numbers in the MBS located within Schleswig-Holstein and between 1 and 13 m water depth. Note that for comparison with the older mapping from 2011, dead fish numbers were restricted to observations made in the depth range between 1 and 10 m only to prevent systematic error due to differing depth ranges in both mappings.

Weight extrapolations were based on weight-length data from fish base (here from Froese and Sampang, 2013) for the minimum landing size (MLS) of cod and the two most important flatfishes in the region, plaice and flounder. MLS for cod is 35 cm, the mean weight for Western Baltic cod at this length is 409 g. MLS for plaice is 25 cm, mean weight at this length is 158 g. MLS for flounder is 23 cm, mean weight at this length is 167 g. As the two flatfish species are not certainly discriminable from our video material, we extrapolated the weight on the basis of the mean of both species at MLS (162.5 g) .

3 Results

3.1 Observations of dead fish specimen

In total, 113 dead fish were observed during three years of video mapping (Fig. 1) of which 20 could be identified as flatfish (Example screenshot in Fig. VI in Appendix; in the study region and mapping depth the most common flatfish species are plaice *Pleuronectes platessa* and flounder *Platichthys flesus*) and 91 as cod (*Gadus morhua*). Two dead specimens were unidentifiable due to advanced decomposition of the carcass, but unquestionably dead fish carcasses (Supplementary Material). In the two subareas of the mapping, Kiel Bight and Mecklenburg Bight, dead fish finds were unequally distributed. In Kiel Bight, although much larger, only 9 dead fish (cod: 5, flatfish: 4) were observed, the remaining (n = 104; cod: 86, flatfish: 16, unidentified: 2) were found in MBS. Additionally, a spatial clustering of dead fish finds around known stone reefs rich in cod like Dahmeshöved and Brodtener Ufer or fishing harbours like Grömitz, Neustadt and Niendorf was noticeable (Fig. 2). Data from our older mapping in 2011 (before the implementation of the landing obligation in 2015) in the MBS revealed for nearly identical transects only one dead fish (species: cod), thus proving the detectability of carcasses with the older camera equipment. To directly compare the older mapping data with our 2018 data we have to account for the depth difference of 3 m on perpendicular transects by omitting the dead fish found deeper than 10 m (n = 6) and concentrating on the MBS. We found 98 dead fish in MBS between ca. 1 m and 10 m depth in 2018 and 1 dead fish in the same area and depth zone in 2011, thus showing a 98-fold increase in numbers of observed dead fish in this time period (Table 1).

Table 1: Dead fish observations from two mappings (2011 and 2018) of coastal habitats along the Schleswig-Holstein coast of Mecklenburg Bight (MBS), depth range restricted to 1 - 10 m, species identification from tow-camera videos.

Species	**dead fish observations 2011 (Jul-Aug)**	**dead fish observations 2018 (Sep-Oct)**
Cod (*Gadus morhua*)	1	80
Flatfish (*Platichthys flesus* or *Pleuronectes platessa*)	0	16
Unidentifiable	0	2
Total number of observed dead fish	1	98

3.2 Size estimation and depth distribution of dead fish

Size estimation of all dead cod that were measurable and where standard deviation between observers was below 3.5 cm (n = 10) is shown in Fig. 3. Additionally, 3 flatfish were measurable (data not shown). Most dead cod measured had body lengths between 22.9 and 35.9 cm (80%), which is just below or around the minimum landing size in SH for commercial fishing (35 cm since 2015). The exception were two carcasses with 40.7 and 46.8 cm length, respectively. Mean length from all measurable dead cod was 32.9 cm.

Next, we examined possible differences in the size distribution of the live Western Baltic cod stock in the respective years of our video mappings that could have produced differences in undersized catches and hence, in the opportunity and motivation to discard for fishermen, both recreational or commercial. ICES Baltic International Trawl Survey (BITS) data from 2011 and 2018 show important differences between fish numbers caught per unit effort by length (Appendix: Fig. I). In 2018, virtually only the 2016-cohort (age class 2, size approx. 28–36 cm) of the Western Baltic cod stock was present in catches, while in 2011 there were more fish in total and catches consisted of different age classes with a clear maximum at around 25 cm length (age class 2) and two more maxima at 15 cm (age class 1) and 42 cm (age class 3) and a lesser pronounced high at around 53 cm (age class 4). Therefore, gillnet fisheries targeting cod would have caught a) more fish and b) more fish above minimum landing size in 2011 when compared to 2018.

