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Spatiotemporal and multispecies comparisons between a citizen science platform and recall surveys in recreational fisheries

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ABSTRACT

Smartphone applications for anglers that function as citizen science platforms are an alternative to the traditional survey methods that are used to collect data from recreational fisheries. Comparisons between these two methods are needed to understand the impacts of the biases associated with data generated from smartphone applications. However, such comparisons are uncommon, especially for multiple fisheries over time and across space. In this study, we compared catch and effort data from an electronic citizen science platform for anglers with an offsite web-based recall survey for consecutive (i) 3-month periods in a spatially distinct (i.e., the Danish island of Funen) sea trout (Salmo trutta) fishery (2017–2020), (ii) 6-month periods in coastal sea trout and coastal/offshore cod (Gadus morhua) fisheries across eight ICES management areas (2016–2020), and (iii) 6-month periods in a freshwater pike (Esox lucius) fishery (2016–2020). Catch and effort data from the two surveys were, in most cases, consistently similar over time for the Funen sea trout and Danish freshwater pike fisheries. In contrast, we found that the recall survey estimates were consistently 100–200% larger than the citizen science platform for both sea trout and cod in ICES areas. Our findings suggest that the applicability of electronic citizen science platforms for anglers can be fishery-specific, and that systematic bias may occur.

1. Introduction

Recreational fishing is a popular leisure activity that engages close to eleven percent of the residents in industrial countries [1]. Participation in fishing as a leisure activity yields economic and social benefits [2–5] but also leads to population- and ecosystem-level impacts [6–8]. In fact, recreational fishers are the primary or sole users of many coastal and freshwater fish stocks [9–11]. Fishing mortality from recreational fisheries can be substantial, and in some instances exceed that of commercial fisheries [12–14]. These impacts might be mitigated by successful management, which requires knowledge about the fish populations as well as the anglers [15,16]. Information from recreational fisheries is often limited by diffuse access and the high mobility of anglers [e.g., [8, 17]. These limits make it necessary to conduct costly and complex survey designs [e.g., [18–20].

Probabilistic surveys for collecting recreational fisheries data are either onsite or offsite [21,22]. Whereas onsite surveys involve in-person interviews during or immediately after a specific fishing trip, offsite surveys are conducted by mail, phone, or internet sometime after one or more fishing trips have taken place. Several well-known biases are associated with offsite and onsite surveys [22]. Offsite surveys can suffer from recall bias, which is the tendency of survey respondents to overestimate their catch and effort proportionally over the recollection period [23–26], and non-response bias, which occurs when a segment of the target population cannot be reached or does not respond e.g., [27].

Traditional probability surveys rely on a random sample as opposed to non-probability surveys; for example, where the sampling frame is unknown, and the participants themselves choose to be part of the survey. Examples of self-selection include traditional diaries [22], web surveys [28,29], and citizen science programs [30,31]. Digital citizen

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science platforms in which anglers register information about their catches and/or trips, often via smartphone applications, offer a relatively fast and inexpensive alternative to traditional surveys methods [32,33]. It has been suggested that the non-probabilistic approaches, such as digital citizen science platforms, are likely to be outperformed by well-conducted probability surveys [34]. In addition to self-selection, citizen science platforms for anglers also rely on self-reporting, which can produce biased estimates [19,35].

Citizen science data often needs validation e.g. due to the potential bias associated with self-selection and self-reporting [e.g., [34,36]. Some validation of data quality from citizen science platforms or angler apps has already taken place. There was general agreement between the Marine Recreational Information Program (MRIP) survey and iAngler app for two years of catch data from three fish species in Florida [37], and between a mail survey and iFish Alberta app for regional effort [38]. Similarly, in comparison to mail and creel surveys and the MyCatch electronic citizen science platform found similar catch rate estimates, regional patterns of fishing, and spatial distribution of participants [39]. Finally, although participants in the Danish citizen science platform Fangstjournalen, were younger, more specialized and had higher catch rates compared to non-participants [30], the platform generated results that were comparable to those from roving creel, recall, and aerial surveys [31]. Although these results suggest that Fangstjournalen data have some value despite differences between participants and non-participants, data from the sea trout (*Salmo trutta*) fishery on the Danish Island of Funen were only available for three months [31].

In this study, we build on the work by Gundelund et al., (2021) by adding temporal, spatial, and multispecies elements to the comparison of citizen science data with data from an offsite recall survey – all within Denmark [31]. Our analysis was in four parts. The first comparison was of angler data reported for the Funen sea trout fishery annually from 2017 to 2020. We hypothesized that catch and effort estimates from the citizen science platform and from the recall survey were consistently similar over time. We based this hypothesis on the fact that anglers fishing for sea trout on Funen are relatively specialized [30], and may be more committed to the resource and thus more willing to provide data. Our second comparison was for biannual data from 2016 to 2020 and across the eight ICES management areas that comprise the Danish coastal sea trout fishery. We hypothesized that reported catches and the proportion of fish released from the citizen science platform and the recall survey were consistently similar over time, but only within the ICES areas that had consistently high fishing activity for sea trout. We based this hypothesis on both the assumption that specialized sea trout anglers were more willing to share data, and the need for sufficient sample sizes. Third, we extended the analysis to include the coastal cod (*Gadus morhua*) fishery within the same spatiotemporal frame as the Danish coastal sea trout fishery. In contrast to our hypotheses for the sea trout fisheries, we hypothesized that there would be disparity between the citizen science and recall survey data because this fishery is less popular (i.e., fewer users providing data). Finally, our fourth comparison was for catch and effort estimates from the freshwater (i.e., inland) pike (*Esox lucius*) fishery in one area biannually from 2016 to 2020. As with the cod fishery, we anticipated small sample sizes that would contribute to disagreement between the citizen science and recall survey data. To the best of our knowledge, this is the first study to address the consistency of citizen science data, collected by anglers, across space, time and multiple fisheries.

