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Commentary

Great Lakes Fish Finder App; a tool for biologists, managers and education practitioners

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ABSTRACT

As technology advances and smartphone use continues to rise, so do the opportunities for community members to collect valuable scientific data via their smart phones. While the iNaturalist project and phone application (app) are widely known and used, only a fraction (<1.5%) of the >26 million observations logged to date represent fishes. To increase georeferenced observational data on fishes, the John G. Shedd Aquarium announces the Great Lakes Fish Finder (GLFF) phone application and iNaturalist project. The GLFF app contains helpful identification tips in its field guide and allows community-sourced species identification through iNaturalist.org. The georeferenced observations are open-source data allowing anyone to employ GLFF as a data collection tool and repository for their projects. We see the GLFF app as a mechanism for public engagement (anglers and the general community), that contributes useful data for researchers and resources managers, as well as a tool for educators. Ultimately, we envision the GLFF app as a tool for freshwater biodiversity conservation via public engagement.

Introduction

Engaging community members to collect scientific data, commonly known as citizen science, has a long history, particularly in the environmental realm (see: Butcher et al., 1990; Cohn, 2008; Conrad and Hilchey, 2011). As technology advances, data collected for these projects have moved from paper records, to online platforms, and lately to phone-based applications (apps). Recent estimates indicate that 77% of Americans own smartphones, capable of collecting photos, georeferencing observations, and interfacing with online repositories (http://www.pewinternet.org/fact-sheet/mobile/). The wide geographic range attainable when smartphones are tied to citizen projects has motivated the development and use of apps to record data and engage the general public in research endeavors (Newman et al., 2012).

App-based citizen science projects, such as iNaturalist, eBird, and eButterfly empower community members to collect data for biodiversity monitoring. Citizens upload information through apps, including images, GPS coordinates, and species identifications that are stored in open-access online databases. Focusing on bird species, eBird has offered important insights into species migrations (Hurlbert and Liang, 2012; Walker and Taylor, 2017), population increases (Clark, 2017), species diversity metrics of urban areas (Gutiérrez-Tapia et al., 2018), and even behavior analyses of the birders themselves (Kolstoe and Cameron, 2017). Similarly, range expansions and shifts in timing of migrations have been noted through eButterfly (Soroye et al., 2018).

While data generated through the iNaturalist platform have not been as widely utilized by the scientific community to offer a diversity of insights on species (but see: Happel, 2019; Moore et al., 2019), the wealth of data that citizens have collected represents one of, if not the largest documentations of species encounters. As of 30 September 2019, citizens on iNaturalist have logged over 26 million observations on more than 238,000 different species representing a variety of taxa (Fig. 1). Of these observations, plant and invertebrate observations make up the bulk of logged data at 41.2% and 25.8%, respectively. Fishes are the least represented group with 1.2% of observations, the top three species reported include the widely distributed bluegill (*Lepomis macrochirus* 4746 observations), largemouth bass (*Micropterus salmoides* 4502 observations), and common carp (*Cyprinus carpio* 2676 observations). The lack of reported fish sightings within the iNaturalist platform may exist because of barriers to observation (e.g., freshwater fishes habitats vary in access and turbidity), difficulty with identification, and engagement challenges of the public (see: Cooke et al., 2013). To this end, we report on our efforts to increase data available on fishes observed in the Laurentian Great Lakes (hereafter referred to as the Great Lakes) and surrounding tributaries using John G. Shedd Aquarium's Great Lakes Fish Finder

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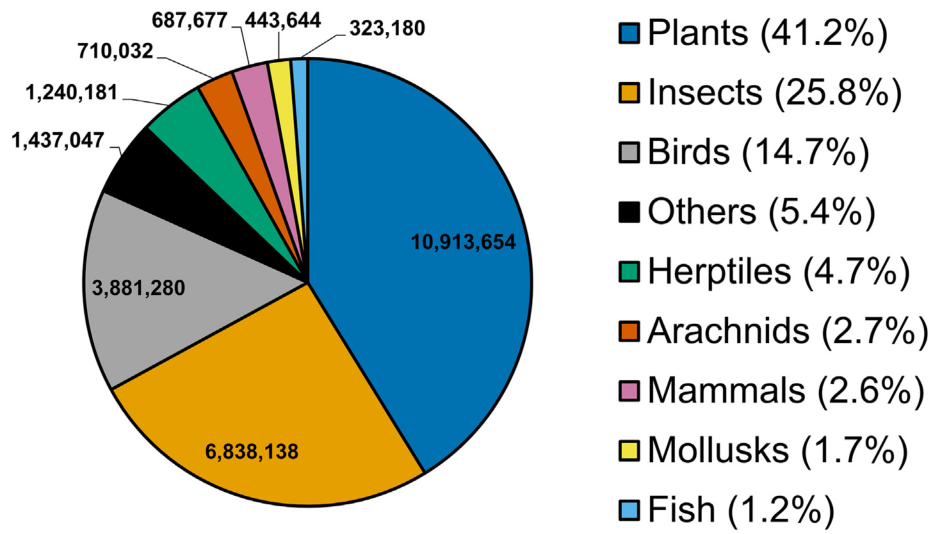

Fig. 1. Number of observations logged on the iNaturalist platform by taxa up through September 2019. Fishes account for only 1.2% of data, thus presenting an opportunity for promotion via the Great Lakes Fish Finder app. Legend, and slices, ranked in order of decreasing observation count (slices clockwise).

