

Comparative analyses with conventional surveys reveal the potential for an angler app to contribute to recreational fisheries monitoring

Fiona D. Johnston, Sean Simmons, Brett van Poorten, and Paul Venturelli

Abstract: Growing interest in apps to collect recreational-fisheries data requires that relationships between self-reported data and other fisheries data are evaluated, and that potential biases are assessed. This study compared results from a mobile-phone application and website for anglers (MyCatch) to results from three types of fisheries surveys — 1 provincial-level mail survey, 2 creel, and 17 gillnet surveys. Results suggest that an app and website can (i) recruit users that have a broad spatial distribution that is similar to conventional surveys, (ii) generate data that capture regional fishing patterns (2218 trips on 289 lakes and 90 streams or rivers), and (iii) provide catch rate estimates that are similar to those from other fisheries-dependent surveys. Some potential biases in app users (e.g., urban bias) and in the relative composition of species caught provincially were identified. The app was not a suitable tool for estimating fish abundance and relative community composition. Our study demonstrates how apps can or cannot provide a complementary data-collection tool for recreational-fisheries monitoring, but further research is needed to determine the applicability of our findings to other fisheries contexts.

Résumé : Étant donné l'intérêt croissant pour les applications de cueillette de données sur les pêches sportives, il est nécessaire d'évaluer les relations entre les données autodéclarées et d'autres données sur les pêches, ainsi que les biais potentiels. L'étude compare les résultats d'une application pour téléphone mobile et d'un site web pour pêcheurs sportifs (MyCatch) aux résultats de trois types d'enquêtes sur les pêches — une enquête provinciale par la poste, deux enquêtes par interrogation de pêcheurs et 17 relevés au filet maillant. Les résultats donnent à penser qu'une appli et un site web peut (i) recruter des utilisateurs présentant une répartition spatiale aussi vaste que celle d'enquêtes traditionnelles, (ii) produire des données qui capturent les motifs régionaux de pêche (2 218 excursions sur 289 lacs et 90 cours d'eau ou rivières) et (iii) fournir des estimations des taux de prises qui sont semblables à celles obtenues d'autres enquêtes dépendantes de la pêche. Certains biais potentiels chez les utilisateurs de l'appli (p. ex. biais urbain) et dans la composition relative des espèces capturées à l'échelle provinciale sont relevés. L'appli ne s'avère pas être un bon outil pour estimer l'abondance de poissons et la composition relative de la communauté. L'étude démontre comment des applis peuvent ou non constituer des outils de collecte de données complémentaires pour la surveillance des pêches sportives, mais d'autres travaux de recherche sont nécessaires pour établir l'applicabilité de nos résultats à d'autres contextes de pêche. [Traduit par la Rédaction]

Introduction

Recreational fishers are one of the dominant users of inland fisheries resources in industrialized nations (Arlinghaus et al. 2015, 2019), important users of marine resources (Coleman et al. 2004; Hyder et al. 2018), and expected to become more important in developing nations (Bower et al. 2020). Recreational fishing provides significant contributions to the global economy, and produces important sociocultural benefits (FAO 2012; World Bank 2012; Arlinghaus et al. 2017a). However, recreational fishing pressure can impact fish populations (Post et al. 2002; Cooke and Cowx 2006; Arlinghaus et al. 2019). Effectively monitoring recreational fisheries is critical for understanding the status of fish resources and detecting emerging issues (e.g., population declines, invasive species, etc.; Radinger et al. 2019). However, sustainable management is challenging when the resource is diverse and widely distributed across a landscape, and the angling population is free to

move among fisheries (Lester et al. 2003; Pereira and Hansen 2003; Carruthers et al. 2019).

Fisheries biologists often use fisheries-independent indices of abundance such as standardized netting to assess fish populations in lakes (Askey et al. 2007b; Ward et al. 2012), and aerial and creel surveys — and more recently time-lapse cameras and traffic counters — to estimate angling effort and catch (Smallwood et al. 2012; van Poorten et al. 2015; van Poorten and Brydle 2018; Hartill et al. 2020). These survey methods can be very costly and time consuming (Greenberg and Godin 2015; van Poorten et al. 2015; Hartill et al. 2020), which can make it logistically impossible and cost prohibitive to assess all waterbodies within the landscape on an ongoing basis (Pereira and Hansen 2003; Hartill et al. 2020). As a result, survey efforts tend to focus on high priority, easily accessible fisheries (Greenberg and Godin 2015; van Poorten et al. 2015), leaving small, remote lakes and rivers that often support

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F.D. Johnston and S. Simmons. Angler's Atlas, Goldstream Publishing, P.O. Box 182, Prince George, BC V2L 4S1, Canada.

B.v. Poorten. School of Resource and Environmental Management, Simon Fraser University, 8888 University Drive, Burnaby, BC V5A 1S6, Canada.

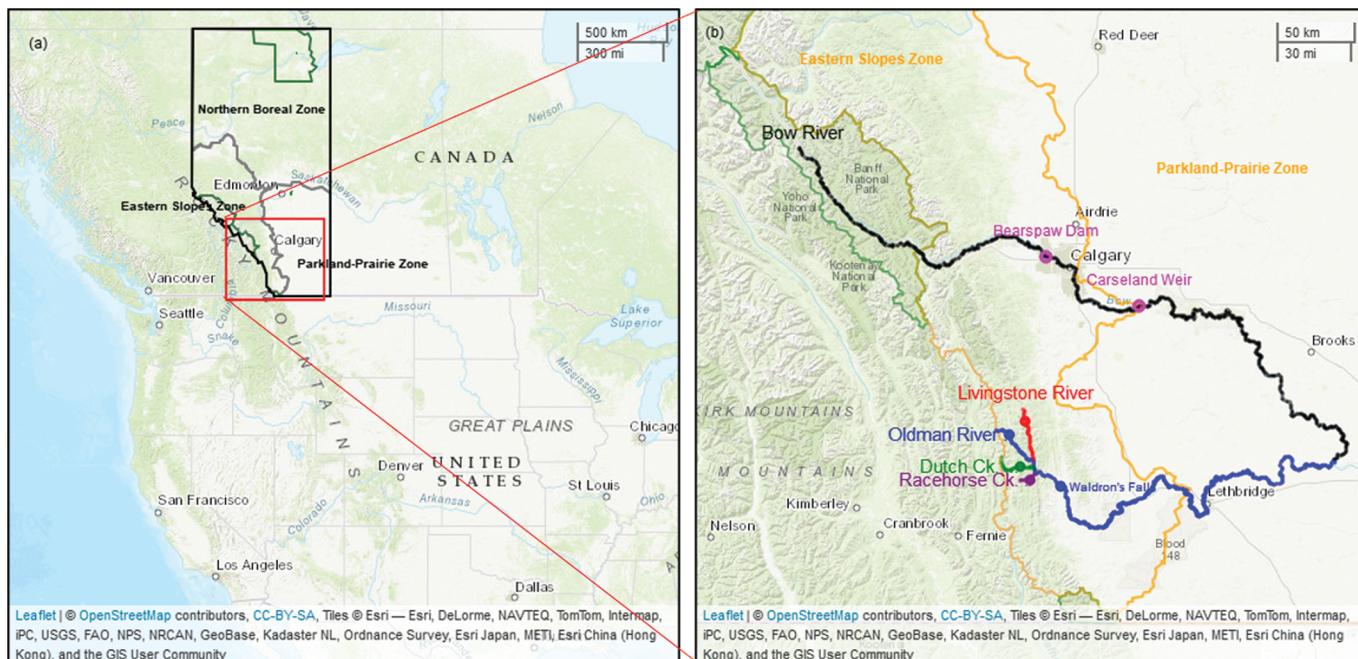
P. Venturelli.* Department of Biology, Ball State University, Muncie, IN 47306, USA.

Corresponding author: Fiona D. Johnston (email: fiona.johnston@ucalgary.ca).

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Fig. 1. The Fisheries Management Zones in Alberta, Canada (panel a), and the Bow River and Oldman River system in southwestern Alberta where creel surveys were conducted in 2018 (panel b). Magenta points indicate the upstream (Bearspaw Dam) and downstream (Carseland Weir) limits of the creel survey area on the Bow River. The blue point at Waldron's Falls indicates the downstream limit of the Upper Oldman creel survey area. Upstream limits of the Upper Oldman creel survey area were as follows: the confluence of South Twin Creek and the Livingstone River (red point), the confluence of Pasque Creek and the Oldman River (blue point), on Dutch Creek ~14 km upstream of its confluence with the Oldman River (green point), and the confluence of Vicary Creek with Racehorse Creek (purple point) (Hurkett and Fitzsimmons 2019). Map created in R-3.6.3 using “Leaflet” (Cheng et al. 2019); leaflet © OpenStreetMap contributors, CC-BY-SA, Tiles © Esri — Esri, DeLorme, NAVTEQ, TomTom, Intermap, iPC, USGS, FAO, NPS, NRCAN, GeoBase, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), and the GIS User Community. [Colour online.]



wild fish populations under- or unmonitored (van Poorten et al. 2015). Thus, critical information gaps exist that could affect recreational fisheries management and the conservation of wild fish stocks.

