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Evaluation of a citizen science platform for collecting fisheries data from coastal sea trout anglers

Casper Gundelund, Paul Venturelli, Bruce W. Hartill, Kieran Hyder, Hans Jakob Olesen, and Christian Skov

Abstract: There are often limited data available to support the sustainable management of recreational fisheries. Electronic citizen science platforms (e.g., smartphone applications) offer a cost-effective alternative to traditional survey methods — but these data must be validated. We compared sea trout (*Salmo trutta*) data from a Danish citizen science platform with three independent traditional surveys: a roving creel survey, an aerial survey, and a recall survey. The comparisons include fisheries data (e.g., catch, release, effort, and fish size structure) and demographic descriptors (e.g., age) that were collected within the same spatial and temporal frame. We found general alignment between recreational sea trout catch and effort data that were provided by citizen scientists, or collected by more traditional survey methods. Our results demonstrate that citizen science data have the potential to supplement traditional surveys, or act as an alternative source of catch and effort data. However, results were from a highly specialized fishery within a limited spatial and temporal frame, so more research is needed to assess their relevance over time and to a broader set of fisheries.

Résumé : La disponibilité de données pour appuyer une gestion pérenne des pêches sportives est souvent limitée. Si les plateformes électroniques de science citoyenne (p. ex. applications pour téléphones intelligents) constituent une option de rechange peu coûteuse aux méthodes d'enquête traditionnelles, leurs données doivent être validées. Nous avons comparé des données sur la truite brune (*Salmo trutta*) d'une plateforme danoise de science citoyenne à celles de trois enquêtes indépendantes, soit une enquête par interrogation itinérante de pêcheurs, une enquête aérienne et une enquête mémoire. Les comparaisons comprennent des données sur la pêche (p. ex. prises, lâchers, effort et structure par tailles) et sur des descripteurs démographiques (p. ex. âge) qui ont été recueillies dans le même cadre spatial et temporel. Nous constatons une concordance générale des données de prises et d'effort sur la truite brune fournies par des citoyens scientifiques et obtenues par des méthodes d'enquête plus traditionnelles. Nos résultats démontrent que les données issues de la science citoyenne pourraient fournir un bon complément aux enquêtes traditionnelles ou constituer une source différente de données sur les prises et l'effort. Cependant, comme ces résultats concernent une pêche très spécialisée dans un cadre spatial et temporel restreint, plus de travaux sont nécessaires pour évaluer leur pertinence dans le temps et pour un ensemble plus large de pêches. [Traduit par la Rédaction]

Introduction

Recreational fishing is a popular activity in many regions of the world, with participation rates approaching 30% of adults in some countries (Arlinghaus et al. 2015). Recreational fishers invest time and money in their activity, which can translate into socioeconomic benefits if participation rates are high (e.g., Cisneros-Montemayor and Sumaila 2010; Hyder et al. 2018). Other benefits could include improved health and reduced stress due to increased physical activity (Parkkila et al. 2010; Griffiths et al. 2017). However, high rates of recreational fishing effort can be unsustainable (Post et al. 2002; Coleman et al. 2004; Lewin et al. 2006, 2019; Hyder et al. 2018; Radford et al. 2018). Sustainable recreational fisheries management requires information about effort, catch, and human dimensions (Arlinghaus et al. 2013; Hunt et al. 2013). This information can also be used in stock assessments for combined commercial and recreational fisheries (e.g., Strehlow et al. 2012) or in other aspects of recreational fisheries, such as managing in a socially optimal way (e.g., Arlinghaus et al. 2017).

On-site creel surveys are commonly used to collect data from fishers, either during or at the end of a fishing trip. A creel survey can be used to estimate total effort and harvest if it is conducted using a comprehensive probabilistic design (Pollock et al. 1994). On-site aerial surveys, in which the number of fishers in a survey area are counted from an aircraft, are also commonly used to estimate total effort probabilistically (Pollock et al. 1994). Total effort and harvest can also be estimated off-site by surveying a random sample of fishers by mail, phone, or email. These traditional methods are well established, and the biases that are associated

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C. Gundelund and C. Skov. Section of Freshwater Fisheries and Ecology, Technical University of Denmark, DTU Aqua, Silkeborg, Denmark.
P. Venturelli.* Department of Biology, Ball State University, Muncie, IN 47306, USA.
B.W. Hartill. National Institute of Water and Atmospheric Research, Auckland, New Zealand.
K. Hyder. Centre for Environment, Fisheries & Aquaculture Science, Lowestoft Laboratory, Pakefield Road, Lowestoft NR33 0HT, UK; School of Environmental Sciences, University of East Anglia, Norwich Research Park, Norwich, Norfolk NR4 7TJ, UK.
H.J. Olesen. Section for Monitoring and Data, Technical University of Denmark, National Institute of Aquatic Resources, Kgs. Lyngby 2800, Denmark.
Corresponding author: Casper Gundelund (email: cgun@aqua.dtu.dk).

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with them (e.g., recall, telescoping, non-response, prestige, coverage) are well understood (Pollock et al. 1994; Jones and Pollock 2012).

The recent growth of smartphone applications (apps) has created opportunities for new approaches to data collection (e.g., Venturelli et al. 2017). Anglers and other recreational fishers can choose from dozens of apps for recording and sharing their catch information (Papenfuss et al. 2015; Jiorle et al. 2016; Venturelli et al. 2017). The most popular fishing apps generate catch information from thousands of fishing trips each month, and potentially provide valuable data that could be used to support management of recreational fisheries (Venturelli et al. 2017). Angler apps vary in their specificity and functionality. They can serve a specific fishery, or all fisheries in all locations. Likewise, they can function as specialized social media platforms that emphasize community and fishing success, or as citizen science platforms that encourage data collection in support of research or management (Venturelli et al. 2017). Apps that are well designed and popular could be a cost-effective and alternative or supplemental source of fisheries data (Venturelli et al. 2017).