Depth distribution of dead fish observations could only be assessed from perpendicular transects (n = 45), due to the systematic bias inflicted by observations from parallel transects, which otherwise would yield an overweight of observations from ca. 4 m depth. Depths of dead fish finds along those perpendicular transects range from 1.8 m to 13.0 m with a mean of 7.8 m. 51% of all dead fish were observed between 7–11 m depth (n = 23; Fig. 4).

3.3 Extrapolation of discards for Mecklenburg Bight subarea (MBS)

The extrapolation of dead fish finds for the MBS in the depth range between 1 and 13 m gives an estimate of 34,219 dead cod and 6,366 dead flatfish in total. Extrapolated numbers calculate to an estimated total weight of all dead cod of ca. 14.0 t. Mean weight of both flatfish species at minimum landing size was used to calculate an estimated total weight of all dead flatfish of ca. 1.0 t. As all observations from MBS were made between 5th September and 5th October 2018, discarded numbers of fish and total weight per year would be considerably higher, depending on decay rate of a carcass and seasonality in catches, decay, and possibly discards. Unfortunately, decay rates for the Western Baltic Sea do not exist. Therefore, we refrained from further estimations considering annual numbers of discarded fish.

3.4 Oxygen levels

Oxygen data from a station near Neustadt (Holstein) were retrieved and checked for hypoxic or low oxygen levels or short events in the time period from July 1st to October 5th of 2018 (data from Franz et al., 2019). In this time period, no low oxygen levels (< 5 mg O2/l) were recorded (data not shown).

4 Discussion

To the best of our knowledge, we provide here the first direct evidence of illegal discard of undersized fish with the help of video transects from this region. Our conservative extrapolation with respect to the area covered by the optical monitoring puts the discard of cod quantified in September / October 2018 at 14.0 t in the MBS alone. The MBS constitutes approx. 2.3% of the area of ICES subdivisions 22–24 (44,310 km²), yet we found approx. 8.9% of what ICES estimated the total discard for all Western Baltic cod to be in 2018 (157 t in subdivisions 22–24; ICES, cod.27.22-24). Therefore, we argue that our estimates could complement the conservative ICES calculations, which are based on observer data and thus are very likely to underestimate actual discard amounts. In particular, the ICES estimate covers heterogeneous regions with different fisheries and also applies to trawling fisheries offshore outside the shallow water monitoring depth of maximally 13 m, where discard ratios are expected to be higher (Kelleher, 2005; ICES, 2021). Additionally, our estimate is based on point data from just about one month of observations and thus most likely underestimates the annual number of discards in the area significantly depending on an unknown decay rate.

Published ICES observer data and our direct method are very different and are hardly comparable. We therefore suggest that they cannot be expected to fall in line, rather they should be viewed to complement each other. Collectively, they show that discards still happen in the shallow coastal zone and in small scale fisheries, but are very variable on a local scale (e.g. note differences between Kiel and Mecklenburg Bight area).

Throughout the study area, it is likely that the real numbers of discarded fish during 2018 are much higher, as we cannot expect dead cod to stay recognizable for several weeks during the summer months, although we lack experimental data in decay rates and losses due to scavengers. Our sampling design was systematic with respect to the spacing of the transects perpendicular to the shoreline. Yet, we cannot think of any systematic error that would have resulted from our approach with respect to the spatial extrapolation. We also suggest that our extrapolated data are rather conservative, since they imply a good visibility and a width of the field of view of 4 m that was not realistic for many days with worse visibility. This may have led to an underestimate of the true number of fish carcasses observed. Still, further similar studies should include a documentation of gillnet positions during the time of mapping to improve the survey and obtain so far non-existing data about the gillnet fishery.

