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Use of a smartphone application for self-reporting in small-scale fisheries: Lessons learned during a fishing closure in the western Baltic Sea

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ABSTRACT

There is a lack of data on the experience of the use of mobile devices in commercial small-scale fisheries but which are important to evaluate the suitability of these approaches for fisheries monitoring. In February and March 2018, the German Baltic small-scale fishery used a smartphone application for self-reporting of fishing activities to demonstrate compliance with the terms of a fishing closure of cod, which prohibited to fish deeper than 20 m. A total of 1618 trips and 7972 gear activities from 107 vessels were identified and categorized. Data review showed that not all data could be used directly due to operating or technical errors (e.g. mismatch in time and space of self-reported and actual gear activities and missing records on geographical positions). By editing during data evaluation, the proportion of useable trips and gear activities increased from 67 to 78% and from 29 to 69%, respectively. These data provided new insights into the activities of small-scale fishing vessels (<12 m), especially of the data-poor segment of vessels smaller than 8 m (e.g. for gillnets: mean net length of 664 m ± 538 SD, mean soak time of 30 h ± 12.9 SD, mean trip duration of 2.9 h ± 1.6 SD). Due to the high spatio-temporal resolution, the fishers could demonstrate compliance with the closure, with 99% of all recorded gear activities performed in areas shallower than 20 m. Based on the fast and short operation at sea observed, recording intervals of max. 1 min are advisable for small-scale vessels. Potential suggested improvements involve training of fishers, an independent GPS sensor, a remote control and tailored tools for data analysis to properly address future developments of smartphone applications for the use in data collection in small-scale fisheries.

1. Introduction

The monitoring of fishing activities covers a variety of approaches, depending on the objectives. Methods involve for instance paper logbooks and electronic logbooks for documenting inter alia catches or landings (EU, 2011). Further, at-sea observers can be used to assess discard (Heery and Cope, 2014) or electronic monitoring systems (combining GPS (Global Positioning System) data with camera footage and sensors that automatically detect gear activity) are deployed to document unwanted bycatch in fisheries (Kindt-Larsen et al., 2012). Strategies for monitoring the spatial distribution and effort of fishing activities include ship-based (Sonntag et al., 2012) and aerial surveys (Zellmer et al., 2018) as well as interviews (Demestre et al., 2015), VMS (Vessel Monitoring System) and AIS (Automatic Identification System) (Russo et al., 2016).

In addition to these monitoring approaches, applications for mobile devices such as tablets and smartphones have gained increasing attention in recent years (Bradley et al., 2019; Gutowsky et al., 2013). These devices combine different practical features including a GPS sensor, storage for data recording and uploading, photo and video recording, data transfer using wireless networks and the option to access the data in near real-time and to reduce transcription and recording errors (Bradley et al., 2019; Lorenzen et al., 2016; Venturelli et al., 2016). A variety of applications are already used among recreational fishers (Bradley et al., 2019) and are perceived to have great potential in supporting current standard reporting methods in marine recreational fisheries management (Skov et al., 2021). In commercial fisheries, applications for mobile devices were used in real-time management to reduce unwanted bycatch of overfished fish species in a trawl fishery (Kauer et al., 2018) or to support fishers in self-management, e.g. to avoid overfishing of a sea cucumber species (Saville et al., 2015).

In 2018, the German Baltic small-scale fishery (herein defined as

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vessels smaller than 12 m (EU, 2021a) but without excluding towed fishing gear) was obliged to use a smartphone application during a fishing closure of cod. Western Baltic cod was formerly the major demersal target species in the western Baltic Sea, but the directed fishery was closed in 2022 (EU, 2021b). Different spawning time-related area closures have been implemented over the years for this stock (e.g. EC, 2005, 2001; Eero et al., 2019; EU, 2021b, 2016) with the aim to ensure undisturbed spawning, increase recruitment and thus support stock recovery (Eero et al., 2019). In 2018, the closure lasted for two months (01.02.-31.03.2018) in ICES (International Council for the Exploration of the Sea) SDs (subdivisions) 22–24 (EU, 2017). During this period, a cod fishery was not allowed. However, vessels smaller than 12 m were permitted to target cod in areas shallower than 20 m (EU, 2017) as western Baltic cod mostly spawn in areas deeper than 20 m (Bleil and Oeberst, 2002) where water is more saline and ensures the egg buoyancy needed for successful spawning (Nissling and Westin, 1997). This exemption was linked to the condition that the fishing activities could be monitored at any time using a monitoring system approved by the respective national control authority (EU, 2017).

The standard monitoring methods for German Baltic small-scale vessels are paper logbooks for vessels with a length between 8 m and 12 m (EC, 2009; EU, 2016, 2011) and landing declarations, also in paper format, for vessels smaller than 8 m (BLE, 2005). Since vessels exempt from the closure in 2018 were all smaller than 12 m, VMS was not mandatory (EC, 2009). Spatial resolution of fishing activities was on the level of ICES statistical rectangles, both for logbooks (EU, 2011) and for landing declarations (the latter slightly more detailed for vessels registered in the federal state of Mecklenburg-Western Pomerania (LALLF, 2021)). Temporal resolution was either on the level of single daily trips for vessels using paper logbooks (Castro Ribeiro et al., 2016; EU, 2011) or on a primarily monthly level for vessels using landing declarations (BLE, 2005).

In advance of the regulation on the fishing closure in 2018, the Thünen Institute of Baltic Sea Fisheries (a German federal research institute) commissioned Anchor Lab K/S (http://www.anchorlab.net/) to develop a smartphone application as a digital option to record fishing effort with a high spatio-temporal resolution for vessels of all sizes. This application (called Mobile fisheries log, in brief Mofi), was proposed by the Thünen Institute to then be used voluntarily by the German fishery to electronically self-report fishing activities during the closure, in addition to the standard reporting by means of paper logbooks and landing declarations. The traditional spatial and temporal resolutions for documenting fishing activities were considered too low and not suitable for demonstrating compliance with the terms of the closure. In the end, the national control authority made the use of Mofi mandatory during the two-month closure (BLE, 2018) to ensure constant monitoring of fishing activities during this period (EU, 2017). This decision was announced few days before the start of the closure and making the use of Mofi mandatory was opposed to the original suggestion to use the smartphone application as a voluntary reporting tool. A pre-test of Mofi under commercial conditions did not take place and the German small-scale fishery was left with little to no time to test or adapt to the first-time use of a smartphone application for fisheries monitoring.

Later in 2018, the proposal for amending the EU control regulation was released, which suggests mobile phone technologies as potential tools for monitoring small-scale vessels (COM, 2018). Specific amendments to the control regulation propose the tracking and digital reporting of catches of all vessels, irrespective of vessel size (COM, 2018). In the light of these developments, the results and experience gained from the first large-scale, two-month application of a smartphone application in a commercial Baltic small-scale fishery might offer useful insights into the viability of such an approach.

In this study, we evaluated the data collected with the smartphone application Mofi during the two-month closure and identified strengths and weaknesses of this method. We examined i) to what degree the self-reported data were useable, ii) if the smartphone application enabled the fishery to demonstrate compliance with the terms of the closure, iii) what type of information could be obtained about the activities of the small-scale fishery from the anonymised self-reported data, and iv) whether the data were supplied on a spatio-temporal resolution appropriately reflecting the activities of small-scale vessels. The analyses iii) and iv) were done separately for the two standard reporting procedures (landing declaration: < 8 m vessel length, paper logbook: 8–12 m vessel length) and different business types (part-time, full-time) and fishing gears (gillnets and trawls).

2. Materials and methods

2.1. Coverage

After the 2018 fishing closure, the German control authority granted the authors access to the anonymised Mofi records as well as to anonymised data on logbook and landing records, technical features (vessel length overall, gross tonnage, power), business types (part-time, full-time) and ownership.

We analysed, how many vessels and respective owners registered on Mofi and recorded data during the closure. For the vessels that participated, the shares for the different reporting procedures (landing declaration, logbook) and business types (part-time, full-time) were determined.