(GLFF) app (Fig. 2), which represents a project nested within the iNaturalist platform.

The John G. Shedd Aquarium is expanding creative opportunities to bridge the divide between the public and fishery scientists (see: Murchie et al., 2018), including the launch of the GLFF app, which is a mechanism for data collection and outreach that has potential to serve both communities in dynamic ways. With a population of around 95 million people, the states and provinces surrounding the Great Lakes region contain a wealth of potential citizen scientists. Additionally, approximately 1.8 million people fish the Great Lakes each year, whether residents or visitors to the surrounding states and provinces (U.S. Census Bureau, 2018). The Great Lakes themselves represent the largest connected surface area of flowing freshwaters globally (244,000 km^2), containing approximately 21% of the world's freshwaters, with catchment of nearly 1 million km^2 (Wang et al., 2015). This large area consists of a patchwork of wetlands, rivers, lakes, forests, agriculture and urban uses, creating a complex network of habitats, that houses over 142 fish species (Bailey and Smith, 2008; Cudmore-Vokey and Crossman, 2000). The large population of potential observers combined with the large variety of habitats offers a unique opportunity to collect data that no single agency or institution could match in geographic and/or taxonomic scope.

We also see GLFF as a mechanism to spark curiosity in the Great Lakes community for fishes of the region, an educational resource for those seeking information on fish and their identification, and a scientific tool offering open access data on species presence. Through the "Guide to Great Lakes Fishes", users can browse profiles and facts about species common to the Great Lakes basin and obtain helpful hints for identifying them. We envision visitors to various public aquaria within the Great Lakes region, being able to use the interactive field guide as a tool to enhance local knowledge to themselves and their children pre- or post-visit. The integration of GLFF within iNaturalist provides both computer assisted species identification along with crowdsourced species identification, fostering a community of Great Lakes fish identi-

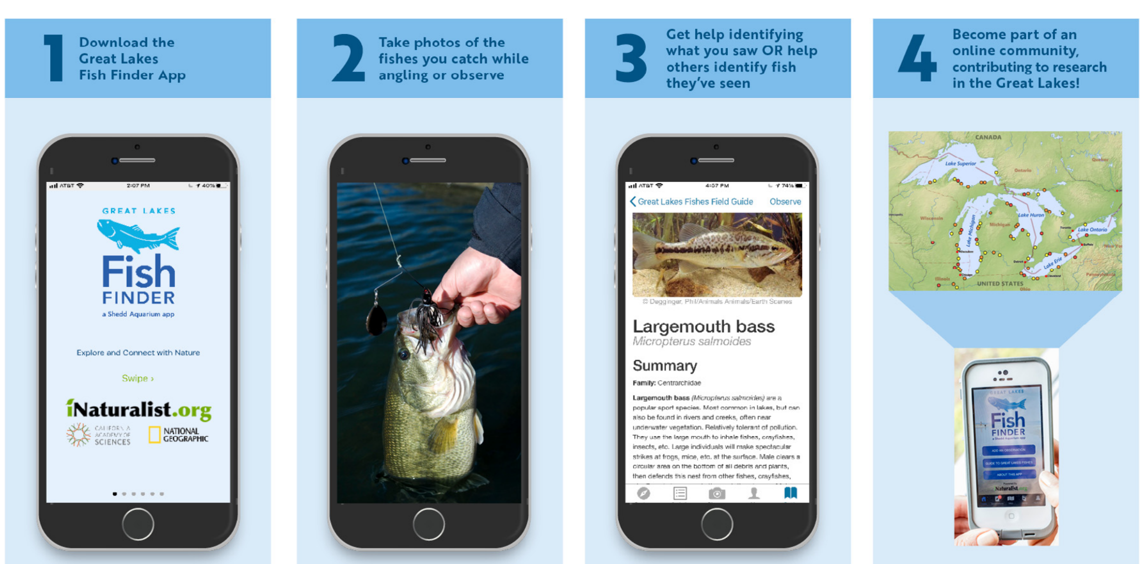

Fig. 2. The Shedd Aquarium Great Lakes Fish Finder (GLFF) project page is nested within the iNaturalist platform page. Users can download the GLFF app from iTunes or Google Play on their smartphone.

Table 1
Example data fields that are recorded for each observation and available for download from iNaturalist's open-access database.

