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Etymology of Ghoti

George Bernard Shaw (1856–1950), polymath, playwright, Nobel prize winner, and the most prolific letter writer in history, was an advocate of English spelling reform. He was reportedly fond of pointing out its absurdities by proving that 'fish' could be spelt 'ghoti'. That is: 'gh' as in 'rough', 'o' as in 'women' and 'ti' as in palatial.

Angler apps as a source of recreational fisheries data: opportunities, challenges and proposed standards

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Abstract

Recreational fisheries surveys are limited in time and place in many countries. This lack of data limits scientific understanding and sustainable management. Smartphone applications (apps) allow anglers to record the details of their fishing trips and catches. In this study, we describe the opportunities and challenges associated with angler apps as a source of recreational fisheries data, and propose minimum standards for data collection via angler apps. Angler apps are a potentially valuable source of conventional and novel data that are both frequent and extensive, and an opportunity to engage anglers through data sharing and citizen science. Realizing this potential requires that we address significant challenges related to angler recruitment and retention, data quality and bias, and integration with existing fisheries programmes. We propose solutions to each of these challenges. Given that the angler app market is diverse, competitive and unpredictable, we emphasize minimum standards for data collection as a way to ensure large and reliable data sets

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that can be compared and integrated across apps. These standards relate to trips and catches, and angler demographics and behaviour, and should be supported through consultation and research. Angler apps have the potential to fundamentally change how anglers interact with the resource and with management.

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Introduction

Fisheries management relies on assessment data that describe both the resource (e.g. population size and structure) and the fishery (e.g. effort and harvest). These data are collected directly from the fishery itself (e.g. Fairclough *et al.* 2014) or through fisheries-independent surveys (e.g. Strehlow *et al.* 2012). Although some agencies routinely conduct recreational fishery surveys (e.g. Hartill *et al.* 2012; Rocklin *et al.* 2014; NOAA 2015), they tend to be undersupported in most jurisdictions or waterbodies (Shuter *et al.* 1998; Post *et al.* 2002, 2008; Lester *et al.* 2003; Rocklin *et al.* 2014). Routine surveys provide valuable information about effort and harvest that can be included in stock assessment (e.g. Eero *et al.* 2015), but they are expensive to conduct (e.g. Vølstad *et al.* 2006) and involve complex methods that may not overcome significant bias (e.g. Hartill *et al.* 2012; Hartill and Edwards 2015). These issues, along with the patchy and time-dependent nature of recreational fishing, limit the precision and extent of data. Failing to account for recreational fisheries in stock assessments can reduce the chance of fishing sustainably (FAO 2012).

Mobile technologies have the potential to generate fishery-dependent data whenever and wherever anglers fish. Smartphones and tablets are portable, and can capture, store and upload large amounts of data. These devices are also becoming ubiquitous: smartphone users are predicted to number 6.1 billion (70% of the projected global population) by 2020, with developed markets nearing saturation (Ericsson 2015). The fact that many anglers are interacting with the resource while carrying a data collection device has inspired the development of smartphone applications (henceforth 'apps') that generate data in support of marine and freshwater fisheries management (Table 1). We anticipate a proliferation of such apps given their rising profile in fisheries (Gutowsky *et al.* 2013; Papenfuss *et al.* 2015; Cooke *et al.* 2016; Lorenzen *et al.* 2016), and as part of a larger trend towards smartphone-based citizen science (Newman *et al.* 2012). We also anticipate benefits from the large and growing number of management-independent angler apps that allow anglers to record, share and network (e.g. Papenfuss *et al.* 2015).

The proliferation of angler apps as a new source of fisheries-dependent data is both an opportunity and a challenge. These apps facilitate big data collection at lower cost, in almost real time, and for any location that an angler visits. However, app data are only useful if they are abundant and relevant, of a reasonable quality, and can be integrated into existing research and management frameworks. These challenges can be exacerbated by multiple realizations of the same tool, which is both inefficient and can complicate or prohibit data comparisons and combinations (Bonar *et al.* 2009). Given the potential for angler apps to generate usable data and the diversity of angler apps that already exist, there is an urgent need to establish data collection guidelines and standards. To do so is to take advantage of a rare opportunity to cooperatively shape the design of an emerging data collection tool (Bonar *et al.* 2009).

In this paper, we review the state of the art of angler apps as an emerging data collection tool, and encourage the development, application and validation of data collection guidelines and standards. We begin by outlining the potential for angler apps to benefit recreational fisheries through data collection and an improved angler experience. We then present some of the major challenges to realizing this potential, and propose solutions. We emphasize data collection guidelines and standards as a way to ensure that app data are useable by and relevant to fisheries governance (Hyder *et al.* 2015). Standards are particularly important given the diversity of fisheries to which angler apps can apply, as well as the

Table 1 Examples of angler smartphone apps that are being used to collect data in support of research or management.

Name	Spatial extent	Environment	Website
Fångstdatabanken	Sweden	Freshwater	http://www.fangstdatabanken.se
Fangstjournalen	Denmark	Freshwater, Marine	www.fangstjournalen.dtu.dk
FishBrain	Global	Freshwater, Marine	www.fishbrain.com
Great Lakes Fish Finder	North American Great Lakes	Freshwater	http://www.sheddaquarium.org/Conservation–Research/Citizen-Science/Fish-Finder
iAngler	Florida, USA	Freshwater, Marine	http://angleraction.org/angleraction/login/auth
iFish Forever	Minnesota, USA; Ontario, Canada	Freshwater	www.ifishforever.com
IGFA catchlog	Florida, USA	Marine	www.igfacatchlog.org
iSnapper	Texas, USA	Marine	http://www.harteresearchinstitute.org/isnapper
Mijn VISmaat	The Netherlands	Freshwater, Marine	www.mijnvismaat.nl
Snapper Check	Alabama, USA	Marine	http://www.outdooralabama.com/mobile-apps

number and diversity of angler apps that can supply data.