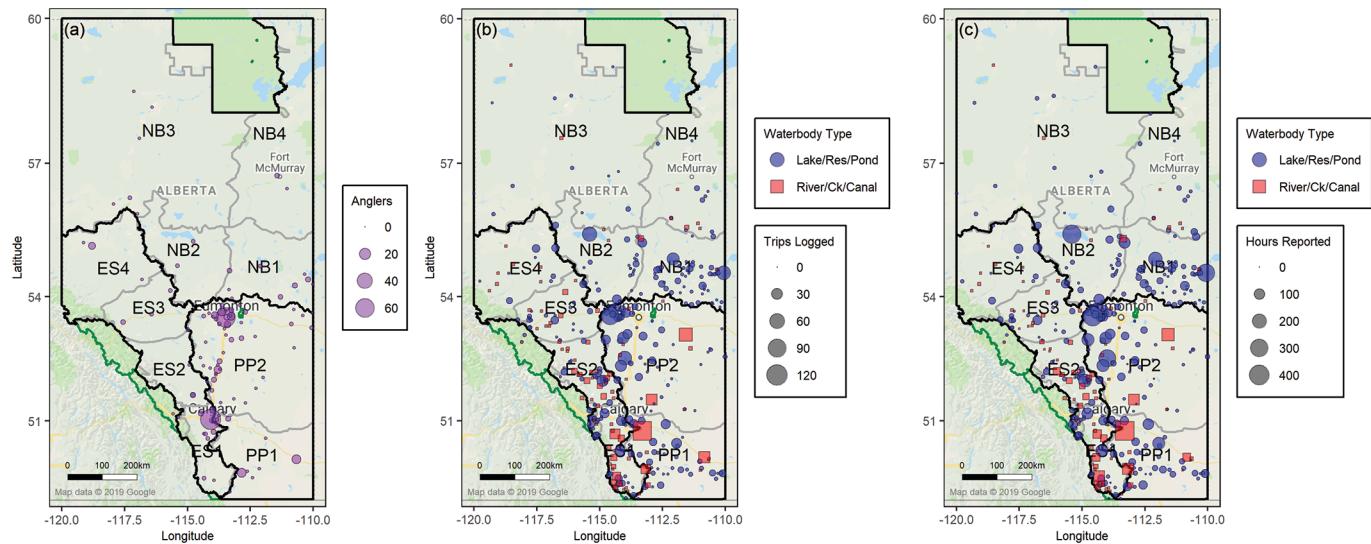
Citizen science, defined here as the voluntary reporting of data by the public for use in scientific studies, is a way to collect data over large spatial and temporal scales (McKinley et al. 2017; Dickinson et al. 2012; Kobori et al. 2016). Citizen science has been an important source of biological information historically (Dickinson et al. 2010; McKinley et al. 2017), but recent advances in digital technology have resulted in the rapid expansion of this field (Dickinson et al. 2010; Gutowsky et al. 2013; Venturelli et al. 2017). Indeed, questions about how angler-reported data can be used in fisheries monitoring were highlighted in a review of future considerations for recreational-fisheries management (Holder et al. 2020). There is growing interest in utilizing digital platforms such as websites, social media, digital log books, and apps for phones and tablets as low-cost methods to collect fisheries data that are meaningful to fisheries managers (Gutowsky et al. 2013; Venturelli et al. 2017). Anglers can use these platforms to voluntarily self-report catch and effort information, which can then be utilized in fisheries analyses and management. Results from initial studies found promising relationships between conventional surveys and angler-reported data for regional effort or catch rates (Stunz et al. 2014; Papenfuss et al. 2015; Jiorle et al. 2016), but also documented spatial and numeric biases (Jiorle et al. 2016; Gundelund et al. 2020). Moreover, concerns about citizen science data quality have limited its use in scientific publications and policy applications (Conrad and Hilchev 2011; Hyder et al. 2015; Theobald et al. 2015).

The paucity of comparative studies in fisheries science means that many questions remain about whether data self-reported by anglers through an app, or other digital platform, can provide

valid fisheries information (Venturelli et al. 2017). Angler recruitment and retention, data quality and quantity, and integration of angler self-reported data into fisheries management frameworks are all key challenges faced by citizen science projects (Hyder et al. 2015; Venturelli et al. 2017). What motivates participation in citizen science activities, and how this affects data quality, is an active field of research (West and Pateman 2016; Lewandowski and Specht 2015; Crandall et al. 2018; Parrish et al. 2019). For example, avitry biases resulting in nonrandom participation are a concern (Jiorle et al. 2016; Venturelli et al. 2017; Gundelund et al. 2020) that has likely limited the adoption of apps as a complementary tool to other fisheries survey techniques (Hyder et al. 2015; Lewandowski and Specht 2015; Venturelli et al. 2017).

The aims of this study were to determine if results from self-reported data from anglers using a mobile phone app (MyCatch) and website were similar to results from other more conventional survey techniques or if potential biases in the self-reported data were identified. More specifically, this project aimed to evaluate if (i) anglers using the app had a similar spatial distribution to what we know about the angler community from conventional surveys, (ii) fishing activities across the landscape determined from self-reported app data were similar to other survey methods, and (iii) catch estimates generated from the app data were similar to estimates from conventional survey techniques. The study focused on anglers that fished in the province of Alberta, Canada. With the growing interest in citizen science, studies such as ours are needed to identify the potential uses of angler apps as a complementary tool for monitoring fisheries and fish populations, and to identify potential biases that will need to be addressed if apps data are to be more broadly adopted in fisheries management.

Fig. 2. (a) Distribution of MyCatch-registered anglers ($N = 369$ anglers) from Alberta by residence, and the distribution of the 379 waterbodies that anglers reported fishing using the MyCatch app or website by (b) number of trips (2217 trips), and (c) and hours fished ($N = 9767$ hours). Locations for larger streams and rivers are represented by a single position rather than fishing locations. Black lines represent the borders of Alberta's three Fisheries Management Units, green lines represent the borders of national parks, and gray lines represent the borders of Alberta's ten Fisheries Management Watershed Units (approximate because this spatial layer is not publicly available). PP = Parkland Prairie, ES = Eastern Slopes, NB = Northern Boreal. Maps created in R-3.6.3 using “ggmap” (Kahle and Wickham 2013); map data ©2019 Google. [Colour online.]



Methods

Anglers used the MyCatch app and website to log information about their fishing trip and catch (further details below). Our study compared data collected by these electronic platforms to findings from three types of surveys — mail, creel, and gillnet — to evaluate the extent to which estimates from self-reported data from the app are similar to estimates of fisheries metrics from more conventional surveys. First, we compared the regional distribution and fishing practices from MyCatch in 2018 to mail survey data collected by Fisheries and Oceans Canada (DFO) for 2015 to determine if an app can capture the broad spatial distribution of the angler community. Second, catch data from MyCatch and creel surveys conducted on the Bow, and Upper Oldman–Livingstone systems in 2018 were used to evaluate the similarities–differences between catch rate and species composition of the catch on specific waterbodies. Finally, summary estimates from 2018 Fall Index Netting (FIN) surveys in Alberta were compared with catch information from MyCatch to evaluate if a correlative relationship between fish abundance estimates and catch occurred.

App data collection

Self-reported data from anglers were collected via the MyCatch mobile phone app and Angler's Atlas website. These data are referred to as the app data or MyCatch data throughout the manuscript without distinguishing the source (i.e., app versus website) unless necessary. A key difference between these two methods of data collection was that anglers had to register to submit data via the app, while most reports (70.3%) using the website were submitted anonymously. Thus, the postal code of some anglers who submitted data through the website were unknown.

Fisheries resources in Alberta are divided into three Fisheries Management Zones — Eastern Slopes Zone, Prairie Parkland Zone, and Northern Boreal Zone (Fig. 1) — that are further subdivided into ten Fish Management Watershed Units (FMWU), (4, 2, and 4 units per zone, respectively), and 5 national parks that are managed federally (Fig. 2). The FMWU (or park) that anglers resided in were identified for Alberta residents based on their postal code. In addition, app users from Alberta were categorized as rural or urban residents

based on the second digit of their postal code; 0 denoted a rural area, and numbers > 0 were categorized as urban as defined by Canada Post's forward sortation areas (Canada Post 2019).

Data collection began 11 May 2018, when the free MyCatch app first became available for download from The App Store and Google Play. The app and website usage were promoted through six separate email-based campaigns (4 national and 2 Alberta only) to existing subscribers of Angler's Atlas (15 954 Albertan subscribers) that took place until 28 August 2018. Data up to and including 10 May 2019 were utilized in this study, although the exact time frame used depended on the comparison of interest (Table 1). Reports from January 2019 to March 2019 were assumed to be winter-ice-fishing trips.

MyCatch allowed anglers to create a digital log of their fishing trip information. For each fishing trip, anglers were prompted to report the date, waterbody, hours fished rounded to the nearest hour, and the number of fish caught by species. Anglers were encouraged to record zero-catch data (i.e., trips that resulted in no fish being caught) via communications that explained the importance of this information, as well as a screen prompt that queried users to confirm a zero after submitting a trip log without anything caught. Anglers also had the option to record fish size measurements, tag information, and whether a fish was harvested. App use was incentivized via feedback in the form of graphical tools that helped anglers to visualize their fishing data (totals, averages, rates, and species composition). Waterbody location was selected using the phone's GPS and matched with a nearby waterbody from Angler's Atlas geo-spatial database. If the waterbody was missing from the database or incorrect, users could override this automatic feature by marking their own location on the map. River systems and streams were not broken down into smaller subunits, so the selection of a large river such as the Bow River meant that fishing could have occurred anywhere on the system.

National mail survey

DFO conducts mail surveys of recreational fishing activities in Canada's provinces and territories every five years to assess the economic and social importance of recreational fisheries

Table 1. Sampling period and sample sizes for conventional surveys and MyCatch reports and analyses used and the variables compared.

Conventional survey				MyCatch app			
Type	Location	Start date – end date (no. of days surveyed)	No. of anglers – reports – waterbodies	Location	Start date – end date (no. of days surveyed)	No. of anglers – reports – waterbodies	Analyses
DFO mail survey	Alberta	Jan.–Dec. 2015 (annual period)	1046 surveys, 1416 region reports	Alberta	11 May 2018 – 10 May 2019 (annual period)	2218 reports: • 390 registered anglers (1362 reports) and 856 unregistered reports • 9773 h • 1 report (6 h) with no location 379 waterbodies: • 289 lakes, 90 streams–rivers	1) χ^2 –Fisher's test: angler residence, regions fished, and species composition
AEP creel survey	Lower Bow River*	5 June – 25 Nov. 2018 (122 days surveyed)	2770 anglers: • 17 without time spent fishing, 1 with time spent fishing of 0 h, 2 with time spent fishing of 26 h • 10 without information on fishing access • 1931 completed trips, 537 of which were guided	Bow River	28 May 2018 – 4 Nov. 2018 + one trip 27 Dec. 2018 (56 dates reported)	91 reports: • 26 registered anglers (58 reports) and 33 unregistered reports	1) χ^2 –Fisher's test: species composition 2) Zero-inflated negative-binomial regression: catch rates
ACA creel survey	Upper Oldman–Livingstone system*	16 June – 31 Oct. 2018 (88 days surveyed)	963 anglers: • 3 without time spent fishing, 170 with time spent fishing of 0 h • 139 completed trips, 5 of which were guided Oldman River: 595 Livingstone River: 344 Racehorse Creek: 16 Dutch Creek: 8	Oldman–Livingstone system	15 June 2018 – 22 Oct. 2018 (31 dates reported)	43 reports: • 16 registered anglers (34 reports) and 9 unregistered reports Oldman River: 27 Livingstone River: 11 Racehorse Creek: 4 Dutch Creek: 1	1) χ^2 –Fisher's test: species composition 2) Zero-inflated negative-binomial regression: catch rates
FIN surveys	Alberta lakes	6 Sept. – 13 Oct. 2018 (varies by lake)	22 lakes	Alberta lakes	11 May 2018 – 10 May 2019 (varies by lake)	17 out of 22 FIN lakes 178 reports: see reports by lake in footnote [†]	1) χ^2 –Fisher's test: species composition 2) Linear regression: catch rates

*See Fig. 1 for specific locations of creel surveys. DFO = Fisheries and Oceans Canada, AEP = Alberta Environment and Parks, ACA = Alberta Conservation Association, FIN = Fall Index Netting.