We can rule out a number of other factors that may have led to the observed dead fish. First, causes of death other than fishing and discard are unlikely since only a particular size class of cod was affected, namely those that were just undersized (Fig. 3). The few fish that were not undersized could have died of natural causes or, more likely, died in the gillnets, but were lost during uphaul of the nets without reaching the surface, which was a very common observation during our video mapping campaigns, when transects accidentally passed over active gillnets. Second, if this was a fish kill triggered by oxygen deficiency, which is a common occurrence in nearshore waters in the Western Baltic Sea in late summer, many other species of the coastal fish community such as eelpout, bullhead, flatfishes, gobies etc. would have been found dead, which was not the case. Only dead cod and flatfish were observed during the complete video assessment. In all fish kills we have witnessed in the past 15 + years, the low oxygen water bodies coming from the deep are concentrating the fish avoiding low oxygen in nearshore areas where they become trapped, so these fish never die alone, while our findings are spatially spread out over a large area and the whole depth range and consist only of economically important fish species. Finally, data from oxygen data loggers installed in the study region in 2 m depth and during the time of the video mapping (10 min intervals) show no hypoxic conditions or events that could have caused a fish die-off (oxygen data from Franz et al., 2019). Angling as a potential source of the dead fish may contribute to the discards, as it is known that the share of recreational fisheries amounts up to 40% to total cod landing (Möllmann et al. 2021, Fig S2). While this gives an upper bound, and hence a lower bound of 60% for the share of commercial gillnet landings, the contribution is likely much lower given the distribution and the observed clustering of corpses around fishing harbours throughout the MBS. While gillnets were a very common and ubiquitous sight during our mapping campaign, anglers concentrated at certain stone grounds, wrecks and reefs in the area and were not as numerous, especially not operating from boats but rather from piers and breakwaters (pers. observations). High-grading and post-release mortality of undersized fish via anglers could nevertheless play a role in the observed dead fish findings.

The extrapolation of our direct observations of dead fish on 0.6 km² to a much greater area (238.74 km² in the MBS from 1–13 m depth) provides a level of uncertainty as in any sample based biological survey. We addressed this uncertainty by conservatively assuming a field of view of 4 m. This was only true during days with exceptional good visibility, so extrapolated fish numbers would be even higher, as the observed area would further contract. Compared to many other marine biological or oceanographic field surveys that operate with a small number of stations to extrapolate on entire basins we consider our length of transects of 150 km to be quite exhaustive.

While we would refrain from arguing that there is a significant increase in discards from 2011–2018 due to restrictions in our sampling design that only encompassed two time points and due to limitations concerning the extrapolation of the observations to the area of the MBS, it is clear that the LO implemented in 2015 has not resulted in preventing frequent discard in Western Baltic cod and flatfish stocks. To the contrary, we even find a 98-fold increase in dead fish observations between an earlier monitoring along nearly identical transects assessed by comparable methods.

We can only speculate as to why there is much more discard in 2018 compared to 2011. One reason may be that in 2011, the size distribution of Western Baltic cod stock was different (Fig. I), with proportionally fewer fish just being undersized (ICES Baltic International Trawl Survey dataset). This could have resulted in small fish that were not caught by the passive gear mesh size in 2011 (first mode in Fig. I). In 2018 on the other side, the cod stock was dominated by the strong 2016-year class now being 2 years old that is represented in only one mode, leading to many individuals that were just undersized. This, in turn, motivated many more discards of fish that were deemed to be unmarketable to upgrade catches

(Catchpole et al., 2017), although ideas to valorise fish below minimum size exist (Pérez-Martín et al., 2020).

Fishing practices and mesh sizes may also have changed between 2011 and 2018, as there is also anecdotal evidence that in the western part of the studied area (Kiel Bight) small scale coastal fisheries voluntarily use a larger mesh size in their passive gear, effectively preventing the catch of under-sized individuals (pers. comm. with fishermen in the area). This could be the reason for the large differences in dead fish observations between the MBS and the Kiel Bight subarea, with more than 92% of the observations occurring in the (smaller) MBS area. Also, an older paper by Catchpole and Gray (2010) about a pilot project in the MBS to prevent discards in the Baltic Sea states that "cod fishery of the Burg/Fehmarn region in the Baltic Sea (…) has a known discard problem".

Another explanation would of course be that the LO rules actually incentive fishermen to discard more (Pope and Weber, 2019). Even ICES states in a current report on Baltic Sea fisheries that "in 2015, a landing obligation was introduced in the Baltic Sea and therefore the observer trips (…) changed from observing a mandatory behaviour towards observing an illegal act. This could have an influence on the fishers´ behaviour and give more biased estimates" (ICES, 2021). Furthermore, the fishermen have an incentive to discard to high-grade, as "current allowed catches do not provide sufficient income to support the present fleet size" (Möllmann et al., 2021). While we acknowledge that there are many differences between the two single time points sampled here, we consider it unlikely that the LO has actually reduced the level of discards, given the very high numbers of dead fish observed in a single season. Rather, the implementation of the landing obligation for undersized catch in 2015 has not resulted in a decrease but possibly an increase of illegal discard.

