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Original Article

Frameless—finding and refining a sampling frame for surveying recreational fisheries: lessons from estimating Swedish harvest of western Baltic cod

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To achieve sustainable fisheries, advice to management should be based on reliable science and unbiased data. Attaining quality data (i.e. precise and unbiased) on recreational fishing can be challenging, particularly when prior knowledge of the sector is limited and a proper sample frame of recreational fishers or vessels does not exist. In this study, a registry of access points was constructed for the Swedish south–west coast and used as a spatial sample frame in determining both effort and catches of the private boat fishery. Sampling dates, times for sampling, and access points visited were selected using probabilistic methods, ensuring unbiased results. The final multi-stage sampling design involved multiple strata, clusters, and probability selection methods and enabled first-time estimation of Swedish recreational landings of western Baltic cod by private boats to be used in stock assessment. Concurrent data collection covering aspects such as boat counts at access points, provided additional information on e.g. activity patterns. That additional information opens possibilities to refine the design of the original survey and optimize the sampling effort towards different goals, such as other fished resources. In this paper, we reflect on the challenges that limitations in initial information poses to the design and deployment of a new recreational fisheries survey. We suggest ways, whereby indirect sampling frames can be developed from initially incomplete or limited information to access the fishers and their catch. Our experience shows that, despite initial frame and knowledge limitations, full probabilistic methods are worth considering in data limited scenarios and that the design-based point estimates and variances they provide on recreational fishing effort and catches are useful in guiding initial management and the next steps of survey improvement.

Keywords: multi-stage sampling, on-site survey, probability sampling, recreational fisheries, western Baltic cod.

Introduction

To achieve sustainable fisheries, advice to management should be based on reliable science supported by unbiased data. Accomplishing such evidence-based management involves identifying the different types of fisheries that exert fishing pressure on the stocks and obtaining "good enough" data ahead of advice to management and management actions. Commercial fisheries have traditionally been treated as having great impact on the stock status, and commercial landings have long been used as the basis for stock assessment and management (Ricker, 1954; Beverton and Holt, 1957). In recent years, other components of fishing mortality have been increasingly considered, such as the additional mortality caused by discards (Aarts and Poos, 2009; Fernandez *et al.*, 2010).

In total, one fishing sector that exerts relevant pressure on many fished stocks is recreational fishing, with an estimated total global catch (retained and landed) of 900 000 t/year from marine waters (Freire *et al.*, 2020). Estimates from recreational fisheries are increasingly being included in stock assessments worldwide (Radford *et al.*, 2018), and the catches have in many cases been shown to be substantial (Hyder *et al.*, 2018; Radford *et al.*, 2018; Freire *et al.*, 2020). In the United States, the recreational catches dominate over commercial catches in several fisheries, such as the fishery for red drum (*Sciaenops ocellatus*), spotted sea trout (*Cynoscion nebulosus*), and striped bass (*Morone saxatilis*; NAS, 2017; Shertzer *et al.*, 2019). In Europe, however, marine recreational fisheries remain largely unquantified and only a few stock assessments have, thus far included marine recreational fisheries in their inputs: European sea bass (*Dicentrarchus labrax*), Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*), and western Baltic cod (WBC; *Gadus morhua*; Radford *et al.*, 2018). Although there are indications of substantial recreational catches in other stocks, recreational catch reporting has only recently been introduced in the EU Data Collection Framework (EU, 2016), and for a limited number of species. As such, for most stocks, recreational catches remain largely unknown and their impacts are still to be quantified.

Attaining high quality (i.e. precise and unbiased) data on catch, effort and biology of a fishery and its target stocks can be challenging, especially where prior knowledge of the sector is limited, and a sampling frame of fishers or vessels involved in the fishery does not exist. For most commercial fisheries of the International Council for the Exploration of the Sea (ICES) European areas, census data collected under fishery control regulations are available that, alongside good direct

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sampling frames (e.g. registers of licensed vessels), can be used to plan the sampling of landings, discards, and biological data. This situation vastly contrasts that of the recreational counterparts, where census data and control are infrequent and sampling plans scarce. For the latter, the essential first step required ahead of any sample planning then becomes establishing the importance and localization of the fishery itself, i.e. the catches and effort exerted by the different recreational components; only after that is it possible to proceed towards a characterization of length, age, and other biological properties of the catches.

Estimates of catch and effort generally require a probabilistic approach and the use of survey sampling methodologies that allow inference about the target population with measurable sampling error (Maiti, 2021). Registries of fishing license holders or boat owners are examples of sample frames from which samples of recreational fishers can be drawn (Pollock *et al.*, 1994), allowing, e.g. a combination between off-site mail surveys and license sales for effort estimation, with on-site methods for catch rate and biology (i.e. Strehlow *et al.*, 2012). However, in many recreational fisheries a complete record of fishers or fishing vessels is not available and an indirect sampling frame must be used to access the fishers and their catch. In some cases, lists of coastal households exist that can be sampled with off-site questionnaires to provide catch and effort estimates (NRC, 2006). Such off-site surveys are then complemented with on-site surveys that gather catch per unit effort (CPUE) and biological data. Still, in many recreational cases such frame information does not exist at all or is deemed poor in quality. In such situations, a possible sampling frame can consist of a list of access points from which randomized selections can be drawn for the purpose of on-site, simultaneous, data collection on catches, effort, and fish biology by means of interviews to fishers and analyses of their catches.

In Sweden, marine recreational fisheries are to a large extent open access and have been for a long time. The fish resources are perceived by the general public as openly available for harvest for private consumption and there has been societal reluctance to the setting of mandatory registration of fishers, fishing activities, or catches. Routine off-site questionnaire surveys and available knowledge on coastline property regimes, indicates fishing is ongoing during all seasons (HaV, 2019), and that the Swedish marine recreational fisheries consists of three main fishing "modes": fishing from shoreline (with rods), fishing from private boats (with rods, nets, or pots), and fishing from for-profit tour boats run by local enterprises (with rods). In southern Sweden, tour boat fishing is recognized as a non-negligible source of fishing mortality on some stocks (ICES, 2020), but thus far catches and effort exerted by private boat and shoreline fishing have not been quantified. Besides the lack of a direct frame of registered fishers or boats, one of the main difficulties involved in the quantification of these fisheries has remained the limited knowledge at hand on access point's location, size, and composition. National and local legislation effectuates that nearly all coastline, marinas, and piers are public access. The ports and marinas vary a lot in size and fleet composition (proportion of fishing boats vs. other boats such as sailboats), and a few beaches exist where both private boats and shoreline fishers can also, at least potentially, be found.

In this study, we report on the development of an indirect frame for data collection on catch, effort, and biology of the private boat fishery operating in south–west Sweden, on the subsequent implementation of the sampling design, and on the estimates it generated, namely with regards to WBC stock, an important EU/management concern. Due to the lack of a registry or mandatory reporting of recreational catches as well as the heterogeneous nature of the recreational fishery, novel methods were warranted to construct a sample frame and obtain data on the effort (number of trips), catch (number of landed and returned fish), and catch composition (sizes of landed and returned fish). A list of access points was constructed and used as a spatial sample frame. Probabilistic methods were used to allocate samples in space and time. Our approach, inspired by the bus route approach (Robson and Jones, 1989; Pollock *et al.*, 1994), made it possible to obtain catch and effort estimates even when starting from an originally frameless situation, where information available was limited and no sampling frame existed of fishers or vessels that could be contacted. In doing this, we demonstrate the impacts that initial assumptions on the fishery, frequently left unchecked in these types of data-limited situations, may have for recreational data collection. Our results are of general interest to researchers responsible for setting up surveys of recreational fisheries in similarly data-limited and frame-limited situations, but also to those specifically involved in the research and management of WBC fisheries.

Methods

Study area

The study area was defined as the Swedish mainland coastline bordering ICES Subdivisions (SDs) 23 and 24 (Figure 1). The coastline extends roughly for 340 km and includes several large cities (e.g. Malmö and Helsingborg) as well as many small villages and towns, with the total population in the coastal municipalities approaching 1 million. The area is located between 55° and 56°N, characterized by mild summers with ca. 17 h of daylight per day and moderately cold winters with ca. 7 h of daylight per day. Oceanography is highly varying due to the outflowing brackish Baltic Sea water and the high saline inflow along the bottom, with key habitats such as vast sandy banks, rocky reefs, mussel beds, seagrass beds, and kelp forests (Højgård Petersen *et al.*, 2018). There is seldom ice coverage on the coastal waters so recreational fishing activity is possible year-round but expected to be highly modulated by temperature, wind, and daylight conditions.