[†]Reports by lake: Lac La Biche: 40, Pigeon Lake: 35, Lac Ste. Anne: 28, Lac La Nonne: 21, Milk River Ridge Reservoir: 11, Pinehurst Lake: 11, Battle Lake: 8, Isle Lake: 7, Lac Bellevue: 8, Wolf Lake: 3, Berry Creek Reservoir: 2, Crane Lake: 2, Hebeephrenic Lake: 1, Kehiwin Lake: 1, Long Lake: 1, Rainbow Lake: 1, Utikumasis Lake: 1.

(DFO 2019). The most recent survey pertained to annual fishing activities from January to December 2015. The DFO survey was designed to obtain a representative sample of anglers fishing in all regions of the country based on provincial-territorial recreational fishing licence databases. Standardized questions were asked in all versions of the survey, but provinces were able to add questions that were relevant to their jurisdiction. The Alberta survey was sent to 5800 license holders (5000 who were residents of Alberta, and 800 who were either Canadian non-residents and foreign anglers) (DFO 2019), and 1046 questionnaires were returned (18% response rate). Like the MyCatch anglers, postal codes were used to assign Alberta-resident respondents to a FMWU (Fig. 2), and categorize them as urban or rural (Canada Post 2019).

Alberta's version of the DFO survey asked a variety of questions about fishing activities, expenditures, demography, aquatic invasive species, and management awareness. Included were questions related to where anglers fished. Anglers were asked to identify which FMWU they lived in (Fig. 2), which FMWUs they fished in, the number of days that they fished in each FMWU, and the number of fish that they caught and kept by species in each FMWU. In addition, anglers were asked how many days they fished in Alberta in 2015, and to break that number down by (1) rivers or streams during the open water period, (2) reservoirs and (or) ponds during the open water period, and (3) through the ice during the ice fishing period. The Alberta version of the DFO survey did not collect waterbody-specific information.

Creel surveys

On-site angler surveys, often called creel surveys, involve interviewing anglers either during or at the end of their trip (Murphy et al. 1996). These surveys are used to obtain information on anglers utilizing the fish resource to produce effort and catch estimates (McCormick and Meyer 2017). We compared the MyCatch results to results from two creel surveys that were conducted in Alberta during 2018. One creel survey was conducted by Alberta Environment and Parks on the lower Bow River between the Bearspaw Dam and the Carsland Weir (Fig. 1) from June until the end of November 2018 (Table 1). This section of the Bow River is ~100 km long with a surface area of 1076 ha (Ripley and Council 2006). It is considered to be a world-class rainbow trout (*Oncorhynchus mykiss*) fishery (Post et al. 2006; Askey et al. 2007a) and receives considerable angling effort (Ripley and Council 2006; Cahill et al. 2018). A second creel was conducted by the Alberta Conservation Association along 199 km of the Upper Oldman River and its major tributaries — the Livingstone River, Dutch Creek and Racehorse Creek (Fig. 1) — from June to October 2018 (Hurvett and Fitzsimmons 2019). The upper Oldman River system is important habitat for a threatened salmonid species, westslope cutthroat trout (*Oncorhynchus clarkii lewisi*; COSEWIC 2016; Sinnatamby et al. 2020), and has received increasing angling pressure over the past three decades (Hurvett and Fitzsimmons 2019).

Both creel surveys utilized a combination of roving and common access point survey methods (Malvestuto 1996; Hurvett and Fitzsimmons 2019). Information collected during the interviews included angler residence, party size, time spent fishing, whether the trip was guided, and the method used to fish (shore-boat, flyfishing-casting). Anglers were asked to report the number of fish caught and kept by species, and creel clerks recorded size and maturity information on harvested fish (Fitzsimmons 2017). Creel clerks also noted the date, time and location of the interview, and whether the fishing trip was completed. Survey shifts were randomly assigned based on spatial and temporal strata in both creel surveys. The survey areas were divided into spatial strata (4 reaches on the Bow River and 3 on the Oldman River system), and the survey periods were divided based on two temporal strata; weekend-holidays and weekdays, and morning (8 am – 3 pm) and evening (3–10 pm) shifts. Further details on the

Upper Oldman River survey methodology can be found in Hurvett and Fitzsimmons (2019). The Bow River survey followed methods similar to those used in a survey on the Bow River in 2006 (Ripley and Council 2006).

AEP surveyed 2770 anglers on the Bow River in 2018, but 17 of these anglers did not report time spent fishing, one reported zero hours fishing, two reported fishing for 26 h, and 10 did not provide information on how they accessed the system (Table 1). We excluded these 30 anglers from our Bow River analysis because we required information on nonzero effort and access. Similarly, our effective sample size in the ACA survey of the Upper Oldman River system in 2018 was 790 because three reports did not include time spent fishing, and 170 reports included zero hours fishing (Table 1).

Gillnetting surveys

Standardized index-netting is a common, fishery-independent method for assessing fish abundance and size structure (Appelberg 2000; Bonar et al. 2009; Sandstrom et al. 2013). Alberta's walleye (*Sander vitreus*) and northern pike (*Esox lucius*) populations are monitored via a standardized gillnetting protocol called a Fall Index Netting (FIN) (Morgan 2002; AESRD 2014). FIN surveys occur in fall when fish are more evenly distributed (water temperatures 10–15 °C) (Government of Alberta 2020). Crews set standardized, multi-mesh gillnets 2–15 m deep at random locations for 21 to 27 hours (Government of Alberta 2020). The number of nets and nights fished are determined by lake size. The number, size, maturity, and species of the fishes that are captured, together with the number of nets and nights fished, are used to obtain walleye and mature pike population estimates (Government of Alberta 2020). In 2018, FIN surveys took place on 22 Alberta lakes between September and October (Table 1). Our analyses were based on 2018 FIN summary data that were obtained from the following website, <https://www.alberta.ca/fall-index-netting-summaries.aspx>.

Analyses

We used multiple analyses to compare MyCatch-based metrics to those from conventional surveys (Table 1). Chi-squared tests ("chisq.test" R-3.6.3) were used to compare results from the 2015 DFO survey and MyCatch reports from May 2018 to May 2019. We compared the relative distribution of anglers among FMWUs based on their residence, the relative distribution of annual fishing effort among FMWUs, and the relative distribution of species caught annually. The Fisher's exact test ("fisher.test" R-3.6.3) was used when the expected frequency of some of the categories was low (Crawley 2007). Post hoc tests of equal proportions were used to examine which categories differed between surveys ("prop.test" R-3.6.3), with *p* values adjusted for multiple comparisons via the Holm method (Holm 1979). All analyses were implemented in R 3.6.3 (R Core Team 2020), and tests with *p* values < 0.05 were considered significant. We also calculated Cramér's *V* because χ^2 and Fisher's tests are likely to return low *p*-values for large sample sizes, even when effect sizes are small. Cramér's *V* is a measure of the strength of association (i.e., effect size) for χ^2 tests that ranges between 0 and 1. In a 2×2 contingency table, a value < 0.1 indicates little to no association (referred to here as negligible), 0.1–0.3 indicates low association, 0.3–0.5 indicates moderate association, and > 0.5 indicates high association (Mangiafico 2016). For larger contingency tables, the Cramér's *V* values that define the thresholds between low, moderate and high association become smaller (Cohen 1988) and can be found in the online Supplementary material, Table S1¹.

MyCatch reports for the Bow River and Oldman River system were compared to 2018 creel data collected by AEP and the ACA, respectively, to determine if catch information was similar at the waterbody level (Table 1). Similar to the comparison of the app to the DFO survey, χ^2 tests ("chisq.test" R-3.6.3) or Fisher's exact test

¹Supplementary data are available with the article at <https://doi.org/10.1139/cjfas-2021-0026>.

Table 2. AIC, delta AIC values (Δ AIC), AIC weights (wAIC), number of parameters (K), and Nagelkerke's (Cragg and Uhler) pseudo- R^2 values ($N\cdot R^2$) for zero-inflated negative binomial models 1–13 for the Bow River and the Oldman River system.

Model number: formula	Bow River					Oldman River system				
	AIC	Δ AIC	wAIC	K	$N\cdot R^2$	AIC	Δ AIC	wAIC	K	$N\cdot R^2$
1: Catch ~ 1 1	9468.2	1087.5	0	3	0	3595.0	221.0	0	3	0
2: Catch ~ Source Source	9466.8	1086.1	0	5	0.0020	3593.0	219.0	0	5	0.0050
3: Catch ~ OT OT	8383.1	2.4	0.1071	3	0.3300	3374.0	0.002*	0.3347	3	0.2362
4: Catch ~ Source + OT Source + OT	8384.5	3.7	0.0544	5	0.3307	3379.8	5.8	0.0183	5	0.2375
5: Catch ~ Source 1	9466.7	1086.0	0	4	0.0013	3589.0	215.0	0	4	0.0050
6: Catch ~ Source OT	9493.7	1113.0	0	4	-0.0087	3589.0	215.0	0	4	0.0050
7: Catch ~ Source Source + OT	9495.7	1115.0	0	5	-0.0087	3593.0	219.0	0	5	0.0050
8: Catch ~ OT 1	8380.7	0*	0.3533	3	0.3306	3374.0	0*	0.3350	3	0.2362
9: Catch ~ OT Source	8382.3	1.6*	0.1568	4	0.3307	3377.1	3.1	0.0714	4	0.2370
10: Catch ~ OT Source + OT	8385.1	4.4	0.0394	4	0.3300	3376.6	2.6	0.0894	4	0.2374
11: Catch ~ Source + OT 1	8382.5	1.8*	0.1453	4	0.3307	3595.0	221.0	0	3	0
12: Catch ~ Source + OT Source	8383.2	2.5	0.1014	5	0.3310	3593.0	219.0	0	5	0.0050
13: Catch ~ Source + OT OT	8385.0	4.2	0.0424	4	0.3301	3374.0	0.002*	0.3347	3	0.2362

Note: "Catch" is catch per trip of rainbow trout or cutthroat trout for the Bow River and Oldman River system, respectively. "OT" is time spent fishing included as an offset variable. "Source" is a categorical variable with levels Creel and MyCatch. The information to the right of upright bar in the model formula indicates the formula for the zero-inflated portion of the model.

* Δ AIC values < 2.