Column name	Description
id	Observation Number on iNaturalist
observed_on	Date of observation
time_observed_at	Time of observation
user_login	Username of observer
created_at	When the observation was Entered, may be different than "observed_on"
quality_grade	Quality Grade: "Research grade" observations have Date, Species ID, Geotag, Is not Captive, and has photos. "Needs ID" is a pre-research grade stage where community members must view the observation and confirm its quality. "Casual observations" have been flagged is potentially non-research grade by community members
license	Photo license chosen by the user
url	Direct web address of the observation
image_url	Direct web address of the first photo
sound_url	Direct web address of the first sound file if included
tag_list	List of tags, similar to using a "#", used in iNaturalist for categorizing
description	Any comments added by the observer
num_identification_agreements	Number of community members that agree on the species
captive_cultivated	Is the observed individual a captive animal
place_guess	Location information as entered by user
latitude	GPS Latitude of the observation
longitude	GPS Longitude of the observation
positional_accuracy	Accuracy as determined by the device used to record observation or the level of precision indicated by manual "zoom" when entering observation through website's map feature
geoprivacy	Classified as either: Open, Obscured, or Private
taxon_geoprivacy	Location of endangered or highly sought organisms may be hidden
species_guess	Name entered by the observer
scientific_name	Scientific name of the taxon in the observation as agreed by the community
common_name	Common name of the taxon in the observation as agreed by the community

fiers. When users upload an observation, the image and identification are georeferenced thus allowing data to be mined for scientific inquiry (Table 1).

Herein, we highlight the immense research and engagement potential with a widescale promotion and adoption of the GLFF app by fisheries biologists and managers, along with anglers, educators, and the general public. We identify where data collection is limited and where concerns of geo-referencing of observations may exist and conclude with additional benefits of citizen engagement in nature-based activities.

Potential research avenues

Data hosted by iNaturalist, and supplied through the GLFF app, are open access and available to any user via iNaturlist.org. A username is required to download the data which can be filtered to a specific region, date range, species, user, or combination of factors. Data are received in .csv format and thus easily manipulated in various programs (i.e., Excel, R, SAS). Opportunities abound for research questions via the iNaturalist platform. For example, Mathew et al. (2014) examined the iNaturalist database for amphibian observations and correlated sightings with water quality parameters collected from across the state of New York. In another example, the prevalence of symptoms of black spot disease in iNaturalist photos was mapped, finding a geographic pattern where fish appear to exhibit symptoms more frequently (Happel, 2019). Because the GLFF app is intended to address in part the relative deficiency of fish observations in the larger iNaturalist platform, we highlight to the scientific community possible research opportunities offered by using data gleaned from the GLFF application.

Species distributions

Fish observations in the GLFF app are geotagged and timestamped, which facilitates the ability to update species distribution maps and to construct "real-time" distribution models. For example, geotagged photographs of bumblebees submitted by Japanese citizens were combined with environmental factors, which led to an updated series of species distribution models for Japan (Suzuki-Ohno et al., 2017). The GLFF app could aid in fish distribution models by increasing the geographic and habitat scope of fish surveys that may be overlooked by state and federal agencies. For example, recent work in northern Illinois documented the regionally threatened iowa darter (*Etheostoma exile*) in ephemeral or headwater ditches, which are areas not sampled by standardized surveys (Sherwood et al., 2018). Sampling was primarily conducted with a kick seine, a task easily replicated by citizen scientists (with associated collection/sampling permits) who could then upload photos of their findings. With the aid of citizen science observations, GLFF could expand similar survey work throughout the Great Lakes region and for other fish species.

To illustrate a proof-of-concept of how iNaturalist observational data already visually correlates with known species ranges, we pulled observations on smallmouth bass (*Micropterus dolomieu*) and rainbow trout (*Oncorhyncus mykiss*) and compared them with published distribution maps readily available from the USGS website (Fig. 3). In smallmouth bass, the southern range for this traditionally warmwater species is nearly identically on both the USGS range map and the iNaturalist observational map. Similarly, the observational range of rainbow trout mirrors closely with their published natural range on the West coast, but also illustrates where the species is observed in mountainous regions when it is heavily stocked for recreational fishing (the east slope of the Rockies and throughout the Appalachians).

Migratory fish data

Species migrations have long captivated researchers and casual observers alike. For researchers, gathering information on the timing of migrations across wide geographic scales is enhanced by citizen-science participation. For example, citizen-derived data on birds through eBird have led to valuable insights on species migrations and how they are influenced by climate (Hurlbert and Liang, 2012). Similarly, Soroye et al. (2018) used citizen-derived observational data of butterflies (eButterfly) to document earlier than expected migratory flights for 6 of 10 species investigated.