2. Methods

2.1. Recall survey

The Danish National Institute of Aquatic Resources and Statistics Denmark has conducted a biannual recall survey since 2009 to provide statutory monitoring of marine recreational fisheries for the European Commission [40,41]. The goal of these surveys is to estimate the annual recreational harvest and release of commercially important species such as cod.

The recall survey sample frame is based on the Danish national fishing license register, which is mandatory for people older than 18 and younger than 65 years of age. Potential respondents from the register are contacted by e-mail, digital postbox, or postal letter (for a detailed description see [42]). The recall survey is divided into two recall periods: the first three months of the six month recall period, and the last three months in the six month recall period. Respondents that are contacted in January for the first of the biannual surveys are asked to provide data from two recall periods corresponding to 1) July to September and 2) October to December of the previous year. Further, respondents contacted in July for the second of the biannual surveys are asked to provide to data from two recall periods corresponding to 1) January to March and 2) April to June in the same year.

Respondents were asked specific questions about the Funen sea trout fishery: the number of fishing trips targeting sea trout, retained sea trout, released sea trout, and released sea trout below the minimum size (i.e., 40 cm in general, but 45 cm in one specific area). These questions are only related to a specific period in spring (i.e., April-June) and they have been part of the second half-year recall survey since 2017.

Survey respondents were instructed to recall the number of harvested and released sea trout and cod from each of the eight distinct ICES management areas surrounding Denmark (Fig. 1). These areas are included in the recall survey to meet the European data collection requirements [40] and to be able to assess recreational fisheries impacts on the stocks (e.g., cod in the North Sea [43]). The catch of a respondent was calculated as the sum of harvested and released fish in a given area, while the proportion released was the fraction of released fish compared to the sum of harvested and released fish. Three questions pertained to the Danish freshwater pike fishery: number of fishing trips for pike in freshwater, the number of catches (i.e., retained and released) of pike in freshwater, and the number of released pike in freshwater.

2.2. The citizen science platform Fangstjournalen

Fangstjournalen is an electronic citizen science platform that operates on a webpage and as a smartphone application [44]. The platform was designed by the Danish National Institute of Aquatic Resources and launched 15 January 2016 as a tool to collect data from recreational fisheries. It works as a logbook in which individual anglers record information about their trips and catches (e.g., date, location, effort, target species, number caught and retained or released). Participants can also provide demographic data such as age, gender, and place of residence (for a full overview of the data collected by the platform see [33]). The data submitted from fishing trips are uploaded to a server and fed back to the angler as personal summary statistics. Additionally, the data are aggregated into a database for research and management purposes (for an illustration of the dataflow between participants and the platform see [33]).

2.3. Comparative analyses

A non-parametric bootstrapping approach was used to compare estimates from the citizen science platform and the recall survey (for a similar approach see [19,31]). A given metric from the two survey data sets was resampled with replacement, and a ratio of the means of these bootstrap samples was calculated as

$$q = \frac{E^{CS}}{E^{RS}},$$

where E^{CS} and E^{RS} are the means from citizen science platform and recall survey, respectively. A q value of 1.0 indicates that the estimates are equivalent. The uncertainty associated with the q estimates were assessed using 1000 bootstrapped samples. The bootstrapped

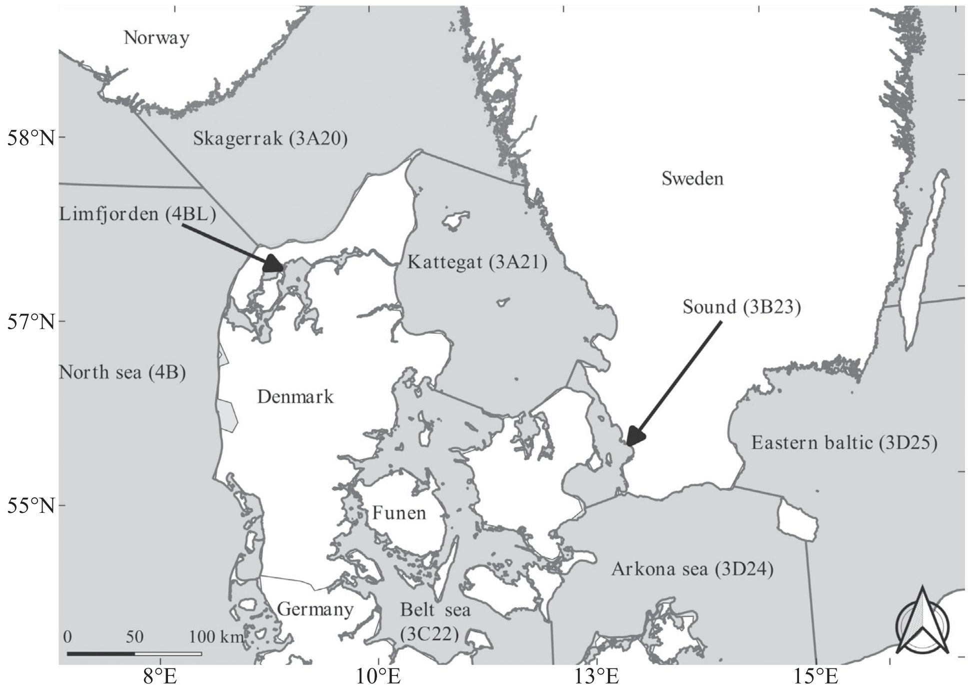

Fig. 1. Overview of the ICES management areas surrounding the Danish coastal and offshore fisheries (in bold). Additionally, the Danish island of Funen is shown in bold.

distributions of q estimates for a given survey metric are shown as median value and a set of error bars showing the 2.5th and 97.5th percentiles, which represent a 95% confidence interval for a two-tailed significance test ($\alpha = 0.05$). We accepted the null hypothesis of no difference between the estimates if $q = 1$ fell within the 95% confidence interval of the bootstrapped distributions.

