Spring 5-1-2021

Using Citizen Science to Determine the Age of Alewife Fish

Rodchill-Paul Jules
University of Connecticut - Storrs, jrodchillp@ymail.com

Rodchill-Paul Jules

Using Citizen Science to Determine the Age of Alewife Fish

Eric T. Schultz

Mark Urban

Abstract

Aging scales of economically important fish like the Alewife (*Alosa pseudoharengus*) is a critical task in the fisheries industry, which can benefit from the help that citizen science offers. In order for those benefits to take effect, common people should be comfortable and fairly knowledgeable about what is expected of them in the study. Then, results can be generated in a way that gives all types of citizens a good opportunity to participate and produces reliable data that can be used for scientific purposes. This experiment studied the effects of simple word instructions versus diagramed instructions on the ability of participants to successfully age Alewife scales. There were two hypotheses: that the participants that work with the detailed set of instructions will have better accuracy in determining the age of the fish, and the increasing familiarity of the participants will correlate with decreasing error. Participants were assigned the task of aging five unknown alewives using instruction sets to learn how to count the annuli on scales. The results supported the hypotheses and gave more insight into how citizen science can be used to both create and verify scientific procedures. It is a step forward to understanding how to convince participants to contribute data and how data can be generated to the benefit of the scientist and the participant.

Introduction

Citizen science is a growing field in the world of STEM. It is defined as science conducted by the average citizen. Although citizen science is a relatively new field, people have been studying the natural environment since recorded history began using data generated from members of the public. In ancient China, residents helped to track outbreaks of locusts who were a frequent problem for harvests (Irwin 2018). In the late 1800s, a member of the American Ornithologists'

Union named Wells Cooke developed one of the earliest formal citizen science programs in the United States (Ullrich 2012).

Citizen science has increased tremendously over the past two decades due to the rise of the Internet in the 1990s and the later development of smartphones and digital media (Ullrich 2012). From microbiomes to galaxies, scientists across the globe are involving people into thousands of research projects through communities like BugGuide, Galaxy Zoo, Zooniverse, Old Weather, Eyewire, and SETI@home. Many challenges face this growing medium. Citizen science suffers from a lack of scientists wanting to initiate them and citizens wanting to participate in them. Traditionally, individuals in the scientific field have been trained less on working with people and more on tight control of carefully planned experiments. Academics and scholars note the growing number of options that can fatigue and discourage people, as well as the challenges concerning ethics, data use, and privacy. In particular, scientists have been known to arrive in a certain area, exploit the community for data, and leave without giving credit where it's due. This affects any future scientific interaction with that community (Piesing 2020).

Some questions have also arisen concerning the reliability of data when utilizing citizen participation. However, many studies show that volunteers with proper protocol, training, and equipment can equal that of experts. Many times, people are helping to speed up meta-analyses and assess images in ways that algorithms have yet to match. New statistical tools can address issues such as sampling bias, measuring error, and identification (Bonney 2014). Citizen science benefits not only the scientific world, but also strengthens the social outcomes of citizens. Collaborations between citizens, agencies, and scientists can help establish protected areas and sustainable practices. Citizen science can include people from many different backgrounds who address local issues by deliberate design according to a wide range of interests.

Citizen science has already been used, albeit not widely, to collect biological data for fisheries stock assessments. The Alewife is a good species for citizen scientists to study as it has many economical and environmental uses for people around the world. The Alewife (*Alosa pseudoharengus*), also known as gaspareau in International French, is one of 216 fishes in the family Clupeidae, which includes herrings, sardines, menhadens, pilchards, sprats, and shads. The Alewife is a historically anadromous fish that originally inhabited the North Atlantic Ocean (Tanner 2019). It rarely reaches 200 millimeters (mm) in length and has a life expectancy of 9-10 years. Adults spend most of their time in the ocean, returning to the rivers in winter to breed. The Alewife tends to reside in deeper waters during daylight hours. It is mostly a filter feeder, but also captures prey by gulping and individual particle feeding (Bean 2002). Its diet consists of amphipods, insects, water fleas, ostracods, annelids, opossum shrimp, and vegetation. They are efficient at catching prey mid-water but have trouble catching prey that are at or near the bottom.

They are ecologically important due to an abundance of species preying on Alewives, including the Lake trout (*Salvelinus namaycush*), Atlantic salmon (*Salmo salarIts*), Chinook salmon, Coho salmon, Whitefishes, Burbot, Largemouth bass, Walleye, eels, and herons. Parasites have also been found in Alewife, such as acanthocephalans (genus *Pomphorhynchus*), cestodes, nematodes (genus' *Hysterothylacium*, *Contracaecum*, *Camallanus*, and *Anisakis*), and the Alewife floater (*Anodona implicata*), as well as coccidian protists (*Goussia clupearum*) (Duszynski 2003). Historically, the native Americans in New England would bury the Alewife with crops as fertilizer. In 1623, the first fishing regulations were established in North America, which protected fish species such as the Alewife (Taft 2017). Today, its market value comes from its source of fish oil and food. Fishermen generally consider Alewives one of the easiest fish to catch, and they can be served fresh, smoked, salted, or pickled (Tobias 2004). Fishing licenses and potential tourists also make the Alewife beneficial for the economy. Costume jewelry can be made from the silvery coating on their scales.