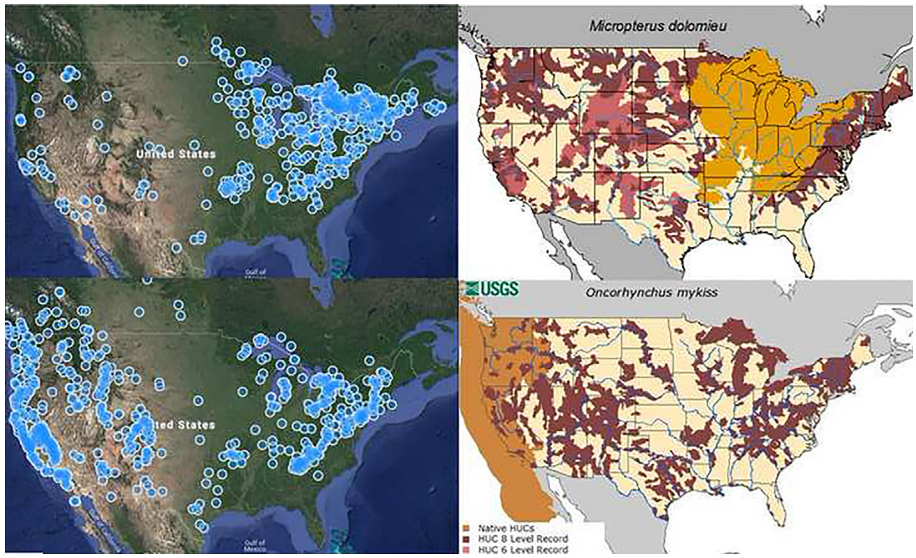

Fig. 3. The geographic range of smallmouth bass (upper row) and rainbow trout (lower row) observations reported on iNaturalist mirrors ranges indicated by USGS for the species. Species range maps (images on right) created by and obtained from the USGS Nonindigenous Aquatic Species (NAS) database and website.

While data on fish movements within the Great Lakes basin have primarily been limited to sport fish to date (Landsman et al., 2011), this can be expanded upon using the GLFF app. For example, migratory fishes that exhibit unique behaviors, such as attempting to leap barriers, aggregating at known sites, or easily visible in clear tributaries or shallow wetlands, are candidates for documentation via the GLFF app. While the observational data provide a geographical location and date-stamp, researchers could source environmental data from other sources (e.g., USGS gauging stations on large tributaries) to link water temperature and water flow to migration phenology. Data could also be used to examine fish community assemblages during migration, or the overlap of larval aquatic insect hatches (which can also be documented via the iNaturalist platform).

Sentinel for invasive species

Early detection of invasive species and the ability to monitor subsequent range expansions, are critical to making informed management decisions about control or policy. Detections of new fishes by community members have become a popular means of identifying encounters with non-native species (Roy et al., 2015). Whether warnings are obtained through phone calls, online forums, or now app records, scientists can now monitor new occurrences of species (Banha et al., 2015) and the spread of their populations (Parrondo et al., 2018). For example, citizen-derived observations of the invasive lionfish (*Pterois* spp.) enables time-lapse distribution maps (animation available at: https://nas.er.usgs.gov/queries/FactSheets/LionfishAnimation.aspx) and real-time point distribution maps (https://nas.er.usgs.gov/viewer/omap.aspx?SpeciesID=963) for the Caribbean and Western Atlantic.

Within the Great Lakes region, round gobies (*Neogobius melanostomus*) were first reported by an angler in the Saint Claire River and have spread quickly among the lakes, expanding their range through adjoining tributaries (Jude et al., 1995). Observations on iNaturalist currently illustrate their known spread north through the Saint Lawrence Seaway (Reyjol et al., 2010) and south through the Illinois River (Merry et al., 2018) adjoining the Mississippi (https://nas.er.usgs.gov/viewer/omap.aspx?SpeciesID=713), but also suggest an emerging range expansion down the Cuyahoga River (Fig. 4). The potential for round goby to spread throughout the Mississippi River basin presents a unique opportunity to engage the general public in invasive species monitoring by using GLFF to interact with users via comment and forum sections online, encourage users to upload observations, educate first-time observers about the invasive characteristics of this species, and update others on new research findings (see supplementary materials).

Georeferencing concerns

While there are risks associated with revealing locations of endangered animal species because it makes them vulnerable to poachers for the illicit wildlife trade (Lindenmayer and Scheele, 2017), these issues appear to be less of a concern for fish species. Instead we acknowledge that location security may be a limiting factor for select users of GLFF. Anglers may not want to reveal their prime fishing site, hindering enrollment in projects that rely on georeferenced observations (McCluskey and Lewison, 2008). GLFF and iNaturalist, however, provide the option for users to completely or partially obscure where they caught a fish (https://www.inaturalist.org/pages/help#geoprivacy). The locality data are still recorded in the app program, but only project team leaders can see and access the georeferenced locations. As such, anglers can fully participate in submitting data while maintaining the privacy of their fishing sites.

Location accuracy

Accuracy of GPS coordinates is dependent on several factors including method of input (manually through the website, or automatically through the app), device, and weather (USDA and USFS, 2019). Further, location accuracy of phone app collected data depends on if the internal GPS is turned on, as well as cell phone triangulation. Relying on triangulation of cell phone towers is thought to reduce the geographic accuracy of observations, especially in areas lacking good reception. After a photo is taken for an observation, users can monitor estimates of location accuracy (while the user is standing stationary) until the estimate stabilizes, prior to saving the observation. The longer a user is in a single location the more accurate the GPS coordinates. In low reception areas, users can create observations with their GPS on and later upload the photos using wifi connections allowing increased accuracy.