We compared the number of fishing trips conducted and the associated catches across a three-month period (i.e., April, May, and June) between recall survey data and citizen science data for the Funen sea trout fishery. We also compared, the proportion of fish released and proportion of fish voluntary released. The citizen science data were aggregated across the three-month period from April to June, (i.e., the second recall period in the recall survey send out in July), for the years 2017, 2018, 2019, and 2020 to match the questions from the recall survey in the same years.

Comparisons involving the general Danish sea trout fishery and Danish cod fishery by ICES areas (Fig. 1) focused on the number of catches and proportion released. For catches and releases, a given recall survey provided information for half of a year (e.g., from January to June). Therefore, ten recall surveys were conducted in the period 2016 – 2020. Henceforth, these survey periods will be written as year.halfyear (e.g., the first and second surveys from 2016 are labelled 2016.1 and 2016.2, respectively). Citizen science data were aggregated across the ten survey periods for each of the eight ICES areas in which recall survey respondents were instructed to state their catches of sea trout and cod. Only ICES areas with a half-yearly average of > 20 recall survey respondents or citizen science participants were included in the analysis to ensure suitable sample sizes. These measures were taken to prevent misinterpretation due to low sample sizes. In addition to catch and release proportions, we used linear regression (number of recall respondents and citizen participants within each survey period and ICES area) to test the hypothesis that the number of citizen science participants can be used to predict the number of recall survey respondents. This analysis tests the assumption that the relative popularity of a specific area in time is similar between the methods.

Finally, we compared the number of fishing trips for pike, the number of pike caught, and the proportion of pike released in Denmark's lakes and rivers. The citizen science data for this comparison were aggregated across ten half-years from 2016 to 2020 so that they matched the data structure from the recall survey.

3. Results

3.1. Funen sea trout fishery

No clear differences were found between the survey methods in the Funen sea trout fishery for any of the investigated metrics (Fig. 2). The median q-value (shown with interquartile range i.e., IQR), across years, was 0.87 (0.35), 1.03 (0.44), 1.02 (0.29), 1.17 (0.42) for number of fishing trips conducted, catches, release proportions, and voluntary release proportions, respectively. These findings indicate that the median estimate from citizen science platform relative to the recall survey was ~15% lower for number of fishing trips, ~3% higher for catch, ~2% higher for release proportions, and 17% higher for voluntary release proportions.

3.2. Danish coastal sea trout fishery

There was a positive, linear relationship between the number of citizen science participants and recall survey respondents contributing with data across the eight ICES areas in each of the ten half-year survey periods from 2016 to 2020 ($df = 1$, $F = 246$, $p < 0.001$, $R^2 = 0.76$; Fig. 3).

Comparisons of summary statistics were limited to four ICES areas in which data were available from an average of ≥ 20 respondents or participants (3A21, 3B23, 3C22, and 3D24) (See supplementary A for average number of respondents and participants). Clear differences were found in areas 3A21, 3B23, and 3C22 for most survey periods in the comparison of catches between citizen science platform and recall survey in the Danish coastal sea trout fishery (Fig. 4). In area 3D24, there was only sufficient data for five survey periods. Compared to the other areas, the differences among sea trout catches in 3D24 were smaller between methods (Fig. 4). The median q-value (IQR), across survey periods, was 0.44 (0.19), 0.30 (0.21), 0.54 (0.32), 0.77 (0.66) for area

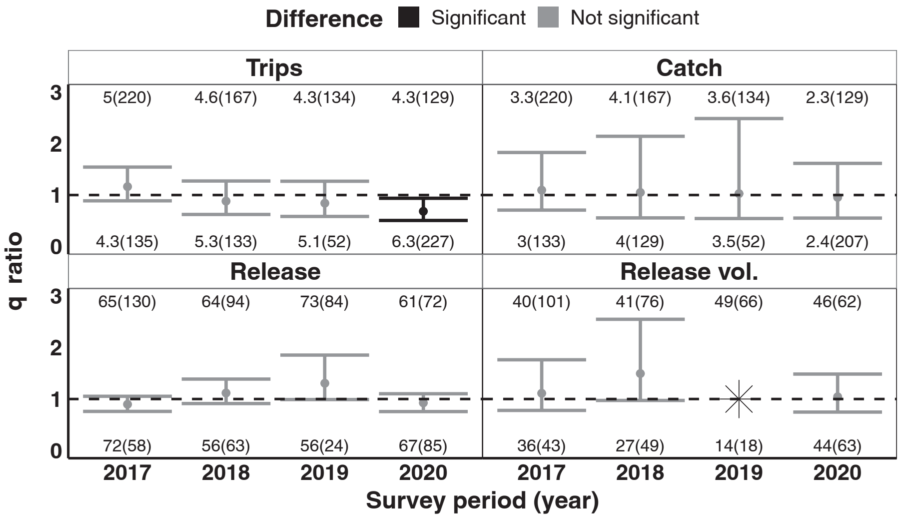

Fig. 2. q-Ratio for number of fishing trips, catches, release proportions, voluntary release proportions for the specialized sea trout fishery on Funen. Dots are the median q-value, and error bars are the 95% confidence intervals. There is evidence of difference between two estimates when q = 1 is not within the 95% confidence interval (black); otherwise the confidence interval is gray. The top and bottom rows of numbers are the parameter average (and number of participants/respondents) in the citizen science and recall survey data, respectively. Results are not shown for cases with ≤ 20 respondents in either of the surveys (*).