("fisher.test" R-3.6.3) were used to compare the relative composition of species in the catch in each of the river systems. Only commonly captured species were included in this analysis — rainbow trout, cutthroat trout, brown trout (*Salmo trutta*), bull trout (*Salvelinus confluentus*), and mountain whitefish (*Prosopium williamsoni*). We classified rainbow trout \times cutthroat trout hybrids from the Oldman River creel survey as cutthroat trout because MyCatch anglers did not identify hybrids.

Catch rates from the app and creel surveys were also compared for the Bow River and Oldman River system. Zero-inflated negative-binomial models with a log link ("zeroinfl", pscl package, R-3.6.3; Zeileis et al. 2008) were used to evaluate similarities or differences between the app and creel catch because the data were over-dispersed and zero-inflated in both systems. We evaluated a series of 13 models that included possible combinations of data source (app or creel) and time fishing (Table 2). Time fishing was included as an offset variable (Kuparinen et al. 2010; Gundelund et al. 2020). Anglers surveyed by the creels were found to be operationally diverse, particularly on the Bow River (see Supplement and Fig. S1¹). Thus, supplementary analyses were also completed for more complex explanatory variables that incorporated information from the creel survey on trip completion, guiding, gear used and access (shore-boat) — $N = 8$ for the Bow River (Supplementary Table S2¹) and $N = 7$ for the Oldman River system (Supplementary Table S3¹). Variables could not be included as covariates in the models because comparable information was not available for the MyCatch data set. For model numbers > 4, the model fit to the non-zero count data (left of the bar in the model formula) was different from the model fit to the zero-inflation component of the data (right side of the bar in the model formula; Table 2). We used delta AIC values and AIC weights to identify the most parsimonious of the candidate models. Delta AIC values < 2 suggest that the model should be considered, whereas models with delta AIC values from 4 to 7 have considerably less support, and delta AIC values > 10 suggest that the model is unlikely to be the most parsimonious (Burnham and Anderson 2001). AIC weights give the probability that a model is the best model among the candidate models evaluated (Wagenmakers and Farrell 2004). In addition, Nagelkerke's (Cragg and Uhler) pseudo- R^2 ("nagelkerke", rcompanion package, R-3.6.3; Mangiafico 2020), which tends to fall between 0 and 1, was used as an indicator of goodness of fit (Mangiafico 2016). The catch rate of the dominant species in the catch was modelled for each system; sample sizes for other species were too small for evaluation (Fig. 6).

We used linear regression ("lm", R-3.6.3) to compare mean catch rates from MyCatch to gillnet catch rates and density estimates for walleye and northern pike from the 2018 FIN survey reports. Density was calculated by multiplying the gillnet catch rate by the percent of the population caught, which is provided in the reports, and divided by the lake area. MyCatch data from the full year of collection were used to improve sample sizes. We used the mean-of-ratios estimator, which is appropriate for measuring average angler catch rates (Pollock et al. 1997). We tested the linear regression assumption of normality with the Shapiro-Wilk Normality Test ("shapiro.test", R-3.6.3) and the Breusch Pagan Test for homoskedasticity ("bptest", lmtest package, R-3.6.3; Zeileis and Hothorn 2002). Violations of homoskedasticity were accounted for by refitting the linear model with robust standard errors ("lm_robust", estimatr package, R-3.6.3; Blair et al. 2020) that used the heteroscedasticity consistent covariance matrix HC3, which is suitable for smaller sample sizes (Long and Ervin 2000). We used χ^2 ("chisq.test" R-3.6.3) or Fisher's exact ("fisher.test" R-3.6.3) tests to compare the relative composition of species in the app and gillnet catches for lakes for which there were sufficient MyCatch data (>30 reports). We only considered the relative proportions of sport fishes because other species (e.g., suckers, shiners) were unlikely to be captured and (or) reported by MyCatch anglers.

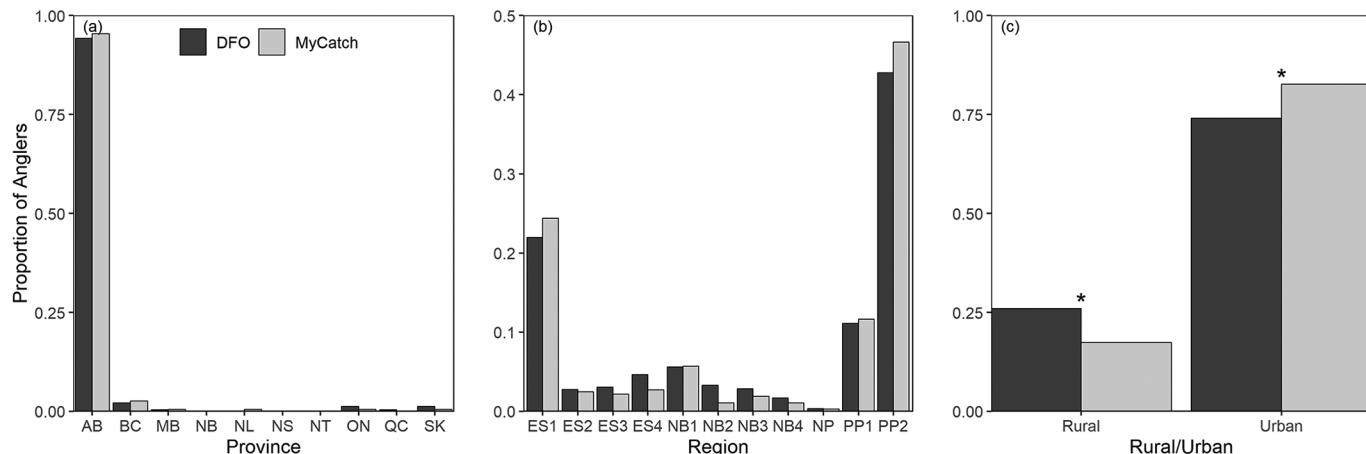
Results

MyCatch usage

Anglers used the MyCatch app and website to report 2218 trips in Alberta over a year (Table 1). This corresponded to 9773 hours of fishing and 12 037 fish caught. A total of 390 registered anglers were identified, 369 (94.6%) of which were from Alberta, predominantly from large population centers (Fig. 2a). Registered anglers accounted for 61.4% (1362 reports) of all reported trips, and 71.1% of these trips were reported through the MyCatch app. However, 55.7% of all reports (i.e., anonymous and registered users combined) were through the website. Just over half of registered anglers (52.3%) only reported a single fishing trip, and the majority reported <10 trips (83.3% \leq 5 trips, 93.1% \leq 10 trips). Anglers reported zero-catch in 635 reports (28.6% of trips), and selected the zero-catch option on the app in all but five (0.8%) of these cases.

App reports were distributed throughout Alberta (Fig. 2b) on 289 lakes and 90 streams or rivers (Table 1), with the majority (79.3%) of effort reported on lakes. However, both trips and effort

Fig. 3. The relative distribution of anglers that fished in Alberta by their place of residence for both the MyCatch app and the 2015 DFO mail survey. Panel (a) illustrates the distribution of Canadian residents by province (DFO $N = 1005$ anglers, MyCatch $N = 387$ anglers), panel (b) illustrates the distribution of Alberta residents among the fisheries management watershed units (i.e., region), and panel (c) illustrates the distribution of Alberta-resident anglers between urban and rural residences (DFO $N = 947$ anglers, MyCatch $N = 369$ anglers, for panels b and c). Asterisks above the bars indicate significant differences at $\alpha = 0.05$. PP = Parkland Prairie, ES = Eastern Slopes, NB = Northern Boreal.



were highest in the southern half of the province (Fig. 2b), and effort was highest near large population centers (Fig. 2c). Ice-fishing-winter effort (i.e., effort from January–March 2019) represented 30.5% and 4.9% of all trips reported for lakes and streams–rivers, respectively, and occurred on 52.9% of the lakes and 13.3% of the streams–rivers that were identified by MyCatch users, respectively. Only 13 waterbodies, 14 if the Oldman River and its tributaries are pooled, had ≥ 30 reports (Table 1). The Bow River received the most MyCatch reports, with 91 reports (320 hours) occurring from May–December 2018 (Table 1), and 117 trips (428 hours) over an annual period (May 2018 – May 2019). The Oldman River system ranked sixth according to MyCatch, receiving 43 reports and 221 hours (Table 1). The Oldman River specifically accounted for 62.9% of MyCatch trips in the Oldman River system, which is similar to the 61.8% of trips that were reported in the ACA Creel (Table 1).

Mail Survey–App comparison

MyCatch reports were compared to DFO mail survey results to determine if there were broad spatial similarities in where anglers resided, how effort was distributed, and which fish species were captured. The distributions by province of Canadian-resident anglers that fished in Alberta did not differ significantly between the two data sources (Fig. 3a; $\chi^2_{[9,N=1392]} = 11.45$, $p = 0.2459$, Fisher $p = 0.3151$, Cramér's $V = 0.0907$ low association), and were dominated by Alberta residents (94% DFO, 95% MyCatch). There was also no significant difference in the relative distribution of Alberta-resident anglers among the FMWUs (Fig. 3b; $\chi^2_{[10,N=1316]} = 11.32$, $p = 0.3330$, Fisher $p = 0.3270$, Cramér's $V = 0.0927$ low association). In both cases, the greatest proportion (42.8% DFO, 46.6% MyCatch) of the Alberta-resident anglers were from the Prairie Parkland 2 region, which incorporates Edmonton and Red Deer. The proportion of urban anglers was significantly higher in the app than the DFO survey (Fig. 3c; $\chi^2_{[1,N=1316]} = 10.51$, $p = 0.0012$, Fisher $p = 0.0009$), but the strength of this association was negligible (Cramér's $V = 0.0914$).

