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Expert opinion on using angler Smartphone apps to inform marine fisheries management: status, prospects, and needs

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Smartphone applications (apps) that target recreational fishers are growing in abundance. These apps have the potential to provide data useful for management of recreational fisheries. We surveyed expert opinion in 20, mostly European, countries to assess the current and future status of app use in marine recreational fisheries. The survey revealed that a few countries already use app data to support existing data collection, and that this number is likely to increase within 5–10 years. The strongest barriers to use app data were a scarcity of useful apps and concern over data quality, especially biases due to the opt-in nature of app use. Experts generally agreed that apps were unlikely to be a "stand-alone" method, at least in the short term, but could be of immediate use as a novel approach to collect supporting data such as, fisheries-specific temporal and spatial distributions of fishing effort, and aspects of fisher behaviour. This survey highlighted the growing interest in app data among researchers and managers, but also the need for government agencies and other managers/researchers to coordinate their efforts with the support of survey statisticians to develop and assess apps in ways that will ensure standardisation, data quality, and utility.

Keywords: catch rates, citizen science, fishing effort, human dimensions, survey methods

Introduction

Recreational fisheries are valuable fisheries that have high participation rates, high effort, and significant socioeconomic benefits (Cooke and Cowx, 2004; Cisneros-Montemayor and Sumaila, 2010; NMFS, 2016; Hyder *et al.*, 2017, 2018; Arlinghaus *et al.*, 2019). For example, recent estimates suggest that there are ∼9 million marine recreational fishers in Europe who spend 6 billion euros fishing for a combined 78 million person-days each year (Hyder *et al.*, 2018). Recreational fisheries are regarded as such an inherently valuable experience that some consider them to be self-subsidizing (Kleiven *et al.*, 2019). However, recreational fishing can have negative impacts on fish populations (Coleman, 2004; Cooke and Cowx, 2004; Kleiven *et al.*, 2016; Hyder *et al.*, 2018; Radford *et al.*, 2018) and the environment (Lewin *et al.*, 2006, 2019).

There are significant challenges to monitoring recreational fisheries that stem from the diverse (many platforms and gears) and dispersed (spatially and temporally) nature of the activity (Jones and Pollock, 2012; Hyder *et al.*, 2017, 2018, 2020b), as well as among-jurisdiction variation in licencing requirements. These challenges limit data collection in many fisheries and countries (Hyder *et al.*, 2018; Monkman *et al.*, 2018). The result is that marine recreational fisheries are often poorly represented in fisheries assessment and management, with the potential to hinder sustainable fisheries management (Hyder *et al.*, 2014; Arlinghaus *et al.*, 2019). Governance of recreational fisheries varies across the world but is not included in key fisheries legislation in many countries (Potts *et al.*, 2020). Fishing effort, target species, catch rates, and socioeconomic benefits can vary greatly over time in response to many factors including physical environment (e.g. Townhill *et al.*, 2019), fishing opportunities (e.g. Hyder *et al.*, 2017), and individual motivations and behaviours (e.g. Magee *et al.*, 2018). Hence, management approaches need to be adaptive in order to identify and respond to these changes (Potts *et al.*, 2020).

The traditional approach to monitoring recreational fisheries is to use on-site (e.g. access point, roving creel) and off-site (e.g. telephone and mail surveys, diary panels) methods to estimate fishing effort and catch per unit effort (Pollock *et al.*, 1994; ICES, 2010; Jones and Pollock, 2012). Although surveys can be biased (e.g. non-response, coverage, recall) (Pollock *et al.*, 1994; ICES, 2010; Jones and Pollock, 2012), well-designed surveys can provide robust data on broad-scale recreational participation, fishing effort, and catches with reasonable precision (Jones and Pollock, 2012). However, the frequent provision of robust data at small spatial and temporal scales can be prohibitively expensive and logistically challenging using traditional survey approaches (e.g. on-site methods).

Smartphone applications (apps) are a recent development that allows recreational fishers to voluntarily record and share fishing information. These apps might provide valuable recreational fisheries data that could support the monitoring and management of the fisheries and augment more traditional survey methods (Papenfuss *et al.*, 2015; Jiorle *et al.*, 2016; Venturelli *et al.*, 2017; Bradley *et al.*, 2019). Recreational fishers can choose among dozens of commercially available apps that vary in their specificity and functionality (Venturelli *et al.*, 2017). Popular apps such as Fishbrain, Fishidy, and FishFriender are appropriate for almost any fishery. They have hundreds of thousands to millions of users around the world who report thousands of catches each month, and generate novel data related to recreational fisher behaviour and social networks. Even apps that are designed for a specific,

localized fishery have the potential to provide higher resolution, spatiotemporal data than traditional surveys. However, recreational fishers that use apps are self-selecting, so are unlikely to be representative of the overall fishing population (Gundelund *et al.*, 2020). Furthermore, recreational fishers who do use apps may under-report small or non-target fishes (declaration bias), or trips where no fish are caught (i.e. zero-catch trips). Despite these biases, examples of app data tracking some catches (Jiorle *et al.*, 2016) and other novel uses (Papenfuss *et al.*, 2015; Liu *et al.*, 2017) indicate a need for research to evaluate the potential for app data to inform fisheries management (Venturelli *et al.*, 2017).

Many government agencies, institutes, and organizations in Europe and beyond are considering fishing apps as a source of useable data. Although there are a few examples of agency-generated or -approved apps [e.g. Fangstjournalen in Denmark (Gundelund *et al.*, 2020); Sea Angling Diary in the UK (Hyder *et al.*, 2020a); iAngler and iSnapper in the United States; VicRLTag in Australia; GoFish in Norway], we are unaware of any non-governmental/commercial apps that have been assessed for their ability to generate data in support of management. It is also likely that the potential for apps to support management is being assessed by individual agencies in isolation, which is inefficient.