We examined, how many German vessels with a length of less than 12 m reported any landings and cod landings originating from ICES SDs 22–24 (Fig. 1). We estimated, how many of the vessels that reported cod landings also had Mofi records and the amount of cod landings they covered, independent of the reporting procedure.

2.2. Functionality of the smartphone application Mofi

The application Mofi was designed as a versatile electronic reporting tool. Data on activities would be self-reported by the fishery and provide directly digitalized data on a high spatio-temporal resolution.

During the closure, the download of Mofi as well the recording of data was free of charge for the fishery. Fishers had to ensure that they had a smartphone on which Mofi worked, and they had to cover the costs for data transfer.

Mofi runs on smartphones with GPS functionality under Android OS 5.0 and higher, and on iOS 9.3 and higher. At the time of the fishing closure in 2018, an iOS version was not yet available and the versions for Android used during the closure were 1.0.25, 1.0.26 and 1.0.27. Connection to a mobile or wireless network was required during registration, while making changes to the user account and when data of completed trips were transmitted to a server for data storage. After an account was created, fishing vessels could be added from a list based on the fleet register of the European Union (more than one vessel can be registered per account).

At the beginning of a trip, the fisher had to choose the vessel and fishing gear to be used (Fig. S1). At the time of the closure only one gear could be chosen during a trip, which is different from logbooks in which fishers enter a new line if they use a different gear or the same gear but with a different mesh size (EU, 2011). Mofi logged two types of data during a trip: i) sensor data and ii) self-reported data. Sensor data were logged continuously at a fixed interval once a trip was started and without any further action required by the fisher, similar to VMS data (ICES, 2019a; Lowman et al., 2013). The sensor data comprised date, time, geographical position, speed and GPS accuracy. For about the first half of the closure the recording interval for the sensor data was set to 5 min and later increased to 1 min.

The self-reported data comprised the time stamps actively set by the fishers using the application to mark activities. By pushing the button for starting and ending a trip or a gear activity, time stamps were set, recording date, time and geographical position as well as the type of the respective action at that specific moment. For example, in case of gillnet

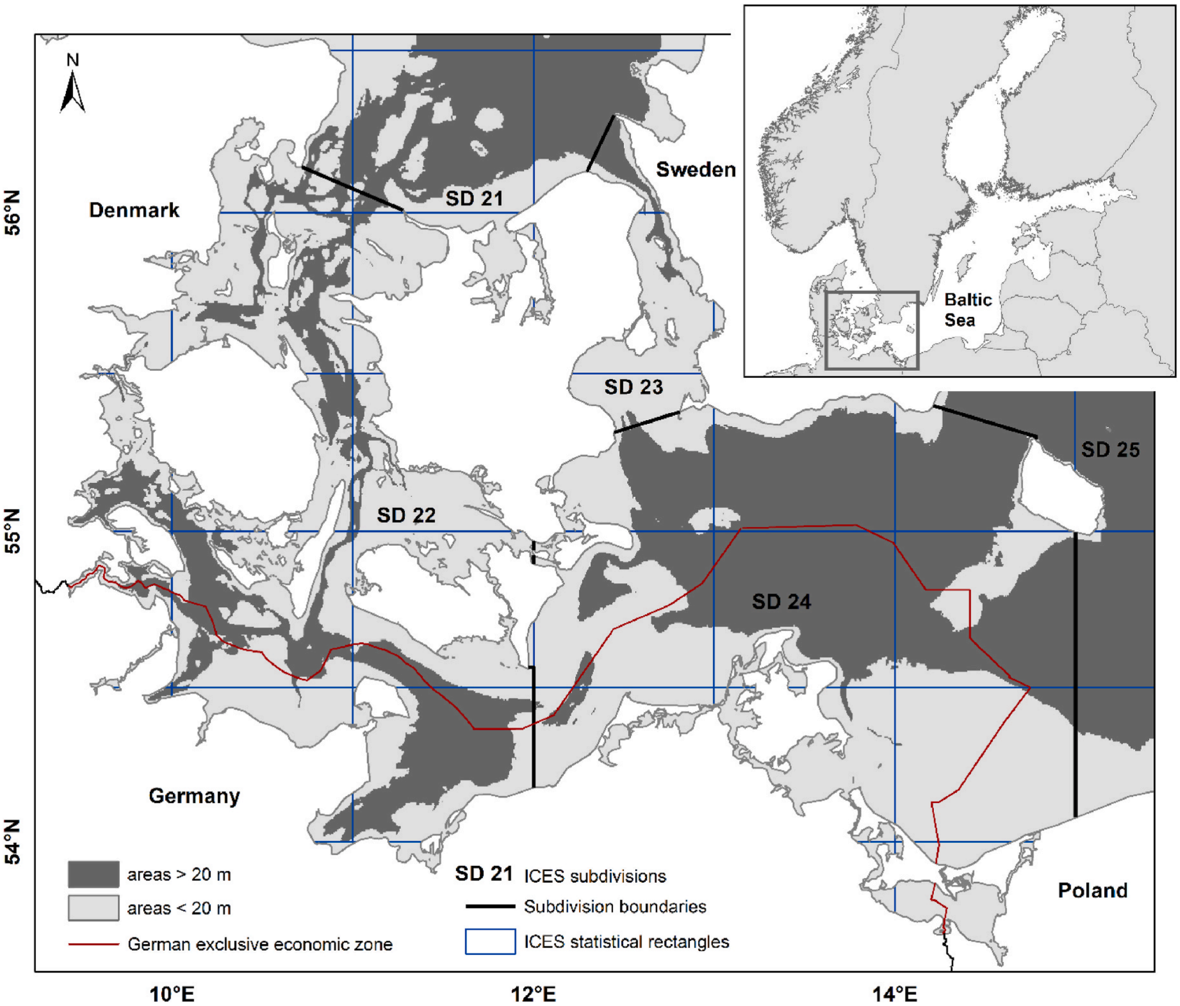

Fig. 1. Western Baltic Sea showing the area of the fishing closure of cod (ICES subdivisions 22–24) in February and March of 2018, covering the German Baltic Sea coast and the German exclusive economic zone. During the closure, cod fishery was allowed for German vessels smaller than 12 m in areas shallower than 20 m as long as they monitored their activities with the smartphone application Mofi.

activities there was the option to push the buttons > Start set gear< and >Stop set gear < if a gillnet was set (Fig. S2). The activity related time stamps were recorded independently of the continuously logged sensor data. Sensor data were always recorded in 1 min intervals once a gear activity was started and until it was ended.

While data was recorded with Mofi, the fishers could view the current track on a map on the interface of the application, including the gear activities marked by time stamps and the areas shallower than 20 m (Figs. S1–S2), which were based on the 20 m isobath adapted from official national nautical charts from Germany (provided by the Federal Maritime and Hydrographic Agency) and Denmark (provided by the Danish Geodata Agency).

2.3. Categorization and editing of trips and gear activities

To assess the quality of the originally recorded sensor and self-reported data, detect potential recording errors and define which data were useable for subsequent analyses, all trips and gear activities of the original data were checked manually using the commercial analyser software BlackBox Analyzer (Anchor Lab A/S, Version 4.6.5.0). During this process trips and gear activities were identified and assigned to different categories and time stamps were edited to correct for mistakes that occurred during self-reporting. In the remainder, these data are referred to as the categorized sensor and self-reported data covering unedited and edited trips and gear activities. No editing was performed to the sensor data at any point.