There are numerous challenges associated with using app data for fisheries science and management (Hyder et al. 2015; Venturelli et al. 2017; Gundelund et al. 2020). An app must be designed to collect relevant data, ideally, in a way that does not burden the participant. Data from angler apps are self-reported, which can lead to large biases as seen in angler diaries (Cooke et al. 2000). This could, for example, include misreported lengths and weights, and underreported non-memorable events, such as trips without catches (i.e., zero catch trips). Angler apps are also a form of non-probability sampling in that the anglers who choose to use apps are self-selecting and therefore unlikely to be representative of the angling population (e.g., Gundelund et al. 2020). This non-random sample of anglers can bias estimators of population parameters, for example, by being a more committed and skilled segment that has higher catch rates than the general angling population (Gundelund et al. 2020). Despite these challenges, examples of app data tracking some catches (e.g., Jiorle et al. 2016) and other novel uses (Papenfuss et al. 2015; Liu et al. 2017) have highlighted the need for research to evaluate the potential for app data to inform fisheries management (Venturelli et al. 2017; Skov et al. 2021).

Danish researchers launched the citizen science project Fangstjournalen in 2016 to increase data on recreational fisheries. Anglers were encouraged to join the project and report their fishing trips through an angler app or webpage. Gundelund et al. (2020) found that Fangstjournalen participants who targeted sea trout (*Salmo trutta*) on the Danish island of Funen in 2017 were younger, more specialized, and had higher catch rates than the general sea trout angling population (Gundelund et al. 2020). They focused on coastal sea trout angling because it is the most popular type of angling in Denmark (Kromand et al. 2010). However, the extent to which these differences affected key fisheries metrics is unknown.

In this study, we compared data from the citizen science project Fangstjournalen with data from three traditional survey methods: a roving creel survey, an aerial survey, and a recall survey. We compared fisheries data metrics such as catch rates, release rates, size structure of the catch, effort information (e.g., fishing trip duration) and demographic information about individual anglers. Specifically, for the aerial survey, we investigated the possibility of using citizen science participants to infer temporal changes in total effort. These analyses were done to evaluate how citizen science data compared to traditional survey methods in recreational fisheries. We hypothesized that our estimates of key fisheries metrics from the citizen science platform would be biased towards larger estimates, compared to the roving creel survey, due to underreporting of non-memorable events (e.g., zero catch trips and catches of smaller fish) and because citizen science participants are more specialized anglers with higher catch rates (Gundelund et al. 2020). We also hypothesized that our estimates of key fisheries metrics from the citizen science platform and recall survey would be comparable under the assumption that the underreporting of non-memorable events by citizen science participants who are more specialized anglers will operate like recall bias. Additionally, we hypothesized that the demographics of citizen scientists would not reflect that of traditional survey methods, due to self-selection issues. The results are discussed in the context of citizen science related platform design, data collection, data quality, and its use to support fisheries management and governance.

Materials and methods

Study design and study area

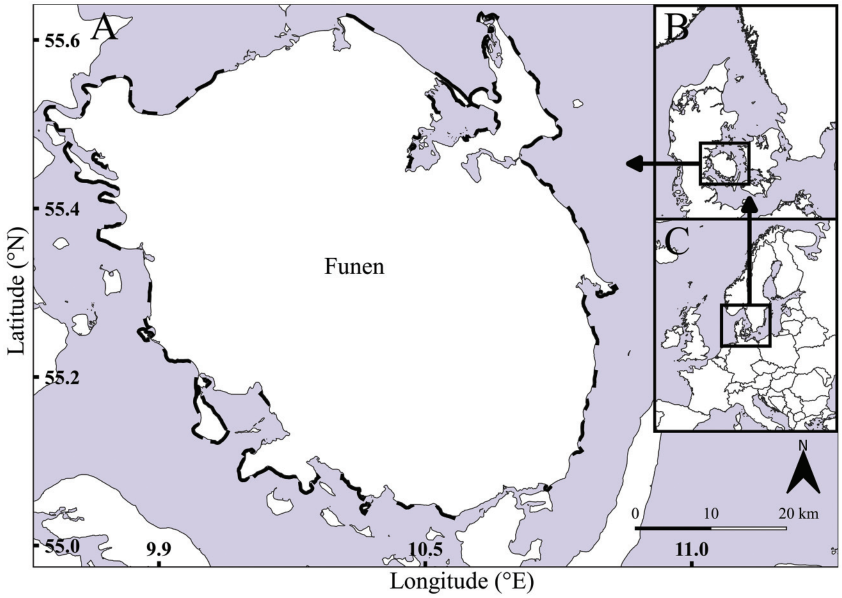
We focused our study exclusively on coastal sea trout angling because there were insufficient citizen science data for other species. Although coastal sea trout angling is the most popular type of angling in Denmark, little is known about the participants in this fishery, their harvest rates, release rates, and effort (Olesen and Storr-Paulsen 2015). The study area was restricted to the island of Funen in Denmark (Fig. 1). Funen is a popular area for sea trout angling that attracts both locals and tourists (Møller and Petersen 1998). Coastal sea trout fishing on Funen is a diffuse access fishery along ~500 km of coastline.

Angling effort for sea trout is assumed to vary seasonally and peak in spring. Hence, data from Funen were collected between 1 April and 30 June 2017 via a recall survey and from 1 March to 31 May 2017 using both a roving creel survey and an aerial survey. Sea trout anglers on Funen used the citizen science platform to log relevant data during the same periods (Gundelund et al. 2020). This made it possible to compare key fisheries parameters from the citizen science platform to three of the most common traditional survey methods — all within the same spatial and temporal frames.