A comparison of the distribution of angling effort in Alberta showed similar trends between the app and the DFO survey. Both methods found that the majority (70% DFO, 76% MyCatch) of anglers fished in only one region, and most (56% DFO, 57% MyCatch) of the trips by Albertan residents were in the region in which they lived. Almost half the fishing effort in both surveys was in PP2 and ES1 (Fig. 4). However, the proportion of trips reported in the NB2 region was significantly higher in the DFO survey than in MyCatch (Fig. 4;

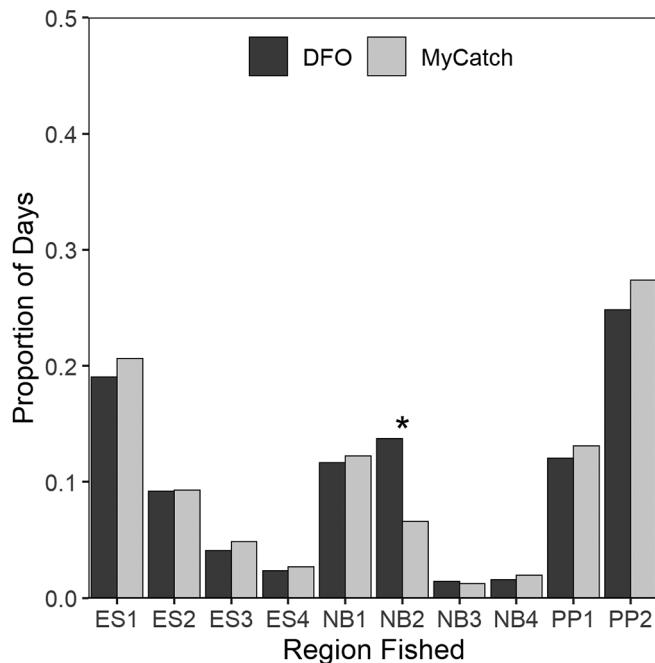
$\chi^2_{[9,N=16009]} = 91.90$, $p < 0.0001$, Fisher $p < 0.0001$, Holm adjusted p for NB2 < 0.0001), but the strength of this association was low (Cramér's $V = 0.0758$). This difference could be due to potential errors in the region reported in the DFO survey. For example, 24% of anglers in the DFO survey reported a region of residence that was inconsistent with their postal code. This error rate was 66% in the NB2 region.

We found significant differences in the relative composition of species caught between the app and the DFO survey (Fig. 5; $\chi^2_{[15,N=74947]} = 1522.14$, $p < 0.0001$, Fisher $p < 0.0001$, Holm adjusted p values BURB: < 0.0001 , CTTR: 0.0342, GOLD: 0.0060, LKST: < 0.0001 , LKTR: < 0.0001 , LKWH: 0.0211, MNWH: < 0.0001 , NRPK: < 0.0001 , RNTR: < 0.0001 , WALL: < 0.0001 , YLPR: < 0.0001 ; species codes defined in Fig. 5), although the general trends between the two methods were similar, and the association was low (Cramér's $V = 0.1425$). Walleye and northern pike were the most common species accounting for $\sim 60\%$ of the reported catch, followed by rainbow trout, yellow perch (*Perca flavescens*), and cutthroat trout (Fig. 5). These five species combined accounted for almost 90% of the reported catch in both data sources.

Creel survey–app comparison

The species composition of commonly caught species in the Bow River was significantly different between the app and AEP creel survey (Fig. 6a; $\chi^2_{[2N=6266]} = 6.58$, $p = 0.0372$, Fisher $p = 0.0461$), but the association was negligible (Cramér's $V = 0.0324$) and post hoc comparisons found no significant differences between species pairs at $\alpha = 0.05$ (Holm adjusted p values: 0.2133 RNTR, 0.0514 BNTR, and 0.4772 MNWH). Rainbow trout dominated the catch by both methods (72% MyCatch and 78% Creel), followed by brown trout and mountain whitefish. For the Oldman River system, there was also a significant difference in the relative composition of species caught between MyCatch and the ACA creel survey (Fig. 6b; $\chi^2_{[3,N=2712]} = 75.54$, $p < 0.0001$, Fisher $p < 0.0001$, Holm adjusted p values CTTR: < 0.0001 , RNTR: < 0.0001). However, like the Bow River, the general trends among the two methods were similar, and the strength of the association was low (Cramér's $V = 0.1669$). Cutthroat trout was the most common species that was reported by both methods (83% MyCatch and 93% Creel). MyCatch did not have the option to report hybrids, so our analysis assumed all hybrids would be cutthroat. However, significant differences with low effect size were present even if all hybrids were assumed to be

Fig. 4. The relative distribution of angling trips among the fisheries management watershed units (i.e., region) in Alberta for both the MyCatch app ($N = 2204$ days) and the 2015 DFO mail survey ($N = 13\,805$ days). Asterisk above the bars indicate significant differences at $\alpha = 0.05$. PP = Parkland Prairie, ES = Eastern Slopes, NB = Northern Boreal.

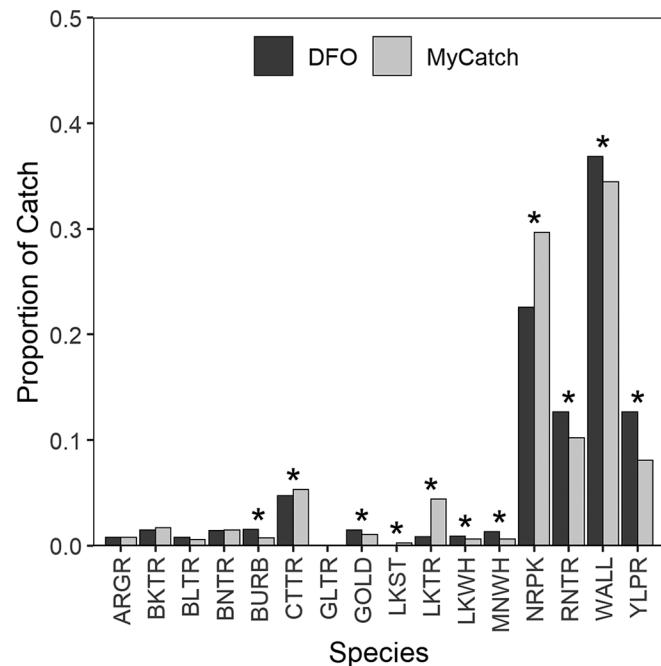


rainbow trout, or if they were removed from the analysis completely (results not presented).

Analyses of catch per trip of rainbow trout from the Bow River found that “Data Source” (app or creel, Model:2) did not improve the null model (likelihood ratio test $\chi^2_{[2]} = 5.38$, $p = 0.0679$), and had a negligible effect size (Nagelkerke’s $R^2 = 0.0020$; Table 2). According to AIC, the most parsimonious model, Model:8, did not include the categorical variable “Data Source” (Fig. 7a), and had an AIC weight of 0.3533 and a Nagelkerke’s $R^2 = 0.3306$ (Table 2). Model:9 and Model:11 had Δ AIC values < 2 , but predictions did not differ greatly from Model:8 (Supplementary Fig. S2¹) and AIC weights were less than half Model:8 (Table 2). Supplementary analyses that considered more complex explanatory variables that segmented creel data found that Model:12, in which creel data were segmented by access, gear, trip completion and guiding (X.Var.8) was the most parsimonious model out of all models considered, having an AIC weight of 0.9998 when all variables were considered and a Nagelkerke’s $R^2 = 0.4126$ (Supplementary Table S2¹). Model 12 predicts that catch per trip of rainbow trout by MyCatch anglers on the Bow River will be intermediate, with shore-based anglers from the creel having lower catch rates, and boat anglers from the creel, particularly those that are guided, having higher catch rates (Supplementary Fig. S3¹).

Analyses of catch per trip of cutthroat trout from the Oldman River system also found that “Data Source” (app or creel, Model:2) did not improve the null model (likelihood ratio test $\chi^2_{[2]} = 4.08$, $p = 0.1301$), and had a low effect size (Nagelkerke’s $R^2 = 0.0050$; Table 2). Model:8 was again the most parsimonious model (Fig. 7b), and had an AIC weight of 0.3347 and a Nagelkerke’s $R^2 = 0.3350$ (Table 2). Model:3 and Model:13 had delta AIC values < 2 (Table 2), but predictions did not differ greatly from Model:8 (Supplementary Fig. S4¹). Supplementary analyses that considered more complex explanatory variables that segmented creel data found that Model:11, in which creel data were segmented by gear and trip

Fig. 5. Comparison of the relative composition of species caught in Alberta as reported by anglers using the MyCatch app ($N = 11812$ fish) or in the DFO 2015 mail survey ($N = 63135$ fish). Asterisks above the bars indicate significant differences at $\alpha = 0.05$. ARGR = Arctic grayling, *Thymallus arcticus*; BKTR = brook trout, *Salvelinus fontinalis*; BNTR = brown trout, *Salmo trutta*; BLTR = bull trout, *Salvelinus confluentus*; BURB = burbot, *Lota lota*; CTTR = cutthroat trout, *Oncorhynchus clarkii*; GLTR = golden trout, *Oncorhynchus aquabonita*; GOLD = goldeye, *Hiodon alosoides*; LKST = lake sturgeon, *Acipenser fulvescens*; LKTR = lake trout, *Salvelinus namaycush*; LKWH = lake whitefish, *Coregonus clupeaformis*; MNWH = mountain whitefish, *Prosopium williamsoni*; NRPK = northern pike, *Esox lucius*; RNTR = rainbow trout, *Oncorhynchus mykiss*; WALL = walleye, *Sander vitreus*; YLPR = yellow perch, *Perca flavescens*.



completion (X.Var.5) was the most parsimonious model out of all models considered (Supplementary Table S3¹). Few (10) trips in this system were guided, and all anglers fished from shore. Like the Bow River analyses, Model:11 predicts that MyCatch anglers have catch rates that fall within the range of the creel segments in the Oldman River system (Supplementary Fig. S5a¹). However, this model only had an AIC weight of 0.1717 and a Nagelkerke’s $R^2 = 0.2542$ when all models and variables were considered (Supplementary Table S3¹). Numerous models (Models 13 and 9) with differing levels of creel segmentation (X.Var.4 and X.Var.7) had delta AIC values close to 2 and AIC weights > 0.05 . Thus, these models also have support and should be considered (e.g., Supplementary Fig. S5b¹), but they also predict that the app catch rates fall within the range of predictions for the creel segments.

Gillnet-app comparison

MyCatch data were available for 17 of the 22 lakes for which we could obtain AEP FIN data summary reports (Table 1). Catch rates of walleye per net night from FIN surveys were significantly related to average catch rates of walleye from the app, and the effect size was moderate (Fig. 8a; $F_{[1,15]} = 15.72$, $p = 0.0012$, robust $F_{[1,15]} = 7.32$, robust $p = 0.0163$, $r^2 = 0.5116$). The model was corrected for heteroskedasticity using robust standard errors because the assumption of homogeneity of variance was violated ($BP = 10.88$, $df = 1$, $p = 0.0010$). The assumption of normality was not violated ($W = 0.95$, $p = 0.4172$). There was also a significant relationship

Fig. 6. The relative composition of commonly caught species in catches from the MyCatch app or the 2018 creel surveys for (a) the Bow River (Creel $N = 6105$ fish, MyCatch $N = 161$ fish) and (b) the Oldman River system (Creel $N = 2472$ fish, MyCatch $N = 240$ fish). Asterisks above the bars indicate significant differences at $\alpha = 0.05$, and numbers above the bars are sample size. $N =$ the total number of fish caught. BNTR = brown trout, *Salmo trutta*; BLTR = bull trout, *Salvelinus confluentus*; CTTR = cutthroat trout, *Oncorhynchus clarki*; MNWH = mountain whitefish, *Prosopium williamsoni*; RNTR = rainbow trout, *Oncorhynchus mykiss*. Cutthroat trout \times rainbow trout hybrids ($N = 73$ for the creel and 0 for the app) in the Oldman River system were included in the CTTR category.