Opportunities

Angler apps are a unique opportunity to efficiently collect conventional and novel data related to the resource and its users at fine spatial and temporal scales, and to connect with and engage anglers through data sharing and citizen science (Fig. 1). These data can be used to address a diversity of research questions regarding, for example, the distribution and movement of fish and anglers, links between catch and environmental conditions, and the assessment of catches. We expect additional innovations and applications to emerge given the novelty of this tool, the availability of secondary and novel data, advances in data analytics and the versatility of mobile devices.

Angler app data have the potential to complement, supplement, and in some cases replace conventional data collection methods such as creels, logbooks, interviews and fisheries-independent surveys. These conventional methods are relatively expensive and time-consuming, and often limited in space and time. A recent analysis found that effort data from a popular angler app in Alberta, Canada, were comparable to creel and mail survey data at regional and seasonal scales (Papenfuss *et al.* 2015; see also Martin *et al.* 2014). Similarly, Stunz *et al.* (2014) found few differences between app and creel data in terms of the harvest, discard and weight of red snapper (*Lutjanus campechanus*, Lutjanidae). Angler app data are also being incorporated into stock assessments for common snook (*Centropomus undecimalis*, Centropomidae) (Muller and Taylor 2013).

Angler apps are an opportunity to collect a diversity of data in 'real time', and over broad spatial and temporal scales. Unlike conventional approaches, apps can provide information about anglers, trips, effort and catch on a single platform, and may be less biased (e.g. with respect to recall) and more likely to reflect actual behaviours rather than intentions or attitudes (Adamowicz *et al.* 1994). Angler apps can also promote the collection of secondary and novel information such as (i) bait and tackle, depth, ice thickness, lunar phase and weather conditions; (ii) fish kills, invasive species, injuries, tags, pollution or water conditions (e.g. California Department of Fish and Wildlife 2015); and (iii) angler behaviour in the context of fisheries, tourism or human health (e.g. the health benefits of fly fishing from a kayak versus trolling with an engine). In addition, because anglers interact with the resource frequently and extensively, app data are likely to be high resolution and widely distributed in space and time. For example, Papenfuss *et al.* (2015) was able to summarize angler behaviour across most of Alberta, Canada, at a 7-day resolution. Frequent and extensive data are particularly valuable for diffuse fisheries that otherwise require compromises in the spatial and temporal allocation of resources (Lester *et al.* 2003). These data can also benefit waterbodies or regions for which little or no fishery information is available (but see Sullivan 2003a).

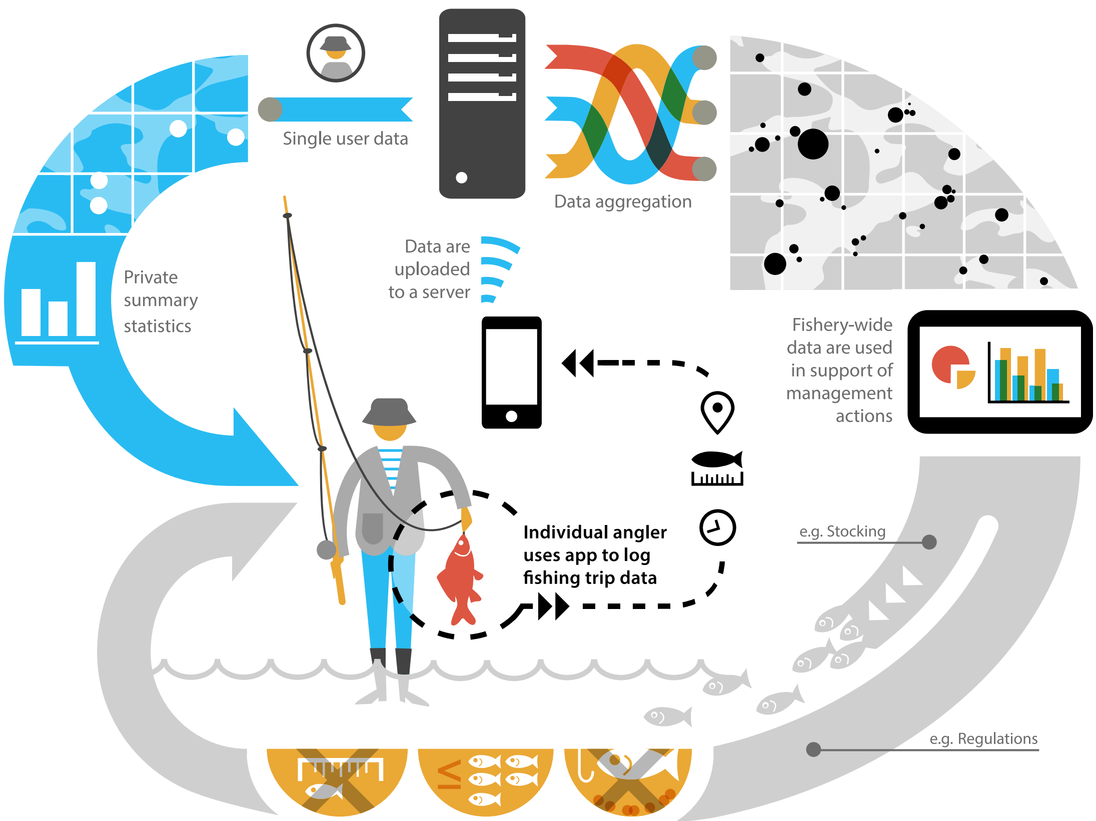

Figure 1 A conceptual illustration of angler app data collection and application in relation to fisheries management. An individual angler uses an app to log fishing trip data that are uploaded to a server. These data feed back onto the angler by contributing to (i) private summary statistics, and (ii) fishery-wide data in support of management actions such as stocking and regulations. [Colour figure can be viewed at wileyonlinelibrary.com].