The BlackBox Analyzer displayed the sensor data together with the self-reported data and enabled us to identify errors in self-reporting, categorize the trips and gear activities and edit time stamps. The sensor data were shown as geographical tracks on a map linked to a time line with corresponding speed profile (Fig. 2). Speed was also reflected in the colour coding of the tracks in the map. The time stamps of the self-reported data representing start and end of trips and gear activities were labelled in the time line. The analyser had the option to adjust, delete and add time stamps and with it, trips and gear activities and thereby editing the self-reported data. The combination of geographical pattern and speed pattern shown in the map, the speed profile of the time line and the possibility to view previous and subsequent trips and gear activities simultaneously, allowed to identify, evaluate and categorize trips and gear activities, edit time stamps, and match related gillnet activities, i.e. setting activity and hauling activity of the same net. This type of data review required training to gain experience in and familiarize with the different patterns observed for different vessels and to be able to evaluate the set or missing time stamps.

Sensor and self-reported data were exported from the BlackBox Analyzer as CSV files before and after data review to obtain the original and the categorized data sets. Based on the assigned categories, trips and gear activities of the categorized data were defined as i) useable without editing, ii) useable after editing and iii) not useable for further analyses in R 4.1.0 (R Core Team, 2021). For an overview of the different

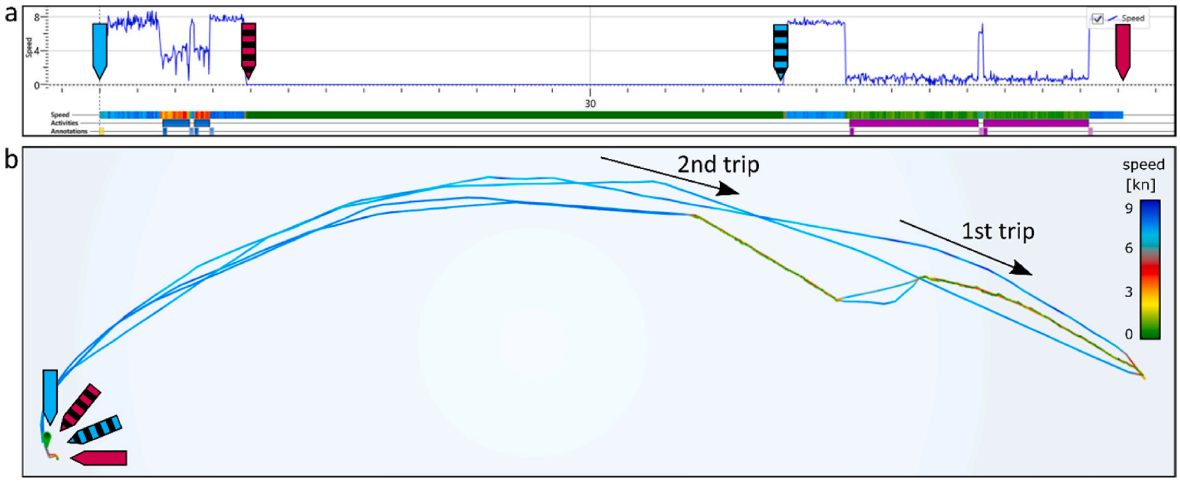

Fig. 2. Example of trips and related gear activities as displayed in the BlackBox Analyzer to illustrate the editing process. Two trips marked as one by the time stamps set by the fisher were separated to represent two single trips. Panel (a): Time line with speed profile of two separate trips from the same vessel (data exported from the BlackBox Analyzer). Blue graph: recorded speed of the vessel. First data series below blue speed graph: colour-coded speed profile, see speed legend in (b). Second data series below blue speed graph: blue bars mark unedited or edited setting activities of gillnets; purple bars mark unedited or edited hauling activities of gillnets. Third data series below blue speed graph: blue rectangles mark time stamps set by the fisher to indicate start and end of setting activities of gillnets; purple rectangles mark time stamps set by the fisher to indicate start and end of hauling activities of gillnets. Blue and red solid arrows: positions of the original time stamps set by the fisher to define start and end of a trip, respectively. Blue and red striped arrows: positions of time stamps that were re-positioned or newly added during editing to define start and end of a trip, respectively. Panel (b): Screenshot of the mapped geographical tracks of the trips and gear activities shown in (a). Black arrows indicate the direction of the vessel during each trip. Speed along the tracks is colour-coded according to the recorded speed as given in the legend in (b) and arrows imply the same as described for (a). The two original time stamps covered two different trips letting them appear as one trip and affecting the total number of trips and the trip duration. During this one trip, the vessel arrived at and left again from a location typical for the respective vessel to start and end trips (taking into consideration other trips done with same vessel) and showed a prolonged time period with zero speed (a) and no movement (b). This indicated that these were actually two different trips. They were then separated during editing by setting new time stamps and assigned to the respective category. To maintain confidentiality of the anonymised self-reported data from the fishers, coastline, bathymetry, coordinates, scale and orientation are not shown in the map.

categories, we assessed their distribution across vessels and over time.

To evaluate the effect of editing the time stamps, we compared data from gillnet activities before and after editing. First, the net lengths of all set and hauled gillnets were calculated from the original as well as from the categorized gillnet activities. The time stamps provided the start and end positions, and the sensor data provided the positions in between needed for the net length calculation using the R package geosphere (Hijamns, 2019). Next, only net lengths of complete gillnets pairs with useable gillnet activities were considered. A complete gillnet pair consisted of a net length for when a net was set and for when the exact same net was hauled again. Then we calculated the percentage difference between the net length for setting and the net length for hauling if both activities were not edited. The same was done for complete pairs of which either the net length of setting or the net length of hauling was edited. The latter was done once before editing (original data) and once after editing (categorized data). We then checked if editing caused a decrease in percentage difference and whether this percentage difference was similar to the one observed for pairs where no editing was considered necessary to neither the setting nor the hauling activity.

2.4. Activity data

Trip duration was calculated from all useable trips according to the time stamps that defined start and end of a trip. From the useable trips a subset was taken only containing trips with useable gear activities to assess the number of gear activities per trip. In case of gillnets, only set nets were considered.

The geographical positions of landing sites were extracted using the BlackBox Analyzer. For each useable gear activity the average linear distance to the respective landing site was estimated (R package geosphere (Hijamns, 2019)).

Trip duration, number of gear activities per trip (several gillnets can be set or hauled and trawls performed per trip) and distance to landing site were calculated for different fishing gears, reporting procedures and business types. The latter two were only possible for gillnet activities as trawl activities were only found among logbook and full-time vessels.

For the gear activities per fishing gear, we calculated the average duration needed (time needed for setting and hauling gillnets, time trawled), the average geographical distance covered (net length of setting and hauling gillnets, distance trawled) and the average speed (speed of setting and hauling gillnets, trawling speed, steaming speed of gillnet and trawl trips) recorded.

2.5. Spatial relation of gear activities to the 20 m isobath

For the useable gear activities, the depths were extracted using the geographical coordinates from the sensor data, ESRI ArcMap (version 10.6) and interpolations from GEBCO (GEBCO Compilation Group, 2019). We then calculated the mean depth for gillnet and trawl activities based on the mean depths of the individual gear activities.

To assess the amount of gear activities recorded completely shallower than 20 m, partially deeper than 20 m and completely deeper than 20 m, we used the same shapefile that was used for the demarcation of areas shallower than 20 m in the map displayed in Mofi (R package rgdal (Bivand et al., 2021) and R package sf (Pebesma and Bivand, 2021)). For the gear activities recorded partially deeper than 20 m, the average maximum distance to the 20 m isobath (taking the point of each gear activity furthest away) was calculated. For the gear activities recorded completely shallower than 20 m, the average minimum distance to the 20 m isobath (taking the point of each gear activity that was closest) was calculated as well as the average distance to the 20 m isobath for 25%, 50% and 75% of the gear activities performed completely shallower than 20 m.

3. Results

3.1. Coverage

During the two-month fishing closure in 2018, a total of 110 fishing vessels registered on Mofi. Three of the 110 vessels were registered but never logged in and recorded any data. This left data from 107 vessels and 105 vessels owners to be evaluated. 102 vessels from 100 owners had trip and gear activity data and five vessels from five owners had trip data only (Table 1). The majority of vessels were operated in full-time (62% of the 107 vessels) and the share of vessels using landing declarations was higher than of vessels using logbooks (57% of the 107 vessels) (Table 1).