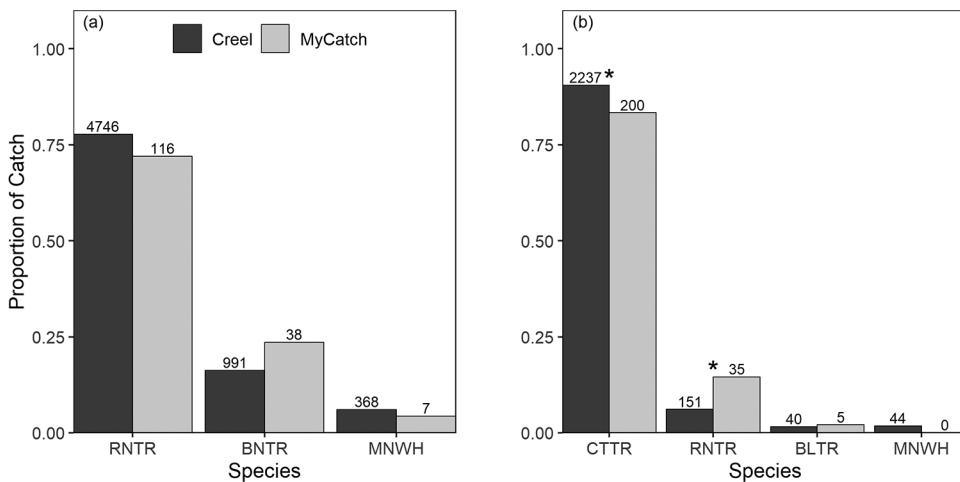
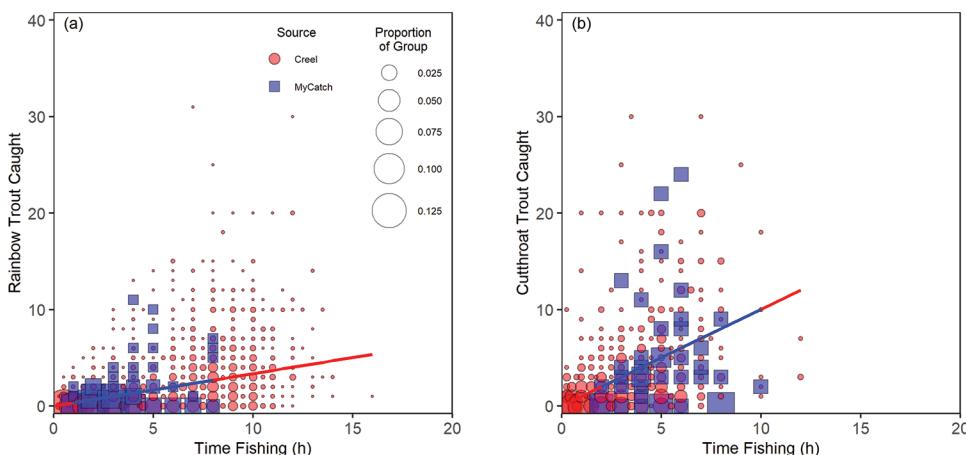


Fig. 7. Data and predictions for the catch per trip of (a) rainbow trout (*Oncorhynchus mykiss*) from the Bow River (Creel $N = 2740$ reports, MyCatch $N = 91$ reports) and (b) cutthroat trout (*Oncorhynchus clarki*) from the Oldman River system (Creel $N = 790$ reports, MyCatch $N = 43$ reports), in relation to the time spent fishing. The panels illustrate the most parsimonious model (Model 8: Catch \sim OT | 1, in both cases) when MyCatch catches were compared to creel catches pooled over all angler segments. Dots represent the raw data and lines are the model predictions. The dot size indicates the proportion of trips in a group. Model details can be found in Table 2. [Colour online.]



between the catch rate of pike per net night from the FIN survey and the average catch rates of pike from MyCatch (Fig. 8b; $F_{1,15} = 5.42$, $p = 0.0343$), but this relationship was less strong ($r^2 = 0.2654$). The assumptions of normality ($W = 0.91$, $p = 0.1134$) and homogeneity of variance ($BP = 1.25$, $df = 1$, $p = 0.2627$) were not violated in this comparison. Results were similar but weaker when app catch rates were compared to fish density estimates, and the relationship for pike was not significant (Supplementary Fig. S6¹).

Only two of the FIN lakes — Lac La Biche and Pigeon Lake (Table 1) — had >30 app reports for comparing species compositions. We found significant differences in catch composition and high to moderate effect sizes between the app and FIN surveys (Fig. 9a: LAC LA BICHE $\chi^2_{[3,N=1118]} = 212.58$, $p < 0.0001$, Fisher $p < 0.0001$, Holm adjusted p values WALL: 0.1914 , NRPK: <0.0001 , YLPR: <0.0001 and LKWH: <0.0001 , Cramér's $V = 0.4361$; Fig. 9b: PIGEON LAKE $\chi^2_{[2,N=687]} = 47.18$, $p < 0.0001$,

Fisher $p < 0.0001$, Holm adjusted p values WALL: <0.0001 , NRPK: 0.0404 and LKWH: <0.0001 , Cramér's $V = 0.2621$). MyCatch had proportionally more reports of northern pike, and few reports of yellow perch and lake whitefish (Fig. 9).

Discussion

This study contributes to growing evidence that apps can provide recreational-fisheries data of comparable quality to conventional survey methods. Our findings suggest that an app and (or) website can (i) recruit a segment of users who have a broad spatial distribution that is similar to that of anglers that respond to the national mail survey, (ii) generate self-reported data that captures similar regional fishing patterns as the national survey, and (iii) provide catch rate estimates that are similar to those estimated from other fisheries-dependent surveys. Some potential biases were identified in the angler segment that was recruited (e.g.,

Fig. 8. The relationship between mean catch per unit effort (CPUE) from MyCatch reports and (a) walleye catch rates and (b) mature northern pike catch rates from 2018 Fall Index Netting (FIN) surveys ($N = 17$ lakes). Points are the mean catch rates from MyCatch reports, and size of the points indicates how many MyCatch reports contributed to the mean estimate for a lake. The black line is the linear regression prediction. $R.sq$ = the coefficient of determination from the model, p = the p value from the regression model and the light gray region is the 95% confidence interval. Robust.p = the p value using robust standard errors that account for heteroskedasticity, and the dark gray region is the robust 95% confidence interval.

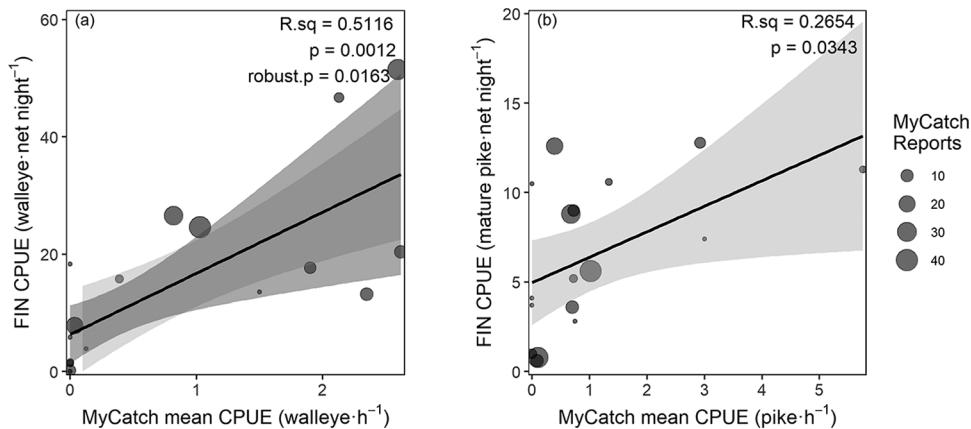
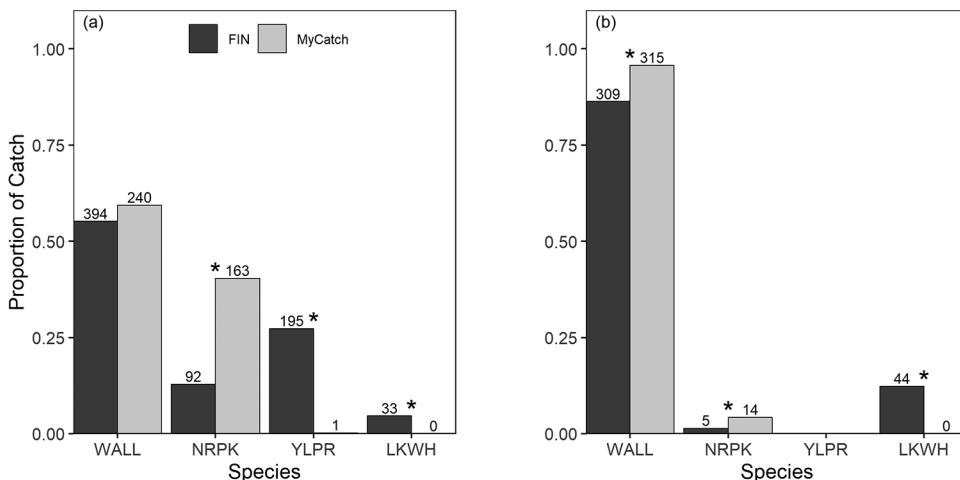


Fig. 9. Comparison of the relative composition of commonly caught sport-fishes in catches from the MyCatch app or 2018 Fall Index Netting (FIN) surveys for (a) Lac La Biche (FIN $N = 714$ fish, MyCatch $N = 404$ fish from 40 reports) and (b) Pigeon Lake (FIN $N = 358$ fish, MyCatch $N = 329$ fish from 35 reports). Asterisks above the bars indicate significant differences at $\alpha = 0.05$, and numbers above the bars are sample size. LKWH = lake whitefish, *Coregonus clupeaformis*; NRPK = northern pike, *Esox lucius*; WALL = walleye, *Sander vitreus*; YLPR = yellow perch, *Perca flavescens*.



urban bias, although results were inconclusive), and the data that they reported (e.g., provincial catch composition). The ability of self-reported app data to complement fisheries-independent netting surveys was less clear. However, our results suggest that apps show promise as complementary tools to estimate fisheries-dependent metrics similar to more conventional surveys.