Angler app data are an opportunity to conduct conventional and novel analyses. Although conventional analyses are possible with conventional data, app data can be collected relatively quickly and cheaply, and at high frequency and broad spatial extent. For example, although it is well-established that fishing pressure is highest near large, urban centres (e.g. Post *et al.* 2008; Ward *et al.* 2013), Papenfuss *et al.* (2015) obtained and analysed the data in a matter of weeks, and described this relationship over a larger area and probably at a fraction of the cost. Novel analyses might infer spawning migrations or range expansions from spatially explicit catch data (e.g. Robinson *et al.* 2015), infer changes in abundance from trophy catches (Richardson *et al.* 2006), or use catch data to determine harvest rates in relation to angling tactics or (a)biotic factors (e.g. Vinson and Angradi 2014). In the same way that data from bicycling apps can benefit transportation planning and health studies (Griffin and Jiao 2015), 'real-time' fisheries data also permit 'real-time' analyses that can contribute to proactive and predictive fisheries management, for example using continually updated effort and harvest data to monitor the quality of a fishery.

App data can also reveal a great deal about angler behaviour. Angler movement between lakes is relevant to the spread of diseases or non-native species (Papenfuss *et al.* 2015) and can be analysed using network analysis. App data can also be used to estimate angler home ranges *sensu* Hamilton *et al.* (2007), identify and characterize angler groups (e.g. Arlinghaus 2004), gain insight into illegal activity, and determine angler responses to regulation changes or the quality of a fishery (e.g. Jansen *et al.* 2013). These and other insights into angler behaviour help to inform angler-based modelling efforts (e.g. Hunt 2005; Drake and Mandrak 2010).

Angler apps are also an opportunity to promote informed fishing. Common and helpful app features include site-specific regulations, access points, hot spots and online fora. Similar to conventional logbooks, angler apps also generate catch log data that anglers (or the app itself) can analyse for trends. Perhaps most exciting is the opportunity to promote informed fishing with respect to the motivation behind and goal of different management actions. For example, it may be possible to show 'real-time' estimates of effort or harvest relative to fisheries reference points. This combination of observation and education (i.e. citizen science) is likely to result in a community that is more engaged and empowered (Dickinson *et al.* 2012) and either supportive of management efforts (Lundquist and Granek 2005; Gallagher *et al.* 2015) or more likely to self-manage. In other words, angler apps have the potential to democratize recreational fisheries (Datta *et al.* 2011). Angler apps can also increase recruitment and retention, thereby stemming the tide of decreasing interest in angling (Wilde and Pope 2013 and references therein).

Challenges and potential solutions

Angler apps have the potential to fundamentally change recreational fisheries, but also pose significant challenges. As with any new tool, fisheries researchers and managers must understand the strengths, weaknesses, benefits and limitations of angler apps within the context of fisheries science. Figuring these out will take effort and time. In this section, we describe three grand challenges associated with this emerging tool (recruitment and retention, data quality, and integration) and suggest solutions that are based on the relevant literature, our own experience and common sense.

Recruitment and retention

Angler recruitment and retention are major barriers to the establishment and maintenance of a useable data stream (Sharpe and Conrad 2006). These challenges are common to both apps and citizen science, and may be exacerbated by reluctance among anglers to share their data (McCluskey and Lewison 2008). The user retention of an average iPhone or Android app is just 5% after 3 months (Furner *et al.* 2014), and there is a growing body of literature dedicated to the issue of recruitment and retention in citizen science (e.g. Prestopnik and Crowston 2012; Rotman *et al.* 2012; Beirne and Lambin 2013; van Vliet *et al.* 2014). This literature converges on diffusion of innovation theory, which predicts that recruitment and retention are likely when participants perceive an advantage, participation is simple and compatible with the participant's existing habits, and there are opportunities for trial participation or to observe others participating (Rogers 1995). In other words, citizen science projects must understand participant motivation (Rotman *et al.* 2012) and be satisfying in that they are easy, fun and social (Dickinson *et al.* 2012).

To maximize recruitment and retention for angler apps, we recommend well-designed apps, user feedback and transparency with respect to data use. A well-designed app is aesthetically pleasing, easy to use, well-incentivized and versatile (Ng and Vuong 2014). Ease-of-use is important because anglers are primarily interested in fishing and are therefore unlikely to enter information accurately or at all if doing so is time-consuming or confusing (Cooke *et al.* 2000; Hobbs and White 2012). For this reason, the future of angler apps for data collection may be in wearable technologies (e.g. glasses, watches, wristbands) rather than hand-held devices. Regardless of the technology, an angler app is well-incentivized when it contains useful features such as a digital catch log, optional social sharing, licence renewal (perhaps at a discount) and easy access to a diversity of relevant information (e.g. rules and regulations, conditions, access points). An app should also be versatile enough to include the diversity of fishing modes and species that a given angler or angler population might pursue. Developing an app that is 'one-size-fits-most' is a challenge, but will contribute to recruitment and retention by appealing to a broad range of anglers and minimizing the number of fishing apps that a given angler might use.