In February and March of 2018, 351 German vessels with a length of less than 12 m reported landings from ICES SDs 22–24. 107 of these 351 vessels reported cod landings and 85 of the 107 vessels (79%) had Mofi records. The total of reported cod landings from these 107 vessels during the fishing closure were 50 166 kg. 47 780 kg of these cod landings (95%) were from vessels that also had Mofi records. About 2.4 t of cod landings were from the 22 vessels that did not use Mofi during the closure.

3.2. Categorization and editing of trips and gear activities

The original Mofi data covered 1637 trips and 6542 gear activities (Fig. S3) and sensor data showed a GPS accuracy of 7.2 m ± 75.5 SD (median = 4.0 m). During data evaluation eleven categories were defined for the trips and twelve for the gear activities (Tables 2 and 3). After identification, categorization and editing, the categorized data (Fig. S3) covered a total of 1618 trips (99%) and 7972 (122%) gear activities. The change in number was due to the categories SPLIT and SEVERAL for trips and due to the categories MISSED and SEVERAL for gear activities (Tables 2 and 3). 67% of the 1618 trips and 29% of the 7972 gear activities were assigned to categories that were considered useable without the need for editing (Tables 2 and 3). Including also the categories that involved editing of time stamps, the useable trips increased to 78% and the useable gear activities to 69%. Trip categories were not evenly distributed across the vessels and certain categories were more typical for some vessels than for others (Fig. 3). In contrast, gear activity categories were more evenly distributed across the vessels (Fig. 4). Regarding the distribution of trip and gear activity categories over time, a decrease of the TRIAL-category was observed (Figs. S16–S17). Other than that, no clear trends were identified.

Table 1
Distribution and length range of vessels with Mofi records across reporting procedure and business type. 107 vessels from 105 owners had data on trips and 102 vessels (covering 100 owners) of these 107 vessels had both data on trips and on gear activities. Totals in bold.

		vessels with trip data			vessels with trip and gear activity data		
		landing declaration (<8 m)	logbook (8–12 m)	total	landing declaration (<8 m)	logbook (8–12 m)	total
number of vessels	part-time	37	4	**41** (38%)	35	3	**38** (37%)
	full-time	24	42	**66** (62%)	22	42	**64** (63%)
	total	**61** (57%)	**46** (43%)	**107**	**57** (56%)	**45** (44%)	**102**
vessel length range [m]		4.00–7.99	8.20–11.99		4.20–7.99	8.20–11.99	
number of vessel owners				**105**			**100**

Table 2
Eleven categories were defined to classify the 1618 identified trips viewed with the BlackBox Analyzer. Categories are specified and listed in descending order according to the relative proportion. Italic categories: most likely involving technical causes. Categorized trips useable for trip duration analysis: (a) yes, without editing, (b) yes, after editing, (c) no, not useable. The total exceeds 100% as the INCOMPLETE-category can overlap with other categories. Examples of some major trip categories are explained in Figs. S4–S8. Proportions were rounded to zero decimals if they were >1.

Trip category	Specifications and details on editing	Proportion (%)
FIT (a)	- good correspondence between set time stamps defining start and end of trip and start and end location typical for the respective vessel; no further editing - missing GPS records during trip possible	67
TOOLATE (b)	- time stamp defining the end of a trip was set with delay (>30 min after vessel arrived back at landing site) - editing of time stamp leading to shortening of trip	7
INCOMPLETE (c)	- trip (sensor data) recording started too late (time stamp set too late) or ended too early (time stamp set too early), with start and/or end further away from a start and/or end location typical for the respective vessel - no previous or subsequent sensor data available as in case of TOOLATE and TOOEARLY to adjust time stamps - can overlap with other categories	7
N (c)	- usually few geographical positions recorded, mostly on land or in vicinity of a landing site indicating that no trip was done - often with successful trips shortly before and after, making the TRIAL-category unlikely	5
SEVERAL (b)	- trip was not ended and covered several independent trips - was split into the different single trips - increased number of trips	3
TRIAL (c)	- trip defined by time stamps did not refer to a trip related to potential activities at sea - mostly recorded on land - assumed to have been a trial by the fisher to test the smartphone application	3
UNK (c)	- not possible to tell whether it was an actual trip - often related to missing GPS data	*3*
NODATA (c)	- sensor data missing completely - data on time stamps still available	*3*
SPLIT (b)	- trip was suspended and resumed by starting a new trip splitting it into two or more sections - sections were fused during editing to form one single trip - decreased number of trips	2
DUPLICATE (c)	- trip recorded more than once (same date, time, speed pattern and geographical pattern)	*0.25*
TOOEARLY (b)	- time stamp defining the start of a trip was set too early (>30 min before vessel left landing site) - editing of time stamp leading to shortening of trip	0.19

Table 3
Twelve categories were defined to classify the 7972 identified gear activities viewed with the BlackBox Analyzer. Categories are specified and listed in descending order according to the relative proportion. Italic categories: most likely involving technical causes. Categorized gear activities useable for further analysis: (a) yes, without editing, (b) yes, after editing, (c) no, not useable. The total exceeds 100% as the GPS-category and the WRONG-category can overlap with other categories. Examples of some major gear activity categories are explained in Figs. S9–S15. Proportions were rounded to zero decimals if they were >1.

Gear activity category	Specifications and details on editing	Proportion (%)
FIT (a)	- good correspondence between set time stamps defining start and end of activity and start and end position of gear activity indicated by speed pattern, geographical pattern and if given in relation to previous and/or subsequent gear activities; no further editing	29
SHIFT (b)	- time stamp of gear activity set too early or too late in relation to speed pattern and geographical pattern and if given in relation to previous and/or subsequent gear activities - editing of time stamp and with it editing of gear activity	18
MULTIPLE (c)	- very large number of subsequent time stamps in quick succession - resulting in very short gear activities within a short time period	*14*
SEVERAL (b)	- gear activity defined by time stamps covers several different gear activities - editing by adding time stamps to represent the single gear activities - increased number of gear activities	12
MISSED (b)	- no gear activity marked by time stamps although speed pattern and geographical pattern suggest a gear activity - often indicated by a previous or subsequent corresponding gear activity that was missing a partner activity (e.g. setting/hauling of gillnet) - adding time stamps to define missed gear activity - increased number of gear activities	11
MISTAKE (c)	- time stamps did not define an actual gear activity in relation to speed pattern and geographical pattern and if given in relation to previous and/or subsequent gear activities	10
GPS (c)	- missing GPS positions or GPS outliers within the recorded track of a gear activity, which can substantially affect its unambiguous identification and estimation of geographical distance covered, e.g. net length in case of gillnets - can overlap with other categories	*6*
WRONG (b)	- wrong type of gear activity stamp assigned, e.g. hauling instead of setting - inferred from speed pattern, geographical pattern and previous or subsequent partner activity if available (e.g. setting/hauling of gillnet) - assignment of correct activity type - can overlap with other categories	2
TRIAL (c)	- part of a TRIAL trip - time stamp did not define an actual gear activity in relation to the speed pattern and geographical pattern - assumed to have been a trial primarily done on land by the fisher to test the smartphone application	0.92
NODATA (c)	- part of NODATA trip - sensor data missing completely - data on time stamps still available	*0.60*
UNK (c)	- not possible to infer from speed pattern, geographical pattern or partner activity if it was an actual gear activity	0.15
DUPLICATE (c)	- gear activities recorded more than once (same date, time, speed pattern and geographical pattern)	*0.03*

The majority of trips (57%) and gear activities (65%) were from logbook vessels and about three-quarter of the trips (73%) and gear activities (77%) were from full-time vessels (Table 4). 76, 16, 2, and 6% of the vessels had records in SD22, SD24, in both subdivisions or could not be assigned as the trips were of the category NODATA or UNK, respectively.