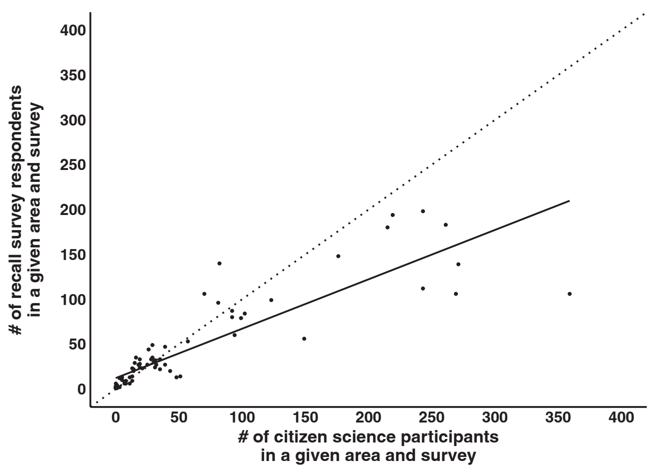

Fig. 3. Number of recall survey respondents plotted against number of citizen science participants, fishing for sea trout, in the eight distinct ICES areas for ten half-year periods from 2016 to 2020. The solid line describes the relationship between citizen science participants and recall survey respondents using linear regression. The regression can be described by: Number of recall survey participants = 12 + 0.55* number of citizen science participants. The dotted line indicates the line for a 1–1 relationship.

3A21, 3B23, 3C22, and 3D24, respectively. In other words, the estimates from the citizen science platform were ~125% smaller in 3A21, ~230% smaller in 3B23, ~85% smaller in 3C22, and ~30% smaller in 3D24 compared to the recall survey.

The number of survey periods with differences in the proportion of releases sea trout varied by area (Fig. 5): from 7 of 10 survey periods in 3C22, to 5 of 10 in 3A21, to 1 of 7 in 3B23, and none in 3D24. However, the proportion released was, on average, ~20% higher for the citizen science platform compared to the recall survey (IQR) of 1.19 (0.26), 1.20 (0.36), 1.15 (0.11), 1.19 (0.26) for 3A21, 3B23, 3C22, 3D24, respectively).

3.3. Danish coastal/offshore cod fishery

There was a positive, linear relationship between the number of citizen science participants and recall survey respondents who contributed data across the eight ices areas in each of the ten half-year survey periods from 2016 to 2020 (df = 1, F = 114, $p < 0.001$, R^2 = 0.59; Fig. 6).

We had cod and effort data provided by ≥ 20 respondents or participants from areas 3B23 and 3C22 only (See supplementary A for average number of respondents and participants). The citizen science data tended to estimate smaller cod catches in 3B23 and 3C22 relative to the recall survey (Fig. 7), with median q-values (IQR) of 0.25 (0.11) and 0.33 (0.21) for areas 3B23 and 3C22, respectively. In other words, estimates from the citizen science platform were 300% smaller and 200% smaller in the areas 3B23 and 3C22, respectively.

The number of survey periods with differences in estimates varied in relation to area for the proportions of cod that were released (Fig. 8). We found no differences in area 3B23. The median q-value (IQR) across survey periods in this area was 0.90 (0.29; i.e., ~10% lower on the citizen science platform). In contrast, there were clear differences between estimates in area 3C22. Here, the median q-value (IQR) across survey periods was 1.3 (0.20), indicating that estimates were 30% larger on the citizen science platform.

3.4. Danish freshwater pike fishery

We did not observe a significant relationship between the number of citizen science participants and recall survey respondents contributing pike data in each of the ten half-year survey periods from 2016 to 2020 (df = 1, F = 0.87, p = 0.38, R^2 = 0.10), or differences between methods in any of the survey periods for pike caught and the proportion released. However, we did observe differences between the estimated number of fishing trips in five of ten survey periods. The median q-values (IQR) across survey periods were 0.72 (0.36), 0.88 (0.60), and 1.00 (0.12) for number of trips, catches, and release proportions, respectively (Fig. 9). In other words, estimates from the citizen science platform were ~40% smaller, 13% smaller, and the same for the number of trips, pike caught, and proportion released, respectively.

4. Discussion

We found interesting and important differences between the citizen science and recall surveys for the four recreational fisheries that we evaluated: coastal/offshore cod and coastal sea trout, freshwater pike, and Funen sea trout.

Denmark's freshwater pike fishery is small relative to the sea trout recreational fisheries, so we expected disagreement between catch and effort estimates from the citizen science and recall surveys. The absence of a systematic, relative relationship in the yearly number of survey respondents and citizen science participants within this fishery suggests that these surveys did not reflect the same yearly popularity of the fishery. However, we found no significant differences in any of the ten survey periods. The tendency of the citizen science platform to