User feedback also contributes to recruitment and retention. Feedback can be 'top-down' via progress reports, press releases, newsletters, meetings and presentations (reviewed by Lewandowski and Specht 2015). Top-down feedback reinforces the link between angler data and the maintenance of healthy, vibrant fisheries. Feedback can also be via personal catch log summaries and analyses (e.g.

catch rates over time with respect to species, waterbody or conditions). This kind of feedback may encourage accurate reporting because anglers cannot use inaccurate data to gain insight into – and ultimately improve – their catch rates. Gamification is a third form of feedback that refers to the use of game elements in non-game situations to increase recruitment, engagement and entertainment (Deterding *et al.* 2011; Ng and Vuong 2014). Relevant examples include scores, points, levels, badges and virtual competitions (Sullivan *et al.* 2009; Galloway *et al.* 2011; Hochachka *et al.* 2012). Finally, anglers may be attracted by social networking features that facilitate sharing and build community (Ng and Vuong 2014). When used in combination, these four forms of feedback have the potential to leverage an underlying conservation ethic (selfish or otherwise) and ensure a useful data stream.

Finally, it is important to be transparent with anglers about how app data will be used and by whom (Ng and Vuong 2014). Our experience is that anglers are particularly concerned about apps revealing secret locations, advertising high catch rates, and being used by agencies to spy on anglers. To encourage user trust (Glenn *et al.* 2012), we recommend project statements and frequently asked questions (van Vliet *et al.* 2014), top-down feedback (see previous paragraph), and policies to publicly summarize data in lag time and at low spatial and temporal resolutions. Minimum sample sizes for reporting (e.g. ≥5 trips by different anglers to a given area) will also limit the exposure of any one angler. Consistent with conventional creel surveys (Pollock *et al.* 1994), we also discourage the sharing of a user's data with enforcement personnel. Borrowing from diffusion of innovation theory (Rogers 1995), we can also foster trust by recruiting early-adopting individuals or groups to serve as ambassadors.

Data quality and bias

Real and perceived data issues must be addressed to realize the potential of angler apps. Although citizen science can generate reliable data (reviewed by Lewandowski and Specht 2015), angler app programs can differ in two important ways. First, because angler app users may be study subjects in addition to data collectors, angler app data may be more prone to biases that result from non-random participation (i.e. smartphone ownership and how and by whom angler apps are used). For example, data from the fishing app iAngler (Table 1) were biased towards urbanized regions and inshore species (Jiorle 2015). Second, whereas citizen scientists are often motivated by a project (Rotman *et al.* 2012), most anglers are probably more motivated by angling than by data sharing (Beardmore *et al.* 2011 and references therein). App data are likely to suffer from avidity bias (Jiorle 2015) because the willingness of anglers to share data increases with avidity (Harris and Bergersen 1985; Tarrant *et al.* 1993; Connelly and Brown 1995), and to underestimate effort if there is little incentive to log trips that do not result in a catch. Alternatively, errors and omissions are likely if data entry competes with angling for time. Common unintentional errors include species misidentification (Chizinski *et al.* 2014 and references therein) and inaccurate length measurements (Ferguson *et al.* 1984; Green *et al.* 1987; Page *et al.* 2004; Matlock 2014). Intentional errors or omissions might stem from a desire for secrecy or prestige, agency distrust or an attempt to influence regulations (Sullivan 2003a; McCluskey and Lewison 2008; McCormick *et al.* 2013). A recent comparison between onsite and online angler surveys highlights some of the data quality issues that can arise when anglers self-report (Hyder and Armstrong 2013), but these biases may be relatively small with apps (Stunz *et al.* 2014). App data may also be spatially biased as a result of user demographics, the relative popularity of different locations, or even app design and content. For example, Papenfuss *et al.* (2015) attributed the tendency of app data to underestimate the popularity of a river-dominated region of Alberta, Canada, to the absence of riverine locations within the app (see also Jiorle 2015). Similarly, although most angler apps can function and collect data without a cellular connection, apps that require a connection are likely to generate data that have a strong spatial bias.

Data quality and bias are challenges that have always existed in fisheries science. The literature on conventional angler survey methods is rich with references to avidity bias (e.g. Thomson 1991), non-response bias (e.g. Fisher 1996), recall bias (e.g. Zarauz *et al.* 2015) and reporting bias (e.g. Gutowsky *et al.* 2013; McCormick *et al.* 2013). As with any form of data collection, the challenge in working with angler apps is to identify data issues, minimize the prevalence of these issues by addressing their cause and mitigate the impact of persistent issues through data processing and analysis. To this end, we recommend comparative and validation studies that involve angler apps and one or more conventional approaches such as phone, mail or creel surveys. Studies of this nature are common in both citizen science (reviewed by Lewandowski and Specht 2015) and fisheries science (e.g. Thompson and Hubert 1990; Soupir *et al.* 2006; Griffiths *et al.* 2013). The literature on angler logbooks (e.g. Connelly and Brown 1995, 1996; Cooke *et al.* 2000; Bray and Schramm 2001) will be particularly informative. App-specific examples include Stunz *et al.* (2014) and Jiorle (2015), who compared app and creel data, and Papenfuss *et al.* (2015), who compared app data to both mail survey and creel survey data. To our knowledge, user demographics have yet to be formally evaluated. Comparative and validation studies are essential to identifying data issues, probably in perpetuity as these issues change over time (e.g. as more anglers adopt mobile technologies or as a result of corrective efforts).