Different data subsets were used for subsequent analyses (Fig. S3) because trips and gear activities covered categories that did not always refer to actual or unambiguously identified trips or gear activities that were considered useable (Tables 2 and 3).

The percentage difference in net length between complete gillnet pairs decreased from 23% ± 25 SD to 7% ± 6 SD by editing either the setting or the hauling activity because time stamps were considered to not have been set at the correct position. No evidence for a significant difference was found between this decreased percentage difference (7% ± 6 SD) and the percentage difference (6% ± 5 SD) observed for complete gillnet pairs of which neither the setting nor the hauling activity was edited (non-normally distributed data, no equal variance, Wilcoxon signed rank sum test: p-value = 0.149, $\text{median}_{\text{WithoutEditing}} = 5.24\%$, $\text{median}_{\text{WithEditing}} = 5.33\%$).

3.3. Activity data

Mean duration of trips with gillnet activities was 4.1 h ± 2.3 SD (1176 trips from 92 vessels, Table S1). Trips with gillnet activities from logbook vessels (4.9 h ± 2.4 SD, 731 trips from 40 vessels) and full-time vessels (4.6 h ± 2.3 SD, 905 trips from 58 vessel) lasted longer than those from landing declaration vessels (2.9 h ± 1.6 SD, 445 trips from 52 vessels) and part-time vessels (2.5 h ± 1.3 SD, 271 trips from 34 vessels). Trawl trips lasted about 11.6 h ± 5.9 SD (59 trips from seven vessels, Table S2) and trips without any identified gear activity were short and took on average 0.9 h ± 0.9 SD (23 trips from 14 vessels). About 20% of the trips lasted less than 2 h, 54% less than 4 h and 77% less than 6 h (Fig. 5).

The pattern of trip duration corresponded to the pattern observed for the linear distance of gear activities to a landing site: gillnets from logbook vessels (11.8 km ± 8.7 SD, 3701 gillnets from 37 vessels, Table S3) and from full-time vessels (10.6 km ± 8.4 SD, 4463 gillnets from 55 vessels) were set further away from a landing site than gillnets from landing declaration vessels (4.2 km ± 3.5 SD, 1696 gillnets from 52 vessels) and from part-time vessels (4.0 km ± 4.5 SD, 934 gillnets from 34 vessels). The mean linear distance of gillnets across reporting procedure and business type was 9.4 km ± 8.2 SD (5397 gillnets from 89 vessels, Table S4). Trips with trawl activities did not only last the longest but the gear activities were also furthest away from a landing site (23.7 km ± 12.5 SD, 73 trawls from seven vessel, Table S4).

Landing declaration vessels set less gillnets (2.8 ± 1.9 SD, median = 2, 788 gillnets from 46 vessels) than logbook vessels (3.5 ± 2.5 SD, median = 3, 1588 gillnets from 37 vessels), and part-time vessels (2.7 ± 1.8 SD, median = 2, 165 gillnets from 31 vessels) less gillnets than full-time vessels (3.4 ± 2.4 SD, median = 3, 1936 gillnets from 52 vessels, Table S5). Across all analysed gillnets, 3.3 ± 2.3 SD (median = 3) gillnets were set per trip (2376 gillnets from 83 vessels) and on average 1.6 ± 0.8 SD trawls were performed during a trip (55 trawls from seven vessels, Table S6).

The mean speed during setting and hauling was 2.9 kn ± 1.1 SD and 1.1 kn ± 0.4 SD (2521 setting and hauling activities each from 84 vessels), respectively (Table S7). Setting and hauling a gillnet lasted on

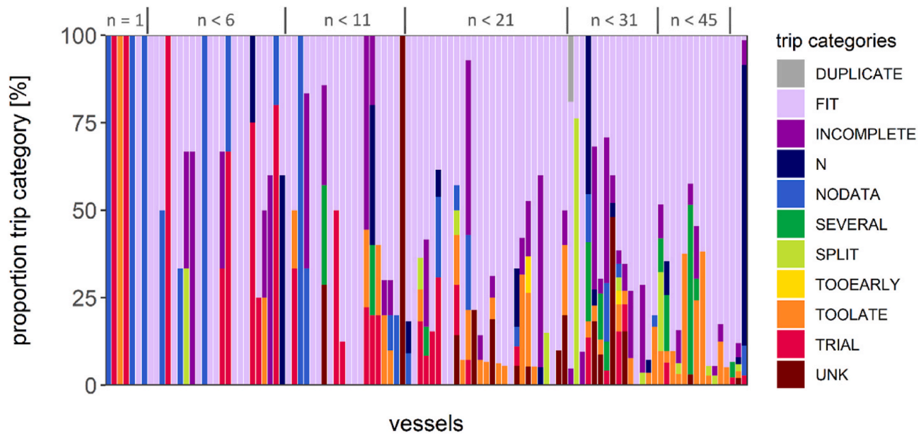

Fig. 3. Proportion of trip categories per vessel (n = 107); each complete bar (100%) represents a single vessel. Vessels from left to right in ascending order with increasing number of trips per vessel. Number of trips per vessel are given as ranges above the bars. The category INCOMPLETE can overlap with other categories (<1% overlap of the 1618 trips). In case of overlap, the INCOMPLETE-category was plotted.

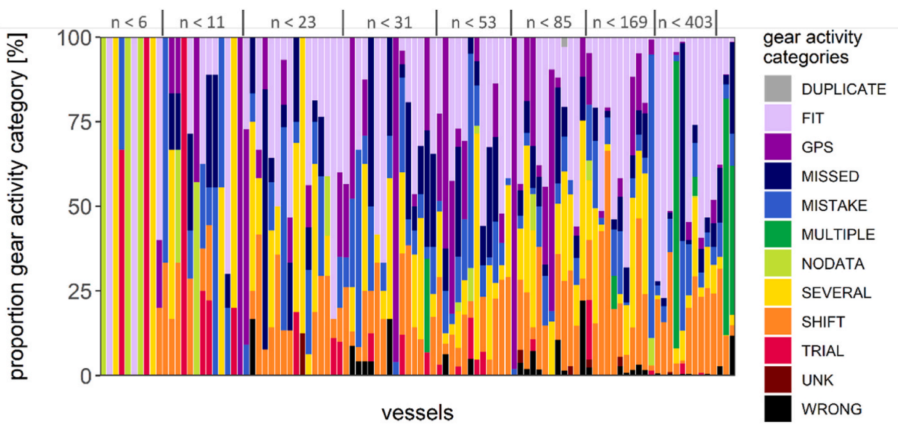

Fig. 4. Proportion of gear activity categories per vessel (n = 102); each complete bar (100%) represents a single vessel. Vessels from left to right in ascending order with increasing number of gear activities per vessel. Number of gear activities per vessel are given as ranges above the bars. The categories GPS and WRONG can overlap with other categories (GPS: 1.5% overlap of the 7972 gear activities; WRONG: 2% overlap of the 7972 gear activities). In case of overlap, first the WRONG-category and then GPS-category was plotted.

Table 4
Distribution of identified and categorized trips (n = 1618) and gear activities (n = 7972) from the categorized data across reporting procedure and business type. Totals in bold.

		landing declaration (<8 m)	logbook (8–12 m)	total
number of trips	part-time	411	23	**434** (27%)
	full-time	281	903	**1184** (73%)
	total	**692** (43%)	**926** (57%)	**1618**
number of gear activities	part-time	1692	120	**1812** (23%)
	full-time	1090	5070	**6160** (77%)
	total	**2782** (35%)	**5190** (65%)	**7972**

average 10.4 min ± 7.6 SD and 29.9 min ± 27.3 SD, respectively (Table S8). Trawling activities had a mean speed of 3.1 kn ± 0.2 SD, lasted 3.4 h ± 1.9 SD and covered a mean distance of 19.2 km ± 11.1 SD (73 trawls from seven vessels, Table S9).