WBC stock

In the area defined by ICES SDs 22–24, there is an active recreational fishery that targets several species but that is mainly driven by the aggregations of large cod in SD 23 (Sundelöf *et al.*, 2013) (Figure 1). The cod stock in this area is the WBC stock and its recreational catches are included in the list of recreationally fished stocks on which EU member states are obliged to estimate catches and gather biological data (EU, 2016). The WBC is a shared stock between Germany, Denmark, and Sweden, is considered biologically distinct from the eastern Baltic cod (SDs 24–32) and Kattegat cod (SD 21), and is managed as a separate stock (ICES, 1974). The western Baltic stock is known to be heavily targeted by recreational fishers in at least some of its distribution areas (Eero *et al.*, 2014), and that motivated the integration of its recreational catches in the stock assessment in 2013 (ICES, 2019). In fact, German recreational catches have been estimated to

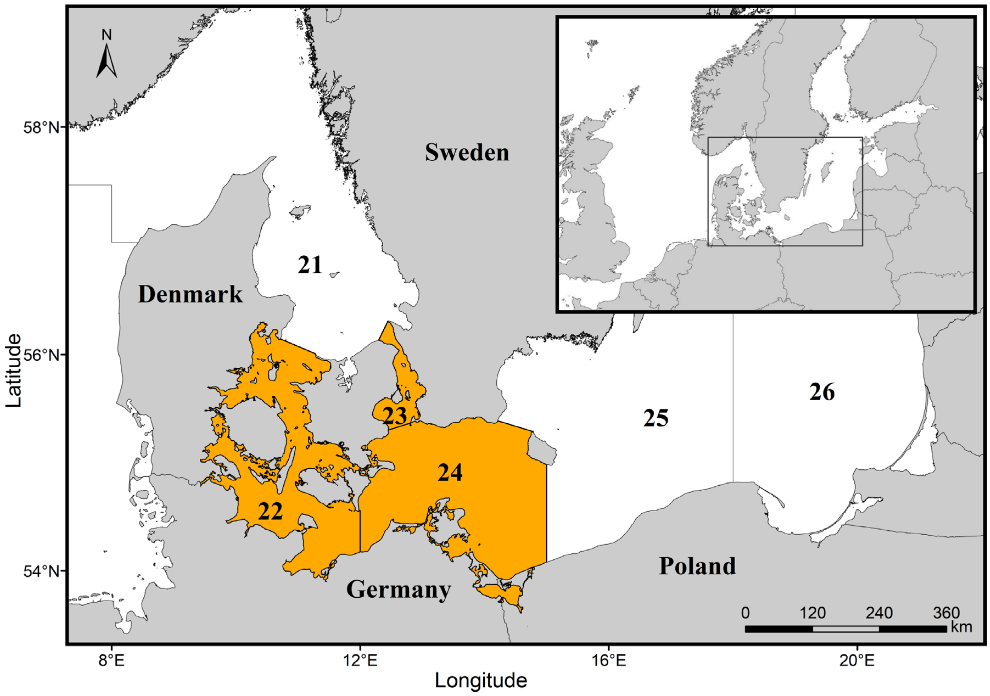

Figure 1. Map of the WBC stock distribution (orange) and the study area. Numbers indicate ICES SDs.

Table 1. Sampling design in the SLU Marine Recreational Fisheries Survey. The temporal sampling stages are marked with prime (′) to distinguish them from spatial sampling stages. [a]Day = a 24-hour period between 06 a.m. and 06 a.m. the following day.

Stage	Sampling frame	Sampling unit	Sampling method
I	List of municipalities	Municipality	Simple random sampling with replacement (SIR).
II	List of access points within municipality	Access point	Stratified simple random sampling without replacement (STSI), with stratification by geographical proximity.
I'	List of days[a]	Day[a]	Stratified systematic sampling (STSY), with stratification by quarter.
II'	List of work shifts	Work shift	Probability proportional-to-size sampling with replacement (pps), using the size measure "expected effort" where size is expected effort.
*II*II'*	Scheduling of observation of selected access points within selected day and work shift.		

constitute ca. one-third of total known catches of the stock, thus constituting a non-negligible part of total fishing mortality (Strehlow *et al.*, 2012). This situation largely motivated the need to estimate the Swedish and Danish recreational catches of the stock (ICES, 2019). The WBC fishery by Swedish tour boats has been monitored *via* voluntary catch journals for quite some time (Lovén *et al.*, 2017), but the private boat and shoreline fishery have remained, thus far unquantified.

On-site survey design

The on-site survey was designed as a multi-stage cluster sampling program (Table 1). The use of stratification within clusters allowed for optimization of travelling times and increased observation time while keeping the design probabilistic and the number of observers required at acceptable levels.

Sampling frames

Probability sampling and well-defined sampling frames are two corner stones of statistical survey theory and a necessary requirement for high quality (i.e. precise and unbiased) survey estimates (Quinn and Keough, 2002). There is no registry of recreational fishers or private boats in Sweden, nor are there mandatory licenses for marine recreational fishing. As such, a list frame was lacking at the start of this study. Additionally, there was limited knowledge on the spatial, seasonal, and diel activity patterns of the private boat fishery. Some recreational fishing clubs and angler associations exist in the area, but it was unknown how representative their registries were in terms of anglers targeting cod. Hence, there was no available sampling frame of anglers from which one could draw a random sample to gather information on effort and catches of the private boat fishery catching cod. Under such circumstances, sample designers are frequently confronted with a dilemma: should they aim at a design involving a non-probabilistic method that makes use of partial (and potentially biased) readily available information (such as assumed fishing activity related to size of marinas or population size) to achieve some degree of efficiency but produces biased estimates? Or should they aim at a probabilistic design that albeit suboptimal in terms of efficiency, still provides unbiased estimates from the fishery? The option taken in this study was the latter.

A possible solution to implement a probabilistic approach in sampling of frameless recreational fisheries, is meeting anglers and their boats directly at the places and times where they are most likely to be found and concentrate. Natural candidates, when the spatial distribution of an off-shore fishery is

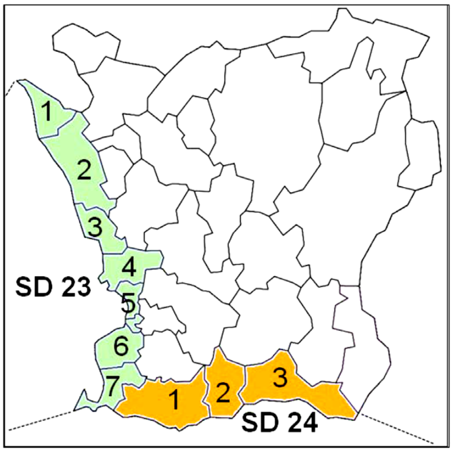

Figure 2. The main survey area corresponds to all municipalities with coastline bordering ICES SDs 23 and 24. The first border municipalities (SDs 21 and 25) were also included in the survey during 2017.

unknown, are local harbours from where boats depart and return daily to/from the fishing grounds. When designing such a survey, one needs to do it in a probabilistic way, securing that all possible harbours and times are included in the frame at the beginning of the study so that all, or nearly all, yet-unknown anglers and boats participating in the fishery have a positive and known chance of being interviewed, and that later decision-making on efficiency improvements to data collection can be *de facto* evidence-based.

The knowledge of the spatial and temporal distribution of the private boat cod fishery and its harbours and landing sites available at the start of the present study was limited or outdated. Since this was a first-time characterization of this fishery, we found it important to use a full frame of spatial and temporal aspects and avoid the impacts that possibly strong erroneous assumptions on harbour importance or diel activity could have on study results and perception of the fishery. As an example, it was unknown whether larger or smaller marinas accounted for most of the fishing activity, since the largest marinas are also known to be prime sailboat spots. Accordingly, a stratified multi-stage cluster sampling survey was designed with the aim of collecting data on angler's effort and catches directly at the places and times of their return from the fishery, i.e. the access points of private boats in southern Sweden, namely marinas, piers, small beaches (< 1 km), and camping sites.

Main spatial sampling frame

In the first spatial sampling stage, municipalities (considered as clusters of access points) were stratified on SD (Figure 2). In each SD, the nearest neighbouring municipality outside of the survey area (in SDs 21 and 25, termed "fringe municipalities") was initially included in the sample frame to examine the chance of "spill-over effort," i.e. boats originating in neighbouring areas fishing inside the survey area waters and returning to those initial places. Municipality was selected by random sampling with replacement, with unequal probability (see Table 1 for a simplified sampling design). All municipalities, where trips aiming at SDs 23 and 24 could depart from were, therefore, included in the study. The main municipalities, i.e. those bordering on SDs 23 or 24, were assigned a selection probability of 0.9, while "fringe municipalities" were assigned the probability 0.1. More sampling effort was allocated to the stratum SD 23 where an existing national survey indicate most catches to be concentrated (HaV, 2019).