There are numerous strategies for addressing data quality issues at their source. Many of the app features that are likely to maximize recruitment and retention (design, feedback and transparency) are also likely to maximize data quality and control some sources of bias: a low reporting burden combined with in-app summaries and analyses should increase data sharing and reduce errors, real-time logging should reduce recall bias, and both top-down feedback and transparency should convince anglers of the benefits of complete and accurate disclosure. Image recognition software can also reduce the reporting burden. For example, the IGFA Catch Log (Table 1) uses image recognition to assist anglers with species identification. This technology could also be used to estimate fish length (White *et al.* 2006). Low-tech alternatives include species identification keys and content to encourage proper measurement techniques (e.g. by discouraging the use of flexible measuring tapes; Page *et al.* 2004).

Numerous strategies and analytical approaches also exist for dealing with persistent data issues (Munson *et al.* 2010; Bird *et al.* 2014; Sullivan *et al.* 2014). Outlier detection rules are one example. Many of these rules can be established *a priori* (e.g. acceptable maximum length), but others, especially those related to angler behaviour, should be continuously informed by the data (e.g. Chiang and Miller 2008; Akerkar 2012). Potential outliers can then be flagged and perhaps repaired algorithmically or via an automated query to the user in question. Outlier detection can also be used to score individual users according to the suspected quality of various data fields (Kelling *et al.* 2011). Large data sets are particularly appealing because they (i) allow for strict data quality thresholds; (ii) are less likely to be influenced by outliers (Cohen *et al.* 2015); and, provided that user demographics and habits are known (e.g. through angler licence sales) or can be inferred, (iii) can be subsampled according to the demographic(s) of interest or reweighted based on statistically rigorous estimates of the general angler population (e.g. economic assessments in Armstrong *et al.* 2013; Monkman *et al.* 2015). Finally, persistent biases can be addressed via correction factors that are obtained through validation or simulation (for conventional examples see Tarrant *et al.* 1993; Connelly and Brown 1995; Connelly *et al.* 2000; Sullivan 2002; Ashford *et al.* 2010). Two particularly relevant examples are Jansen *et al.* (2013), who used state-space modelling to compensate for missing logbook data, and Jiorle (2015), who used a zero- and avidity-adjusted geometric mean to correct for an avidity bias in the iAngler app (Table 1).

Fisheries integration

Assuming a large and reliable stream of high-quality, unbiased data, we are still faced with the significant challenge of integrating these data into fisheries management frameworks. One aspect of this challenge is overcoming the perception that angler app data are prohibitively biased and inherently low quality. This perception probably stems from a resemblance to the often-maligned angler logbook (Pollock *et al.* 1994), concerns about angler credibility (Essig and Holliday 1991; Sullivan 2002, 2003a) and a healthy dose of caution (Rogers 1995). Although it is helpful to point to the success of citizen science projects such as eBird and Zooniverse (Smith *et al.* 2013; Sullivan *et al.* 2014), which have so far resulted in over a hundred peer-reviewed articles (see also Hyder *et al.* 2015), angler apps will only gain acceptance where we can demonstrate that the data have value. We are not suggesting that angler app data have value in all circumstances; only that the value of angler app data in a given circumstance should be known. Demonstrating this value requires a phase of testing and evaluation similar to the NOAA's concerted efforts to improve conventional survey methods (NOAA 2015). Moving through this phase both efficiently and effectively will require an integrative approach involving statisticians, computer scientists, developers and data managers (Sullivan *et al.* 2014).

Data analysis and management are also significant integration challenges. Conventional approaches are guided by well-developed protocols (e.g. creel surveys; Soupir and Brown 2002) that have existed for decades and continue to evolve (e.g. Ma *et al.* 2012; NOAA 2015). Relevant aspects of this knowledge should be applied to angler apps. However, angler apps also have unique elements that will require unique approaches in the same way that some protocols for mail surveys are inappropriate for phone surveys. Perhaps most unique is the potential for angler apps to quickly generate large amounts of diverse data in 'real time'. Fully realizing the value in these data will require big data approaches that are being developed in other fields (Marx 2013). We must also recognize that data analysis and management solutions will be question-specific. For example, it is important to adjust for avidity bias when estimating catch rates, but not when estimating total harvest (Jiorle 2015).

Finally, we must embrace opportunity and change when integrating angler apps into fisheries science and management. Although it is important to integrate with 'business-as-usual' approaches, angler apps are likely to render some conventional approaches obsolete, or at least consign them to supporting roles such as validation or calibration. It already appears that angler apps can replace some aspects of conventional surveys (Jiorle 2015; Papenfuss *et al.* 2015), and similar results have been found for online social media (Martin *et al.* 2014) and Internet search volume (Carter *et al.* 2015). We must also be open to a new science and management paradigm that is relatively data-rich, enlightened, nimble and user-defined. Mobile technologies are contributing to a swarm intelligence *sensu* Krause *et al.* (2009) that individual anglers are using to satisfy both catch and non-catch motives. If anglers are informed and mobile – as well as effectively unregulated (Post *et al.* 2002) and increasingly likely to practice catch-and-release (Brownscombe *et al.* 2014) – then the future of recreational fisheries governance may be less about devising clever regulations (Sullivan 2003b) than it is about developing general approaches to monitoring the resource, estimating reference points (e.g. Lester *et al.* 2003, 2014), and influencing effort (Cooke *et al.* 2013). Angler apps can play an important role in this future by supplying 'real-time' data in support of monitoring and reference point estimation, and by contributing to the intelligence of the swarm through outreach and education, and 'real-time' estimates of the current and future status of a population or fishery.