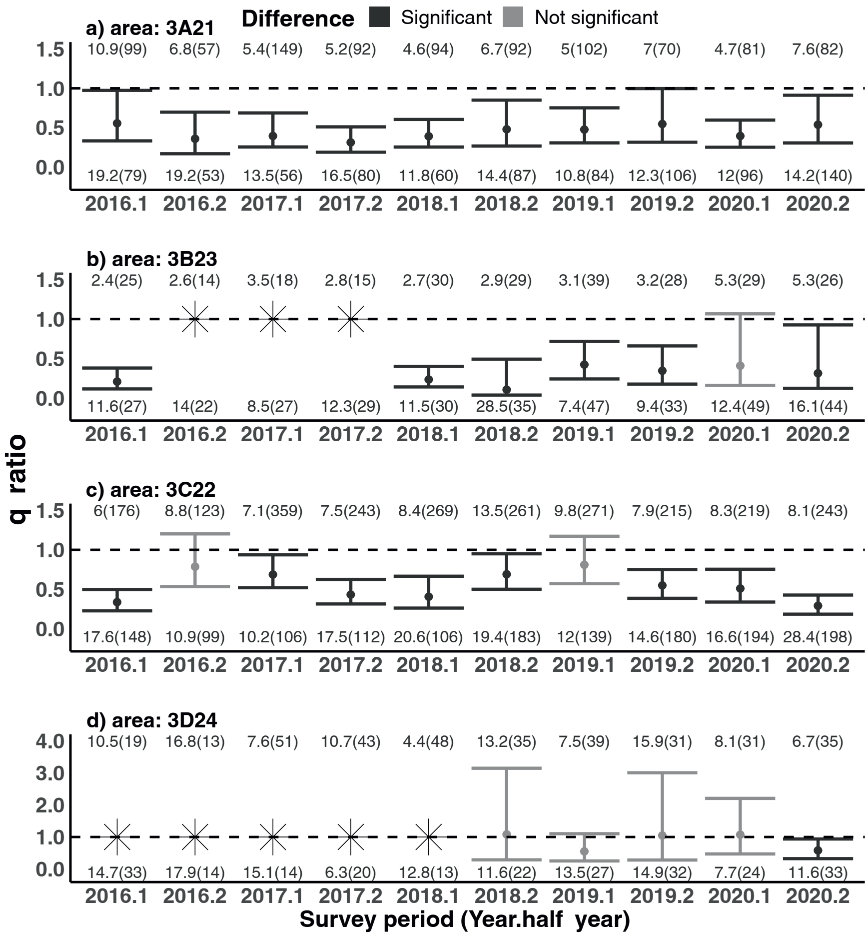

Fig. 4. q-Ratio for catches of sea trout in the areas a) 3A21, b) 3B23, c) 3C22, and d) 3D24. Dots are the median q-value, and error bars are the 95% confidence intervals. There is evidence of difference between two estimates when $q = 1$ is not within the 95% confidence interval (black); otherwise the confidence interval is gray. The top and bottom rows of numbers are the parameter average (and number of participants/respondents) in the citizen science and recall survey data, respectively. Results are not shown for cases with ≤ 20 respondents in either of the surveys (*).

consistently (and sometimes significantly) underestimate the number of fishing trips compared to the recall survey, could be due to recall bias in the recall survey [e.g., [45], an overrepresentation of avid anglers in the recall survey [e.g., [27], underreported fishing trips through the citizen scientist platform, or higher catch rates among citizen science participants [e.g., [30]. Nonetheless, the citizen science platform generated estimates of catches and release proportions that were similar to the recall survey. These results indicate that the citizen science platform could be an alternative to the recall survey to inform this fishery – directly for catches and release proportions, and indirectly for effort via a correction factor.

As with freshwater pike, there was general agreement for the number of fishing trips, catches, release proportions, and voluntary release proportions as measured in four surveys from 2017 to 2020 in the relatively small and well-defined Funen sea trout fishery. The similarity in catch and effort estimates over four years is notable because: 1) they suggest that similar findings for the 2017 Funen sea trout fishery [31] were not spurious, 2) data collection seemed consistent despite the fact that the citizen science platform was advertised differently and likely to a lesser degree in 2018, 2019 and 2020, and 3) the number of citizen science participants and recall survey respondents varied among years (Fig. 2). Our results suggest that data from the citizen science platform could be an alternative to the current recall survey to inform the management of this specific fishery.

We hypothesized consistent results over time for the national coastal sea trout fishery because it is a relatively specialized type of angling that is likely to attract citizen science participants [30]. Our hypothesis was supported by a significant relationship between the number of survey respondents and citizen science participants at a given time and area. The relationship was not exactly one-to-one, but indicated that the relative temporal and spatial popularity of the fishery was somewhat similar between survey methods. However, catch estimates from the citizen science platform were consequently 100–200% lower compared to estimates from the recall survey for the three ICES areas that had the most respondents/participants. Further, the release proportions were generally higher on the citizen science platform. The consistency of our results over as much as 10 survey periods suggests that area-specific weighting factors can be applied when using the citizen science platform to generate national estimates of catches and the proportion of fish released.

The relatively small number of citizen scientists who participated in the cod fishery limited our ability to make comparisons with the data provided by the recall survey. However, the overall low number of recall survey respondents in a few of the areas and survey periods may indicate low angling activity in general, which is further indicated by a significant relationship between the number of survey respondents and citizen science participants. The relationship suggests that the relative spatial and temporal popularity of the fishery was adequately characterized by the two survey methods. However, it is worth noting that obtaining an adequate sample size is a challenge when using citizen science to explore vulnerable fisheries with low participation. In the two ICES areas that had sufficient sample sizes, we observed the same differences between the two methods as in national coastal sea trout fisheries: fewer catches and a greater proportion of released cod in the citizen science data.

We recognize that our results were dependent on data that were provided by as few as 21 participants, and accept that this is a low threshold. Basing management actions and extrapolating to population level for large geographical areas using 21 respondents might be necessary for some fisheries, but is far from optimal. Additionally, we recognize that random variation would make it difficult to detect clear