Our study was motivated by the growing interest in, and emerging status of, recreational fishing apps (Venturelli *et al.*, 2017; Bradley *et al.*, 2019), and the potential need for government agencies to coordinate their efforts to develop and assess these apps. Our aim was to collect and assess expert opinions from 20, mostly European, countries, regarding the current availability, use, and potential of apps to collect data from marine recreational fisheries. Our survey also aimed at identifying associated barriers to and research needs for the use of fishing apps.

Methods

Expert elicitation

We surveyed key individuals working on marine recreational fisheries in academia and management agencies who were responsible for data collection in their countries. These individuals were participants at the International Council for Exploration of the Sea (ICES—http://www.ices.dk/) Working Group on Recreational Fisheries Surveys (WGRFS—https://www.ices.dk/community/groups/Pages/WGRFS.aspx), who were asked to complete a survey about the use of apps to support data collection for marine recreational fisheries. The WGRFS is made up of over 75 scientists and managers from more than 20 countries across the world (e.g. United States, Canada, Australia, New Zealand and several European countries) that have experience with recreational fisheries surveys, and are responsible for planning and coordinating marine recreational fishery data collection for stock assessments. The majority of participants were based in Europe, and varied in their experience with surveys and recreational fisheries management from PhD students to senior scientists and from junior to senior advisors (Table 1).

We conducted our voluntary survey of WGRFS participants during the June 2018 annual meeting, which was attended by experts from 20 countries. The survey was designed and executed by three of the WGRFS members (KH, PAV, CS), who did not participate in the survey. The survey contained questions about the participant (experience, age, location, role), the current status of app use within their country (availability, uptake, potential for use), prospects for future use (future uptake by data type, barriers, owners), and research needs (see Supplementary material for the complete survey). The survey included additional questions that were excluded from the analysis because they were outside of the scope of this paper, biased by the non-random nature of the sample, or later deemed to be poorly worded. We established a common starting point among participants by prefacing the survey with a brief introduction that included instructions (maximum one hour without discussion) and objectives to gain insight into: (i) current status of using angler apps as a source of data in marine recreational fisheries; (ii) prospects of angler apps in relation to other app types (commercial vs. government) and data collection methods; and (iii) major research needs and data standards. We also explained to participants that, although the term "angler app" refers only to apps that collect data from angling activities, we wanted them to consider all forms of recreational fishing (hook and line, but also spearing, netting, etc.). We therefore use broader terms such as "fishing apps" throughout this paper. We implemented the survey as an online questionnaire in the electronic survey platform survey gizmo (https://www.surveygizmo.eu/).

Data treatment and survey topics

Responses were pooled in country-specific groups to account for potential correlation among respondents from the same country. For countries with several respondents, we calculated an average and maximum numerical response weighted by experience (except for the question of app awareness, see below). Experience weighing was based on the stated number of years working professionally within recreational fisheries, with weights of 1, 2, and 3 assigned to <2 years, 2–5 years, and >5 years, respectively. Respondents had the opportunity to explain many of their answers in free text fields. Selected comments were included to illustrate sentiments and opinions. In some cases, minor changes were made to correct grammar and improve clarity, and to preserve anonymity. A complete list of questions and the design of the questionnaire is provided in the Supplementary material.

Current use and future plans of app data to inform marine recreational fisheries management

The current status of app use was explored by asking respondents if they were aware of: (i) any fishing apps that could provide data to inform marine recreational fisheries management in their country (yes or no): and (ii) plans to use such app data in the future. Data for the latter were ranked (certain no plans = 1, unlikely there are plans = 2, likely there are plans = 3, certain there are plans = 4, don't know = NA) and weighted by respondent experience.

We explored patterns in the future likelihood of app data use by asking respondents about the likelihood of app data being used to inform marine recreational fisheries management in their country within different time horizons, where 1 was very unlikely and 10 was very likely. If a respondent provided a likelihood for only a single timeline rather than all timelines, then we assumed a likelihood of 1 for shorter time frames (i.e. very unlikely), and the same likelihood as the previous time period for later time frames (i.e. we did not assume that likelihood would decrease over time).

Table 1. A summary of characteristics of respondents by country who provided expert opinion on the availability, use, and potential of fisher apps to collect data from marine recreational fisheries.

Country	Participants	Range of experience in years	Availability of robust national survey data
Australia	1	20	High
Belgium	1	3	Low
Canada	1	16	High
Denmark	1	6	High
Estonia	1	1	Low
Finland	2	20, 30	High
France	1	3	Medium
Germany	2	6, 9	High
Greece	2	5, 6	Low
Italy	2	1, 10	Low
Latvia	2	7, 10	Low
Lithuania	1	10	Low
Norway	4	2–20	Low
Poland	2	3, 7	Low
Portugal	6	1–20	Low
Spain	3	10	Medium
Sweden	4	1–6	Low
The Netherlands	1	8	High
United Kingdom	2	1, 2	Medium
United States	1	29	High

The potential of fishing app data compared to other methods

Respondents were asked to rank the potential of recreational fishing apps as a source of data compared to other traditional data sources (e.g. creel, recall, diary surveys). This question was asked for different data types (e.g. catch rates, fishing effort) and ranked on a 10-point Likert scale from "very bad compared to other sources" to "very good compared to other sources". After the survey, we ranked the availability of sufficient recreational fisheries data through traditional methods (e.g. creel, telephone surveys) in each country so that we could test the hypothesis that countries with limited data were more optimistic about the potential of fishing apps to supply data. The availability of robust national survey data was ranked for each country as either "low" (1 year or less of data), "medium" (1–5 years of data), or "high" (>5 years of data). We also divided participants into one of two categories (researcher or manager) based on their response to question 2, and tested the hypothesis that researchers would be more sceptical of the potential of data because they are very familiar with method limitations in general. Participants who stated a position that implied both research and management were excluded from this particular analysis.