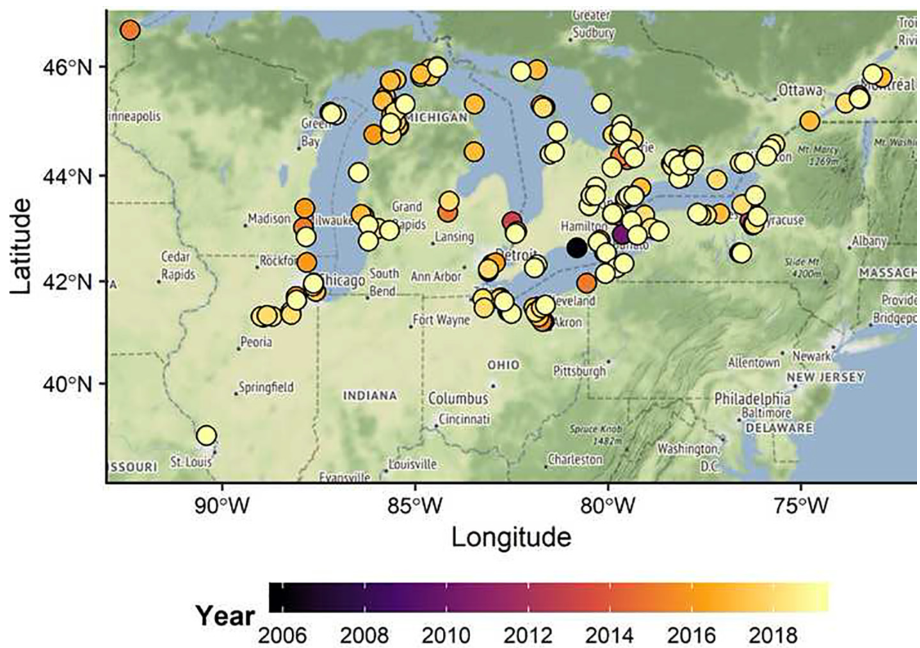

Fig 4. Observations of round goby submitted through the iNaturalist platform (through September 2019) document their spread north through the Saint Lawrence Seaway and south through both the Illinois and Cuyahoga Rivers.

Users are also able to upload photos of organisms they have taken through normal camera functions (non iNaturalist or GLFF camera modes). In such cases, users can locate, as best they can, were they took the photo, by scrolling and zooming on the map when uploading an observation to the website. Alternatively, users can use the metadata stored when smartphones take photos to obtain location information. In such cases, the accuracy recorded is dependent on how far users "zoom in" on a spot in the map when uploading but is also dependent on user's memory of the location.

Data limitations

Unfortunately, neither GLFF nor iNaturalist serve as efficient means of collecting data beyond location, date/time, and species identification. Although length data are the backbone of fisheries management and associated analyses, there are several issues related to trying to collect such information using apps. For one, iNaturalist's database is unable to efficiently record and store such information at the moment. Technically, users can enter size metrics for their catches within the description section when uploading an observation. However, lack of standardized measuring protocols and measuring equipment would infuse multiple types of biases into the dataset. More importantly, and more difficult to control, is the lack of certainty with repeat captures of individuals. Heavily-fished bodies of water may result in the same individual fish caught and photographed multiple times, resulting in skewed length-frequency data.

There may be statistical solutions for potential length-frequency bias depending on the question. If so, we suggest that if anglers are retaining their catches, images should be taken next to a fish board or other object of known length. Fish lengths could then be calculated using image software such as imageJ, which has been successful in other studies (White et al., 2006).

Benefits beyond research

Interactions with wildlife and increased awareness of biodiversity through direct contact increases feelings of personal well-being (Dallimer et al., 2012; Richardson et al., 2016). Indeed, a recent meta-analysis of 32 controlled studies, including over 2000 participants, indicated that contact with nature can increase a person's positive affectivity (i.e., mind and body wellness) and potentially even decreases negative affectivity (McMahan and Estes, 2015). With increasing urbanization and subsequent reduction in value and feelings of connectedness to nature, apps that encourage the exploration of wild places provide psychological benefits (Fuller and Gaston, 2009). As such, GLFF can encourage those seeking opportunities to get outdoors, explore waterbodies, and participate in a meaningful project that not only aids science but enhances their personal well-being.