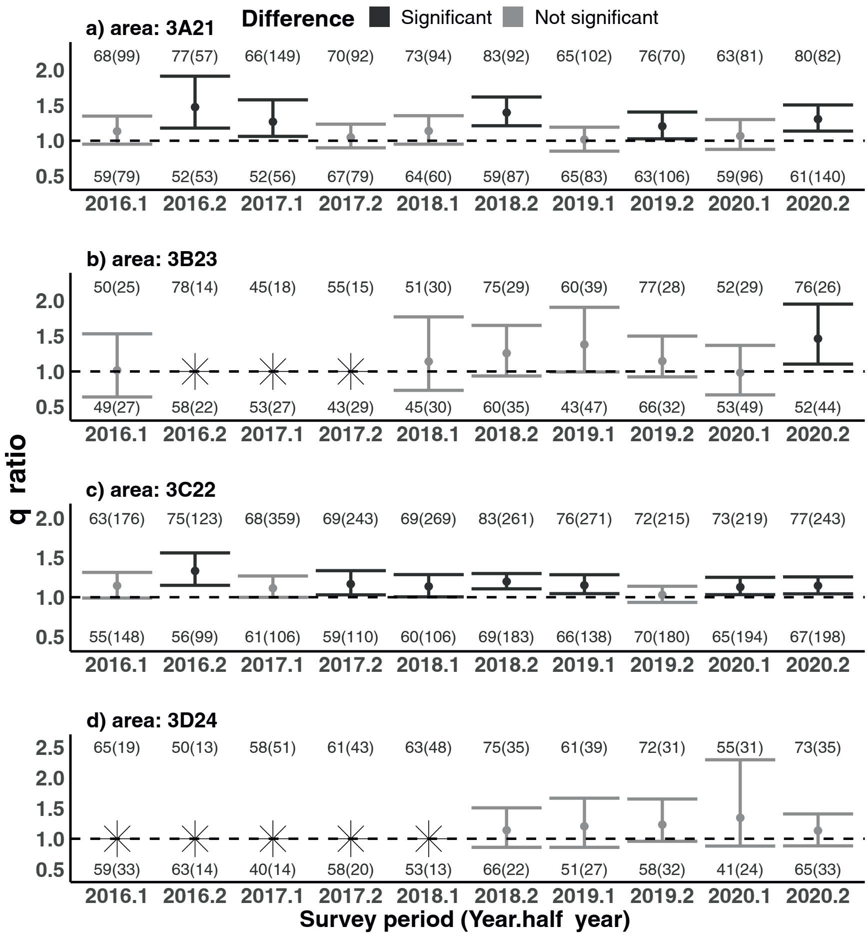

Fig. 5. q-Ratio for release proportions of sea trout in the areas a) 3A21, b) 3B23, c) 3C22, and d) 3D24. Dots are the median q-value, and error bars are the 95% confidence intervals. There is evidence of difference between two estimates when q = 1 is not within the 95% confidence interval (black); otherwise the confidence interval is gray. The top and bottom rows of numbers are the parameter average (and number of participants/respondents) in the citizen science and recall survey data, respectively. Results are not shown for cases with ≤ 20 respondents in either of the surveys (*).

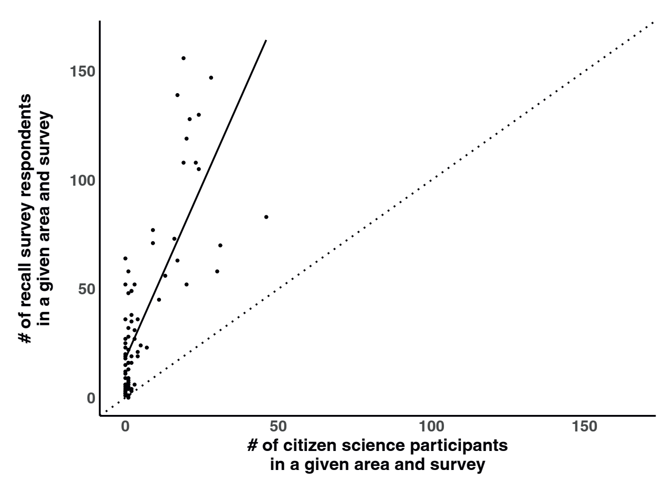

Fig. 6. Number of recall survey respondents plotted against number of citizen science participants, fishing for cod, in the eight distinct ICES areas for ten half-year periods from 2016 to 2020. The solid line describes the relationship between citizen science participants and recall survey respondents using linear regression. The regression can be described by: number of recall survey participants = 18 + 3.2* number of Citizen science participants. The dotted line indicates the line for a 1–1 relationship.

differences if these analyses were based on low number of participants. Very few participants reported data to the citizen science platform from the Danish coastal cod fishery, i.e., at most, only 46 citizen science participants reported fishing activity during a survey period (i.e., in a six-month period). Small samples sizes could be enough to infer bias, but were low compared to the Funen sea trout (n = 220 participants) and Danish freshwater pike (n = 194) fisheries. The results from these fisheries indicate that survey results can be similar when sample sizes are large. However, differences can occur in other fisheries for which the number of participants is high (e.g., sea trout in the ICES areas). Although, it is not possible to identify the source(s) of bias, our findings from the Funen sea trout and Danish freshwater pike fisheries provide some insights. First, it is important to recognize that the citizen science platform collected data from all four fisheries in a consistent manner, i. e., the citizen science anglers report their data by trip on the electronic platform. In contrast, responses to the recall survey were based on questions that differed in wording and specificity between fisheries. Hence, it seems relevant to explore and highlight the main differences in recall survey context for the four fisheries. Methods were similar in the Funen sea trout fishery in that respondents were asked to record information about their trips, harvested catch, etc. for a restricted area. Funen is a well-known Island, so we argue that it was easy to separate from other areas. Further, the recall period was relatively short because the survey was sent out shortly after the end of the three-month period of interest. In comparison, there was a 6-month recall period for the freshwater pike fishery. However, respondents in this fishery were also asked to recall trip, catch, and release details for a relative well-defined area (e.g., the freshwater locations in Denmark). In contrast to these two fisheries with similar estimates of catch and effort between the recall survey and the citizen science platform, the two fisheries with apparent differences in catches and release proportions were set up differently in the recall survey. First, respondents are asked to recall the number of fish they harvested, and released, for eight ICES areas that are well defined, but may seem arbitrary or confusing to nonprofessionals (even