Roving creel survey

The roving creel survey was planned as a traditional random multistage survey (Pollock et al. 1994) with two levels of temporal stratification (weekday versus weekend/holidays and time of day). The allocation was almost equal between weekdays (53%) and weekends/holidays (47%), which covered all weekends and holidays in the survey period. Time of day was, for each sampling day, allocated as either a morning or an evening survey. An even allocation between mornings and evenings was chosen to ensure that the entire fishing day was surveyed. To cope with change in day length, and thus light levels, mornings were defined as being from one hour after sunset and eight hours forward, while evenings were defined as being eight hours prior to sunset until sunset. We identified 79 designated interview sites using a local guidebook for anglers targeting sea trout. With the help of local expertise and the "Sea trout Funen Secretary", a secretary formed by the local municipalities, the designated interview sites were assigned one of three popularity levels: not very busy (50% chance a site should be visited), medium busy (75% chance a site should be visited), and busy (100% chance a site should be visited). In the daily planning of routes, a starting site was chosen randomly from 79 designated interview sites, and then the travel direction from that site (clockwise or counter-clockwise) was determined randomly. For each subsequent site in that travel direction, the site popularity level (i.e., chance to visit a given site) would determine which of the sites should be visited. The roving creel survey was conducted by a single clerk to avoid interviewer bias (Pollock et al. 1994). The clerk would spend up to two hours at each site, implying that at least four sites were covered each day. In situations where it was not possible to interview all of the anglers within the two-hour limit, the clerk was instructed to interview every other angler. When large fishing parties were encountered,

Fig. 1. The Danish island of Funen (A) in Denmark (B) and Europe (C). The island is ~3000 km^2, with ~500 km of diffuse access coastline. The highlighted areas of the coastline represent the 79 designated interview sites used in the roving creel survey. The map was created using QGIS version 3.0.2 (QGIS Development Team 2021). Mapping layers were available from the Eurostat database (Eurostat 2021). ©EuroGeographics for the administrative boundaries.



the clerk approached the fishing party and requested to interview all party members, but one at a time and outside of the hearing of the other party members.

The interviewees participated in a 10-minute survey, during which they were asked how long they had been fishing for, how many sea trout they had caught and harvested, how many sea trout they had caught and released, and how many sea trout above the minimum size limit they had caught and released. The clerk also asked participants to report their gender, age, and area of residence (postal code), and measured the length of all harvested sea trout.

Aerial survey

An aerial survey was carried out over the same period as the roving creel survey (1 March – 31 May 2017) as a means of estimating angling effort. The aerial survey was carried out using a single engine plane that took ~3 hours to survey the entire coastline of Funen (Fig. 1). The design followed a three-stage, stratified random design comprising 26, randomly selected survey days that were distributed with unequal probability between weekdays (40%) and weekends/holidays (60%) and with equal probability among three-hour windows during daylight hours (Pollock et al. 1994). The sampling days were divided into two categories that were sampled with equal probability: from sunrise to midday (mornings) and from midday to sunset (evenings). For March and April, the three-hour windows were defined as 07:00–10:00 and 10:00–13:00 for mornings, and 13:00–16:00 and 16:00–19:00 for evenings. In May, an additional three-hour window for evening was included, and the three-hour windows for mornings were changed to adjust for the increasing light hours. Consequently, the morning windows in May were 06:00–09:00, and 09:00–12:00 (mornings), and 12:00–15:00, 15:00–18:00 and 18:00–21:00 (evenings). These time windows were defined to provide the best possible temporal coverage of fishing effort. The aerial survey followed a four temporal strata design that was identical to the roving creel survey design in that it was based on the four possible combinations of day type (weekdays and weekends) and time of day (mornings and evenings).

Recall survey

The Danish National Institute of Aquatic Resources and Statistics Denmark have been conducting recall surveys twice a year since 2009 to deliver statutory monitoring of marine recreational fisheries for the European Commission (European Commission 2016, 2019). The goal of these surveys is to estimate the annual recreational harvest and release of sea trout and other fish species. The sample frame for the recall survey was based on the Danish national fishing license register. It is mandatory for recreational fishers 18–65 years old to hold such a license when fishing in Danish waters. Potential respondents were randomly selected from the Danish national fishing license register. They were contacted by e-mail, digital postbox, or postal letter, and encouraged to answer the questions via the internet (Olesen and Storr-Paulsen 2015).

Respondents were asked about the number of angling trips targeting sea trout on Funen, the number of sea trout retained on Funen, the number of sea trout released on Funen, and the number of released sea trout below minimum size on Funen between 1 April and 30 June 2017 (see online Supplementary A[1] for exact wording). Anglers were also asked about their average fishing trip duration within the last six months and their postal code. The request to participate was sent on 27 July 2017, and data were collected until 1 September 2017.

The citizen science platform Fangstjournalen

The Danish citizen science platform Fangstjournalen (webpage and smartphone app), provides a way for anglers to submit data from their fishing trips. This platform works as a logbook that anglers can use to record information about their trips and catches (e.g., date, location, effort, target species, number caught and retained or released). Participants also have the option to provide demographic data in the form of age, gender, and place of residence (see Venturelli et al. 2017 for a full overview of the

[1]Supplementary data are available with the article at https://doi.org/10.1139/cjfas-2020-0364.

data that are collected by the platform). The platform was designed by researchers to be a tool for data collection in support of recreation fisheries research and management. Submitted data are uploaded to a server, and both feed back to the angler and are aggregated into a database (see Venturelli et al. 2017 for an illustration of the dataflow between participants and the platform). Fangstjournalen was first launched 15 January 2016.

Comparative analyses

We began our comparative analysis by ensuring that the data from the citizen science platform were within the same temporal frame as the roving creel survey (1 March – 31 May 2017) and recall survey (1 April 2017 – 30 June 2017). For the aerial survey comparison, we only considered citizen science data that were logged during one of the 3-hour flights. We also constrained citizen science data to flights that were conducted in March and April because the coastal fishery becomes mixed in May when coastal anglers begin to fish for migratory garfish (*Belone belone*). Data from the roving creel survey and the citizen science platform indicated that anglers fishing for sea trout represented 98% and 99%, respectively, of the fishing trips on Funen in March and April 2017. Thus, all four surveys were effectively limited to sea trout anglers.