MyCatch usage

MyCatch demonstrates the potential of an app to capture a broad, landscape perspective of where anglers come from and how they distribute their effort. Understanding how fishing activity is distributed across the landscape is critical for managing fisheries effectively (Ward et al. 2016; Arlinghaus et al. 2017a). The availability, accessibility, and quality of fishing opportunities determines how angler pressure distributes on the landscape (Hunt et al. 2011; Carruthers et al. 2019; Kaemingk et al. 2018; Matsumura et al. 2019). MyCatch anglers tended to reside in

larger urban centers and in the southern part of the province, which is consistent with the distribution of general population in the province. This spatial pattern has important implications for the distribution of angling pressure (Post et al. 2008; Hunt et al. 2011; Papenfuss et al. 2015). Similar to Papenfuss et al. (2015), we found that lakes that were close to well established transportation routes, and in the vicinity of the relatively populated Calgary-Edmonton corridor were more popular (i.e., more trip reports and hours fished). Travel distance is an important constraint on fishing decisions (Hunt 2005), and the range travelled may vary seasonally (Papenfuss et al. 2015). Maintaining viable fisheries close to large urban centers can be challenging (Post et al. 2002, 2008; Hunt et al. 2011). As a result, different management measures, such as more restrictive regulations or maintaining put-and-take fisheries close to urban centers, may be required to maintain fisheries (Post et al. 2008; Post and Parkinson 2012; Kaemingk et al. 2018). App information on the spatial distribution of effort could be used to identify

which waterbodies are of conservation concern. For example, high effort fisheries or fishing pressure on populations that are particularly vulnerable to overexploitation, such as threatened populations, are potential candidates for increased monitoring and (or) more restrictive regulations.

A strength of apps is that they have the potential capture the spatial resolution of fishing activity at both regionally and on specific waterbodies over a relatively short timeframe. MyCatch users identified 289 lakes in the first year. To put that number in perspective, there are ~800 sportfishing lakes in Alberta. Fish-status assessments have been done on ~500 lakes in Alberta, and ~250 more lakes are stocked annually — primarily with rainbow trout (Government of Alberta 2018). In addition, the MyCatch lake count after one year was 58% of the number of lakes that were identified by an established app over a three year period (Papenfuss et al. 2015). These results suggest that longer-running apps can sample a broad number of fisheries across a landscape. Our study also demonstrates the importance of including both rivers and lakes in the app. Rivers accounted for 24% of the reported fishing effort, and the Bow River was the most popular waterbody in the province. Including all components of the province's fisheries will improve the ability of apps to provide high-resolution data to estimate effort and catch, and to understand fisheries dynamics on the landscape.

Mail survey-app comparison

Our comparison to the 2015 DFO mail survey suggests that MyCatch was used by a sample of anglers that were spatially distributed in a similar manner as respondents to the federal survey, both regionally and provincially. MyCatch users were significantly more urban than DFO survey respondents, but the effect size was negligible. Recruitment and retention are important factors when trying to establish and maintain a reliable supply of angler-reported data (Cooke et al. 2000; Venturelli et al. 2017; Crandall et al. 2018). Our study shows that an app can recruit anglers from a broad geographic range that extends beyond management zones. In its first year, the MyCatch app recruited 390 registered users who fished in Alberta, which is equivalent to 37.3% of the number of responses to the national DFO mail survey; the survey that is used to monitor provincial trends in recreational fisheries (Zwickel 2012). Another angler app for Alberta documented 2827 users over a three-year period (Papenfuss et al. 2015). Agreement in the spatial distribution of anglers and the potential to achieve larger sample sizes suggest that app information can be used to monitor the broad-scale trends in Alberta's fishing community in intervening years between DFO surveys (five-year cycle). More studies are required to determine if this finding is consistent across platforms and locations, and what spatial biases can be identified.

The app generally captured the same, broad spatial distribution of angling activity as the DFO mail survey. Effort in the Northern Boreal 2 FWMU may have been underrepresented by the app, but the results were equivocal and misidentification of FMWU's by DFO respondents may have been responsible for the effort mismatch. Catch composition from the app also had gross similarities to the DFO survey, in that both identified walleye and northern pike as the primary target species in the province, followed by yellow perch, rainbow trout and cutthroat trout. However, there were significant differences in the relative proportions of species. For example, the app had proportionally more reports of northern pike and lake trout catches. Opportunistic data collection, such as anglers choosing when and where to report fishing trips, can generate spatial biases relative to more systematic survey designs (Lewandowski and Specht 2015). Pike lakes are 2.7 times more abundant than walleye lakes in Alberta, and more pike fishing opportunities are close to urban centers (Government of Alberta 2018). Most of the lake trout recorded through the app (58%) came from Cold Lake, which could reflect an affinity bias for that lake or species. Our findings could also represent real differences in the

fisheries between 2015 and 2018, or recall biases by mail-survey respondents. Thus, while broad spatial trends can still be used to identify preferred species and focus management efforts, further work is needed to identify potential biases in targeted or reported species, and to determine if data collection over the longer term reduces variation. In addition, analyses at a regional level that reflect differences in species distribution could minimize some spatial biases associated with app recruitment and reporting.

Identifying biases in recruitment and retention is important if app data are to be used as a complementary fisheries-monitoring method (Venturelli et al. 2017). Determining what motivates participation in citizen science activities is an active field of research (West and Pateman 2016; Lewandowski and Specht 2015; Crandall et al. 2018; Parrish et al. 2019). Anglers are a heterogeneous group with diverse motivations for fishing, angling preferences, fishing practices, skills and commitment (Bryan 1977; Fisher 1997; Scott and Shafer 2001). This diversity likely influences who participates in citizen science projects, and the digital platforms that they use (Venturelli et al. 2017; Gundelund et al. 2020). Our study found that the dual web and app interface was important for data collection because 55% of reports were via the website (38.6% of reports from unregistered users), which could reflect preferences for data sharing. Some citizen science contributors, even repeated contributors, prefer to stay anonymous, but omitting them can result in biased outcomes (Jackson et al. 2018). Underrepresentation of some angler segments (e.g., rural) could also result from differences in how an app is marketed (e.g., advertising vs. word of mouth). Lack of awareness about an app or project is a common barrier to participation (West and Pateman 2016; Crandall et al. 2018). Demographic and behavioural biases (age, gender, technological affinity, commitment to angling, etc.) may also be present in self-reported data (Cooke et al. 2000; Crandall et al. 2018; Gundelund et al. 2020). Gundelund et al. (2020) found that app users were more specialized, and suggested that higher app use by younger anglers could be due to greater technological affinity. However, app reporting could also reduce some biases; for example, reduced recall bias because reports are made in real time (Jiorle et al. 2016). Recall and non-response biases can significantly impact estimates from mail surveys (Connelly et al. 2000). MyCatch did not collect data to investigate biases beyond the spatial distribution of users and their activity. It is difficult to design an app that collects information to evaluate a broad range of biases without impacting participation (Crandall et al. 2018; Gundelund et al. 2020). However, despite these difficulties, sources of biases should be investigated further with follow-up studies and monitoring, as should methods for engaging diverse segments of the angling community.

The utility of an app for fisheries monitoring depends, not only on the recruitment of angler segments, but also on long-term retention. While our study did not investigate retention, it found that more than half of registered users only reported one trip. This finding is likely due, in part, to a recruitment issue, because not all anglers started using the app when it was released, but rather at some point later in the study period. Only 10.3% of respondents to the DFO survey reported 0 or 1 days fished annually, with a median of 8 days per year. However, the DFO survey likely suffered from recall bias which can result in the overestimate of angler effort by as much as 45% (Tarrant et al. 1993; Connelly and Brown 1995; Connelly et al. 2000). Respondents tend to round up when recalling their participation (Tarrant et al. 1993), and there was evidence of this in the DFO reports (i.e., reports of 5, 10, 15, 20, etc., days were outliers with high reporting frequency). It is possible that the relatively lower number of reports from the app could have introduced biases (e.g., seasonal if unique spring fishing trips were missed), but we found generally good agreement between the DFO and app results. In addition, reporting is likely to become more consistent as the angler base using the app gets established.

Our findings of low angling participation could also indicate infrequent fishing or poor retention. Lack of leisure time is an important constraint on fishing participation (Aas 1995; Crandall

et al. 2018). In addition, the vast majority of participants are not retained in most citizen science projects (Venturelli et al. 2017; Parrish et al. 2019). Gundelund et al. (2020) found that 26% of users were retained over the long term (>359 days), and that these users were older and more committed anglers. Many citizen science studies rely on few reports from many individuals to obtain sufficient sample sizes to address the study question (Lewandowski and Specht 2015; Parrish et al. 2019). If less avid anglers are continuously recruited and sample size is maintained, then the broader input from a wider segment of the angler population could be beneficial. The interface and feedback (e.g., catch statistics, project results and updates) that users experience can influence retention (Lewandowski and Specht 2015), and may be particularly important for angler apps because most anglers are using the app to enhance their fishing experience rather than to participate in a scientific study (Venturelli et al. 2017; Crandall et al. 2018). It is important that data reporting is quick and easy (Dickinson et al. 2012; Venturelli et al. 2017; Crandall et al. 2018). Iterative changes to app design and feedback based on input from users could improve recruitment and retention (Dickinson et al. 2012), particularly if it is designed to appeal to less avid users (Gundelund et al. 2020). Longer-term studies are needed that evaluate how user demographics and behaviours change over time, and what worked and what did not for angler recruitment and retention in terms of app design and feedback.

Creel survey-app comparison

Having quality information from a broad spectrum of waterbodies over time could greatly expand the information that is available to fisheries managers. Comparisons of catch composition on the Bow River found there was good agreement between the app and creel survey results, while results for the Oldman River system were less conclusive. Our findings highlight some key considerations when comparing app and creel data. First, species misidentification can bias comparisons. This is a particular concern for the Oldman River system because cutthroat and rainbow trout hybridize (COSEWIC 2016; Sinnatamby et al. 2020). Identifying hybrids can be difficult using morphological characteristics alone (Popowich et al. 2011), and often requires molecular techniques (Allendorf et al. 2001). Hybrid misidentification rates for trained biologists can be between 20% and 50% (e.g., Weigel et al. 2002; Seiler et al. 2009; Meyer et al. 2017), so the ability of untrained anglers to provide accurate information is likely low. Moreover, the option to select hybrids may not be included in the app (e.g., MyCatch).