Barriers and types of app

Respondents also ranked the significance of likely barriers to the use of fishing app data (11 items, including legal issues, app availability, costs, proof of value and more) on a scale from 1 (no barrier) to 10 (strong barrier). Respondents were then asked about the likelihood of specific or general apps, and if several or a single app were likely. This question was designed to gain insight into the types of fishing apps that respondents anticipated seeing in the future.

Research needs

The need for research that evaluates the value of four types of app-generated recreational fisheries data (i.e. catch rates, fishing effort, fish size distributions, and aspects of human dimensions) was assessed on a scale from 1 (no need) to 10 (strong need). Respondents were also asked to elaborate on what they were most enthusiastic and/or pessimistic about regarding the use of fishing apps as a source of recreational fisheries data.

Data analysis

Responses from survey topics were plotted using violin plots (Hintze and Nelson, 1998). This is a box plot with a symmetrical kernel density overlay that shows the probability density as a function of responses. We also used ordinal linear regression (McCullagh, 1980) to determine if the availability of conventional data in each country influenced the perceived potential of app data compared to other methods (e.g. creel surveys). Ordinal linear regression was appropriate because responses to the potential of app data were given on a Likert scale, which is ordinal by nature (e.g. $1 < 2 < 3$). In contrast to the analyses in which we explored country averages by pooling data across countries, we based this analysis on individual responses weighted by experience. This approach was in response to the high degree of variation among responses within some countries. This made it possible to test for statistical differences in the three data availability categories while accounting for the experience (i.e. years of experience in the field) of individual respondents. Ordinal logistic regression was used to predict the probability of an answer within each response on the Likert scale, and allowed comparisons for each level of the scale. We used a similar approach to determine if respondent profession, i.e. manager or researcher, influenced the personal perception on the potential usefulness of app data. Verification of regression assumptions was done by investigating homogeneity of variance and independence (Zuur and Ieno, 2016). Data analyses were conducted in R 3.6.1 (R Core Team, 2019), using the *MASS* (Venables and Ripley, 2002), *sure* (Greenwell *et al.*, 2017), and *ggplot2* (Wickham, 2016) packages.

Results and discussion

Current and future use of app data

Participants from 12 of the countries (60%) represented were, at the time of the survey (2018), aware of at least one recreational fishing app that had potential to provide data to inform marine recreational fisheries management. Apart from five respondents who indicated "don't know", most of the respondents (63% of those who participated), representing 70% of the countries in the survey, indicated that app data were likely to support marine recreational fisheries in the future (i.e. rating the plans in their country to use app data as "likely" or "certain") (Figure 1). Combined, these results suggest that app data are gaining attention, and being considered as a potential data source in several countries.

Agencies that want to use app data for fisheries management are in general evaluating specific test-cases in partnership with researchers and NGOs. However, widespread testing or adoption has not occurred yet, and most plans to use app data are still in an early stage of development. The survey identified that fishing app data are already being used to inform management. For example, an app is currently being used in specialized supplemental surveys developed for the short-season red snapper (*Lutjanus campechanus*) fishery in Mississippi and Alabama, United States (Liu *et al.*, 2017). Another example is a fisheries-general app that managers of Denmark's Baltic coast northern pike (*Esox lucius*) fishery are using to gain insights into angler behaviour (e.g. release rates) and fish biology (e.g. temporal changes in size structure and migration) (CS, pers. comm.). Finally, the application of catch tags, in combination with mandatory app reporting of tag usage, is being evaluated as a means of assessing recreational harvest of rock lobster in Victoria, Australia (VFA, 2020).

Most respondents considered the use of fishing app data in recreational fisheries management to be in its infancy (Figure 2). Respondents from 15 of 20 countries suggested that it would take at least five years for app data use to become likely (i.e. a weighted rank above 5) and that likelihood increases with time (Figure 2). Respondents indicated that adoption rates were likely to depend on factors such as interest from authorities, the amount of advertisement to fishers and decision makers, and app quality (e.g. coverage, data quality, bias corrections, user friendliness). Some respondents suggested that the time frame for data use would be short. They reasoned that recreational fishers would be likely to start using apps because app use is already common in many aspects of everyday life, and/or because of perceived personal benefits (e.g. through features that improve fishing success or quality). In contrast, other respondents reasoned that managers would be slow to adopt app data due to concerns over data quality and a lack of studies comparing app data to data from traditional methods. These respondents thought that early adoption would be limited to a few species, and specialized fisheries/fishers (see also Table 2).

Apps as a potential source of data, and barriers to adoption

Respondents generally ranked the potential of fishing apps compared to other methods (e.g. creel, recall surveys) to be as good as other methods, although with some variation among data types (Figure 3). For example, the data type "size distribution" was distributed equally around "just as good", whereas "catch rates" was skewed and below "just as good". Moreover, the potential of effort data had a strong, but relatively uniform distribution around "just as good", suggesting pronounced variation among countries. The average opinion was that app data have the potential to supplement existing surveys (e.g. creel, human dimensions surveys) and may provide novel data (Table 2). For example, the potential for apps to be "everywhere all of the time" could increase the spatial and temporal resolution of fisheries data when combined with existing methods, such as creel surveys. However, respondents also expressed concern about the quality of app data given the voluntary nature of participation, and the need for verification or compulsory reporting (Table 2), which is in line with general concerns that relate to the uses of fishing apps as a tool for data collection (Venturelli *et al.*, 2017).