In the second spatial sampling stage, a stratified random sample of access points was selected without replacement. A registry of access points was created during field trips to the area in late 2016, starting from information available from scientific and technical SLU personnel with *a priori* knowledge of the area. The list was then both validated and slightly augmented using present and historical Google Earth satellite images. In the end, a list of 84 access points was built that included all access points in the study area from which private boats could initiate a fishing trip. The access points ranged in size from marinas accommodating just a few boats to several hundred boats, with variable proportions of boat types (fishing, sailing, and so on) and sites such as beaches or camping sites. Access points were clustered in municipalities and further stratified within municipalities according to the geographical proximity to facilitate the logistics of data collection. Within each municipality, between one and three strata of access points were determined. The R package "ggmap" (Kahle and Wickham, 2013) was used to determine the travel time between access points within municipalities, and a cluster analysis was then used to identify access points with a driving distance of less than 20 min within strata and 30 min between strata (R Core Team, 2013).

Main temporal sampling frame

In the first temporal sampling stage, days of the year (here defined as the time spanning between 06 a.m. of one day and 06 a.m. the next day) were stratified into quarters. Days to sample each quarter were selected systematically with a random start. During the first year (2017), planned sampling effort was initially set to 18 days per quarter (Quarter 1 (Q1) and Q2) and then increased to 30 days per quarter during Q3 and Q4. In 2018, planned sampling effort was lower in Q1 and Q4 (15 days per quarter) and higher during Q2 and Q3 (30 days per quarter). Since only one municipality could be sampled each day, days where SDs 23 and 24 would be sampled were grouped in sampling "waves" to optimize the staff travelling time to the area during the multiple sampling occasions undertaken each quarter. Within each quarter a predetermined number of sampling waves were planned, spaced 15 days apart. This design implicitly ensures the proportional coverage of both weekdays and weekends throughout a quarter.

In the second temporal sampling stage, one work shift was selected for each day and municipality. Partitioning the day into work shifts was necessary to comply with Swedish working-hours regulations, which stipulate a max number of working hours in regular days. At the start in 2017, the work shifts were 06:00–14:00, 14:00–22:00, or 22:00–06:00. Unequal probabilities (0.4, 0.4, and 0.2, respectively) were used to accommodate probabilistically the expectation of lower activity during the 22:00–06:00 shift while maintaining its coverage (Diogo and Pereira, 2016). In the Northern Hemisphere, light conditions vary substantially between seasons, increasing from about 7 h daylight during winter solstice to 17.5 h at summer solstice (Figure 3). The combination of a partition of days into daily shifts and full coverage of all periods of the day enabled the comparability of estimates across quarters.

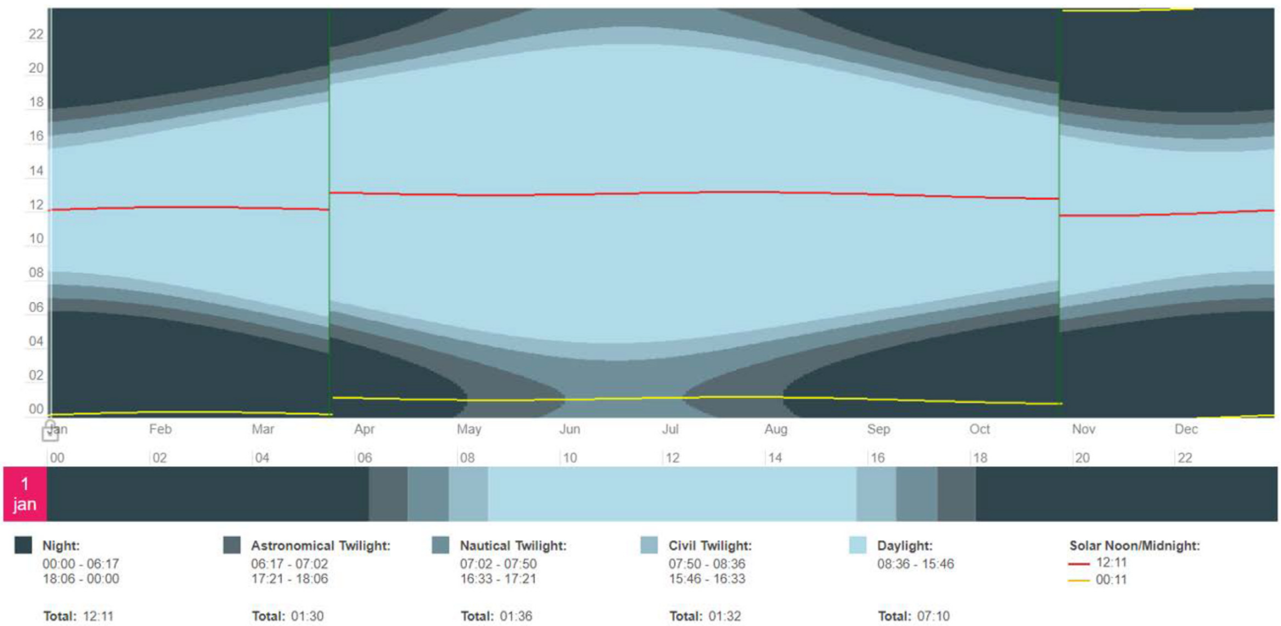

Figure 3. 2017 Sun graph for Malmö. "Night" occurs when the sun is more than 18° below the horizon. Red and yellow lines indicate solar noon and midnight. Daylight varies between ~7 h at winter solstice (December 21) and 17.5 h at summer solstice (June 21). Copied with permission from https://www.timeanddate.com (Copyright © Time and Date AS 1995-2022. All rights reserved). Accessed and retrieved on 3rd March 2021.

Combination of spatial and temporal frames

One sampling day consisted of a calendar day, a municipality, and a work shift (06–14; 14–22; and 22–06). For each municipality, public access points to visit and their order was set randomly within each stratum, and the starting time and duration of each access point visit was allocated via an R script. The design ensured randomized geographical and temporal coverage of the coast. For further details on the survey design see supplementary material SM1–3.

On-site sampling procedure

Upon arriving at an access point, observers took position on pre-selected look-out points with a clear view of the entrance to the access point and easy access to the docking places where incoming boats would anchor. Contact was also made with the marina personnel or equivalent, informing them about the observer presence and the purpose of the survey. The observers worked in pairs, and followed strict protocol on task partitioning. While one observer kept the entrance in sight at all times to observe, count, and classify incoming traffic, the other observer carried out interviews, and counted and classified the boats currently located in the access point. When access points were beaches or camping sites, sampling procedures were maintained with only minor adaptations needed to meet the specifics of each place. Communication between observers by walkie-talkie and the use of a bike ensured the possibility of reaching the incoming boats for interviews even when anchoring places were more distant or the incoming activity high.

The sampling procedure was divided in two main components:

I) Boat activity in access points.

During designated access point visit times, all vessels arriving to the access point were counted, separating recreational fishing boats from other boats based on external characteristics. Incoming boats were approached for an interview about their trip and potential catches were inspected. Information obtained about the trip was collected, including the fishing mode and gear used, targeted species, area fished and time spent fishing there, the number of fishers in the boat, and whether more fishing trips were planned that day. The fishers were also asked to recall the total number of fishing trips of that fishing mode completed in the last quarter, and demographics such as gender, age, and postal code were noted (for complete interview form see supplementary material SM4). Participation in the survey was voluntary.

II) Catch.

At the start of the interview the fishers were asked about their catches, namely numbers or weight retained and released per species. The retained catch was then identified at the species level by the observer, individual fish were measured and weighed (when possible), and otoliths removed for age determination. When catches had been processed at sea (e.g. gutted, cleaned, and/or filleted), weights were not obtained. The observer counted the fish, or provided an estimated count of individuals landed per species (based on filets). The number of released fish per species was estimated by the fisher.

Adjustments to the sampling frame in 2018

With the information and knowledge gathered during 2017, some adjustments to the sampling frame, focused on increasing precision, optimizing observer field time, and improving work conditions of observers while increasing the likelihood of interviews, were introduced in 2018. Available evidence from data collected during the first year of the survey indicated that recreational fishing vessel arrivals were rare during the dark hours, irrespective of the time of the day, and that cod fisheries during such dark periods were negligible.

Consequently, the shift 22:00–06:00 was dropped in Q1 and Q4 2018 and, within the 06:00–14:00 and 14:00–22:00 shifts only ports selected for sampling during “light hours” (defined as the part of the day between nautical dawn and nautical dusk + 2 h; Figure 3) were surveyed, the ports in the shifts to be visited during dark hours being assumed to have registered zero activity during their scheduled “dark hour” visit. The spatial sampling frame was also adjusted by removing the two “fringe municipalities” that in 2017 revealed negligible contribution to SDs 23 and 24 fishing effort, the merging of two adjacent municipalities (4 and 5 in Figure 2) and the merging of two access points in municipality 7, which experience revealed could be surveyed simultaneously. Alongside a range of other minor changes, including some within municipality re-stratification to optimize travel times, the adjustments allowed for a significant increase in observation time in the most active times of the day and areas of the coast, and an overall increase in the probability of selection in the stage I of the design that could, as results demonstrate, be used to provide observers with a much needed 30 min resting break in each shift, with only a slight reduction in average observation time (< 5 min, see results).