Steaming speed was 5.5 kn ± 1.9 SD for gillnet trips (1087 trips from 84 vessels) and 4.5 kn ± 3.2 SD for trawl trips (46 trips from seven vessels) after excluding outliers using more than two standard deviations from the mean as the threshold (Table S10). For the estimation of the steaming speed of trawl trips we noticed a large difference in the steaming speed between the mean (4.5 kn) and the median (6.1 kn) and that the mean was smaller than that of the gillnet trips (mean = 5.5 kn). Viewing the respective trawl trips in the BlackBox Analyzer showed that this was due to the fact that the gear activity was ended directly after the actual trawling was finished. As a result, gear and catch handling following trawling was marked as part of the steaming phase. Gear and catch handling after the actual trawling can take a considerable amount of time and thus covered many sensor data corresponding to a period when the vessel moves at low speed. However, attributing these data points to the trawling activity would then bias the speed of the actual gear activity. We decided to exclude data from the steaming phase that were below the first quantile (0.7 kn), and re-estimated the steaming speed of the trawl trips, which resulted in 6.0 kn ± 2.3 SD (median = 7.1 kn). This observation was not noticed for the steaming speed of gillnet trips as gear and catch handling is usually already included in the hauling activity.

For the analysis of net length, the means between single pairs of set and hauled nets were used (showed significant linear relationship and no evidence for a significant difference in net length, see Figs. S18–S19). The mean net length was 853 m ± 690 SD (across the mean net lengths of 2521 pairs of set and hauled gillnets from 84 vessels, Table S11), irrespective of reporting procedure and business type and showed a peak at around 500 m (Fig. 6). The mean net length of landing declaration vessels and of logbook vessels was 664 m ± 538 SD (median = 527 m, 792 gillnet pairs from 48 vessels) and 940 m ± 734 SD (median = 765 m, 1729 gillnet pairs from 36 vessels), respectively. The mean net length of part-time vessels and of full-time vessels was 557 m ± 464 SD (median = 475 m, 439 gillnet pairs from 32 vessels) and 916 m ± 713 SD (median = 715 m, 2082 gillnet pairs from 52 vessels), respectively. Soak

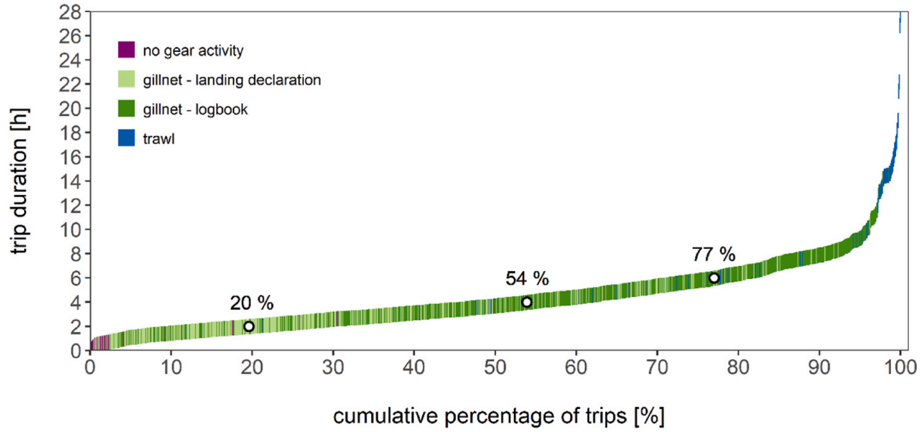

Fig. 5. Cumulative percentage of trips (1258 trips from 95 vessels) from left to right with increasing trip duration, coded as trips without any gear activity, with gillnet activities from landing declaration vessels, with gillnet activities from logbook vessels and with trawl activities. White circles indicate the cumulative percentage of trips at a trip duration of 2, 4 and 6 h.

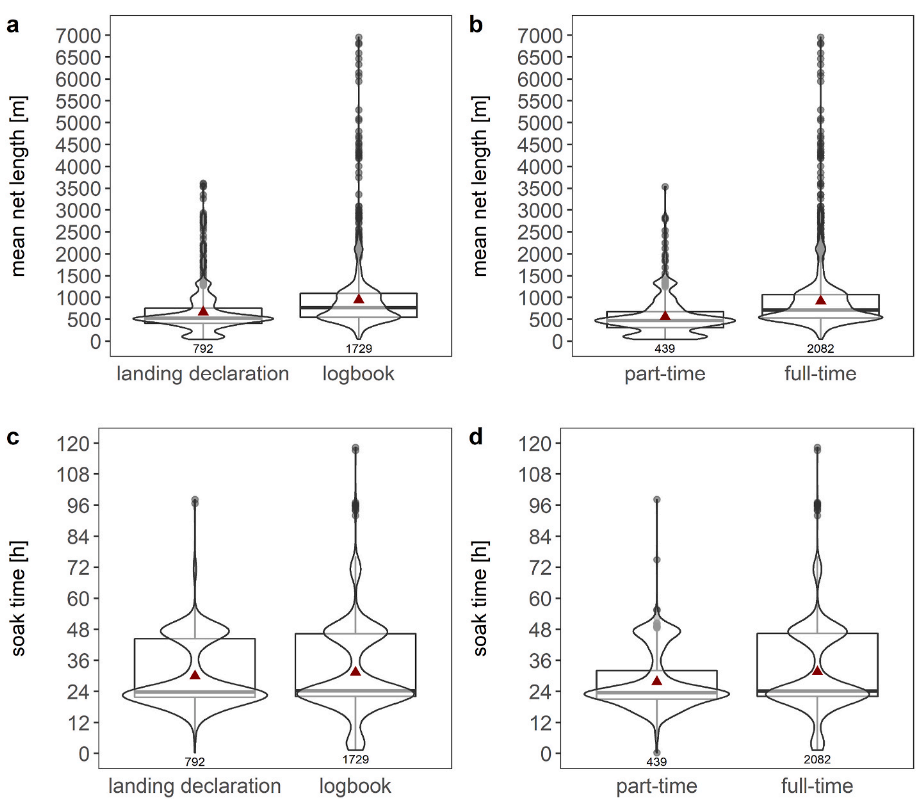

Fig. 6. Mean net length, panels (a) & (b), and soak time, panels (c) & (d), of 2521 pairs of set and hauled gillnets from 84 vessels. (a) & (c) grouped by reporting procedure (landing declaration, logbook) and (b) & (d) grouped by business type (part-time, full-time) (Tables S11–S12). Each graph shows a combination of a boxplot overlaid with a probability density plot of the underlying data distribution. Boxplots: whiskers extend by a maximum of 1.5 times the interquartile range. Red triangle: mean. Density plots: based on kernel probability density function using normal distribution and the Silverman estimation to define the bandwidths.

time across all pairs of set and hauled gillnets was 31.0 h ± 15.7 SD (median = 24 h, 2521 pairs of set and hauled gillnets from 84 vessels, Table S12) and peaked at around 24 h and 48 h (Fig. 6), irrespective of reporting procedure and business type. Soak time of landing declaration vessels and logbook vessels was 30.0 h ± 12.9 SD (median = 23.7 h, 792 gillnet pairs from 48 vessels) and 31.3 h ± 16.8 SD (median = 24.2 h, 1729 gillnet pairs from 36 vessels), respectively. The soak time of part-time vessels and full-time vessels was 27.7 h ± 11.6 SD (median = 23.6 h, 439 gillnet pairs from 32 vessels) and 31.6 h ± 16.3 SD (median = 24.2 h, 2082 gillnet pairs from 52 vessels), respectively.

3.4. *Spatial relation of gear activities to the 20 m isobath*

Gillnets were set at a mean depth of 11.2 m ± 5.5 SD (5413 gillnets from 89 vessels) and trawls were operated at a mean depth of 18.10 m ± 1.8 SD (73 trawls from seven vessels). 99% of all 7972 identified and categorized gear activities were performed completely in areas shallower than 20 m. Similarly, 99% of the 5486 useable gear activities were performed completely in areas shallower than 20 m. There was one single gillnet that was set and hauled completely deeper than 20 m (representing two gear activities, i.e. 0.04% of the 5486 gear activities). In the other cases, only parts of the gear activities were recorded deeper than 20 m.