Towards standardized data collection

Ensuring that angler apps are generating large amounts of reliable data is arguably the first step in realizing the potential of this tool. An angler app is unlikely to contribute significantly to fisheries if data are sparse, of poor quality, or irrelevant; and anglers are unlikely to use an app if feedback is incorrect, uninformative or lacking. The ability of an angler app to generate usable and reliable data can also be compromised by angler apps that compete for data (Bonney *et al.* 2014) and may introduce unique biases.

Standardization is common in fisheries and other disciplines as a way to facilitate the combination, comparison, and evaluation of data and results (Bonar *et al.* 2009). Angler apps are a new and appealing platform for data collection. A number of apps are specifically designed for data capture (Table 1) with more in development. In addition, and more abundant, are the apps that are designed to satisfy angler needs (such as providing information about conditions or rules and regulations, or as a social platform) that can be modified for data capture. We advocate for a standardized approach to app-based data collection in the light of the cost of designing and implementing new apps, the number of apps now and in the future, and the effect that competing and unstandardized apps may have on data quality and quantity. Standardization is likely to reduce redundancy and waste, provide quality assurance, encourage collaboration, innovation, and data synthesis, and ultimately maximize the impact of a given project or group of projects (Bonney *et al.* 2014; Hyder *et al.* 2015).

In this section, we focus primarily on data for generating unbiased estimates of recreational effort and catch: the time and place that a fishing trip occurred, the effort that was associated with a given trip (e.g. hours of fishing), and the resultant catch or harvest. Ideally, trip and effort data are collected even when no fish are caught or harvested. Auxiliary data for nuancing these results and detecting and addressing bias include background information such as angler demographics and behaviour. We explore each of these categories in more detail below, summarize proposed standards (Table 2), and show how some of these standards appear when incorporated into an app (Fig. 2). Our objective in proposing these standards was to stimulate debate and research in support of the development of formal standards that extend to other potential uses of app data.

Fishing trip

All angler apps should record the location and date of a given fishing trip. To avoid recall bias (Pollock *et al.* 1994), trips should be reported 'live' with start and stop buttons that automatically capture geolocation, date and time. In case anglers cannot or do not want to live report, apps should also permit retrospective reporting. In this case, location should be reported by dropping a pin onto a map, via a place name provided that it can be reliably converted to a geolocation, or sourced from geocoded photographs of fish caught during that trip. Anglers should also manually report trip date and start time. Retrospective reporting should trigger a record of the length of time that passed before a trip was logged. This information can be used to correct for or understand recall bias (e.g. Connelly and Brown 1995), or to impose a threshold time beyond which retrospective data are ignored. Anglers should also report the species that is or was targeted during a trip. This information is useful for profiling anglers, and for ignoring certain trips when estimating effort for certain species (e.g. regardless of effort, anglers that target large predators are unlikely to catch small cyprinids). In some regions or fisheries, anglers should also report fishing rights (e.g. private, fishing club, public) so that data can be summarized accordingly and are more informative for managers and stakeholders (e.g. landowners, fishing clubs).

Optional trip data can include the type of fishing and conditions. Fishing type refers to the way in which an angler is interacting with the water (e.g. fishing from shore, fishing from a boat). These options can be nested to increase detail (e.g. is the boat human-powered? A tour boat?). To minimize entry burden, options can also be trip-specific (e.g. anglers that are targeting offshore marine fishes must be in a boat) and sensitive to a user's previous or usual fishing type. In some cases, fishing type can be inferred from other data; however, a record of these types is useful for validating such inferences and delineating fisheries for targeted analyses. Conditions refer to weather and other factors that may affect the success of a fishing trip (e.g. Vinson and Angradi 2014). This information can be captured automatically, or obtained retroactively by researchers or managers via date, time and location stamps.

Fishing effort

Apps should require anglers to report hours fished. If a trip is being reported live, then this information will be recorded automatically provided that trip end time is accurate. Because anglers might forget to end a trip or trip recording may end prematurely (e.g. due to a dead battery), apps should also make it possible to edit uncompleted trips or require anglers to predict trip length at the start of a trip. Periodic reminders that the app is recording a trip could also help in this regard, as could geofencing or proximity beacons. If reporting retrospectively, the angler should enter trip length manually. Effort may also be determined by the number of lines that are being fished by an angler or group, and the number of anglers that are in a group. These two fields should be defined clearly so that information is not missed or duplicated.

Catch and harvest

Catch data should include species caught, number caught and some information about size (length, weight or both). In fisheries in which catch-and-release is common, anglers should also report the fate of the catch (e.g. kept, released alive, released dead). When reporting the catch and harvest, anglers should have the option of reporting fish singly or in aggregate (number and mean size). Although single records are appropriate for many fisheries (e.g. trophy fishing), aggregate reporting by species is appropriate for fisheries with high catch rates or bag limits (e.g. match or pan

Table 2 A summary of the proposed standards that are met by some of the apps in Table 1. We obtained information for each app by consulting with a developer or administrator between late 2015 and mid-2016.