Auxiliary data collection

With the aim of better characterizing the study area and facilitating the future improvement and optimization of the sampling scheme, observers were requested to count all vessels present at the access points. These counts took place in all visits to access points and made use of the available time (e.g. before the start of the observation time or during periods of low incoming trip activity), involving the classification of moored vessels into categories chosen to indicate the likelihood of the boat in question to contribute to recreational fishing effort: (1) *private boats—non-fishing* (e.g. sailboats and large yachts), (2) *private boats—fishing*, and (3) *commercial fishing vessels* (district code on hull). This classification of boat-type was developed and refined as experience was gathered, and in 2018 category 2 was further separated into (a) *private boats—fishing* (smaller yachts), and (b) *engaged fishing* (boats with clear signs of being used actively for fishing such as rod holders, nets, rods, fishing baskets, or gillnet flags inside or near the boat). Inter-calibration among the field observers (using a photo library) was performed to minimize bias in individual category identification.

Data analysis

Design-based estimation of retained catch

From our sample survey, we mainly wanted to estimate one finite population total: the total number of cod landed by recreational fishing from private boats in a given geographical area during a year. Because we used a multi-stage sampling design, this unknown total is expressed as a sum over the sampling stages. The primary sampling units in our multi-stage design were municipalities. We denote a set of all municipalities of interest by U_I of size N_I. The secondary sampling units were access points. We denote a set of all access points in municipality $i \in U_I$ by U_{IIi} of size N_{IIi}, $i = 1, \ldots, N_I$. To take the extension of our population over time into account, we first introduce a set of all days of interest. This population is denoted by $U_{II'}$ of size $N_{II'}$. The set of all (three) work shifts in day $d \in U_{II'}$ is denoted $U_{III'd}$ of size $N_{III'}$. Now, the population total we wanted to estimate is given by

$$t_y = \sum_{U_I} \sum_{U_{IIi}} \sum_{U_{II'}} \sum_{U_{III'd}} y_{q,k},$$

where $y_{q,\,k}$ is the number of cod caught by all recreational fishers arriving with a private boat to access point q during work shift k. This equation denotes an unknown quantity that must be estimated.

Before we proceed to the estimation of t_y, let us recapitulate the sampling design and at the same time introduce some more notation. To simplify, in this section, we ignore the stratification in stage I and II'—in other words, we consider only one municipality stratum and one quarter. Expansion to all strata is straightforward, but requires more notation. Another more important simplification is that we do not take the use of “waves” or travel routes into account, but treat all sampling in time (of days and work shifts) as completely random.

Stage I. By use of simple random sampling with replacement, we made m_I draws of municipalities from U_I. The draws of municipalities resulted in an ordered sample $os_I = (i_1, \ldots, i_v, \ldots, i_{m_I})$, where i_v denotes the municipality selected in the vth draw, $v = 1, \ldots, m_I$. In each draw, the probability of selecting municipality $i \in U_I$ was $p_{Ii} = 1/N_I$.

Stage II. For every municipality drawing i_v in os_I, we independently selected a simple random sample without replacement of access points. The sample from municipality drawing i_v is denoted s_{IIi_v} of size n_{IIi_v}. The conditional probability (conditional on the drawing of municipality i) for access point $q \in U_{IIi}$ to be included in s_{IIi_v} was given by $\pi_{IIq|i_v} = n_{IIi_v}/N_{IIi}$.

Stage II'. For every municipality drawing i_v in os_I, we independently and randomly selected 1 day during the quarter. The conditional probability (conditional on the drawing of municipality i) for day $d \in U_{II'}$ to be selected was given by $\pi_{II'd|i_v} = 1/N_{II'i}$. The selected day for municipality drawing i applied to all selected access points in this municipality drawing.

Stage III'. For every combination $(q,\ d)$ of access point and day selected in the preceding stages, we independently and randomly selected one 8-hour work shift with unequal probability. The conditional probability (conditional on the drawing of municipality i and day d) for work shift $k \in U_{III'd}$ to be selected is denoted by $\pi_{III'k|i_v,\,d}$.

In each selected combination $(q,\ k)$ of access point and work shift, we made observations for $T_{q,\,k}$ minutes. Let $y_{q(obs),\,k}$ denote the observed number of cod caught by all recreational fishers arriving with a private boat to access point q during *the observed part* of work shift k. The total length of the work shift was T_k minutes. Consider the observed minutes as a random sample from all minutes during the work shift. Under this assumption, $\hat{y}_{q,\,k} = (T_k/T_{q,\,k})\, y_{q(obs),\,k}$ is an unbiased estimator of $y_{q,\,k}$.

Estimation of the total landings of cod, t_y, was much simplified by the fact that sampling was done with replacement in Stage I. Then, from Särndal *et al.* (1992, Result 4.5.1), an unbiased point estimator of t_y is given by

$$\hat{t}_y = \frac{1}{m_I} \sum_{v=1}^{m_I} \frac{\hat{t}_{i_v}}{p_{Ii_v}} = \frac{1}{m_I} \sum_{v=1}^{m_I} N_I \hat{t}_{i_v},$$

where

$$\hat{t}_{i_v} = \sum_{s_{IIi_v}} \frac{\hat{y}_{q,k}}{\pi_{IIq|i_v}\pi_{II'd|i_v}\pi_{III'k|i_v,d}},$$

Table 2. Summary of sampling effort and observed activity of fishing during the survey years 2017 and 2018. AP = access point.

	2017	2018	Total
Sampling days (n)	95	88	183
Observation time (h)	593 h 16 m	483 h 14 m	1 076 h 30 m
Daylight observation (h)	387 h 41 m	441 h 11 m	828 h 52 m
% daylight observation	65.1	87.0	75.1
Effective observation time/sampling day (h)	06 h 16 m	05 h 30 m	05 h 53 m
Unique access points (n)	83	68	88
Visits to access points (n)	533	487	1 020
Visits to access points/sampling day	5.61	5.53	5.57
Average time in AP (h)	01 h 7 m	0 h 59 m	01 h 3 m
Incoming boats—observed	173	272	445
Incoming boats class rec fishing	34	46	80
Interviews			
Incoming fishing	31	34	65
– With fish landed	20	28	48
– With cod landed	10	16	26
Number of cod landed	35	57	92

and an unbiased estimator of the variance of $\hat{t}_y$ is given by

$$\hat{V}\ (\hat{t}_y) = \frac{1}{m_I\,(m_I - 1)} \sum_{v=1}^{m_I} \left(\frac{\hat{t}_{i_v}}{p_{Ii_v}} - \hat{t}_y \right)^2 .$$

If instead we want to estimate the total number of recreational fishing trips, let $y_{q(obs),\ k}$ in the above estimation procedure denote the observed number of incoming private boat “fishing” to access point q during *the observed part* of work shift k.

Calculations were made using R version 4.0.3 (R Core Team, 2013, 10-10-2020, RStudio Team, 2021).

Results

The total sampling effort of the 2017 and 2018 surveys amounted to 183 days and over 1000 h spent at access points. A total of 83 unique access points were visited in the first year. During this survey, 445 private boats were observed returning to an access point and approached for an interview. A total of 80 of these were classified as a recreational fishing vessels by the observers, i.e. only 18% of all private boats arriving to the access points displayed signs of routine involvement in recreational fishing. Interviews confirmed 65 (14.6% of all traffic) were actual fishing trips (Table 2).

Effort and catch

Fishing effort

The number of observed incoming boats (completed “trips”) was generally higher during Q2 and Q3 compared to Q1 and Q4 when all boat-types are considered. The number of boats returning after a completed fishing trip, private boats landing fish, and private boats landing cod (all confirmed by interview) varied somewhat between quarters (Figure 4). Of all the observed incoming boats, 20% and 17% were classified as recreational fishing boats by observers in 2017 and 2018, respectively, while interviews confirmed that 18% (2017) and 12,5% (2018) had actually been fishing (Table 2).

The number of completed fishing trips is estimated by quarter and SD for 2017 and 2018 (Figure 4 and Table 3). A total of 27 000 fishing trips is estimated to have taken place in 2017, increasing to 36 000 in 2018. It is noticeable that the increase can almost alone be justified by the contribution of Q4. In 2018 the good weather conditions that occurred during Q2 and Q3 and also during much of Q4 (Supplementary material SM5) have been the likely main driver of the increase in point estimates and variance in 2018 relative to 2017.