The mean maximum distance to the 20 m isobath of useable gear activities partially deeper than 20 m was 36 m ± 45 SD. For the gear activities performed completely in areas shallower than 20 m, the mean minimum distance to the 20 m isobath was 3290 m ± 3799 SD, with 25, 50 and 75% of the gear activities closer than 606, 2032 and 3852 m to

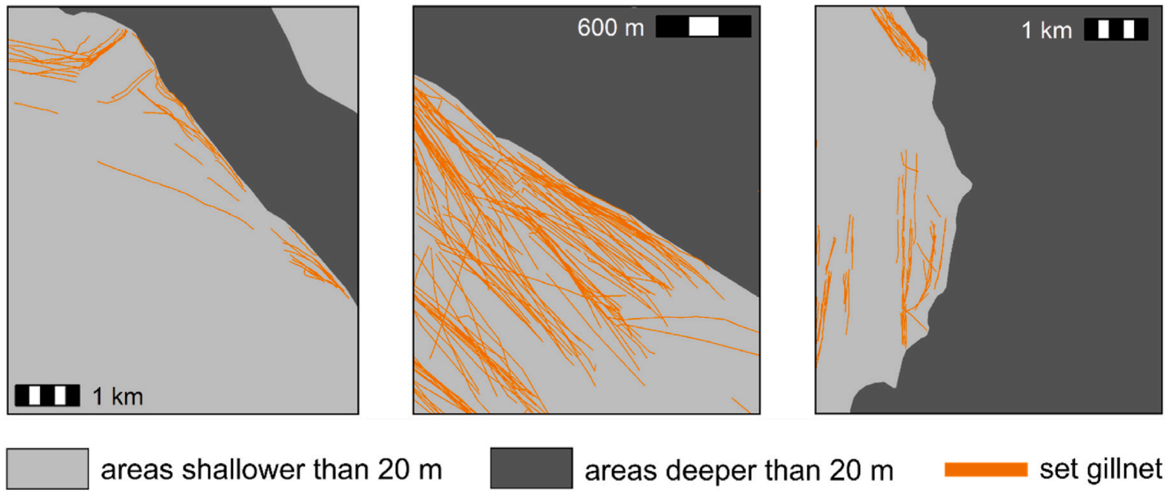

Fig. 7. Illustrative details of set gillnets from three different areas. Gear activities of at least four vessels across the two-month closure of cod fishery in 2018 are shown per panel. To maintain confidentiality of the anonymised self-reported data from the fishers, coordinates and orientation are not given.

the 20 m isobath, respectively. The gillnets were set with a high level of spatial precision in relation to the 20 m isobath and with a clear cut-off in gear activities between areas shallower and deeper than 20 m (Fig. 7).

4. Discussion

The two-month use of the smartphone application Mofi produced a unique set of self-reported data from small-scale fishers in European temperate-zone waters. Not all data could be used for subsequent analysis, though it was possible to increase the proportion of useable gear activities and trips from 29 to 69% and from 67 to 78%, respectively, by editing during the data review. This offered a comprehensive data set for the analysis of activities and showed that 99% of the gear activities were performed shallower than 20 m proving high compliance for the vessels whose activities were monitored with Mofi. Nothing can be said about individual trips or activities that might not have been recorded or the 22 vessels that covered 2.4 t of cod landings during the closure and did not use Mofi.

A combination of sensor and self-reported data allowed for detailed analyses of general trip information (trip duration, location of landing sites and fishing grounds and the linear distance between them, the number of gear activities per trip and the steaming speed), fishing effort (length and soak time of gillnets, trawled distance, trawling duration) and gear handling (speed during setting and hauling of gillnets and during trawling) on the level of single gear activities and trips. This was possible for all vessels independent of their size, including the data-poor segment of vessels smaller than 8 m.

The gillnet fishers conducted fast and precise operations at sea that require a high recording interval to ensure that the spatio-temporal resolution of their activities is appropriately reflected in the collected data. As already noted by Mendo et al. (2019b) for vessels smaller than 9.5 m and supported by our study, recording intervals of max. 1 min provide a reasonable spatio-temporal resolution for small-scale fisheries.

Circumstances for the introduction of Mofi were challenging given that the obligatory use was communicated only shortly before the start of the closure. Fishers were untrained in the use of Mofi and for many it was likely the first time that they had to use such an electronic reporting tool at sea. Several commercial small-scale fishers even desisted from fishing for cod during the closure because they did not want to use Mofi (pers. communication with fishers).

4.1. Activity data

The coverage of vessels smaller than 8 m allowed for first-time insights into the activities of part-time vessels as they were mainly found within this segment. Part-time vessels were less active (covered roughly one-fourth of the trips and gear activities, set fewer and shorter gillnets, trips were shorter and gear activities were closer to a landing site) than full-time vessels. The lesser activity of the part-time vessels might reflect lesser allocated quota. In Germany, part-time vessels that are not organized in a producer organization are part of a rationed quota pool of which each vessel gets the same predefined amount of cod quota per month (in 2018: 100 kg cod per month (BLE, 2017)). This quota is then not related to historical landings, landings of previous years or the fishing capacity (SeeFischG, 1984; STECF, 2020) of the respective non-organized part-time vessel, in contrast to the quota for organized part-time vessels and full-time vessels. Such highly resolved activity data at hand offer the possibility to then assess whether the degree of activity is also reflected and corresponds to the landings declared by the different business types and reporting procedures or whether disparities are observed. Though the vessels smaller than 8 m including part-time as well as full-time vessels were less active than logbook vessels, they still showed a high activity (43% of the trips, 35% of the gear activities), which supports the need for an improved monitoring of this segment.

The mean soak time of 31 h for gillnets was within the range of what has been reported from other demersal gillnet fisheries in the same (western Baltic Sea) or in nearby (Skagerrak) regions of 8, 12 and 41 h in Danish gillnet fisheries (Glemarec et al., 2020; Kindt-Larsen et al., 2016) and of 22 h in a Swedish gillnet fishery (Glemarec et al., 2021). Also, the median net length for logbook vessels (765 m) was similar to what was observed for three Danish gillnetters (731 m) (Glemarec et al., 2020), which however had a higher median number of nets per trip ($n = 5$) compared to the German gillnetters ($n = 3$ for logbook vessels). Whether the trip characteristics and gear activities recorded with Mofi during the closure reflect standard gillnet operations typical for targeting demersal fish during the first quarter in the western Baltic Sea can only be assessed if data is also collected under similar conditions but without the provisions set by a closure.

4.2. Spatio-temporal resolution

During our study, we observed a mean duration of setting a gillnet of 10.4 min ± 7.6 SD. In case of a 5 min recording interval for the sensor data, as used at the beginning of our study, the short setting activities would on average only be covered by two data points if not marked by time stamps (which then increased the recording interval to 1 min). This makes it more likely to miss short activities, and our results suggest recording intervals of max. 1 min for the monitoring of small-scale fisheries, which is in line with the findings of previous studies. For example, other electronic monitoring tools worked with intervals as short as 10 s for the recording of GPS positions (Glemarec et al., 2020), and Mendo et al. (2019b) showed that results on area fished were consistent when the recording interval of GNSS (Global Navigation Satellite System) data in a Scottish small-scale pots and trap fishery was <1 min and <2 min for vessels with a length of <9.5 m and 9.5–12 m, respectively.

The short trip duration observed also supports the need for a high temporal resolution in monitoring. About 50% of the trips were shorter than 4 h, and if standard VMS monitoring would be used with typical recording intervals of about 1 h (range: 15 min to 2 h; ICES, 2019b), the data coverage would be very low making it more likely to miss activities. It was already shown that even for vessels larger than 12 m the use of VMS at a recording interval of 2 h (common also for the monitoring of German vessels >12 m (von Dorrien et al., 2013)), causes trips and fishing sets (defined as shooting, closing and hauling a purse seine and transferring the fish on board) not to be identified (Katara and Silva, 2017).