The data provided by the citizen science platform were from a self-selected population that was not sampled in a probabilistic fashion. Hence, it may not be valid to apply traditional hypothesis-testing methods to test for differences between data provided by this data source and another. A common approach (e.g., when comparing self-selected web panels to probabilistic surveys) is to present point estimates from the raw unweighted data, such as the means (e.g., Bethlehem 2010, 2015). We follow this approach by bootstrapping a 95% confidence interval for the mean value of the raw unweighted data from the probabilistic survey, and present a point estimate, the mean, of the raw unweighted data from the self-selection survey. Additionally, we used a non-parametric bootstrapping approach to compare estimates provided by two concurrent surveys, based on the methods described by Hartill and Edwards (2015). With this comparative approach, two survey data sets were resampled with replacement, and a ratio of the means of these bootstrap samples was

$$q = \frac{E^a}{E^b}$$

where E^a is the mean of the bootstrapped data from survey method a, and E^b is the mean of the bootstrapped data from survey method b. If the means are equivalent, then q should be close 1.0. This bootstrapping procedure was repeated 1000 times to gauge the uncertainty that was associated with estimates of q, and their distribution relative to an equivalence value of 1.0. The distributions of q estimates for a given survey metric comparison are shown as box plots. The 95th percentiles of the q distributions, which are also shown on these box plots, are a non-parametric equivalent of the confidence intervals that are usually calculated when conducting parametric significance tests at α = 0.05. If an equivalence value of 1.0 falls within the 95th percentiles of a distribution of bootstrapped q estimates, then we reject the null hypothesis of no difference between the estimates of the metric provided by the two alternate concurrent surveys. This inference, two-tailed significance test performed at a 5% significance level, is used in this context to provide an indication of the bias associated with one survey method relative to another. Using the sample instead of a point estimate to identify biases in nonprobability surveys, using classic statistical inference, is common practice (e.g., Miller et al. 2010; Yeager et al. 2011; Sohlberg et al. 2017; Legleye et al. 2018; Lehdonvirta et al. 2021)

In the comparison of roving creel survey data to citizen science data, we compared estimates of catch rates (fish per hour), proportion of fish released (henceforth proportion released), length of harvested fish, and age. We also explored nationality, gender, and residence. In the catch rate estimation, fishing trips shorter than 0.5 hours were removed to reduce the variance in the estimates (Hoenig et al. 1997; Pollock et al. 1997). For nationality (Danish vs. foreign), gender (male/female), and residence (9 major geographical areas) the relative share in each category was inspected. Age, gender, and residence were only investigated for Danish participants due to data constraints.

In the comparison between recall survey and citizen science data, we compared average estimates of number of fishing trips conducted, total number of fish caught, proportion released, proportion released voluntarily, and fishing trip length. With the exception of fishing trip length, the otherwise trip-specific data for participants on the citizen science platform were aggregated across the three-month period (i.e., 1 April to 30 June) to match the recall period in the recall survey. Fishing trip length for all available fishing trips (including those that targeted species other than sea trout), was aggregated across a six-month period (i.e., 1 January to 30 June) to match the recall period and the framing of the question, regarding fishing trip length, in the recall survey (see Supplement A[1]). We also explored residence (i.e., postal codes).

In the aerial survey data and citizen science data comparison, we explored the possibility of using citizen science participants to infer changes in temporal patterns of total effort. This was done by investigating the linear relationship between the anglers counted in the aerial survey and the number of citizen science participants that were active during the three-hour flight windows (i.e., the users who logged a fishing trip in a period that overlapped with the time of the aerial survey on the given day).

The total catch of sea trout around Funen, during this study, was investigated by multiplying total effort in each aerial survey stratum (strata length times the number of counted anglers) by the average stratum specific catch rate (fish per hour) from the roving creel survey, and then summing across all strata (Pollock et al. 1994). The associated variance was determined using non-parametric bootstrapping. We generated 10 000 estimates of total catch by multiplying bootstrapped stratum-specific estimates of effort and average catch rate, and then summing across strata. All bootstrap samples were with replacement. We estimated the total catch from citizen science and aerial survey data by replacing the roving creel survey catch rates with citizen science catch rates for each of the four strata, and then repeating the analysis. This implies that all coastal fishing trips conducted on the citizen science platform were assigned to the respective stratum. The roving creel survey and aerial survey estimates were compared to the citizen science and aerial survey estimates of total catch graphically by comparing medians and 95th percentiles (i.e., 2.5% and 97.5%, corresponding to a 95% confidence interval around the mean for bootstrapped estimates).

All Statistical analyses were conducted using R version 3.6.1 (R Core Team 2019) and the boot (Davison and Hinkley 1997); ggplot2 (Wickham 2016); and tidyverse (Wickham 2017) packages.

Results

We approached 729 anglers during the 3-month roving creel survey of Funen. Six hundred and seventy-nine of these anglers agreed to participate (93% response rate), and 592 of these anglers stated that they targeted sea trout and were therefore within the sampling frame of this study. A total of 283 citizen science participants reported at least one fishing trip that targeted sea trout on Funen during the same period (Table 1). The aerial survey in March and April comprised 16 flights and counted 1445 anglers. Ninety-two unique participants used the citizen science platform to log 162 fishing trips across all 16 of the 3-hour windows in which the aerial survey flights occurred (Table 1). A total of

Fig. 2. Roving creel survey and citizen science comparison of average estimates of catch rates, proportion released, length of harvested fish, and participant age, using the survey coefficient q. The boxplots display the general direction of difference between the estimate (i.e., $q > 1$ and $q < 1$ indicate that estimates from the citizen science platform are larger or smaller, respectively). There is a clear indication of bias if $q = 1$ (dashed line) is not within the 95% confidence interval for the q value (black dots).

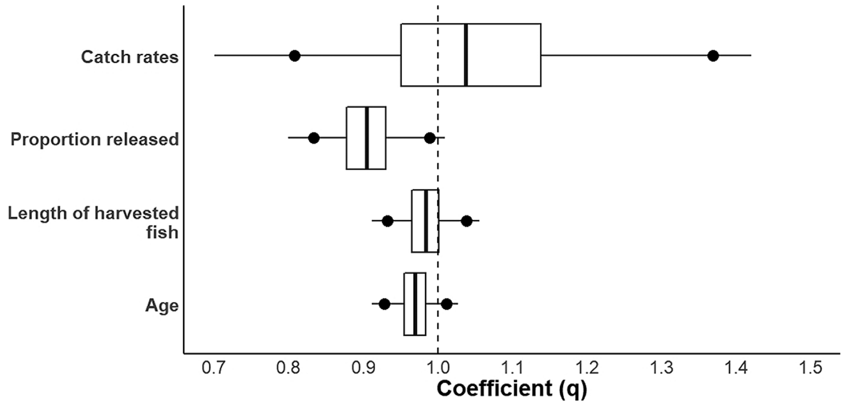


Table 1. Overview of key data elements from the comparison of citizen science (CS) data to roving creel survey (RCS) and recall survey (RS) data.