Respondents from countries for which the availability of data to support marine recreational fisheries management was low or medium were more optimistic about app data than respondents from countries for which data availability was high (e.g. as a result of specific survey programmes). This difference was largest for catch rate ($\chi^2 = 27.07$, df = 2, $p < 0.001$; Figure 4) and effort data ($\chi^2 = 58.97$, df = 2, $p < 0.001$; Figure 4).This result implies that app data are more likely to be adopted in relatively data-poor countries or fisheries because app data are better than no data at all. Interestingly, the results also suggested that countries with medium data availability were most optimistic about app data in relation to fish size distributions ($\chi^2 = 4.50$, df = 2,

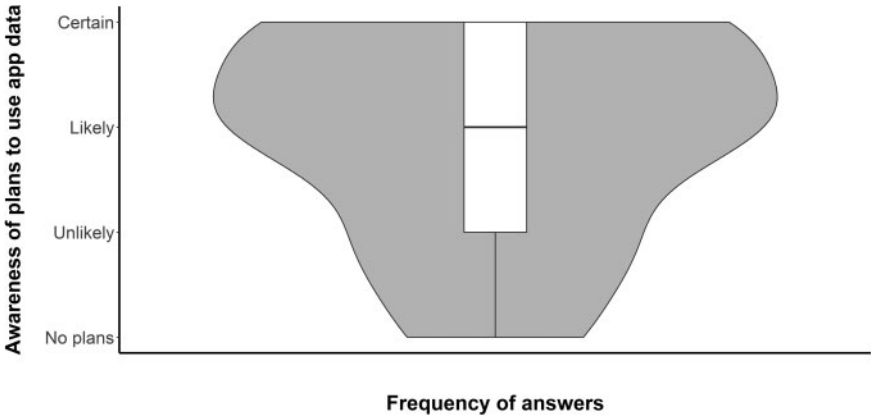

Figure 1. Violin plot showing the awareness of plans to use app data in a country stated by the survey respondents ($n = 20$ countries, question 8).

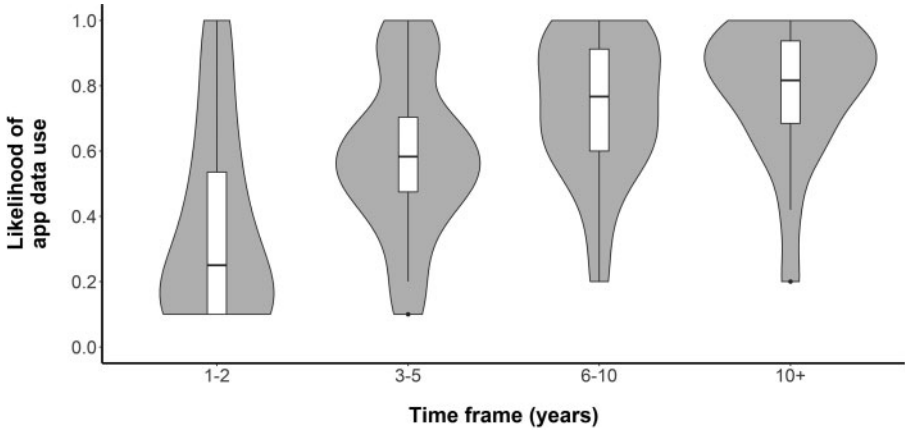

Figure 2. Violin plot showing the likelihood of the use of app data to inform recreational fisheries management over different timeframes stated by the survey respondents ($n = 20$ countries, question 10).

$p = 0.11$; Figure 4) and human dimensions aspects ($\chi^2 = 6.15$, df $= 2$, $p < 0.05$; Figure 4), even though the effect was not significant (fish size) or not highly significant (human dimensions). This optimism could stem from a perception that these types of app data are less biased than catch and effort data. We found no evidence that researchers were more sceptical of the potential of app data compared to managers. Hence, there were no differences in optimism, for example, in relation to catch rate data ($p = 0.29$), size distributions ($p = 0.88$), or human dimension ($p = 0.56$). Only for effort data ($p = 0.07$), there was a tendency for managers to be more optimistic than researchers. We recognize that it could also be influenced by the relative low number of participants in the manager group (i.e. ten people) and resulting lack of statistical power. The most important barriers to app data uptake and utility tended to be that: "There are no app data available to me"; "proof of value (i.e. it remains to be shown that app data are high quality, reliable, or comparable to other methods)"; "using angler apps as a data source is inconsistent in time and/or space (e.g. for specific, short-term projects)"; and "cost or budgetary priorities" (Figure 5). In contrast, relatively unimportant barriers were: "angler-generated data are evolving too quickly to be used effectively (e.g. new devices that allow hands-free catch recording—thereby leading to more catches recorded)"; "Inherent institutional resistance (i.e. This is how we have always done it!)"; "Lack of institutional leadership/support for using app data"; and "Too difficult to develop a user-friendly app or form partnerships with existing apps". In other words, with the exception of resource availability, respondents tended to identify external (i.e. app-related) rather than internal (agency-related) barriers.