A call to action

Anglers

As stated previously, an estimated 1.8 million anglers fish the Great Lakes, resulting in approximately 13.4 million annual fishing days (U.S. Census Bureau, 2018). This degree of effort cannot be matched by government, university, and non-profit fish surveys. Great Lakes anglers serve as ideal early adopters of the GLFF app. For every biologist, there are hundreds of anglers and their collective knowledge of species identification and distribution can contribute to the observational database, aide in the identification of other catches, and promote an overall sense of community for the project. The birding community is a great example of how non-consumptive resource users can provide data useful to biologists. For example, the recent analysis of bird populations combing citizen science programs and scientific monitoring projects depicted a drastic decline in bird populations since the 1970's (Rosenberg et al., 2019). We seek to promote data collection and cooperation through the promotion of GLFF toward fostering a similar community of fish observers.

Creel surveys represent a routine and standard means of collecting angler catch data, however such programs require clerks (i.e., cost money) and miss many locations and anglers. For example, a rather large microfishing community (anglers whom target small-bodied fishes) exists which has >4000 users subscribed to r/Microfishing on reddit, and another >1100 subscribers to the Micro-Fishing facebook group. Such anglers could provide information on often understudied and thus underappreciated fishes. As microfishers target small-bodied fishes, which are often abundant and could have higher catch rates, there is a great potential to garner data on species that would be overlooked by traditional game-fish surveys and creel surveys. The large number of anglers outweighs the field capabilities of the comparatively sparse resource managers, biologists, and technicians, and thus GLFF may provide larger temporal and spatial scope for many fish species than traditional scientific surveys.

Educators

A main benefit of both GLFF and iNaturalist is the crowdsourced identification of organisms. This requires including species guides to overcome difficulty in identifying fishes which may be a strong deterrent to creating and implementing a field-based lab exercise. A teacher with limited taxonomic knowledge can use the app to confidently identify fish while in the field with students. Hopefully this app aids educators and expands opportunities for outdoor class experiences that foster an understanding of aquatic life, aids identification of unknown fish species, and contributes to meaningful research.

Potential research questions that teachers can explore with students using the GLFF include 1) what species are found in fast-flowing versus slow-flowing sections of a stream, 2) does the assemblage of fishes differ in sunny versus shaded stretches of a stream, 3) are fish assemblages different in urbanized versus forested stretches of a stream, or 4) does the fish assemblage change following remediation, habitat rehabilitation and enhancement, or dam removal. Students can be tasked with identifying species using the guide or to look for species with similar functional traits. We encourage these lines of inquiry from aquatic professionals when looking for outreach events and from educators when exploring activities that expose students to the natural world.

Fish researchers, biologists, and managers

Research biologists and managers are well aware of the time and effort required to conduct widescale surveys of fish communities. The potential to collect vast amounts of georeferenced data from anglers is unprecedented and could be used to answer questions about the most prominent species caught by anglers by season, areas fished most often, distribution of sport fish, etc. The open-source nature of the database means that local biologists can encourage the use of the app in return for free data collection and storage mechanisms.

Maintaining engagement

Surveys of citizen scientists illustrate that the opportunity to contribute to conservation and scientific research acts as a strong motivator for enrolling as a volunteer in citizen science programs (Campbell and Smith, 2006). Observational data from eBird has led to at least 159 documented tangible conservation actions, summarized by Sullivan et al. (2017). For example, spatial coverage of eBird data exceeded standardized locations U.S. Fish and Wildlife surveyed, which provided crucial data to support the listing of the rufa red knot (*Calidris canutus rufa*) as a threatened species (Fish and Wildlife Service, Interior, Federal Register Vol. 79, No. 238). Such actions validate citizens' efforts, and similar outputs in aquatic habitats would aide in maintaining engagement. Further, volunteer retention in biological surveys increases when users are updated regularly on data collected, and how it is being used (Lewandowski and Specht, 2015). As GLFF is maintained by Shedd Aquarium, research staff will monitor and answer user questions about observations while also producing annual reports on species, research progress, and unusual or exciting observations to bolster both enrollment and retention.

Conclusions

As freshwater biodiversity continues to decline (Reid et al., 2019), public engagement in aquatic resource protection is paramount. The GLFF app is a free tool accessible to anyone with a smartphone and has potential to engage the public in a meaningful way to be connected to the fish community of the Great Lakes region while providing useful data to the scientific community and resource managers. As such, we encourage academics, resource managers, researchers, educators, and non-governmental organizations to promote and celebrate the use of the app within the Great Lakes region to maximize the utility of the collected data. We also recommend promoting success stories where citizen-led efforts contribute useful data in supporting an understanding of our local aquatic resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jglr.2019.12.002.

References

Bailey, R.M., Smith, G.R., 2008. Origin and geography of the fish fauna of the Laurentian Great Lakes Basin. Can. J. Fish. Aquat. Sci. 38, 1539–1561. https://doi.org/10.1139/f81-206.

Banha, F., Ilhéu, M., Anastácio, P.M., 2015. Angling web forums as an additional tool for detection of new fish introductions: the first record of *Perca fluviatilis* in continental Portugal. Knowl. Manag. Aquat. Ecosyst. 03. https://doi.org/10.1051/kmae/2014039.

Butcher, G.S., Fuller, M.R., McAllister, L.S., Geissler, P.H., 1990. An evaluation of the Christmas bird count for monitoring population trends of selected species. Wildl. Soc. Bull. 18, 129–134.