Taken together, our data provide the first direct and comprehensive data of discards ending up in any shallow water ecosystem that complement estimates of discards based on observer data. Little is known on the decay rates and ecological effects of fish carcasses in shallow water ecosystems, but it is clear that their local nutrient input will profoundly impact benthic communities and enhance the abundance of scavenging species (Groenewold and Fonds, 2000). These data highlight that the Baltic Sea continues to be an area heavily impacted by human influence, including non-sustainable fishing practice.

Declarations

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Author contributions

PRS, TBHR and RK conceived and designed the study. PRS performed the data acquisition, statistical analysis and wrote the first draft of the manuscript. TBH and RK wrote sections of the manuscript. All authors contributed to data interpretation, manuscript revision, read, and approved the submitted version.

Declaration of interests

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.

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Figures

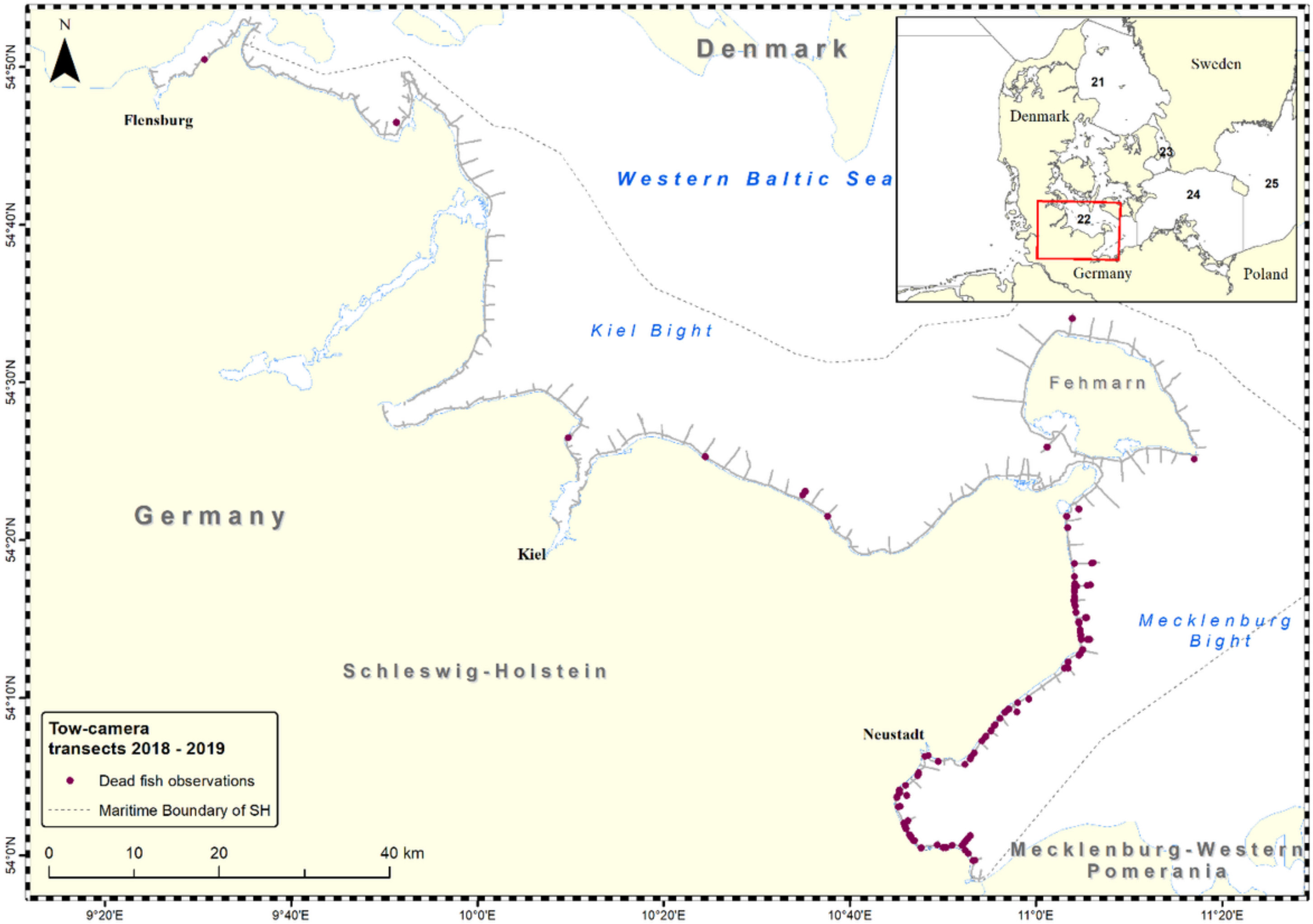

Figure 1

Map of study region (Baltic Sea coast of Schleswig-Holstein) with tow-camera transects (grey lines) and observed single dead fish. Inset map: Overview of Western Baltic Sea region with ICES subdivisions and map extent (red rectangle). Dotted grey line: Maritime boundary of Schleswig-Holstein.