The type of app that is likely to be adopted

Respondents indicated that a fisheries-general app was more likely to generate future data than an app that focused on few (one or several) specific fisheries (Figure 6). Respondents reasoned that most anglers participate in multiple fisheries, so a general app is probably best unless there is a strong need for data from a specific or unique fishery. However, it was also noted that it could be difficult to accommodate both marine and freshwater recreational fisheries within the same app.

The respondents found it more likely that future recreational fisheries data will be collected from country-specific apps rather than from general apps that were shared by several countries (Figure 6). Many respondents acknowledged that a pan-European, multi-lingual app was ideal because it would facilitate data sharing and collaboration between countries. However, it will be difficult to develop and maintain an app that will generate useable data for such a diversity of fishing methods and fisheries (see also Table 2).

Research needs, optimism, and pessimism

The respondents indicated a strong need for research to evaluate the ability of app data to inform marine recreational fisheries. This was especially important for catch and effort data, both of which were assigned a median rank of 9 out of 10 (strong need). The need for research on size distributions (median rank 8) and human dimensions (median rank 7) were relatively lower. These differences illustrate the overall concern about data quality related specifically to catch rates and fishing effort.

Many respondents were enthusiastic about the opportunity for managers to communicate with recreational fishers in an engaging and instructive manner; for example, for sharing information (e.g. about regulations) and education. Some respondents indicated that apps had the potential to identify spatial patterns of fishing, which could support planning of creel surveys (e.g. understanding site-specific activity). Respondents also pointed out that a well-designed app and survey could generate a large data set with low recall bias and a high response rate. Finally, some respondents were enthusiastic about the potentially low cost of apps relative to conventional means of data collection (see also Table 2).

Respondents were most pessimistic about the quality and reliability of self-reported data, including species identification. Another concern was low rates of smartphone use among large segments of the fishing population (e.g. retirees). Some respondents were not sure if it was possible to develop a user-friendly app that would satisfy the majority of recreational fishers. Finally, some respondents were concerned about the potentially high cost of developing and maintaining an app, despite other respondents expressing enthusiasm for a relatively low cost (see above). This discrepancy could result from inaccurate cost information, cost or budget differences among countries,

Table 2. Entries in free text fields in the survey that capture sentiment/central topics about the potential future use of apps.

Area	Positive attitudes	Negative attitudes
Uptake	"There have been conversations in this regard in recent years, but mostly from my research group and an NGO. We have also discussed this with management authorities, which are aware of this potential tool." "If bias is considered/corrected for, then app data can be as valuable as classical methods." "Angler catch rates and size distributions would suffer from the same issues as other offsite methods as avidity or recall bias, but it would be a weaker method than onsite surveys. For angling effort, it would probably be a bad tool for estimating the total number of anglers, but as good as other tools to estimate the average number of fishing trips per year, and hours per fishing trip. Its strength as a data source would be to include information on human dimensions, and also for particular areas/periods that are challenging using onsite methods (e.g., night fishing)"	"There are plans to assess the feasibility of using app data, but future use will be dependent on study outcomes. However, it is very likely that some aspect of app data will be used in future." "While attractive within certain sectors (including managers and some researchers who seem to assume that an app can replace probability-based surveys, etc.) there are issues that need to be worked through before apps will be used to inform management." "Self-reporting without a method or survey of verification of the reported data can be a serious drawback." "Potential recording bias (anglers more likely to record high or low catch rates or large fish, inconsistent recording of effort)."
Use	"Potential easy use for anglers and direct feedback (both push and pull). The potential for a widespread use, reaching a large proportion of the population. Direct feedback of such a large group on anything would be very beneficial. Also if it is widely used, it could dramatically lower the costs of the (mandatory) data collection." "Hopefully large amounts of data compared to written diary and telephone surveys. Especially if the app is user friendly for the participant." "The fact that managers will have access to 'live' data about MRF and (if compulsory) a clearer picture of the RF population. Also the fact that fishing-spot regulations and best practices can be promoted through the app."	"Some recreational fishermen still have old NOKIA type phones without any apps." "The key challenges are longevity of the solution (monitoring), data quality, and understanding how to use the data. There is also a strong organisational barrier to change." "Two challenges are coverage (older anglers are less likely to use the app), and keeping the app up to date, which will require regular funding (e.g., fishing license sales)."
Likelihood	"If you require similar information for all species caught, then one app may be a better approach for simplicity. However, for species or areas that were particularly tricky or of high interest maybe an individual app would be helpful." "A single app would be more likely to be developed, and also used by the fishing community. In many cases, fishermen practice several recreational fishing modes. It would also be easier to maintain a single app." "The apps currently used by anglers are mostly by region, so it seems likely to continue to move in that direction."	"Unless an app can be adapted to different countries, then it will be impossible to have a functional app for all fishing styles and target species." "A general app would be a much more cost-efficient way of doing it, and people could share their experiences when developing these app."
Data quality	"I am in favour of design-based probability sampling, but understand that they are not always possible in given budgets and time frames. If catch/activity reporting via an app would be compulsory, then the resulting data would be a nice option."	"Questionable accuracy of reported data unless it is possible to follow up individual fishers."
Research	"Research on the reliability of using catch rates and angling effort from apps is most important as I see a higher risk of getting biased estimates from app data compared to estimates on biological catch data and aspects of human dimensions."	

or differences in approach (in-house development versus external partnerships).