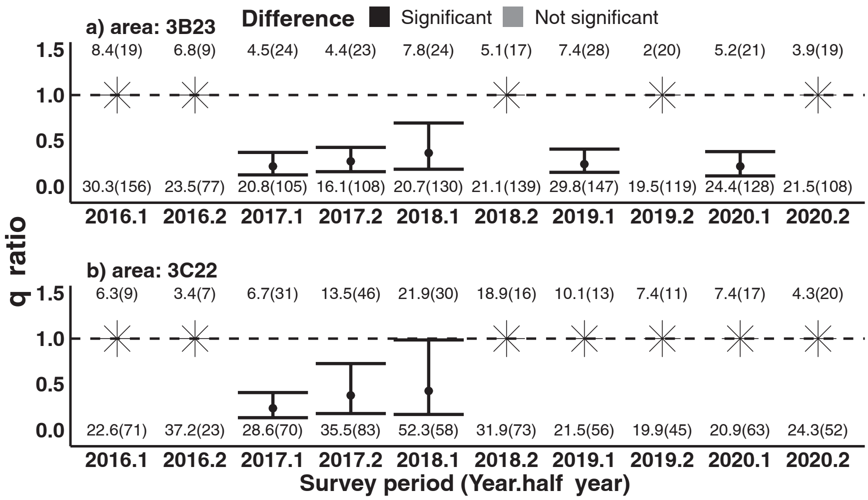

Fig. 7. q-Ratio for catches of cod in the areas a) 3B23 and b) 3C22. Dots are the median q-value, and error bars are the 95% confidence intervals. There is evidence of difference between two estimates when q = 1 is not within the 95% confidence interval (black); otherwise the confidence interval is gray. The top and bottom rows of numbers are the parameter average (and number of participants/respondents) in the citizen science and recall survey data, respectively. Results are not shown for cases with ≤ 20 respondents in either of the surveys (*).

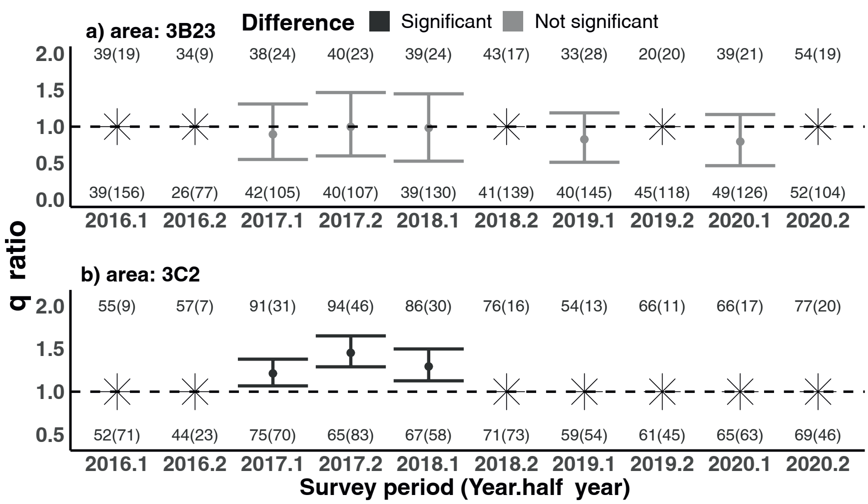

Fig. 8. q-Ratio for release proportions of cod in the areas a) 3B23 and b) 3C22. Dots are the median q-value, and error bars are the 95% confidence intervals. There is evidence of difference between two estimates when q = 1 is not within the 95% confidence interval (black); otherwise the confidence interval is gray. The top and bottom rows of numbers are the parameter average (and number of participants/respondents) in the citizen science and recall survey data, respectively. Results are not shown for cases with ≤ 20 respondents in either of the surveys (*).

though maps were provided during the survey). Second, respondents were asked to recall their fishing activity separately for the first three-month period, and then again for the second three-month period in the half-year period. Recalling for two time-frames, and thus a longer period, may have led to overestimation [23,24,26]. The combined effect of having to recall for ICES areas and two time-periods may be evidenced in area 3C22. This area should include data from the Funen area. When comparing sea trout catches in 3C22 to the specialized fishery on Funen, it is evident that doubling the period approximately doubled the estimates from the citizen science platform, but approximately tripled the estimates from the recall survey. It is also possible that non-response bias may have affected the recall survey. Non-response is likely to act in a similar direction as self-selection, namely that more committed anglers are more willing to participate, as they have higher resource dependency [46–48].

Data collection via the citizen science platform were similar across the four fisheries. However, it is possible that the types of anglers who participated in these surveys differed by fishery. This could include their propensity to (consistently) engage in citizen science. Our study did not consider the demographics of either participants or respondents. However, Gundelund et al., (2020) found that citizen scientists in the Funen fishery were specialized [30]. Therefore, we cannot exclude angler heterogeneity as a contributing factor to the differences that we observed. Recall and citizen science surveys can generate similar estimates despite differences in participant demographics [31], but this is unlikely to hold for all fisheries or surveys. For example, the low number of citizen science participants in the cod survey may reflect a lower propensity to participate in citizen science – perhaps due to a lower level of specialization [e.g., [46]. In contrast, it is difficult to argue that the difference between the two sea trout surveys was because sea trout anglers on Funen were markedly different than sea trout anglers in the rest of the country. Further research should focus on mapping the components of the angling community who participate in different survey types, such as recall surveys and citizen science platform. Relating these segments to the angler population would be useful – not only in relation to demographics, but also for behavioral indicators, such as recreation specialization [46].