	RCS vs. CS		RS vs. CS	
Survey	RCS	CS	RS	CS
No. of respondents	550	283	135	221
No. of respondents with Danish postal code	344	273	135	215
No. of fishing trips	592	1486	578	1097
No. of fishing hours	1034	4205	2017	3119
Reported trips without catches	80%	66%	NA	NA
No. of fish caught	272	916	394	718
No. of released fish	229	731	296	546

Note: NA, not applicable.

135 recall survey participants reported at least one fishing trip on Funen within the sampling frame (April to June 2017). Two hundred and twenty-one citizen science participants reported at least one fishing trip during the same recall period (Table 1).

We estimated average catch rates for the roving creel survey and the citizen science platform to be 0.27 fish per hour (0.20–0.33 fish per hour, 95% CI) and 0.27 fish per hour, respectively. Anglers in the roving creel survey on average released 83% (77%–89%, 95% CI) of their catch, while citizen science participants released ~75%. Additionally, the average length of a harvested sea trout was 51.5 cm (49.1–53.9 cm, 95% CI) and 50.7 cm for the roving creel survey and citizen science platform, respectively. Compared to the roving creel survey, we found higher catch rates (4% or 0.01 fish per hour), and lower estimates of the proportion released (11% or 9% less fish) and length of harvested fish (2% or 1 cm) on the citizen science platform. Based on the q values, there was only a clear indication of bias in the estimates of proportion released (Fig. 2).

In relation to demography, we found a clear difference in the proportion of foreign anglers between the roving creel survey respondents (37%) and citizen science participants (3%). Roving creel survey respondents were, on average, 48 years old (46.5–49.4 years, 95% CI), while citizen science participants were, on average, 46.5 years old. The citizen science estimate was smaller (3% or 1.4 years), but there was no clear indication of bias from the q values (Fig. 2). The gender ratio among Danes was 99.7%/0.3% (male/female) for respondents in the roving creel survey, and 97%/3% (male/female) for citizen science participants. We found no clear differences in the spatial distribution of the Danish postal codes between citizen science and roving creel survey participants (Fig. 3).

In comparing recall survey data and citizen science data, we found that the average number of fishing trips conducted within the three-month period was 4.28 trips (3.36–5.22 trips, 95% CI) in the recall survey and 4.96 trips on the citizen science platform. For the number of fish caught, the averages were estimated to be 2.96 fish (1.88–4.04 fish, 95% CI) and 3.32 fish for recall survey and citizen science platform, respectively. For the proportion released, an average of 72.2% (63.6%–80.7%, 95% CI) of the fish were reported released in the recall survey, while an average of 64.6% fish were reported released through the citizen science platform. For the proportion released voluntarily, averages of 36.2% (23.5%–48.8%, 95% CI) and 40.3% were estimated in the recall survey and citizen science platform, respectively. Additionally, fishing trip length across a six-month period was compared. Here, the estimates for the recall survey and citizen science platform were 3.68 hours (3.28–4.07 hours, 95% CI) and 3.18 hours, respectively. We found larger estimates on the citizen science platform for the number of fishing trips conducted (16% or 0.64 trips), number of fish caught (10% or 0.3 fish), and proportion released voluntarily (12% or 4% more fish) and smaller estimates for proportion released (12% or 8% less fish) and fishing trip length (16% or 0.6 hours), compared to the recall survey. Based on the q values, there was only a clear indication of bias for fishing trip length (Fig. 4).

Compared to recall survey respondents, citizen science participants were more likely to be from 5000–5999 (i.e., Funen) postal codes, less likely to be from 1000–2999 (i.e., Copenhagen) and 4000–4999 (i.e., eastern, middle and southern Zealand) postal codes, and equally likely to be from 6000–9999 (i.e., Jutland) postal codes (Fig. 5).

In the comparison of aerial survey data and data from the citizen science platform, we found a positive relationship (df = 1, F = 113.05, $p < 0.0001$; Fig. 6) between active citizen science participants and the number of anglers counted during the aerial survey.

The estimated total catch of sea trout within the three-month study period was 24 483 (17 095–34 045, 95% CI) according to the aerial survey and roving creel survey data (Fig. 7A), and 23 358 (18 344–28 962, 95% CI) according to the aerial survey and citizen science data (Fig. 7B). The degree of overlap between these confidence intervals suggests that there was little difference between using roving creel survey catch rates and citizen science catch rates to estimate total catch in this instance (Fig. 7).

Fig. 3. Roving creel survey and citizen science comparison of residences (i.e., postal code). Shown as the relative distribution of Danish roving creel survey respondents and citizen science participants within eight geographical areas, in the period 1 March – 31 May 2017.