Catch composition

The survey design covered all recreational fishing trips returning to access points in the survey area, regardless of target or bycatch species in the catch. Interviews in access points revealed a large number of species caught (n = 20; Figure 5) but also large variability on what was kept and released. Cod was the most common target species by far, with more than half of the interviewed boat fishing parties stating this to be their primary target species (Supplementary material SM6). The second largest group (8% of the interviewed) had no particular target species in mind, while mackerel or herring were targeted by 6% of the interviewed fishers. In 2017 and 2018, respectively, about 63% and 82% of those interviewed who had been fishing actually landed fish. In total, 27% of the interviewed fishers returned without any catch (Table 2).

Catch estimates—the case of WBC

About 11% of all observed incoming boats landed fish (Table 2 and Figure 4). A total of 32 % (2017) and 47% (2018) of the completed fishing trips (as confirmed by interview) resulted in landed cod. In total, we observed 445 incoming private boats, and less than 6% of them landed cod. The total number of cod caught and retained estimated by ICES SD and quarter is displayed in Table 3, along with confidence intervals.

Spatial and temporal distribution of the fisheries

Diel pattern

Trips categorized as recreationally fishing were observed returning to access points throughout the day (Figure 6), being registered between 06:00 and 16:00 during Q1 and Q4, and between 06:00 and 20:00 during Q2 and Q3 (Figure 6). Such extension of arrival times in Q2 and Q3 corresponds well with the extended daylight duration of Swedish summer (Figure 3).

Fishing trips returning to fringe municipalities

The two “fringe” municipalities, Simrishamn (SD 25) and Ängelholm (SD 21), were sampled on 12 days during 2017,

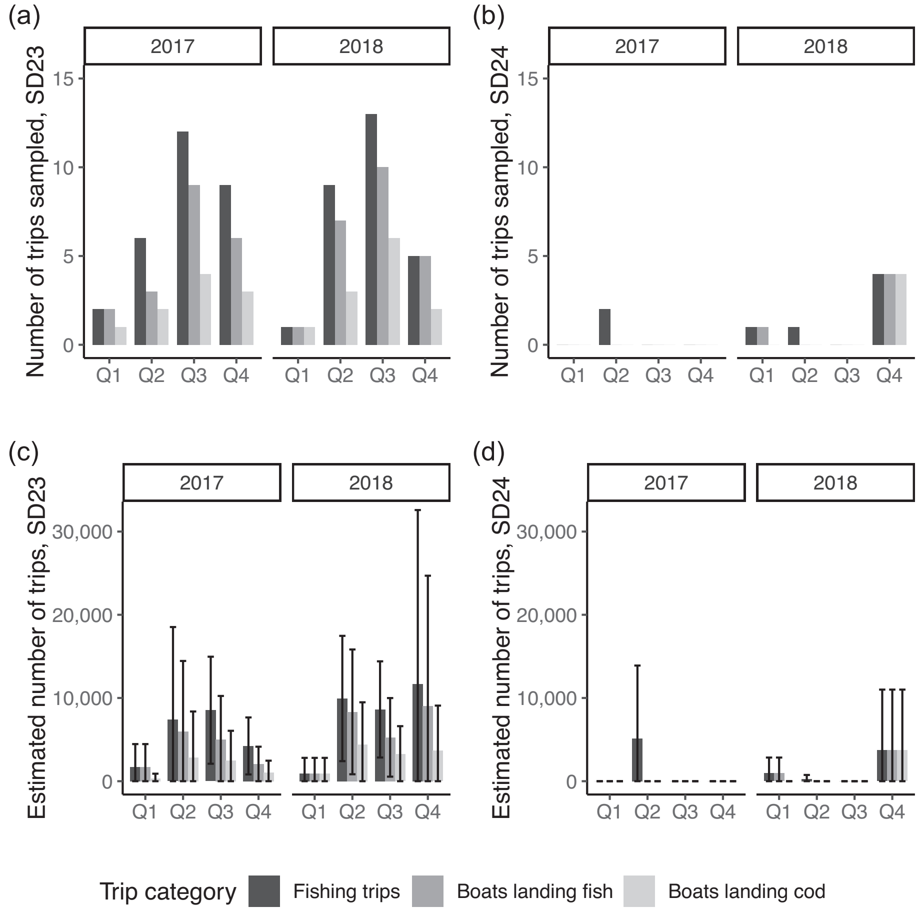

Figure 4. Observed and estimated boat trips. (a) and (b): observations of boats returning after a completed fishing trip by year, quarter and SD (a—SD 23, b—SD 24, raw data). (Note: in 2017, sampling effort was higher during Q3 and Q4 in comparison to Q1 and Q2. In 2018, sampling effort was highest during Q2 and Q3). (c) and (d): design-based estimates of fishing effort, boats landing fish, and boats landing cod, with 95% *CI*s (c—SD 23, d—SD 24). All boats classified as "private boats" were approached for an interview and asked whether they had been fishing. The interview was carried out if the incoming vessel had been fishing.

totaling 72 h and 80 access point visits. Access points were visited 32 times in Simrishamn, and 48 times in Ängelholm. The number of incoming trips amounted to 20, all in Q2 and Q3, of which only two were classified as recreational fishing-type. None had been fishing in SDs 23 or 24, which was the area of interest, and none had any catch. For 2018, these municipalities were excluded from the survey, allowing more days to be spent in the target area.

Sampling considerations and adaptation

The interview form remained similar, with minor updates to accommodate ease of the observers. During 2017 and 2018, no fisher refused to participate in the interview.

In 2017, the 22:00–06:00 shift was performed throughout the year, amounting to a total of 75 visits to access points and ca. 71.6 h of observation. In this time, no incoming trips were observed in Q1 or Q4 (51.9% of observed time). Access points were observed on an average of 66.8 min per visit in 2017, and the observation time spent in daylight (after sunrise and before sunset) amounted to 65%.

Updates to the design done in early 2018 led to less time observed and fewer visits to access points, but increased records of number of incoming vessels, including those fishing cod (Table 2). From the start of 2018, the sampling of the 22:00–06:00 shift could be conservatively restricted to Q2 and Q3 as effort had been proved lower in Q1 and Q4. This option was further corroborated by the 2018 data that indicated that in over 52.7 h of observation in this shift (during Q2 and Q3) only one boat was seen arriving, and it was not fishing (Figure 6). The assumption made in 2018 that arrivals during dark hours would be null (restricting sampling to the period between nautical dawn and nautical dusk + 2 h) only affected 6% of the access point visits during the year and can, therefore, be considered to have negligible impacts in final estimates. After the 2018 elimination of fringe municipalities, updates to the design and introduction of a 30-minutes lunch break in each shift, access points were observed, on average, 59.5 min per visit, and the number of unique access points visited was reduced to 68. More time was spent sampling in daylight, particularly during Q1 and Q4, following the implementation of changes to the survey design in 2018. The observation time spent in daylight (after sunrise and before sunset) was increased to 87% in 2018 (Table 2).

Auxiliary data

The number of boats present at access points showed large variability when counted on multiple occasions, quite pronounced between hours of the day, but also quarter of the

Table 3. Fishing effort as number of trips and retained catch estimates in total numbers of cod landed, by quarter and SD. Upper and lower bond of the confidence interval are shown in brackets. For indicative purposes only, an approximation of landed catch in Kg is also provided (assuming an average weight of 1.8 kg derived from a parallel study of tour boats operating in SD 23).

Year	Subdiv	Quarter	Fishing trips	Cod landed	Catch (kg)
2017	SD 23	Q1	1 704 (+/– 2 755)	913 (+/–1 790)	1 643
		Q2	7 386 (+/– 11 140)	4 247 (+/– 8 323)	7 644
		Q3	8 530 (+/– 6 430)	7 587 (+/– 13 718)	13 656
		Q4	4 239 (+/– 3 425)	5 911 (+/– 7 890)	10 640
	SD 23	Total	21 858 (+/– 13 593)	18 657 (+/– 17 971)	33 583
	SD 24	Q1	0	0	0
		Q2	5 139 (+/– 8 760)	0	0
		Q3	0	0	0
		Q4	0	0	0
	SD 24	Total	5 139 (+/– 8 760)	0	0
2017			**26 997 (+/– 16 172)**	**18 657 (+/– 17 971)**	**33 583**
2018	SD 23	Q1	947 (+/– 1 857)	4 737 (+/– 9 284)	8 526
		Q2	9 939 (+/– 7 529)	9 804 (+/– 14 442)	17 648
		Q3	8 626 (+/– 5 778)	15 397 (+/– 25 523)	27 715
		Q4	11 691 (+/– 20 896)	5 634 (+/– 7 455)	10 140
	SD 23	Total	31 204 (+/– 23 025)	35 572 (+/–31 651)	64 030
	SD 24	Q1	960 (+/– 1 882)	0	0
		Q2	254 (+/– 498)	0	0
		Q3	0	0	0
		Q4	3 719 (+/– 7 288)	11 156 (+/– 21 866)	20 081
	SD 24	Total	4 933 (+/– 7 544)	11 156 (+/– 21 866)	20 081
2018			**36 137 (+/– 24 229)**	**46 728 (+/– 38 470)**	**84 111**

year (Supplementary material SM 7). Some access points were completely closed off during winter, with all boats, and sometimes also the jetties, hauled on land. Since each access point was visited on multiple occasions (mean 10, median 8 times), the maximum boat counts were used to check the validity of boat counts as auxiliary data for future sampling allocation proportional to size (Figure 7). Based on such counts we estimate at least 9000 vessels could have been harboured in the study area in periods of high activity, 12% of them displaying signs of fishing activity.