Due to the high spatial resolution, the fishers could prove compliance with the terms of the closure, which would not have been possible at the spatial resolution of ICES statistical rectangles (approx. 30 × 30 nm (ICES, 1977)). Very specific fishing patterns were observed and showed that fishers operated with a very high spatial precision setting gillnets parallel right next to the 20 m isobath and still staying shallower than 20 m. ICES statistical rectangles are often considered too coarse to be effective for marine spatial planning and more spatially explicit information could support a better integration of fisheries into the process of planning the use of marine space (Janβen et al., 2018).

Spatial data on fishing activities are an essential element in fisheries management and could become even more valuable if supplied with high spatio-temporal resolution. Damasio et al. (2020) demonstrated with spatial fisheries data obtained from semi-structured interviews that the geographical extent of fishing areas from Brazilian small-scale fisheries had changed over a time span of 20 years and moved further offshore into deeper waters. There were indications that depletion of the target species might have been the reason for shifting fishing grounds. By applying regular and highly resolved spatial monitoring with reporting tools such as smartphone applications there might be the potential to detect gradual and small changes in time earlier and adapt fisheries management accordingly to circumvent potential negative socioeconomic and ecological consequences.

Also, the design and the assessment of the efficiency and the impact of marine protected areas rely on spatial information. Stelzenmüller et al. (2008) assessed the distribution of fishing effort density from small-scale fisheries in relation to no-take zones in France, Malta and Spain and identified a concentration of effort density around the borders of some of these zones. The coverage of total possible fishing effort ranged from 7 to 100%. Except for Malta where the fishers were obliged to report their catch positions, members of the research team accompanied the fishers on-board of the vessels to record geographical positions of the deployed gear. Such data collections might be facilitated if trained fishers used smartphone applications for data recording, leading to less staff required on-board of the vessels and potentially increasing data coverage to support evaluation of the effectiveness of marine protected areas. This self-reporting approach would also be much more cost-effective.

In a Polish study participatory mapping was carried out to localise fishing grounds used by the small-scale fishery with the aim to highlight areas, which are essential for them and to foster their participation and inclusion in the management of marine space (Psuty et al., 2020). Provided that this is supported by the fishery, the use of a smartphone application for the recording of fishing activities could potentially strengthen their grounds and stress the importance of specific coastal areas reserved for small-scale fisheries.

Spatial information also plays an important role with respect to incidental bycatch. Mustika et al. (2021) showed that fishing area was either the first or second most important factor influencing the amount of marine megafauna bycatch at the northern part of the island Sulawesi, Indonesia. Data on available fishing effort was on the level of number of trips per week and the coastal zones analysed covered several kilometres. Being able to record fishing activities on a high spatio-temporal resolution could help to focus on the areas in which bycatch occurs more frequently and thus develop a specific bycatch mitigation approach.

These studies present examples that show that the use of a smartphone application might be beneficial for fishers and small-scale fisheries management because they can complement data collection and document inter alia fishing grounds, distance to landing site or fishing effort parameters such as net length of gillnets at high spatio-temporal resolution. However, it should be assessed case by case if this electronic reporting approach is the most feasible and suitable for a given situation and the prevailing conditions.

4.3. Challenges and improvements

The majority of trips and gear activities that required editing were related to errors in operating the smartphone application and setting time stamps while at sea. In the following we discuss potential improvements on how these challenges could be overcome.

Training: The lack of training prior to the introduction of Mofi was inter alia reflected by the TRIAL-category and its decrease over time. Each fisher has an individual on-board workflow, sometimes established over years, and it needs time and practice to implement and incorporate new routines. Training to practice the handling of a specific electronic reporting tool could help to decrease operating errors (e.g. Paul et al., 2016). Given the distribution of gear activity categories among the vessels, a general training might be advisable. In the few cases, where a vessel is dominated by a specific category (e.g. SPLIT or SEVERAL for trips) individual support and training might be more appropriate.

Time stamps: Fishers reported that at times it was challenging to simultaneously operate a smartphone application and fishing gear while at sea, especially if only one person was on board and work required the use of gloves (pers. communication with fishers). This can cause delays, either in setting time stamps or in operating the gear. A possible solution to facilitate the handling and reduce the time delay could be a waterproof remote control deployed onboard that connects via Bluetooth to the mobile device and allows to remotely operate the application. Direct handling of the mobile device would then not be required anymore. This might also help to avoid the MULTIPLE-category, which could have been caused by water droplets on the sensitive touch screen disrupting the functionality of the application.

GPS: Missing GPS data or extreme GPS outliers could be related to the challenge of designing a smartphone application across a variety of hardware (different smartphone companies and GPS sensors) and software (different operating systems covering different versions), in combination with the dependency on the user to regularly update any necessary software and thus ensure optimal operability. Also, the recording of GPS data can be hampered if the GPS sensor is shielded by metal. One possible solution could be an external, standardized and dedicated GPS sensor to ensure a more reliable GPS recording. Other electronic reporting tools having their own dedicated GPS sensor could ensure a failure-free GPS recording (Kindt-Larsen et al., 2012). Improvements like an independent GPS sensor or a remote control, including the associated additional costs, challenge the idea of using a mobile device as a universal stand-alone tool for reliable data collection.

Other: Trips without any sensor data (NODATA-category) were mostly very short and there was potentially not enough time for the smartphone application to retrieve data from the GPS sensor or for the GPS sensor to receive a geographical position. In the rare cases where the exact same trip and gear activities were recorded twice (DUPLICATE-category), it is likely that a user logged in into the same account on two different devices at the same time on the same vessel. This can be solved by not allowing for a simultaneous login into the same account.

Data processing: Data evaluation, including the manual identification, categorization, editing of trips and gear activities, and matching of set and hauled gillnets was labour-intensive, required training and experience and was done with our best available knowledge assuming standard trips. In general, the data evaluation and editing seemed acceptable, which was inter alia reflected by the decrease in percentage difference in net length before and after editing and that no evidence for a significant difference was found between the net lengths of corresponding set and hauled gillnets covering edited as well as unedited gear activities. Such detailed and for a large part manual data processing might be justifiable to assess the first-time application of an electronic reporting tool but for routine use more automated, objective and effective evaluation algorithms are essential in order to ensure that data processing and analysis are efficient (Needle et al., 2015). For the development of analytic routines, it could be advantageous that Mofi can provide a combination of self-reported and independently collected data (the sensor data). For the latter, routines already exist, e.g. for VMS data (Hintzen et al., 2012; Watson and Haynie, 2016) or for the analysis of GNSS data (Mendo et al., 2019a) and non-VMS related GPS data (Behivoke et al., 2021).

5. Conclusion

The first large-scale use of the smartphone application Mofi showed potential of this approach to collect highly resolved spatio-temporal activity data, specifically from a temperate-zone European small-scale fishery. In the proposal for amending the EU control regulation, mobile phone technologies are suggested as easy and cost-effective tools to monitor especially small-scale fishing vessels (COM, 2018). However, a variety of aspects must be considered such as quality, accuracy, consistency, standardization, access, ownership and privacy of the recorded data as well as costs involved, handling of the devices and effective routines to analyse the collected data (ICES, 2019a; Skov et al., 2021). The experience gained during the application of Mofi suggests to invest into the training of fishers on how to use a new electronic reporting tool, thereby avoid reporting errors later on and ease the evaluation of the collected data. In some aspects the use of a mobile device as a stand-alone method is challenged and it might be worth investigating if an independent dedicated GPS sensor and a remote control can improve data recording. If the identified deficiencies are tackled, smartphone applications are likely able to complement standard reporting procedures and provide a tool for sharing the burden of proof in fisheries management (Fitzpatrick et al., 2011) and aiding results-based management (Nielsen et al., 2018).

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2022.106186.

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