Our study corroborates previous findings that citizen science platforms and angler apps can generate data that contribute to our understanding and management of recreational fisheries [31,37–39,49,50]. Findings from Jiorle et al., (2016) indicate that smartphone applications for anglers can provide comparable catch estimates to traditional survey methods in fisheries with sufficient sample sizes [37]. Similar findings can be highlighted in our study e.g. when looking at the Funen sea trout fishery or the Danish freshwater pike fishery as opposed to the Danish coastal cod fishery. However, the catch estimates from Jiorle et al., (2016) were based on on-site creel surveys as opposed to off-site recall surveys and they had to aggregate across space and time to get sufficient sample sizes [37]. Other studies have also found comparable catch estimates using on-site surveys [e.g., [31,38,39]. In addition to using creel

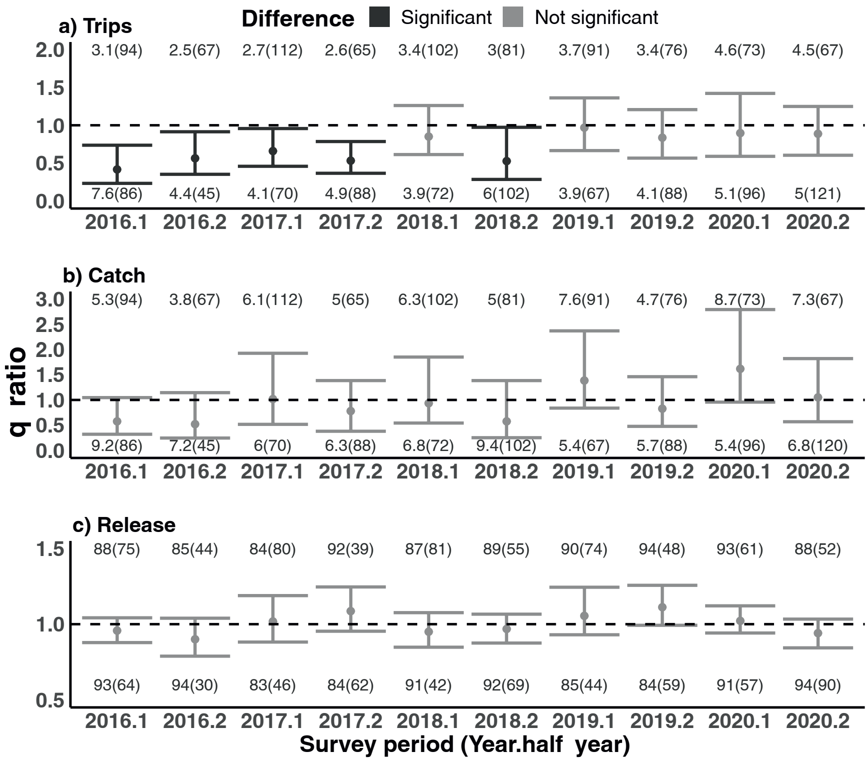

Fig. 9. q-Ratio for number of fishing trips (a), catches (b), and release proportions (c) for the Danish freshwater pike fishery. Dots are the median q-value, and error bars are the 95% confidence intervals. There is evidence of difference between two estimates when $q = 1$ is not within the 95% confidence interval (black); otherwise the confidence interval is gray. The top and bottom rows of numbers are the parameter average (and number of participants/respondents) in the citizen science and recall survey data, respectively. Results are not shown for cases with ≤ 20 respondents in either of the surveys (*).

surveys, the studies from Gundelund et al., (2021) and Johnston et al., (2021) also evaluated data from citizen science platforms using recall surveys [31,39]. Although these comparisons were also somewhat similar, some differences were noted that could be contributed to associated biases in either method, e.g., self-selection or recall bias. Our study builds on this by highlighting that the design of a recall survey (e.g., the number of recall periods and framing of questions) may affect the estimates that are being generated. This implies that differences might not be fishery-specific but could be due to the design of the recall survey, as highlighted by our findings for the national coastal sea trout estimates. We cannot rule out that all or some of the differences in the estimates for national coastal seatrout or coastal cod fishery were due to bias related to the citizen science platform, but still suggest that it worth considering the recall survey design.

In summation, our findings indicate that citizen science platforms can generate catch and effort estimates from anglers that are consistently similar over a period of four to five years relative to a traditional recall survey in fisheries with adequate sample size. It is also clear that the citizen science platform does not generate sufficient data from some fisheries (e.g., coastal cod), and, further studies are recommended before fisheries managers include electronic citizen science reporting platforms e.g. mobile apps as their only survey methodology. This research should focus on why data collection via citizen science platforms may provide reliable data in some cases and not in others, and in validating the results of both of the survey types used in this study (e.g., by comparing to onsite surveys).

Our study also suggest that it can be necessary to scrutinize the design of surveys that is used to validate the data generated by citizen science platforms. Recall surveys are by no means the gold standard as a basis for comparison, however, they are used in many countries, and for many fish stocks, to inform management of recreational fisheries. For comparative purposes, and data collection in general, large scale stratified random sample surveys (e.g., onsite creel surveys) are the safe choice. However, that is not always a possibility, e.g., due to logistics or policy. In these cases, electronic citizen science platforms can be considered as an alternative. Not least, because such platforms, e.g. mobile apps, in addition to collecting data on fisheries metrics, also provide novel opportunities that allows managers to engage directly with the users. Well-designed apps can provide real time and on-site information about management actions (e.g., closed seasons, closed areas, protected species and much more) that may increase compliance. They can also promote education and information, which may lead to increased acceptance of management actions, self-regulation, and a more engaged community of recreational fishers.

CRediT authorship contribution statement

CG: Conceptualization, Writing – original draft, Methodology, Formal analysis, Software; **PV:** Conceptualization, Writing – review & editing, Supervision; **BWH:** Conceptualization, Methodology, Writing – review & editing; **KH:** Conceptualization, Writing – review & editing; **HJO:** Conceptualization, Data curation, writing – review & editing; **CK:** Conceptualization, writing – review & editing, Supervision, Data curation, Project administration.

Declaration of Competing Interest

The authors have no conflicts of interest to declare.

Data Availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2023.105780.

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