Conclusion

This survey of experts in marine recreational fisheries data collection from 20, mainly European, countries showed that recreational fishing apps are widely recognized as a potential data collection tool (Figure 7). A few countries already use fishing app data to support other methods (see above), and there are plans in some countries to include fishing apps as a data collection method. For example, data from the iAngler app have been incorporated into stock assessments for common snook (*Centropomus undecimalis*) (Muller and Taylor, 2013) and spotted seatrout (*Cynoscion nebulosus*) in Florida (Addis *et al.*, 2018). Respondents in more than half of the countries surveyed indicated that it was likely that app data to some extent will be used locally or nationally to manage recreational fisheries in the next 3–5 years.

The survey identified three major barriers to the adoption of app data: a lack of evaluation and validation, non-representative sampling, and a potentially high cost of development and maintenance (Figure 7). The respondents agreed that app data have the potential to support current methods, but were unlikely to be a credible, stand-alone method to explore important fisheries metrics (e.g. catch rates, fishing effort) within 5 years. In the short-term, it is possible that fishing apps will provide novel data on specific fisheries (e.g. daily distributions of effort or recreational fisher behaviour). Even in these

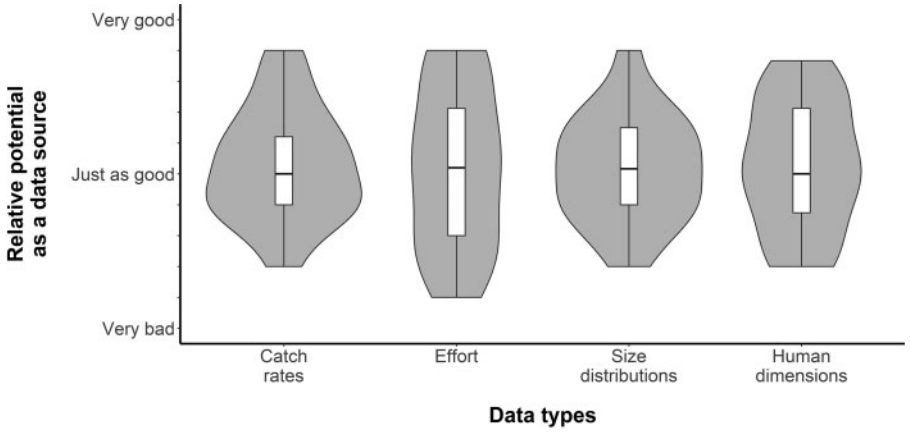

Figure 3. Violin plot showing the potential for apps to be used for collection of different types of data in comparison to traditional survey approaches stated by the survey respondents ($n = 20$ countries, question 13).

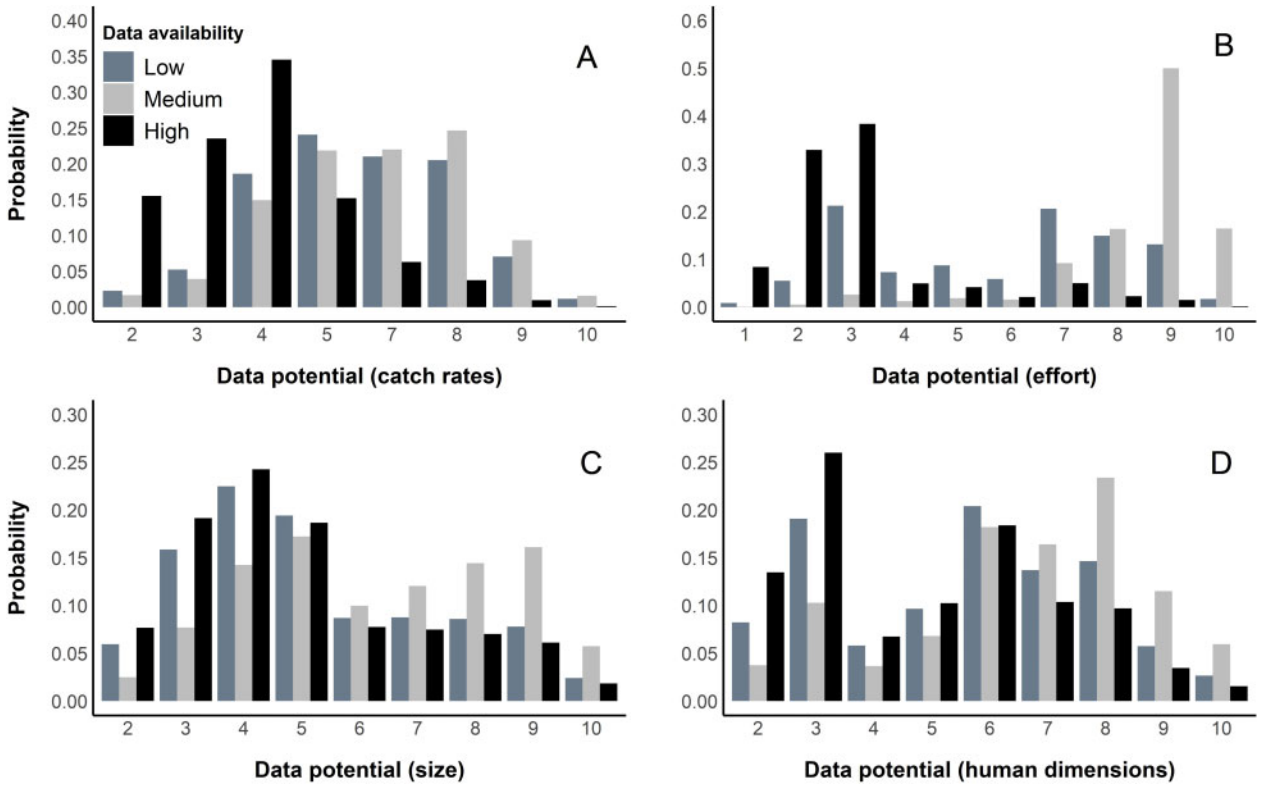

Figure 4. Potential for apps to be used to collect different types of data grouped by the extent to which a country already has quality survey data available to support marine recreational fisheries management (low, medium, high data availability) in relation to catch rates (a, $n = 39$ respondents), effort (b, $n = 40$ respondents), size distributions (c, $n = 40$ respondents), and human dimension aspects (d, $n = 40$ respondents). In the survey, the potential was ranked from 1 (very bad compared to other sources) to 10 (very good compared to other sources) (question 13), and probability estimates were calculated based on the ordinal logistic regression model.