	Standard	Fishbrain	Snapper Check	iFish Forever	Fangst Journalen	IGFA catchlog	Fångstdatabanke
Demographics	Angler age	●		●	●		●
	Angler sex			●	●		●
	Postal/zip code			●	●	●	●
	Nationality	●		[h]	[h]	[h]	
	Fishing experience (years of fishing)				●		
	Importance of fishing relative to other leisure activities				●		
	Preferences (e.g. species, habitat, type of fishing)	●[a]			●	●	
	Member of any fishing clubs?				●		
Trip and effort	Trip duration		●[f]	●	●	●	
	Trip location (lake name, coordinates, etc.)	[c]	●[g]	●	●	●	●
	Trip track (i.e. where the user moved while fishing)						
	Trip date	[c]	●	●	●	●	
	Trip start time	[c]		●	●	●	
	Trip end time		●	●	●	●	
	Target species			●	●	●	
	Fishing method (i.e. from boat, or from shore)	●	●[e]		●		●
	Fishing gear (i.e. bait, lure, jigs)	●			●	●	●
	Fishing depth	●			[i]		
	No. in fishing party (and if reporting their catch)		●	[i]		●	
	Number of lines fished			[i]	●		
	Can report a blank fishing trip (no catch)		●	●	●	●	●
Catch and harvest	Species caught	●	●[d]	●	●	●	●
	Number caught	●	●	●	●	●	●
	(Mean) length and/or (combined) weight of fish	●		●	●		●
	Fate (released alive, released dead, harvested)	●	●	●	●	●	●
	The gender and/or spawning status of the fish	[b]		[i]	●[j]		
	Fin clips or other tagging information			[i]	●[j]		●
	Abnormalities (e.g. parasites, wounds, deformities)			[i]	[i]		

[a]Species and methods.
[b]Any additional information can be added in a comment.
[c]Date, timestamp and location are related to catch and not trip.
[d]Only red snapper is reported.
[e]Red snapper is only caught from vessels.
[f]If one- or two-day trip for charter vessels.
[g]County of landing is mandatory.
[h]To some extent can be inferred from postal/zip code.
[i]Anglers can provide this information via a comment box.
[j]This information can be provided for some species.

fishing, fishing) or when catch rates of non-target species are high. Angler apps are also an opportunity to collect a suite of ancillary information such as gear type, hooking location, the sex and spawning status of the fish, and any tags, marks or abnormalities. Ancillary data will often be fishery-

Figure 2 iFish Forever user flow diagram. Users start a new trip (bottom right) by entering relevant information. The 'Caught One!' button allows users to record information related to a specific catch, and the 'Done Fishing' button saves the trip and returns users to the main menu. Users can view the details of past trips and catches (top right), export these data (top left) and have access to information about data collection and use (bottom left). [Colour figure can be viewed at wileyonlinelibrary.com].

specific, and the benefit of these data should be weighed against the increased reporting burden.

Angler demographics and behaviour

Angler catch rates depend on the quality of the fishery, but also angler traits and behaviours such as angler experience and specialization (Pollock *et al.* 1994). Demographic data such as sex, age, postal code and nationality are also useful. Therefore, we recommend a short survey as part of the registration process that captures demographic data and other important traits and behaviours. For example, anglers could report the number of years that they have been angling. Because experience does not necessarily extend to all fisheries, the survey could also include the average number of trips per year in different habitats (e.g. lake, rivers and streams, coast, sea) and a list of the species that are most often targeted. Other potential questions include preferred gear type, the importance of fishing relative to other leisure activities (which is another window into specialization; Ditton *et al.* 1992), and membership in fishing clubs (which will allow managers to generate specialized reports and form partnerships that encourage recruitment and retention). Although some of the information that is collected above can be gleaned from the app data, a short survey will provide insight into stated versus revealed preference (Whitehead *et al.* 2011), and help to track changes in demographics and behaviour over time (Ditton *et al.* 1992), which can be useful when collecting, analysing and correcting for inter-angler variability in catch rates and, more generally, angler behaviour and motivation. The survey should be designed in consultation with the appropriate experts, and anglers should be invited to update their responses periodically (e.g. at the start of each year or season).

As an initial assessment of the extent to which these proposed standards are being met by angler apps, we profiled six of the apps in Table 1 (Table 2). These apps captured all or most of basic creel data (location, date, hours of effort, catch and harvest), including trips that did not result in a catch. Demographic data were less common, which could limit certain forms of bias detection and correction (e.g. location bias) or analyses. Overall, these five apps met 36–83% of our proposed standards. Although standardization is likely to improve data capture, we recognize that apps are usually designed for certain fisheries or purposes, and are therefore unlikely to meet all standards. However, if an app is known to meet with at least one standard, then the data that are generated under that standard have potential value.

The way forward

Angler apps are an exciting new tool for efficiently collecting conventional and novel fisheries data, and have the potential to fundamentally change how anglers interact with the resource and how the resource is managed. We anticipate a significant learning curve in working with angler apps and the data that they generate. We must not only encourage anglers to use angler apps, but also address issues with data quality and integration. If the development of conventional angler survey science is any indication, the incorporation of angler app data into fisheries is likely to take decades. However, an important first step is to develop standards and guidelines that will ensure that apps – both individually and in aggregate – are generating a large and reliable data stream.

We believe that the way forward for angler apps is not to develop, promote, or 'bet on' a single app or subset of apps; but to (i) identify a minimum data set that the majority of app developers are willing to share for scientific or management purposes; (ii) adopt formal, internationally recognized, and general standards for metadata and data collection that can be applied to any angler app; (iii) identify those apps that meet some or all of these standards; and (iv) conduct research to evaluate standards (Fig. 3). Our emphasis on standards recognizes that numerous angler apps already exist (e.g. Table 1), that more are being developed, and that many will fail. Angler apps vary in popularity and are tailored to specific fisheries to varying degrees. It is exceedingly difficult to develop an app that will appeal to all anglers in all fisheries and in all locations, or to establish and maintain a popular app in a given fishery or location. Standards allow scientists and managers to utilize multiple apps, and to synthesize data from multiple platforms.