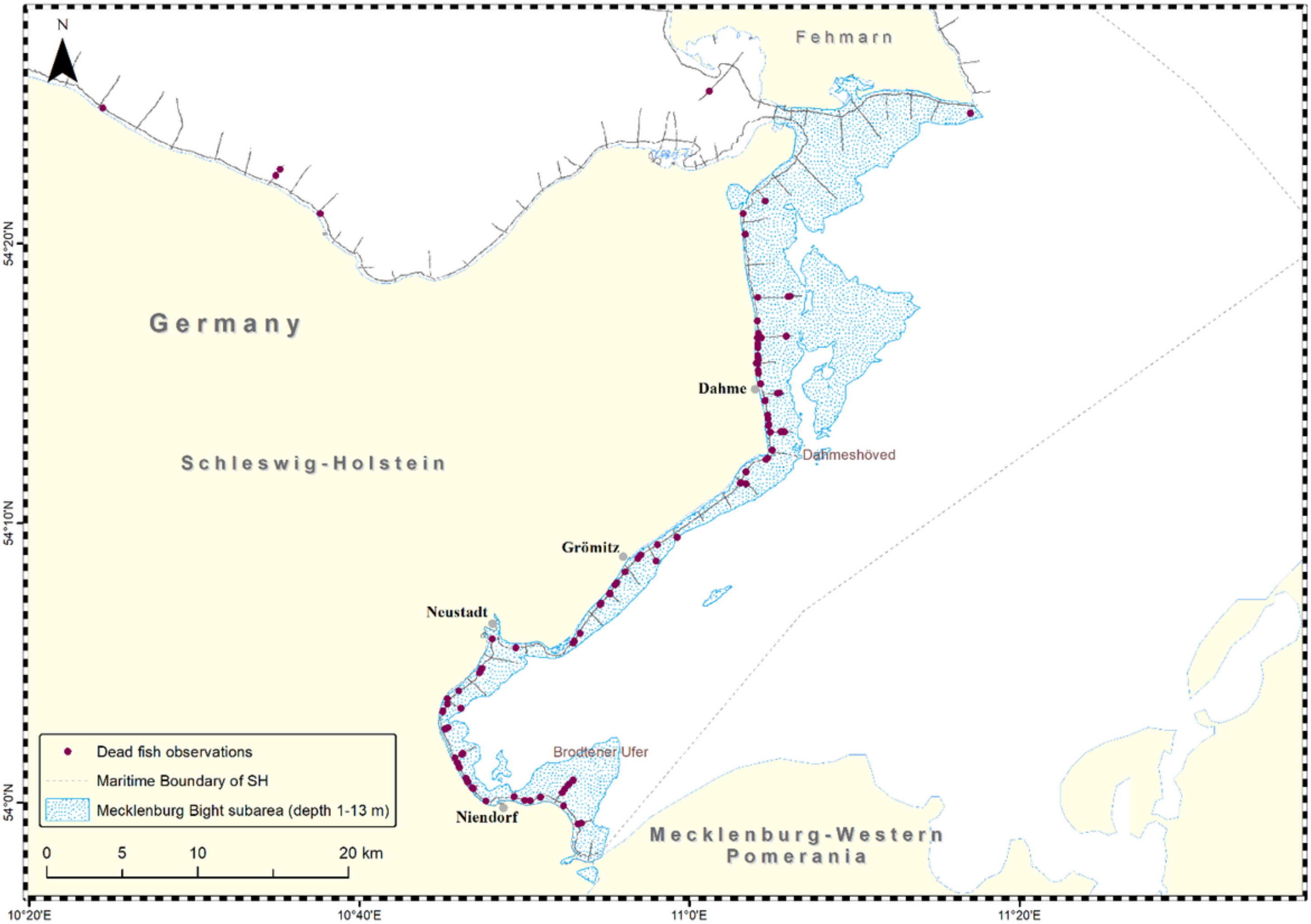

Figure 2

Map of Mecklenburg Bight subarea (MBS, 1-13 m depth, blue dotted polygon, area: 238.74 km²) with tow-camera transects (solid grey lines) and observed single dead fish. Dotted grey line: Maritime boundary of Schleswig-Holstein.