cases, characteristics of app and non-app users must be collected to understand bias and increase data quality (Gundelund *et al.*, 2020). In addition, the uptake of app data is likely to be faster in specific and data-limited fisheries as this may be the only data source available.

There seemed to be some agreement among the respondents that the quality of app data could be improved if reporting was related to licence sales or even mandatory. Interestingly, the use of mandatory reporting in recreational fisheries was recently highlighted as having multiple benefits for future management of recreational fisheries (Arlinghaus *et al.*, 2019).

There is a great deal of potential and enthusiasm about using apps as a communication tool between managers and recreational fishers (Figure 7). For example, it could be possible to increase recreational fisher engagement and compliance by providing location- and species-specific regulation information directly to

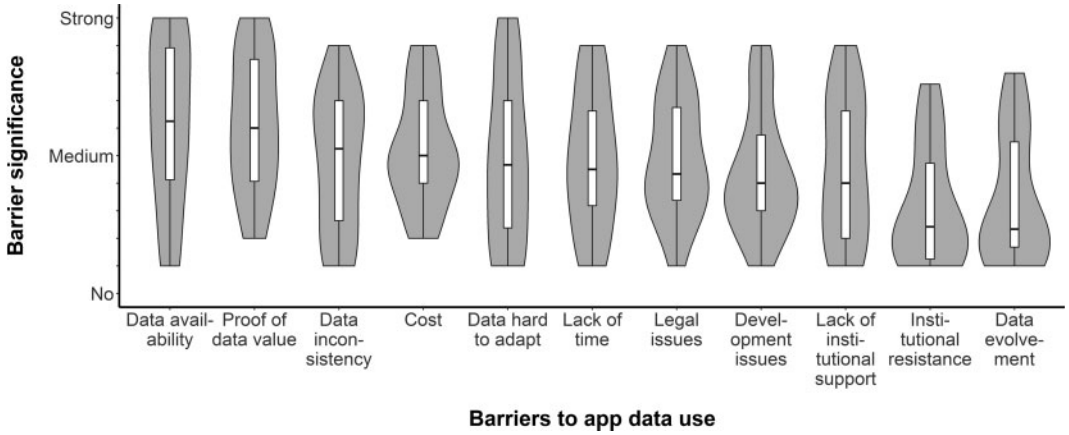

Figure 5. Violin plots showing the significance of various barriers to the uptake of apps in a country stated by the survey respondents ($n = 20$ countries, question 14). A complete description of each barrier is provided in the Supplementary material.

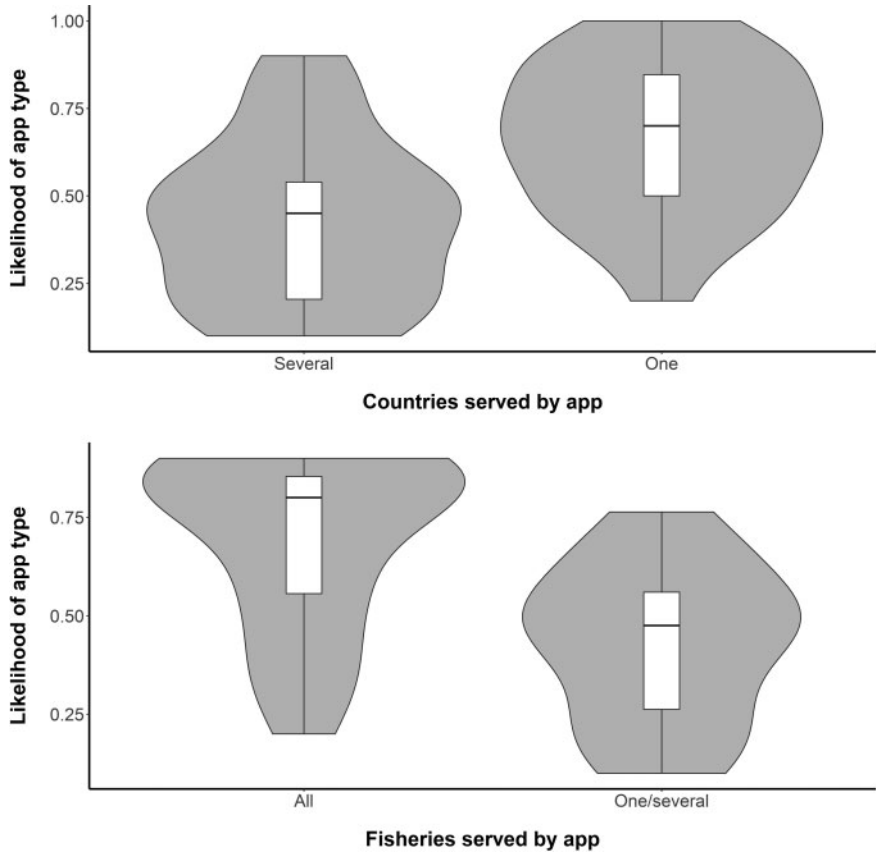

Figure 6. Violin plot showing likelihood stated by the survey respondents that their country will use data from apps that serve several countries versus just one (top, question 16), and many fisheries or just one/some (bottom, question 18) ($n = 20$ countries).

recreational fishers in real time. Moreover, recreational fishers could use the app to participate in citizen science projects, provide general feedback, or inform managers about local issues or unusual occurrences (e.g. fish kills, illegal activities, new records of fish species).