Campbell, L.M., Smith, C., 2006. What makes them pay? Values of volunteer tourists working for sea turtle conservation. Environ. Manage. 38, 84–98. https://doi.org/10.1007/s00267-005-0188-0.

Clark, C.J., 2017. eBird records show substantial growth of the Allen's Hummingbird (*Selasphorus sasin sedentarius*) population in urban Southern California. Condor 119, 122–130. https://doi.org/10.1650/condor-16-153.1.

Cohn, J.P., 2008. Citizen Science: can volunteers do real research?. Bioscience 58, 192–197. https://doi.org/10.1641/B580303.

Conrad, C.C., Hilchey, K.G., 2011. A review of citizen science and community-based environmental monitoring: issues and opportunities. Environ. Monit. Assess. 176, 273–291. https://doi.org/10.1007/s10661-010-1582-5.

Cooke, S.J., Lapointe, N.W.R., Martins, E.G., Thiem, J.D., Raby, G.D., Taylor, M.K., Beard Jr, T.D., Cowx, I.G., 2013. Failure to engage the public in issues related to inland

fishes and fisheries: strategies for building public and political will to promote meaningful conservation. J. Fish Biol. 83, 997–1018.
Cudmore-Vokey, B., Crossman, E.J., 2000. Checklists of the fish fauna of the Laurentian Great Lakes and their connecting channels. Can. Manuscr. Rep. Fish. Aquat. Sci. 2550, v+39p.
Dallimer, M., Irvine, K.N., Skinner, A.M.J., Davies, Z.G., Rouquette, J.R., Maltby, L.L., Warren, P.H., Armsworth, P.R., Gaston, K.J., 2012. Biodiversity and the Feel-Good Factor: understanding associations between self-reported human well-being and species richness. Bioscience 62, 47–55. https://doi.org/10.1525/bio.2012.62.1.9.
Fuller, R.A., Gaston, K.J., 2009. The scaling of green space coverage in European cities. Biol. Lett. 5, 352–355.
Gutiérrez-Tapia, P., Azócar, M.I., Castro, S.A., 2018. A citizen-based platform reveals the distribution of functional groups inside a large city from the Southern Hemisphere: e-Bird and the urban birds of Santiago (Central Chile). Rev. Chil. Hist. Nat. 91, 3.
Happel, A., 2019. A volunteer-populated online database provides evidence for a geographic pattern in symptoms of black spot infections. Int. J. Parasitol. Parasites Wildl. 10, 156–163. https://doi.org/10.1016/J.IJPPAW.2019.08.003.
Hurlbert, A.H., Liang, Z., 2012. Spatiotemporal variation in avian migration phenology: citizen science reveals effects of climate change. PLoS One 7, e31662.
Jude, D.J., Janssen, J., Crawford, G., 1995. Ecology, distribution, and impact of the newly introduced round and tubenose gobies on the biota of the St. Clair and Detroit Rivers, in: Munawar Edsall, T., and Leach, J, M. (Ed.), The Lake Huron Ecosystem: Ecology, Fisheries and Management. SPB Academic Publishing, Amsterdam, The Netherlands, pp. 447–460.
Kolstoe, S., Cameron, T.A., 2017. The non-market value of birding sites and the marginal value of additional species: biodiversity in a random utility model of site choice by eBird members. Ecol. Econ. 137, 1–12.
Lewandowski, E., Specht, H., 2015. Influence of volunteer and project characteristics on data quality of biological surveys. Conserv. Biol. 29, 713–723.
Lindenmayer, D., Scheele, B., 2017. Do not publish. Science (80-) 356, 800–801. doi: 10.1126/science.aan1362.
Landsman, S.J., Nguyen, V.M., Gutowsky, L.F.G., Gobin, J., Cook, K.V., Binder, T.R., Lower, N., McLaughlin, R.L., Cooke, S.J., 2011. "Fish movement and migration studies in the Laurentian Great Lakes: research trends and knowledge gaps.". Journal of Great Lakes Research 37 (2), 365–379.
Mathew, S., Barshy, B., Hobday, D., 2014. The basic truth: how pH level affect amphibian abundance. Retrieved from web Novemb. 10, 2017.
McCluskey, S.M., Lewison, R.L., 2008. Quantifying fishing effort: a synthesis of current methods and their applications. Fish Fish. https://doi.org/10.1111/j.1467-2979.2008.00283.x.
McMahan, E.A., Estes, D., 2015. The effect of contact with natural environments on positive and negative affect: a meta-analysis. J. Posit. Psychol. 10, 507–519. https://doi.org/10.1080/17439760.2014.994224.
Merry, J.L., Fritts, M.W., Bloomfield, N.C., Credico, J., 2018. Invasive Round Goby (*Neogobius melanostomus*) nearing the Mississippi River. Am. Midl. Nat. 180, 290–298.