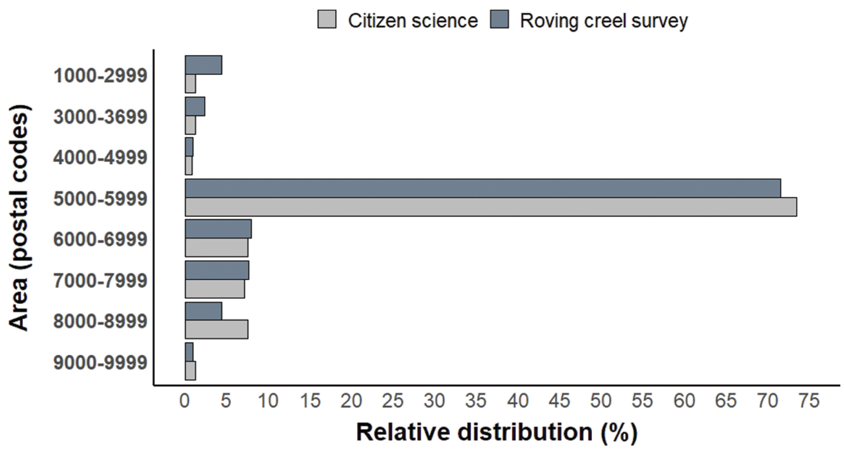
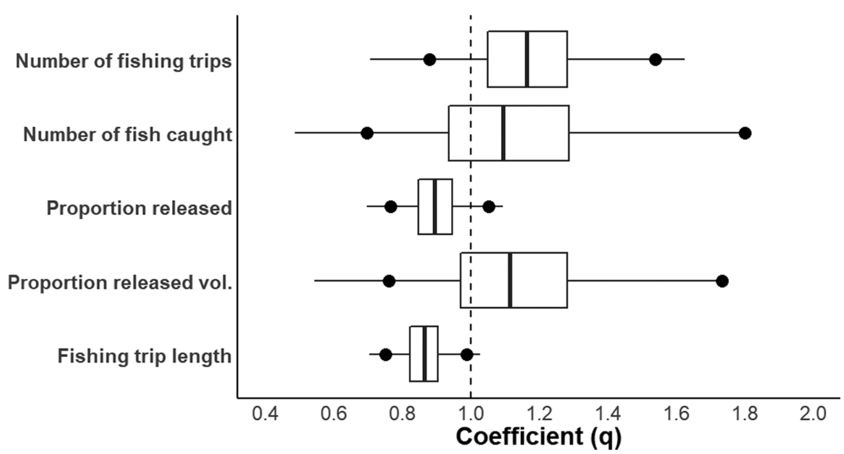


Fig. 4. Recall survey and citizen science comparison of average estimates of the number of fishing trips, number of fish caught, proportion released, proportion released voluntarily, and fishing trip length, using the survey coefficient q. The boxplots display the general direction of difference between the estimate (i.e., $q > 1$ and $q < 1$ indicate that estimates from the citizen science platform are larger or smaller, respectively). There is a clear indication of bias if $q = 1$ (dashed line) is not within the 95% confidence interval for the q value (black dots).



Discussion

Our study shows that a citizen science platform can estimate fisheries metrics that are comparable to estimates from both roving creel survey and recall survey, despite some demographic differences among participants (see also Gundelund et al. 2020).

The high degree of similarity between citizen science and roving creel survey in catch rates was unexpected. Anglers in roving creel surveys are usually interviewed during a fishing trip, which results in records of incomplete trips that can produce highly variable estimates (Hoenig et al. 1997; Pollock et al. 1997). Our analysis suggests that catch rates, in fish per hour, from the incomplete trips in the roving creel survey and complete trips in citizen platform were comparable, which could imply that sea trout catchability is constant over the duration of a fishing trip. This comparability also suggests that anglers were willing to report their zero catch trips on the citizen science platform. Almost 70% of the citizen science trips were zero catch trips, which is close to the 80% observed in the roving creel survey. This effect might indicate that the importance of submitting zero catch trips was clear from the design and marketing of the citizen science platform. However, more research is needed to determine the relative importance of design and marketing towards zero catch reporting in citizen science projects and, more generally, how this influence the agreement between citizen science and roving creel survey catch rates in this fishery and others.

We found evidence of bias in the proportion released from the citizen science platform, in that ~9% fewer fish were released, on average, compared to the roving creel survey. The impact of a bias of this magnitude on (e.g., harvest estimates) is debatable, but might be avoidable. We suspect that this difference could be due to the design of the citizen science platform. There are two choices for the fate of a fish that is being logged: retained (default) or released (user-selected). A potential solution is to require the participant to actively choose "released" or "retained".

As with the catch rates, we found comparable estimates of length of harvested fish (i.e., 51.5 cm and 50.7 cm) and no clear indication of bias. The similarity in estimates from roving creel survey and the citizen science platform, within catch rates and

Fig. 5. Recall survey and citizen science comparison of residences (i.e., postal code). Shown as the relative distribution of Danish recall survey respondents and citizen science participants within eight geographical areas in the period 1 April – 30 June 2017.

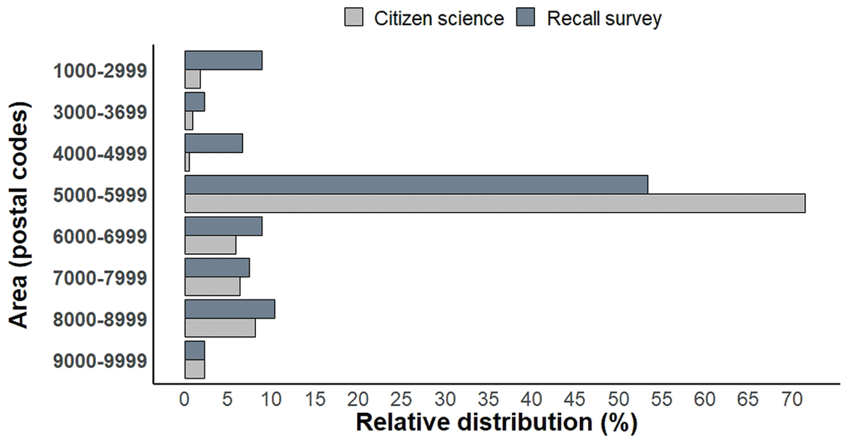
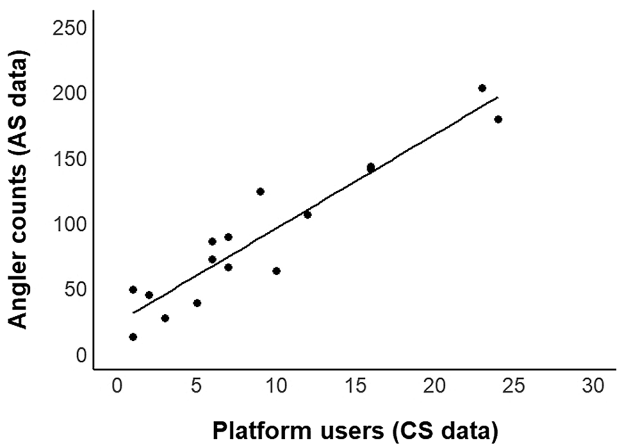


Fig. 6. Output from the linear model investigating whether citizen science participants (from the citizen science data) can be used as a proxy for angler counts. The number of platform participants are found within the same temporal and spatial frame as the flights conducted, March and April, in the aerial survey. The flights from May were not included due to the arrival of garfish anglers. The linear regression, $y = 7.2x + 23.9$, explains ~90% of the variation in the data ($R^2 = 0.89$).