Our survey focused on marine recreational fisheries, but we suspect that some of our results will apply to freshwater fishing apps as well, for example, the potential of different data types (Figure 3), and the different barriers (Figure 5). Other results, such as the awareness of plans to use app data (Figure 1) and the likelihood of app data use (Figure 2), are agency specific and therefore likely to require separate surveys.

More research is needed to determine how best to use recreational fishing apps to collect usable fisheries data, especially for catch and effort. Very little is known about the intrinsic motivations of app users; their response to on-going innovation, maintenance, support, and messaging; and how these affect the quantity and quality of data among fisheries and over time. As an example,

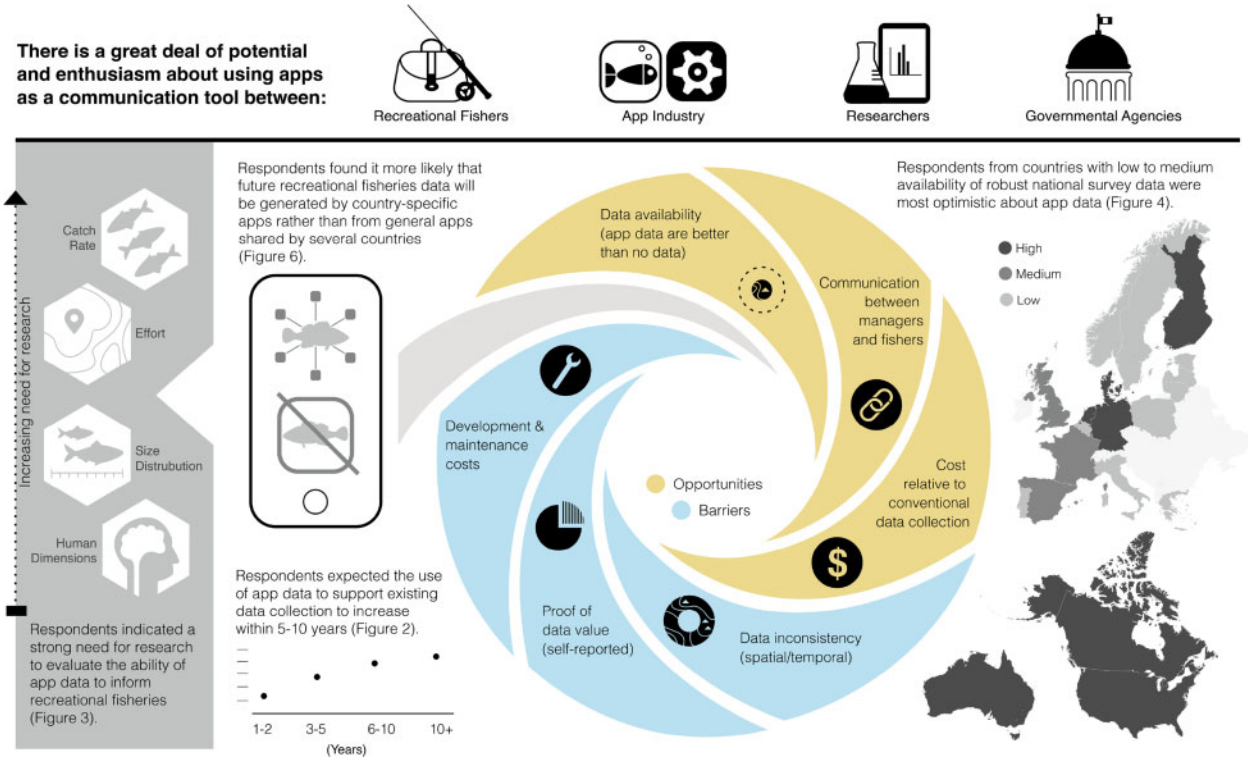

Figure 7. Summary of the key outcomes from the survey in terms of contributors, data types, likelihood of uptake of apps and barriers and opportunities for the use of apps in future.

fishers could be less prone to openly share some of the results collected with the app than scientists, who conversely usually try to maximize dissemination in international journals. Furthermore, fisheries managers could implement new regulations based on the app data that could be against the interest of groups of fishers. Thus, ownership of the data and the use of derived results should be addressed in early stages of app development between all the parties involved, as they may have different agendas (Gourguet *et al.*, 2018).

Studies are also needed to compare app data with traditional survey approaches, explore novel applications, and develop criteria for including data from non-probability approaches (Cornesse *et al.*, 2020). Evaluations of the reliability of catch and effort estimates from opt-in surveys based on apps will require models that adjust for selection biases, and will rely heavily on the quality of the variables used for post-hoc adjustment. Catch rates and effort estimates gathered from app data should be interpreted and used with caution until these studies have been conducted. This survey demonstrates a growing interest in app data among researchers and managers, but also the need for government agencies and other managers/researchers to coordinate their efforts. We encourage this to take place in collaboration with app developers and support from survey statisticians to develop and assess apps in ways that will ensure standardization, data quality, and optimal utility.

Supplementary data

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

Data availability statement

Data are available on request.

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