In the 14 largest access points, i.e. the access points with the highest number of private boats, relatively few landings of cod were observed ($n = 23$, from a survey total of $n = 92$; Figure 7, Supplementary material SM 8). A substantially higher amount of cod landings were observed in the 14 access points with highest numbers of private boats with signs of fishing ($n = 77$) and private fishing boats ($n = 80$). These results indicate that some improvement to cod estimates may be attained in the future by adjusting the sampling design towards increased sampling of access points with large number of vessels with signs of fishing, but not necessarily so by a design that just increases sampling on the largest access points.

Discussion

Our multi-stage random sampling program enabled the quantification of the recreational cod fishery along the Swedish coast of the western Baltic Sea and revealed recreational catches that consist of a wide range of species. Herring, mackerel, cod, garfish, and flounder were the main species caught, but also a variety of other marine, brackish, and freshwater species were caught in this coastal area. Although cod was the focus of this study, and cod catch expectations drove initial sampling effort allocation across strata (higher in SD 23, where the cod fishery was expected to be more prevalent), that objective did not constrain the survey design itself. Accordingly, the initially little informed randomized sampling design not only allowed the estimation of recreational effort and cod landings (present study), but will also enable the future estimation of the total catch of the entire range of species as well as the provision of extensive information about the distribution in time and place of the fishery.

The randomized setup of the survey allowed the identification of the main spatial and temporal patterns in fishing activities. The survey confirmed recreational fishing to be more popular during spring and summer (Q2 and Q3) and occurring mostly in daylight or twilight. The assumption that fishing takes place mostly during daylight/normal-working hours is commonly made in recreational fisheries studies, many of which schedule similar work-shifts all year round (Pollock *et al.*, 1994; Lai *et al.*, 2019). In the case of higher latitudes, however, large differences in daylight/dark periods occur and normal working hours do not necessarily cover all non-negligible fishing activity. The initial decision made in 2017 to sample between 22 o'clock and 06 o'clock all year, irrespective of light conditions, was deliberate and a necessary one to validate the assumptions made in 2018 of not sampling specific times of the day in specific times of the year. We recommend this procedure to all studies where it can be implemented, particularly in areas of medium/high latitude, but not only, since fishing outside working hours or even at night has been found common in many fisheries and countries where that possibility was evaluated (Diogo and Pereira, 2016; Taylor *et al.*, 2018). Night fishing or dark-fishing ended up not being common in southern Sweden during Q1 and Q4, and because we sampled probabilistically in 2017, we are confident that was also

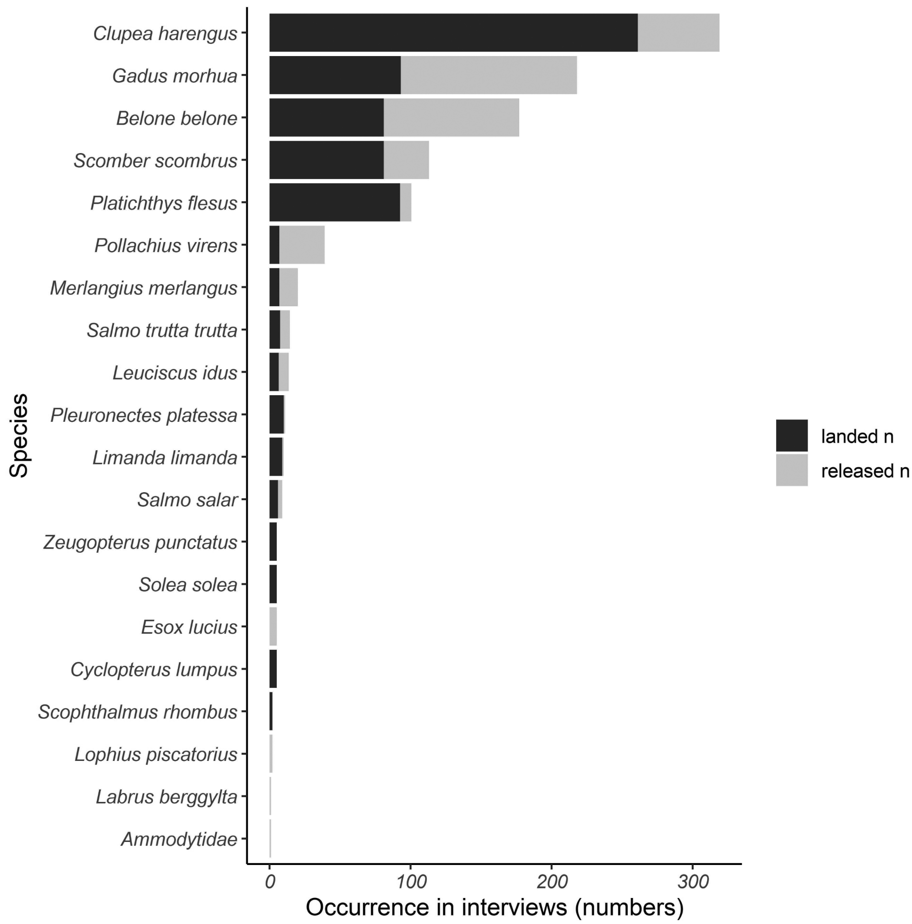

Figure 5. Fish species (targeted and non-targeted) retained (dark) and released (light) by intercepted and interviewed returning fishing trip parties sampled in southern Sweden during 2017–2018. Bar length indicates the number of fish by species caught. *Clupea harengus*—Atlantic herring, *Belone belone*—Garfish, *Scomber scombrus*—Atlantic mackerel, *Platichthys flesus*—European flounder, *Pollachius virens*—Saithe, *Merlangius merlangus*—Whiting, *S. trutta trutta*—Sea trout, *Leuciscus idus*—ide, *Pleuronectes platessa*—European plaice, *Limanda limanda*—common dab, *S. salar*—Atlantic salmon, *Zeugopterus punctatus*—common topknot, *Solea solea*—Common sole, *Esox lucius*—Northern pike, *Cyclopterus lumpus*—Lumpfish, *Scophthalmus rhombus*—Brill, *Lophius piscatorius*—European angler, *Labrus berggylta*—Ballan wrasse, and Ammodytidae—Sandlance.

true in 2018. However, as daylight lasts longer in Q2 and Q3, fishing activity also extends past working hours well into the evening (Figure 6). In summer, when dusk sets late if at all, light conditions would not necessarily be a limiting factor for fishing trips to take place, yet no fishing activity was found after 23:00 during any month in the present survey, and no fishing trips were observed during or after dusk (astronomical twilight).

Our survey design makes a clear distinction between strata (that we used for sampling) and domains (where we aimed to obtain our estimates). As such, the spatial strata of the initial survey design (2017) included access points from "fringe municipalities", located outside the target area to account for the possibility of boats returning there after having fished in the target areas SDs 23 and 24. A substantial sampling effort was made and no completed fishing trips in the target area were observed at these access points, so the municipalities were removed from the survey design in 2018. If there was any fishing in the target area departing from the "fringe" municipalities, its contribution to the total catches is now known to be null or very small and, thus, negligible. Defining a target area and a corresponding list of access points for a survey is not always straightforward and will largely depend on the spatial scale of management and the need for data. International, national, or regional delimitations have often been used, particularly when these correspond well with fish stock management units (NRC, 2006), as was the case in the present survey. Spatial strata might also be shaped by natural geographical delimitations or by empirical knowledge of particular fisheries (Herfaut *et al*., 2013). At finer management scales, such as is the case for the WBC, the cost of achieving adequate precision of the estimates is high, and a continuous evaluation of the survey design and the sampling frame will be beneficial for such on-site surveys. We recommend the inclusion of ports that are outside the target area in initial stages of the design. These ports may harbour vessels that fish in the target area, and the decision on whether or not they are maintained in a second stage will be evidence-based. Assigning a lower, but non-negligible, probability to fringe ports or municipalities should, in general, be enough to allow for such evidence gathering without jeopardizing the core part of estimates, naturally expected to come from the main ports or municipalities, nor sacrificing the overall statistical quality of the study.