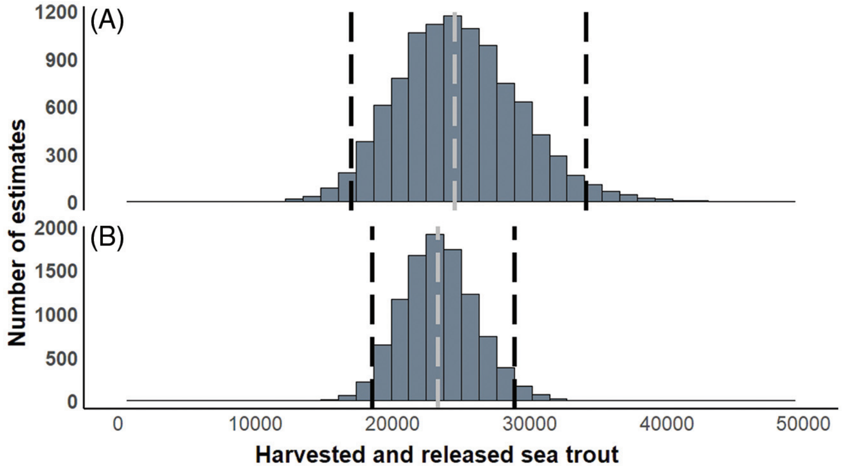
length of harvested fish, and to a lesser degree release rates, is further support for the potential of citizen science data to inform the management of this fishery.

We found few demographic differences between citizen science participants and the respondents from the roving creel survey. The higher proportion of resident anglers among citizen science participants compared to roving creel survey respondents might be because the Fangstjournalen platform was not translated into English and German until a few weeks before the start of this study. The estimates of age for the Danish participants were similar between citizen science participants and roving creel survey respondents. Anglers from different regions of Denmark participated in the Funen sea trout fishery in equal proportion according to citizen science and roving creel survey. Female anglers appeared more likely to use the citizen science platform (3% of anglers) than were observed in the roving creel survey (0.3% of anglers), but sample sizes were low (7 and 1 female anglers, respectively). Both metrics are well below a previous study that indicated that female anglers conduct 12% of the fishing trips in the Danish recreational fishery (Kromand et al. 2010). Although these demographic differences did not appear to affect catch metrics, it may be prudent to devote more effort to advertising the platform to international tourists, and verify that female participation in the Funen sea trout fishery is lower than the national average.

We found no clear indication of bias in the number of fishing trips conducted, the number of fish caught, the proportion released, or the proportion released voluntarily when comparing estimates from the citizen science platform to a recall survey. Some of these results were unexpected given that recall survey participants tend to overestimate catch and effort as the recall period increases (Tarrant et al. 1993; Connelly and Brown 1995; Roach et al. 1999; Connelly et al. 2000). Further research is needed to determine if the overall similarity between methods occurs because potential recall bias was largely absent from the recall survey, or if potential bias on the citizen science platform operates in a similar way as in the recall survey. Although we found no clear indication of bias in the number of fishing trips conducted, number of fish caught, and proportion released voluntarily, the citizen science estimates were skewed towards being slightly larger. This could indicate that the citizen science platform was used by more avid and committed anglers. Such anglers tend to favour voluntary catch and release (Bryan 1977; Oh and Ditton 2006; but see Dorow et al. 2010) and have higher catch rates (e.g., Monk and Arlinghaus 2017; Gundelund et al. 2020). The difference seen in residence (i.e., a larger share of Funen-based anglers on the citizen science platform), could also explain these slightly skewed estimates. This alternative hypothesis is that the local, Funen-based anglers fish more often on Funen, catch more due to local expertise, and are more inclined to conserve local fish stocks as compared to visiting anglers. The slightly lower estimate of the proportion released could be explained by the fact that fate was set to "retained" by default, as mentioned previously. We found a clear indication of bias in the average fishing trip length, which suggests that the recall survey participants have slightly longer fishing trips or overestimate the time that they spent fishing. The average fishing trip length was a summary of all fishing trips in a six-month period for recall survey and citizen science platform, but an overall difference in target species could be an explanation (e.g., that participants from the citizen science platform more frequently fish for sea trout). Another hypothesis is that the large share of Funen-based anglers on the citizen platform had shorter fishing trips because they were closer to home.

We found a strong relationship between the number of anglers counted in aerial survey and the number of citizen science

Fig. 7. Bootstrapped total catch of sea trout, from Funen in the period 1 March 2017 – 31 May 2017. Estimates were calculated using catch rates from roving creel survey data (A) and from citizen science data (B). The median and 95% CIs are shown as light and dark grey lines, respectively.



participants active within the same temporal and spatial frame. This indicated that citizen science data could supplement aerial survey data in this specific case. One potential use of the citizen science data in this instance would be to fill the missing data gaps, meaning that effort on days with cancelled flights could still be estimated by using the citizen science platform as a complementary survey (Pollock et al. 1994).

Another potential use of the citizen science data are illustrated when comparing the total catch of sea trout calculated using roving creel survey catch rates and citizen science catch rates, respectively. We found only marginal differences in the two estimates, which likely reflects the similarity of citizen science and roving creel survey catch rates, and that fact that both estimates relied on the same aerial survey effort estimate. Nonetheless, it is tempting to imagine a potentially cost-effective approach wherein total catch is estimated via a traditional aerial survey and roving creel survey design in which roving creel survey data are substituted with citizen science data. However, more work is needed to determine if these findings are consistent across space and time, and in other fisheries.