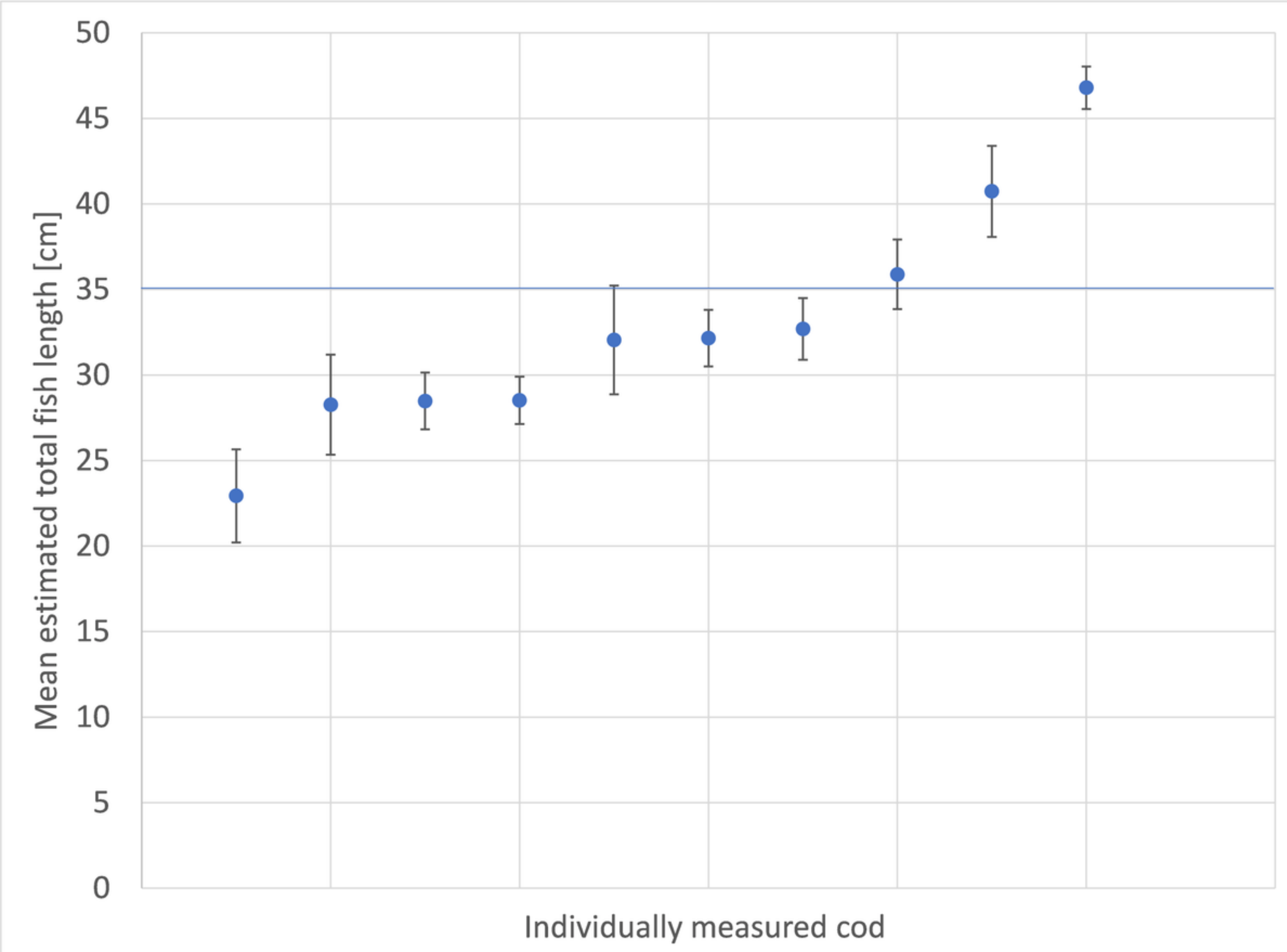

Figure 3

Scatterplot of estimated total cod lengths measured from the video transects (n=10). Blue line: Minimum landing size of cod for commercial fishing in the study region (35 cm), error bars: ±standard deviation of mean from five independent observers.