The Swedish recreational WBC landings from private boats in 2017 and 2018 were small compared to those of neighbouring countries fishing in the same area (the total recreational

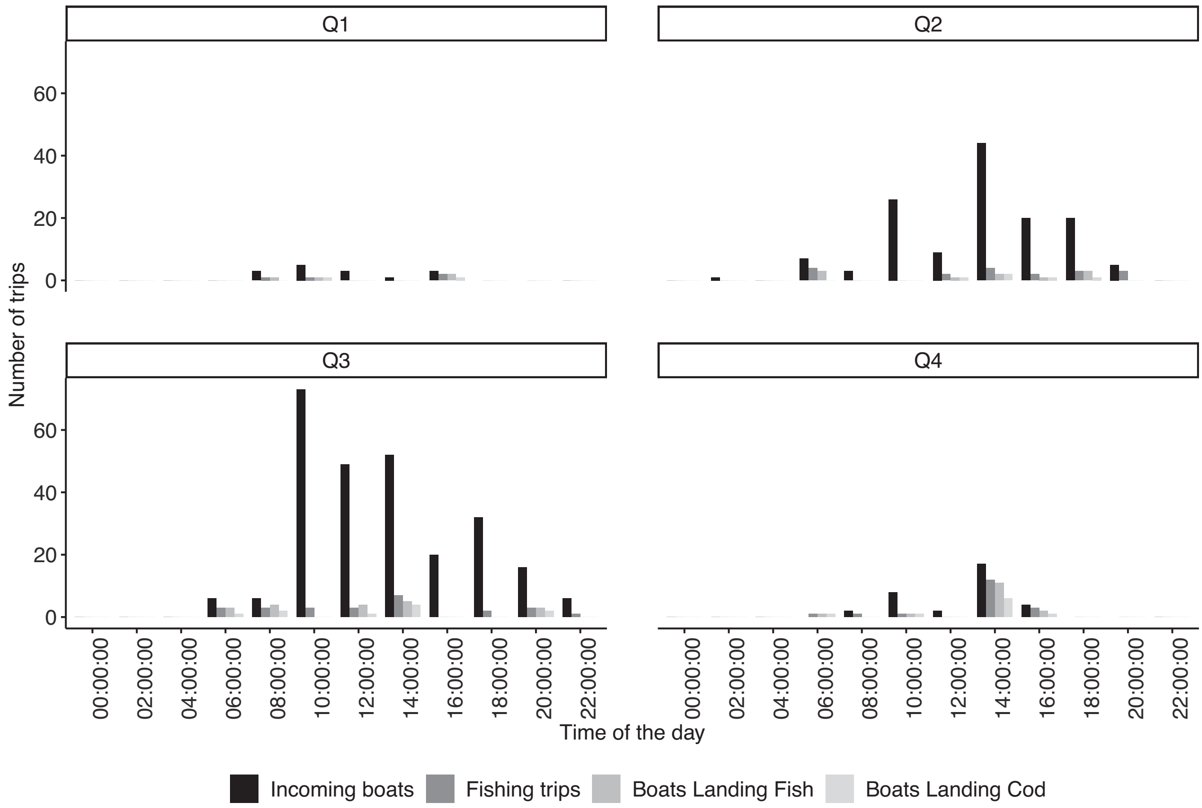

Figure 6. Number of trips sampled according to trip category and time of day shown by quarter.

catches of WBC, dominated by German and Danish catches, was estimated at 1315 and 1600 t in the 2017 and 2018 stock assessments; ICES, 2021). Swedish recreational landings were small, also when compared to the total commercial cod landings of the WBC stock (3861 t and 3555 t, respectively; ICES, 2021), and will, thus have had little impact *per se* on the stock assessment of the WBC. However, the most recent stock assessment estimates for the WBC stock depicted a stock below B_{lim} since 2016 (ICES, 2021). In addition, the stock recruitment has been very low in recent years. This has resulted in the advice for landings in 2022 to be severely reduced, at less than 12% of the advice for 2021. The resulting advised Total Allowable Catch is, hence, below the estimated *recreational* catches of WBC, and not much higher than the Swedish recreational landings of WBC registered during 2017 and 2018. Moreover, restrictions on recreational anglers have tightened in 2022, with a daily bag limit of 1 cod per angler between April and January and a complete ban during spawning season (EU, 2021). As greater constraints are put on the fishery, recreational catches may not only come to represent a significant part of the total mortality of this stock, but also enter in direct conflicts with the commercial fishery over a limited resource.

Most of the Swedish recreational cod catches are caught in the Sound between Denmark and Sweden (ICES SD 23), where there is evidence of locally spawning cod populations (Svedäng *et al.*, 2010a). A strong population with a healthy size structure has been found in this geographical area (Svedäng *et al.*, 2002, 2010b; Lindegren *et al.*, 2013; Sundelöf *et al.*, 2013), in contrast to deteriorated cod populations in adjacent waters (Jonzén *et al.*, 2002; Eero *et al.*, 2015). Recently Wenne *et al.* (2020) demonstrated genetic differentiation within the WBC stock, indicating a need for sub-stock consideration in the management process. In lieu of this, the Swedish recreational catches of cod might very well be significant on a local (SD 23) level, and thus impact this sub-stock in question more severely than previously assumed. Many of the recreationally caught species seen in this survey are also targeted by commercial fisheries, and hence recreational fisheries add to the total mortality of commercially fished stocks, possibly impacting the stock assessment and contributing to declines in fish stocks (Post *et al.*, 2002; Coleman *et al.*, 2004; Smith and Zeller, 2016; Freire *et al.*, 2020).

The funding for the current survey was grounded on the need for recreational fisheries data of one particular stock, the WBC stock. The data quality required for assessment is high, and on-site surveys, while expensive, can provide this level of quality, if well-designed. However, such a survey is spatially and temporally complex, and usually cannot give accurate information on the fishery beyond the defined spatial and temporal sampling frame.

There is no “one fits all” template for recreational fisheries assessments, and survey designs must accommodate needs for data based on continuously changing policies and management strategies while being adapted to local circumstances. Designing an on-site angler survey is challenging for extensive coastlines with many access points. Applying a typical access point survey, where each site is chosen independently and randomly, requires substantial observer effort and significant travelling, rendering that type of survey an often expensive option. The bus route design, on the other hand, minimizes the number of observers and travelling time by grouping nearby