Moore, M.P., Lis, C., Gherghel, I., Martin, R.A., 2019. Temperature shapes the costs, benefits and geographic diversification of sexual coloration in a dragonfly. Ecol. Lett. 22, 437–446. https://doi.org/10.1111/ele.13200.
Murchie, K.J., Knapp, C.R., McIntyre, P.B., 2018. Advancing freshwater biodiversity conservation by collaborating with public aquaria: making the most of an engaged audience and trusted arena. Fisheries 43, 172–178.
Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S., Crowston, K., 2012. The future of citizen science: emerging technologies and shifting paradigms. Front. Ecol. Environ. 10, 298–304. https://doi.org/10.1890/110294.
Parrondo, M., Clusa, L., Mauvisseau, Q., Borrell, Y.J., 2018. Citizen warnings and post checkout molecular confirmations using eDNA as a combined strategy for updating invasive species distributions. J. Nat. Conserv. 43, 95–103. https://doi.org/10.1016/J.JNC.2018.02.006.
Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T.J., Kidd, K.A., MacCormack, T.J., Olden, J.D., Ormerod, S.J., 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biol. Rev. 94, 849–873.
Reyjol, Y., Brodeur, P., Mailhot, Y., Mingelbier, M., Dumont, P., 2010. Do native predators feed on non-native prey? The case of round goby in a fluvial piscivorous fish assemblage. J. Great Lakes Res. 36, 618–624. https://doi.org/10.1016/J.JGLR.2010.09.006.
Richardson, M., Cormack, A., McRobert, L., Underhill, R., 2016. 30 days wild: development and evaluation of a large-scale nature engagement campaign to improve well-being. PLoS One 11,. https://doi.org/10.1371/journal.pone.0149777 e0149777.
Rosenberg, K.V., Dokter, A.M., Blancher, P.J., Sauer, J.R., Smith, A.C., Smith, P.A., Stanton, J.C., Panjabi, A., Helft, L., Parr, M., Marra, P.P., 2019. Decline of the North American avifauna. Science (80-) 366, 120–124. https://doi.org/10.1126/science.aaw1313.
Roy, H.E., Rorke, S.L., Beckmann, B., Booy, O., Botham, M.S., Brown, P.M.J., Harrower, C., Noble, D., Sewell, J., Walker, K., 2015. The contribution of volunteer recorders to our understanding of biological invasions. Biol. J. Linn. Soc. 115, 678–689. https://doi.org/10.1111/bij.12518.
Sherwood, J.L., Stites, A.J., Dreslik, M.J., Tiemann, J.S., 2018. Predicting the range of a regionally threatened, benthic fish using species distribution models and field surveys. J. Fish Biol. 93, 972–977. https://doi.org/10.1111/jfb.13819.
Soroye, P., Ahmed, N., Kerr, J.T., 2018. Opportunistic citizen science data transform understanding of species distributions, phenology, and diversity gradients for global change research. Glob. Chang. Biol. 24, 5281–5291. https://doi.org/10.1111/gcb.14358.
Sullivan, B.L., Phillips, T., Dayer, A.A., Wood, C.L., Farnsworth, A., Iliff, M.J., Davies, I.J., Wiggins, A., Fink, D., Hochachka, W.M., Rodewald, A.D., Rosenberg, K.V., Bonney, R., Kelling, S., 2017. Using open access observational data for conservation action: a case study for birds. Biol. Conserv. 208, 5–14. https://doi.org/10.1016/J.BIOCON.2016.04.031.
Suzuki-Ohno, Y., Yokoyama, J., Nakashizuka, T., Kawata, M., 2017. Utilization of photographs taken by citizens for estimating bumblebee distributions. Sci. Rep. 7, 11215. https://doi.org/10.1038/s41598-017-10581-x.
U.S. Census Bureau, 2018. U.S. Department of the Interior, U.S. Fish and Wildlife Service, and U.S. Department of Commerce, 2016 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.
USDA, USFS, 2019. USDA Forest Service Global Positioning System: MTDC Accuracy Reports.
Walker, J., Taylor, P.D., 2017. Using eBird data to model population change of migratory bird species. Avian Conserv. Ecol. 12. https://doi.org/10.5751/ACE-00960-120104.
Wang, L., Riseng, C.M., Mason, L.A., Wehrly, K.E., Rutherford, E.S., McKenna, J.E., Castiglione, C., Johnson, L.B., Infante, D.M., Sowa, S., Robertson, M., Schaeffer, J., Khoury, M., Gaiot, J., Hollenhorst, T., Brooks, C., Coscarelli, M., 2015. A spatial classification and database for management, research, and policy making: the Great Lakes aquatic habitat framework. J. Great Lakes Res. 41, 584–596. https://doi.org/10.1016/J.JGLR.2015.03.017.
White, D.J., Svellingen, C., Strachan, N.J.C., 2006. Automated measurement of species and length of fish by computer vision. Fish. Res. 80, 203–210. https://doi.org/10.1016/J.FISHRES.2006.04.009.