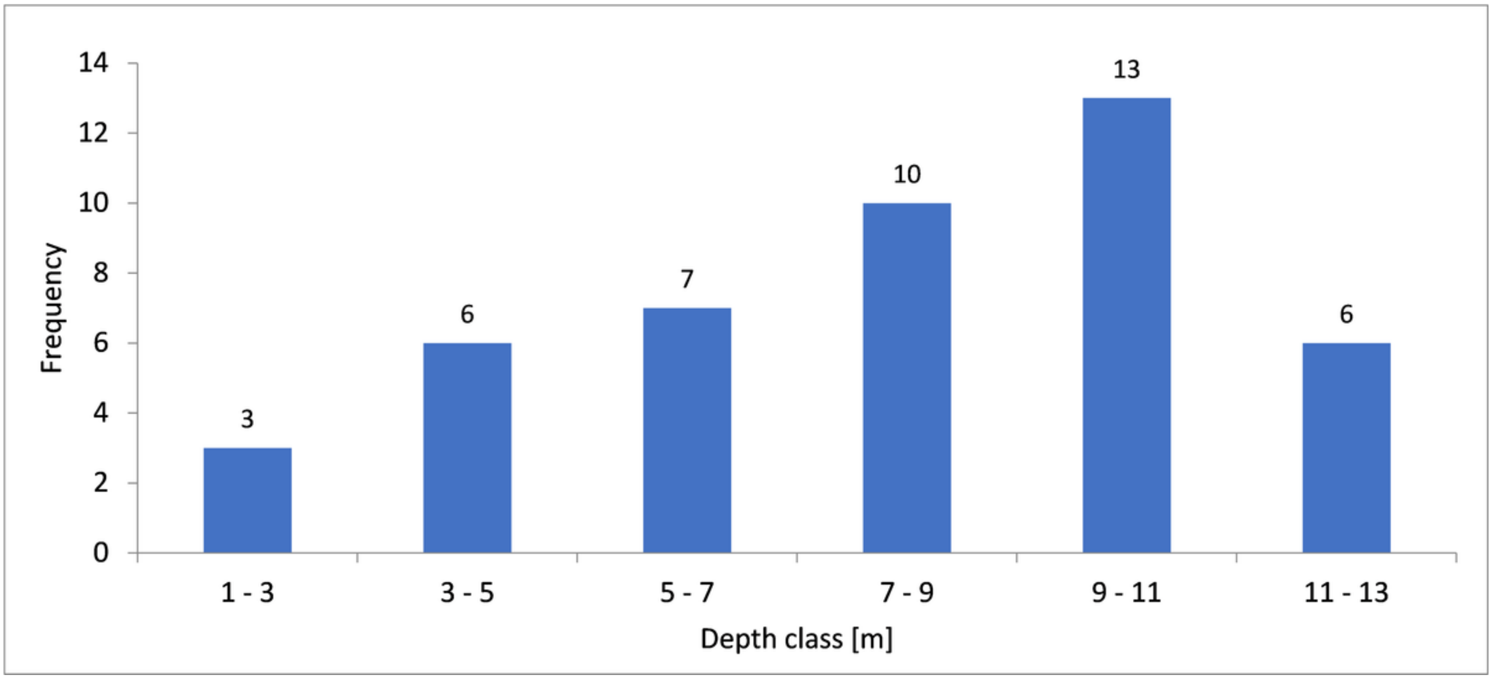

Figure 4

Histogram of depth distribution of dead fish observations along perpendicular transects (n=45).

Supplementary Files

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- floatimage2.png
- Appendix.docx