It is also necessary to investigate the effect of non-response in offsite surveys and self-selection within citizen science platforms. Several studies have shown that higher avidity anglers and committed anglers are more likely to respond to recall survey and other offsite surveys (Fisher 1996; Bray and Schramm 2001; Dorow and Arlinghaus 2011), and that citizen science participants are more likely to be specialized and have higher catch rates (Gundelund et al. 2020). The tendency of recall survey and citizen science platforms to attract anglers that are more specialized could explain the similar catch metrics. Gundelund et al. (2020) compared catch rates between participants and non-participants of the citizen science platform Fangstjournalen, using roving creel survey data. In contrast, we compared catch rates between a roving creel survey and the citizen science platform Fangstjournalen and found similar estimates. This divergence could relate to a relatively low sample size in Gundelund et al. (2020) compared to the present study. Another potential explanation is that it is more likely to encounter more avid and committed citizen science participants during a roving creel survey. A less avid and specialized segment of citizen science participants would have a lower chance of encounter in the roving creel survey, but still be represented on the citizen science platform.

It is important to note that these findings are from a highly specialized fishery in one place and time. Although this implies that our quantitative results cannot be generalized, our study clearly suggests that data from a citizen science platform have a potential to provide useable information about recreational fisheries. In fact, the citizen science data were comparable to three independently conducted probability surveys, which demonstrates a high degree of versatility. Another important aspect is that the citizen science data were based on self-selection, which implies that care should be taken when applying a traditional statistical framework. This is a major barrier in the validation process of data from citizen science platforms and smartphone applications for anglers. There is a growing interest in the use of smartphone apps to collect recreational fisheries data, and a subsequent need for comparative studies (Venturelli et al. 2017; Skov et al. 2021). We tentatively suggest our approach to self-selection data, despite it violating some assumptions, as a way forward in the validation of data from comparative studies.

Conclusion

We have shown that citizen science data that are taken from a specialized fishery within a limited spatial and temporal frame can complement and even replace traditional survey data. Jiorle et al. (2016) found that the utility of an angler app varied spatially and by fishery, and required adequate sample sizes. We build on this result by showing that citizen science platforms can generate stand-alone survey data over a three-month period in a spatially distinct fishery. Although our results are encouraging, we remain cautiously optimistic pending additional research. We also recognize that angler reporting via apps will be low in most fisheries unless these apps are designed or actively promoted as citizen science platforms through which anglers report data for the expressed purpose of managing recreational fisheries. Further research should focus on the temporal and spatial stability of catch related data and demographic variables from well-designed citizen science platforms (i.e., platforms that collect catch, effort, and data about participant demographics). This study focused on coastal sea trout, one of the most popular fisheries in Denmark; future work should include other species and fisheries. Moreover, because sea trout anglers in this study are generally committed anglers (Gundelund et al. 2020) who may be more willing to engage with citizen science platforms, future research should explore the comparability between methods when a segment of less committed anglers is targeted. Further work could also focus on finding a minimum threshold for the number of participants that are needed to generate valid data from citizen science platforms.

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Supplementary A

Recall survey questions

Below are the additional questions about sea trout fishing on Funen that were asked in the Recall survey that was distributed in August 2017. The recall survey overall targeted the first half year of 2017 (January-June), but the questions about sea trout fishing on Funen only targeted the second quarter, i.e., April, May and June of the half-year period. The questions were presented in Danish, but below, we also included a English translation.

Effort (number of fishing trips)

Danish: Hvor mange fisketure efter havørred har du samlet set haft på Fyn i de tre sidste måneder af dette halvår? Bemærk spørgsmålet omhandler udelukkende øen Fyn og ikke tilhørende øer f.eks. Langeland, Ærø, Æbelø osv.

English: In total, how many fishing trips on Funen, targeting sea trout, have you had in the last three months of this half-year period? Please note, this question only regards the main island of Funen and not the adjacent islands e.g., Langeland, Ærø, Æbelø etc.

Harvest

Danish: Hvor mange havørreder har du samlet set fanget og taget med hjem på Fyn i de tre sidste måneder af dette halvår? Bemærk spørgsmålet omhandler udelukkende øen Fyn og ikke tilhørende øer f.eks. Langeland, Ærø, Æbelø osv. Fisk der er genudsat skal ikke indgå.

English: In total, how many sea trout have you caught and harvested on Funen, in the last three months of this half-year period? Please note, this question only regards the main island of Funen and not the adjacent islands e.g., Langeland, Ærø, Æbelø etc. Released fish should not be considered here.

Releases in total

Danish: Hvor mange havørreder har du samlet set genudsat (i antal) på Fyn i de tre sidste måneder af dette halvår? Bemærk spørgsmålet omhandler udelukkende øen Fyn og ikke tilhørende øer f.eks. Langeland, Ærø, Æbelø osv.

English: In total, how many sea trout have you caught and released (in numbers) on Funen, in the last three months of this half-year period? Please note, this question only regards the main island of Funen and not the adjacent islands e.g., Langeland, Ærø, Æbelø etc.

Releases of sea trout below minimum size

Danish: Hvor mange af de havørreder du genudsatte på Fyn i de tre sidste måneder af dette halvår var mindre end gældende mindstemål? Bemærk spørgsmålet omhandler udelukkende øen Fyn og ikke tilhørende øer f.eks. Langeland, Ærø, Æbleø osv.

English: How many of the sea trout you caught and subsequently released on Funen, in the last three months of this half-year period, had a size below the mandatory minimum size limit. Please note, this question only regards the main island of Funen and not the adjacent islands e.g., Langeland, Ærø, Æbelø etc.

Effort (Angling hours)

This question was not specific for sea trout angling on Funen, but asked in general for all angling trips in the half-year recall period.

Dansk: Hvor mange timer er en gennemsnitlig fisketur for dig?

English: How many hours do you fish on an average angling trip?