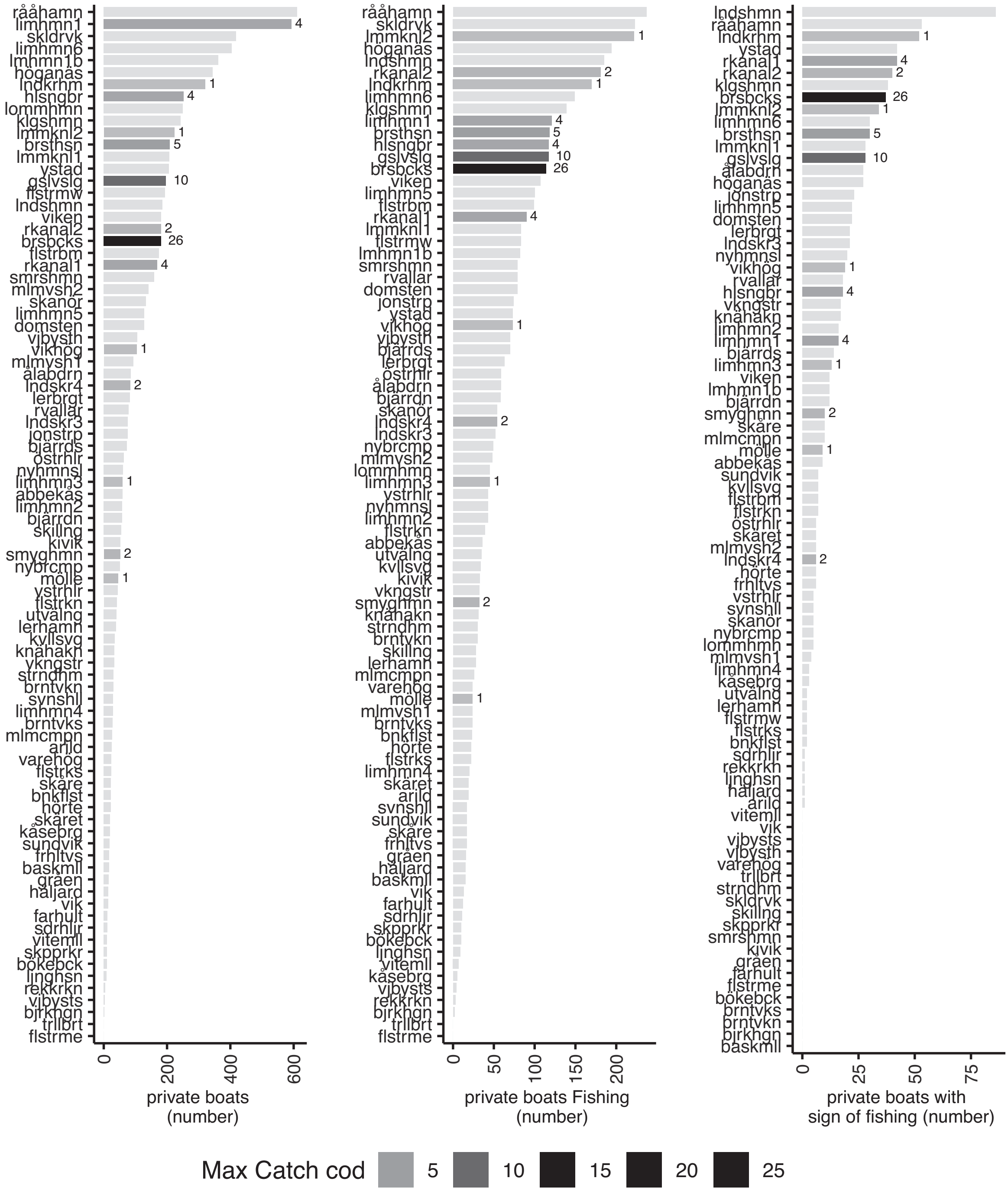

Figure 7. Boat counts (maximum) in the access points, (left) the total number of boats, i.e. size of marina, (middle) the number of boats classified as recreational fishing boats, (right) the number of boats classified as "engaged fishing," i.e. private boats with signs of fishing. Signs included rod holders, nets, pots, fishing gear, and so on. The access point bars are coloured according to the maximum number of cod that were observed landed there in one sampling occasion during the survey, and the maximum number of cod is shown in text to the right of the bar (Note the different range on the *x*-axis.).

sites within a route that is then surveyed as a unit (Robson and Jones, 1989; Lai *et al.*, 2019). In the current survey, a stratified multi-stage cluster sampling design was used. The design is inspired by the bus route method but has significant modifications. In the bus route design, every site is sampled in the course of the day on the route that is selected, but in this study, since the number of sites and the distances were too large to be covered in a single route we divided the area into clusters (coastal municipalities). Each day, we randomly sampled one cluster. When the number of ports within clusters were large, geographical stratification of ports and/or their subsampling along the route was used. This approach draws on the strengths of both the bus route method and the access point method, and allowed us to avoid large travelling times, and thus increase observation time while maintaining the number of observers needed at adequate levels. Cluster sampling allowed sampling efficiency to be increased, and therefore, costs to be reduced, while no assumptions were made on the relative level of activity emanating from differently sized access points. This design enabled a general mapping of the recreational fisheries taking place in the study region, laying the foundation for multi-species recreational fisheries surveys and catch estimation.

In a situation where prior knowledge about the fishery is poor, it is important to sample in a randomized manner and avoid biases caused by unverified assumptions. Doing so necessarily leads to observational time being spent in access points that have low or negligible activity, increasing the final variance of the design-based estimates (see results). However, the data collected probabilistically, alongside the auxiliary data also collected (which benefits from the same underlying statistical randomization as the main data) are invaluable for assumption checking, safe later reduction of costs and improvements of accuracy of global effort and catch estimates or their redirection towards more specific objectives (e.g. the estimation of catch and effort targeting a specific resource or taking place in a specific area). It can also support evidence-based shifts towards other types of more efficient sampling methods such as those that involve separate sampling for effort and CPUE. In fact, auxiliary data can be attained by traffic counts at boat ramps (Steffe *et al.*, 2008; van Poorten and Brydle, 2018) or digital camera monitoring (Hartill *et al.*, 2020). This type of data collection can facilitate accurately quantifying fishing effort at the access points. Auxiliary data can also be used to inform data collection and sampling design. It is necessary to verify auxiliary data, so as not to leave bias unknown (Steffe *et al.*, 2008). In this survey, while probabilistic sampling took place, an effort matrix was also constructed with moored boat counts of all access points, with details of boat category based on likelihood of the boat to be contributing to the fishing activity. This revealed that fishing activity was not proportional to the size of the access point (a likely erroneous assumption that could have been made to save costs at survey start), and hence, a proportional inclusion probability for access points based on size alone would likely have led to less precise estimates of both effort and catch (since the target variable does not correlate well with port size) or even erroneous ones (if ports with smaller size had been left out of the sampling frame). The effort matrix (i.e. boat counts) also showed a strong seasonal variation in occupancy at certain access points, some being completely closed off during parts of the year. It is, however, necessary to determine the underlying cause of the variation in counts of occupied boat slots. In some locations, winter storage in dry docks might be common, while in others empty slots are equivalent to the boats being out fishing. This issue can be overcome in several ways, e.g. by considering only occupancy counts done at night, in bad weather, or using the max count when repeated counts are performed. In this survey, counts were carried out at every visit to an access point, and importantly, access points were visited also at times when sampling could be assumed inefficient, rendering "max counts" a good measure of access point occupancy. This type of auxiliary knowledge, when linked to fishing activity, allows future optimization with regards to the temporal and spatial strata, where sampling effort can be allocated proportional to empirical knowledge on the probability of fishing taking place. By separating the sampling for catch rate and the sampling for effort determination, more sampling effort can be concentrated at the sites and times of high activity. Coupled with, e.g. unequal probabilities based on likelihood of fishing taking place, it is possible to maintain full coverage of the population while making sampling more efficient. There are several examples of large-scale recreational fisheries survey, where catch rate and effort sampling are separated (NRC, 2006; NAS, 2017), and different methods on how to assess these components exist.

A prerequisite for probabilistic sampling is knowing the characteristics of the target population to be sampled. The more one knows about the target population and the better delimited it is, the more efficient the sampling design can be and the more precise estimates one can expect to obtain. A good sampling frame covers all the units in the target population, whether it be a list frame (boat owners, license registries) used for off-site surveys or a spatiotemporal frame (access points) used for on-site surveys (NRC, 1998). To sample recreational fisheries, the most efficient frame is a list of all those participating in the fishery, but where that is not available, indirect list frames such as national registries, address lists or lists of access points (as in our study) can be also be used. Such indirect frames can be sampled probabilistically. However, where participation rate in fisheries is not very high (NRC, 1998; our results: only 6% of boat arrivals had been fishing) and estimates are needed for smaller geographical areas (like SDs 23 or 24), they are usually burdened with lack of precision.

Attempting to cover all fishing modes, access points, and fished species in a recreational fisheries survey leads to complex and extensive surveys that come with a high cost. Making some assumptions about, e.g. angler behaviour might ameliorate this, but such assumptions can be hard, or impossible, to verify, and when taken too early and without evidence, based on expert judgement only, may be the cause of significant bias in the estimates that will later be derived. Constructing a proper indirect sample frame can be a resource demanding task, yet it might be worthwhile considering those alternatives against, i.e. unknown bias and a failure to correctly represent the target population or producing very variable estimates. As we have shown, where good direct frames are not available, the inefficiency of a randomized design and an indirect frame (largely evident in the present study in the low number of encounters of cod fishers) provide the necessary framework for obtaining a first set of estimates, with known variance, and a path to the future optimization of the efficiency of surveys and its estimates. Their apparent inefficiency (evident in the less precise estimates) is easily counterbalanced by the unbiased characteristics of the estimates obtained from them, the extensive additional information and characterization they render possible, and the forward opportunities they offer to evidence-based evolution and optimization of the sample design in the medium–long term. Nevertheless, the underlying assumptions, although evidence-based, might change over time, and should, therefore, be checked regularly, e.g. every 5–10 years.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript:

SM 1) Cluster dendrogram showing stratification of municipality Helsingborg; SM 2) Selection probabilities of a) municipalities and b) work shifts; SM 3) Sampling allocation in number of days by quarter and subdivision; SM 4) The interview form (english); SM 5) Weather data and analysis excluding sampling effects of weather on the results; SM 6) Primary target species as percentage of all interviews; SM 7) The counts of moored boats shown by quarter for a) private boats fishing and b) private boats with signs of fishing; SM 8) The number of landed cod for the 14 largest access points according to the three main boat categories.

Authors' contributions

HS: conceptualization, data collection, data curation, formal analysis, visualization, and writing—original draft (lead). NP: conceptualization, design and methodology of the survey, and the analysis, data curation, formal analysis, and writing—original draft. AdG: formal analysis and writing—original draft. MC: conceptualization, funding acquisition, supervision, discussion of results, and writing—review and editing. CJ: supervision, discussion of results and methodology, and writing—review and editing. AS: conceptualization, funding acquisition, project administration, methodology, resources, data collection, supervision, and writing—review and editing.

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Competing interest statement

The authors have no conflict of interest to declare.

Data availability statement

The data underlying this article may be shared on request to the corresponding author.

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