If the angler app market is diverse, competitive and unpredictable, then minimum data collection guidelines and standards are a way to promote a large and reliable data stream. We proposed the above standards based on the relevant literature, our experience and expertise, and input from a handful of researchers and developers. Ultimately, standards should be (i) based on extensive consultation with researchers, developers, policymakers and users (Ng and Vuong 2014); (ii) reflective of needs, constraints, preferences and laws; (iii) broadly applicable and adaptable (e.g. so as not to stifle competition and innovation); and (iv) both formalized through and borne by an organization such as the FAO or AFS. Standards should also cover metadata that describe what data are collected and how, and other elements such as data management (e.g. year–month–day versus month–day–year), data exchange, archiving, and ethics.

App standards only have value if we know that they are being met. It is possible to obtain this information informally and as needed by individuals or groups, or by maintaining an online database (e.g. based on Table 2). However, we advocate for a formal certification process that verifies that a given app adheres to one or more standards for mobile-based fisheries data collection. Other fisheries examples include the Marine Stewardship Council's process for certifying wild seafood fisheries and NOAA's certification requirements for electronic reporting by commercial fisheries in the Western Pacific (NOAA 2009). Certification can not only encourage analysis and application by identifying those apps that are generating usable data, but also incentivizes app companies to participate by creating opportunities to collaborate, ecolabel and add value to an existing data stream.

Standards are only as strong as the research on which they are based and revised. Therefore, we encourage standards-based research as a part of an iterative framework (Fig. 3). This research should (i) be both general (e.g. is a given standard effective?) and specific (e.g. what is the best design for a given data entry field?); (ii) complement research into data quality and bias, fisheries integration, and recruitment and retention; and (iii) include evaluations of the overall programme (e.g. Ward 2008). Research is particularly important for allowing standards to evolve in response to changing user demographics (e.g. increased app use by older anglers) and rapid advances in mobile (and increasingly wearable and voice-controlled) technologies.

Angler apps are a unique opportunity to standardize a data collection tool before it is in widespread use by researchers and managers. Most data collection tools are governed by a diversity of local or regional standards that have evolved in

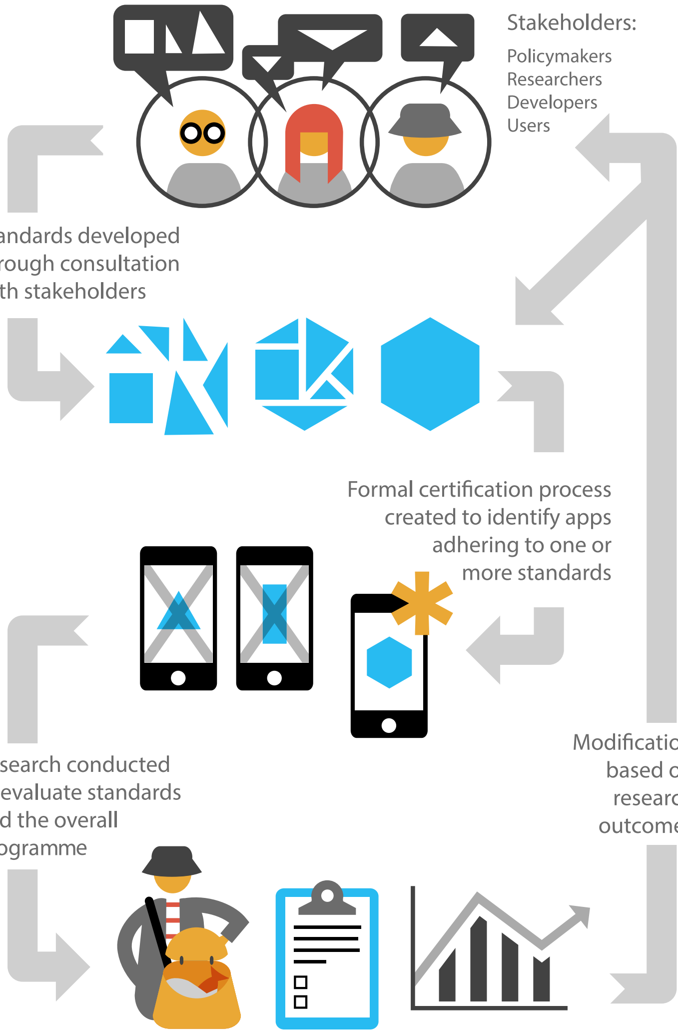

Figure 3 A conceptual diagram of the relationship between data collection standards, app certification and research. Standards should be developed through consultation with researchers, developers, policymakers, users and others, and then borne by an agency or organization (first and second rows). These standards can be used (e.g. within a formal certification process) to identify those apps that adhere to one or more standards (third row). Research is important for evaluating and modifying standards and the overall programme (fourth row and feedbacks). [Colour figure can be viewed at wileyonlinelibrary.com].

isolation (Bonar *et al.* 2009). There are certainly challenges associated with standardizing data collection via angler apps, and in using angler apps in fisheries science in general. As with any new tool, the ultimate challenge is in understanding how angler apps can contribute to fisheries science. In this paper, we outlined how angler apps can benefit well-developed recreational fisheries through the two-way flow of information. It is likely that these benefits also extend to developing recreational fisheries and other fisheries sectors (e.g. small-scale commercial, subsistence) (Cooke *et al.* 2016; Lorenzen *et al.* 2016). Realizing this potential could lead to win–win–win–win scenarios in which managers and researchers benefit from data, app companies and developers benefit from revenue, the resource benefits from improved stewardship and anglers benefit from an interactive tool that contributes to vibrant fisheries. The interactive nature of angler apps is particularly important because it will allow large numbers of anglers to participate in fisheries in ways and to an extent that has never before been possible and, in doing so, could fundamentally change the science, management and governance of some fisheries.

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