A second consideration when comparing catch information from larger river systems is the areal coverage of the surveys. Species composition can change over the length of larger river systems. Cold water fishes such as cutthroat and bull trout are limited to the upper reaches of the Bow River and Oldman River system while rainbow trout, which are more tolerant of warmer temperatures, are more common in the middle and lower reaches (Mee et al. 2016). The relatively warmer lower Oldman River also supports cool water species, such as lake sturgeon (*Acipenser fulvescens*). On the Bow River, the creel survey and app likely encompassed similar areas and species, because this is the section where the majority of fishing effort on the river occurs. Based on previous creel surveys (Ripley and Council 2006; Fitzsimmons 2017), the section of the Bow River surveyed by the creel used in our comparisons experiences roughly eight times the effort that a similar-sized upstream area experiences. The lack of cutthroat or bull trout in the app catch reports supports our hypothesis. By contrast, the creel on the Oldman River system focused on the upper reaches. However, MyCatch reports of lake sturgeon in the catch suggest that app anglers were fishing lower reaches of the system as well, which could also explain the larger proportion of rainbow trout in the app catch relative to the creel. The absence of species in a river reach should be considered when evaluating catch composition. While self-reported data are appealing given the logistical difficulties of surveying river systems, our results demonstrate the importance of designing the

app to capture effort on different segments of larger river systems, rather than on the system as a whole. GPS logs of catch location are one option for addressing this issue, although anglers may be reluctant to share specific catch locations. Another option would be to provide a number of river segments for anglers to select from.

Comparisons of catch rates of the dominant species suggest that apps have the potential to provide catch-rate estimates that are similar to conventional creel surveys. One of the major concerns of using self-reported data are that avidity biases resulting in nonrandom participation will influence the quality of the data (Jiorle et al. 2016; Venturelli et al. 2017; Gundelund et al. 2020). For example, Gundelund et al. (2020) found that app users had higher catch rates than non-users. Similar to Jiorle et al. (2016), we found no evidence of a catch rate bias. Moreover, findings from our supplementary analyses indicate that the app may reflect the diversity of the angling community. How anglers accessed the Bow River was important for determining fishing effort and catch rates. Yet, catch rates from pooled creel data were not distinguishable from app catch rates in either river system, suggesting that the app captured a blend of different angler types, or that any biases that were present had negligible effects on catch rate estimates. Biases are common in data from other survey techniques such as mail or telephone surveys, creel surveys, and angler diaries and log books (Pollock et al. 1994; Fisher 1996; Cooke et al. 2000; Barrett et al. 2017), and can be corrected for when documented (Cooke et al. 2000; Pollock et al. 1994; Dickinson et al. 2010; Jiorle et al. 2016).

Gillnet-app comparison

We evaluated the relationships between fisheries-dependent app estimates and fisheries-independent gillnet estimates of catch rate and relative species composition. We found that app catch rates were more strongly related to gillnet catch rates than density estimates, and the relationships were better for walleye than pike. Pike biology and behaviour make them more vulnerable to gillnetting than walleye (Government of Alberta 2020). In addition, despite findings that catch rates from angler logbooks can reveal long-term population trends of pike (e.g., Jansen et al. 2013), the angling catchability of pike can also be highly variable and unrelated to pike density (Pierce and Tomcko 2003). Differences in the angling vulnerability of pike could explain the weaker relationship between app catch rates and FIN estimates for pike. The higher pike catch rates from the limited reports in this study relative to estimates reported by Mogensen et al. (2014) for Alberta lakes suggests that sample size was also an issue. Moreover, the positive intercepts in the app-FIN relationships for both species suggest that there are densities below which angler catch rates are not sensitive to population abundance. Thus, at present sample sizes, the wide confidence intervals in the relationships limit their use for predicting gillnet catch rates, fish density, or the density thresholds that anglers are sensitive to.

We interpreted the positive relationships between app catch rates and gillnet catch rates with caution for two reasons. First, gillnet catch occurs over a small temporal window when the fish population is relatively constant. By contrast, app catch rates are collected over the entire fishing season during which time the fish population is likely not constant (van Poorten et al. 2016). Second, angler catch rates may not be proportional to density due to, for example, environmental conditions (Kuparinen et al. 2010), regional differences (Mogensen et al. 2014), seasonality (van Poorten and Post 2005), fish behaviour (Askey et al. 2006; Kuparinen et al. 2010; Erisman et al. 2011), and angler behaviour and skill (Ward et al. 2013a, 2013b). Different capture efficiencies by anglers can result in hyperstability of catch rates (Ward et al. 2013a; van Poorten et al. 2016), which can have serious consequences for the sustainable management of recreational fisheries (Post et al. 2002; Erisman et al. 2011; Hunt et al. 2011; Post 2013).

Our comparison of fisheries-dependent and -independent catch also found that angling was an ineffective way to monitor the composition of fish communities. This result was expected because anglers tend to target sportfish species of specific sizes (Beardmore et al. 2011) by utilizing gears that are effective at capturing that species or size (Arlinghaus et al. 2008) and concentrating their effort in locations where fish aggregate (Matthias et al. 2014; Arlinghaus et al. 2017b). Gillnets are also size-selective (Askey et al. 2007b; Hubert et al. 2012), but designed and deployed to capture a broader range of size classes, and are more likely to capture non-sportfish species (Hubert et al. 2012). Given the more selective nature of angling relative to gillnets, it is not surprising that the species distribution from the app is dominated by the most popular sportfish species in the province, while less targeted species like yellow perch and lake whitefish were less likely to be reported by anglers, even if they were relatively abundant.

Limitations

Despite promising results from this study, there are some limitations that should be highlighted. Sample sizes from the app at the waterbody-level were relatively low; with only 3.7% of the waterbodies having ≥ 30 trip reports. Although an app is likely to provide quality and frequent data for the most popular waterbodies, small sample sizes will limit the ability for an app to expand the information that is available for a large range of waterbodies, and a diverse range of less dominant species. In addition, limited sample sizes result in more uncertainty when trying to inform the relationships between apps and other conventional estimates. A single report for a lake may not be representative, and could bias models. More data are required to determine if biases such as density-dependent catchability are of concern. Small sample sizes also limit the ability of the app to provide information over finer time scales (e.g., over a fishing season), because further partitioning of the data would result in even smaller sample sizes. To address sample size issues, spatial and temporal extent and resolution of analyses should be limited as appropriate, and increased app use should be encouraged through marketing, outreach, design, and incentives.

A second limitation of the app was its inability to provide estimates for fishing effort beyond relative participation. Unlike creel surveys, there is no instantaneous count of angler effort. App users could be asked to report angler counts, but it is unclear if they would be willing to participate, or to know what portion of the waterbody the angler count applies to (i.e., is visible to the user) (van Poorten et al. 2015). An alternative solution is to develop predictive relationships between app reports and other conventional effort surveys (e.g., creel estimates). For example, Martin et al. (2014) found that the number of posts to online social networks was highly correlated with fishing effort estimates for reservoirs and regions. Papenfuss et al. (2015) also found a positive relationship between the frequency of app reports and creel estimates of summer effort based on 36 lakes in Alberta. However, the number of creels surveys conducted in any given year may be low. Thus, relationships must be developed from creel estimates from multiple years. For example, Papenfuss et al. (2015) pooled data over a 17-year period. Moreover, such an approach requires the assumption that effort was constant among years, which may not be valid (Hartill et al. 2020).

A final limitation of the app was its ability to collect information on angler demographics, motivations, preferences, and behaviour. One solution is to request (but not require) desired information when users create an account, although questions should be limited to prevent respondent fatigue (Gundelund et al. 2020), and repeat at some interval given potential changes in anglers' preferences and motivations over time. Response fatigue is also a concern when users log trips (Crandall et al. 2018). Making fields such as harvest, fish size, gear used, and access method optional is one solution, but could introduce biases if

used by a nonrandom segment of anglers. Specialized add-ons to apps that are limited to particular user groups may allow for the collection of data that are required for specific studies. Repeated app use by individual anglers may also address some of these limitations by collecting data which can be used to evaluate angler movements (e.g., Papenfuss et al. 2015), and potentially identify different angler segments based on their characteristics. For example, Ward et al. (2013b) used distance travelled, harvest rates, and catchability to identify four angler segments in a region of British Columbia, Canada. While understanding the diversity in angler populations is important for management (Johnston et al. 2013; Ward et al. 2013b), mining app or other social media data to conduct research that users may not have explicitly agreed to does raise ethical concerns (Monkman et al. 2018). Ultimately, how the data are utilized will determine what information must be collected, and app designers and scientists must carefully consider what additional information might be of value and whether ethical standards are addressed.

Conclusions

Our study contributes to growing evidence that apps can be complementary tools that provide fisheries data to enhance and broaden the information that is available from conventional fisheries surveys that is of comparable quality. Combining survey techniques takes advantage of differences in techniques to reduce error and improve estimates (Pollock et al. 1994; Smallwood et al. 2012; Barrett et al. 2017). However, the app was unable to capture fish population metrics such as abundance and species composition that were reported by fisheries-independent surveys. The contributions that apps can make to fisheries management and monitoring will depend on the questions being asked, but the more studies that show that apps can provide data that is comparable to the data provided by conventional surveys will help to address concerns about using apps as a fisheries-data collection tool. Although concerns about biases and sample size limitations need to be addressed, angler self-reporting can provide data that are otherwise impossible to collect due to logistic and budgetary constraints (Smallwood et al. 2012; Hartill et al. 2020). There is interest in using apps to collect fishery- and angler-specific data simultaneously across waterbodies, regions and temporal strata (Venturelli et al. 2017). By providing information on a broad spectrum of waterbodies over time, this tool could be used to fill knowledge gaps on data-deficient systems, such as lotic systems and low effort fisheries (Cooke et al. 2000). Apps can be used to detect the presence and spread of invasive species and disease (Papenfuss et al. 2015), and might also detect range expansion or contraction in response to environmental change, such as climate change. By identifying areas of concern, apps allow for a more efficient and targeted allocation of resources. For example, the app could identify high-pressure fisheries of fishing pressure on vulnerable population that require monitoring and (or) more restrictive regulations. Finally, information collected through the app about anglers could help to better understand the human dimensions side of fisheries. This information could be used to improve the fishing experiences of anglers. Engaging anglers could also help them to feel more connected to the resource and involved in the management process, strengthening relationships between fisheries biologists and the angling public (Granek et al. 2008). Ultimately, the tools that are used to survey populations will depend on management objectives, logistics, and budgetary constraints (Smallwood et al. 2012; Hartill et al. 2020). However, having a better understanding of where anglers originate, how they distribute on the landscape, and the species and number of fish that they catch will contribute to the long-term sustainability of recreational fisheries.

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