Due to construction of dams and introduction events in the United States beginning in the late 19th century, some populations have recently adopted a landlocked freshwater lifestyle (Grunberg 2019). Some differences between the two populations are diet, with landlocked Alewifes feeding on pelagic prey and anadromous Alewifes feeding on different types of prey depending on their life stage and ecosystem. Landlocked populations are also smaller; they rarely reach more than 200 mm while anadromous ones can grow 360-380 mm. Anadromous populations harbor more parasites than landlocked populations.

Alewives are indeed an important fish for both nature and humanity, yet studies have found it nearly impossible to measure their age and growth in the wild. One important way that citizen science can aid in the study of Alewives is by involving participants in fish aging, which is defined as studying the life history and population dynamics of fish stocks. It is one of the most important biological methods for fisheries biologists and managers as it allows them to examine vital traits of species and populations, such as lifespan, age at recruitment, reproduction periods, migrations, and mortality. By doing this, they can better understand how fish populations are affected by commercial and sport fishing, natural mortality, and environmental effects. Fish are mainly aged by their scales or otoliths, but other structures such as opercula, vertebrae, spines, and fin rays have been used as well (Myers 2020).

Scales are small, thin, keratinous structures that fit tightly on the body or overlap like shingles. The scales on a fish are its exoskeleton. Scales can vary in size and shape, and the morphology of scales can vary with different species and even sexes of fishes (McGrouther 2019). Cycloid scales and ctenoid scales are the most common types and are found in the Osteichthyes. Composed of bone and collagen, cycloid and ctenoid scales differ in their outer edge. The cycloid has a smooth edge and the ctenoid has a spiny one (Sharma 2020). When cycloid and ctenoid scales grow in size, they produce growth rings called circuli. In the cooler months of the year, the scales grow more slowly and the circuli are closer together in a band called an annulus.

Otoliths are calcified ear stones that have the purpose of aiding fish in balance and hearing. They are located near the brain and are usually no bigger than the size of a fingernail. The rate of calcium carbonate accumulation varies with the rate of a fish growth, with more material being laid the quicker a fish grows (Miehls 2020). Layers accumulate on both a daily and annual rate, although as a fish ages the daily bands become less apparent compared to the annual ones. The structure of the otoliths can also change with the seasons by showing two annual increments, or bands with different opacity. These zones can be seen in both untreated otoliths and otoliths that have been prepared by cutting, breaking, burning, or slicing.

The advantage of scales over otoliths (and vertebrae) is that they can be easily removed and that they do not require the fish to be dead. Scales are also easier to age than otoliths, mainly because it is difficult to ascertain the first-year annuli on an otolith. However, otoliths have the advantage of typically generating more accurate measurements due to their calcium makeup (Stuby 2007). Unlike scales, otoliths also continue to grow as the fish ages (Abecasis 2007).

Just like foresters do with aging trees, aging fish by their scales is accomplished by counting the growth rings, or annuli.

It is necessary in the field of citizen science to know how to make effective communication for any participants of a study. These citizens may not be knowledgeable about the scientific subject and also have barriers such as religious and family matters. Human behavior is not easy to gauge, but certain protocols can still be guaranteed to achieve positive results for both parties. The main focus of this study is to evaluate the effectiveness of scale aging instructions in a citizen science application. This is done by giving participants the task of aging scales and setting it up so that every alternating participant has a different instruction set, with one being simple and the other having detailed demonstrations.

We hypothesized that the participants that work with the detailed set of instructions will have better accuracy in determining the age of the fish, due to the added aid that clarifies what participants should do. For this hypothesis it is therefore important to consider the preliminary of whether some participants give readings of more error than others. Another hypothesis is that the increasing familiarity of the participants will correlate with decreasing error in the determinations of the Alewife ages.

Methods

The scales were scraped from Alewives using the blunt edge of a plastic knife, and then the knife would be placed in an envelope like one that would be used by coin collectors. The fishers would squeeze the knife in the envelope for the scales to fall in. Important information was written on the envelope: the name of the collector, type of fish, location and method of capture, date and time, and the length and weight of the fish (Garling 2016). The scientists scraped the scales where there was a low probability of getting scales that were regrown, since those types of scales have not grown up throughout the fish's life and will not provide an accurate reading of the fish's age. Scales were collected from the shoulder above the pectoral fin and lateral line and below the dorsal fin. The fishers took multiple scales in case there were still scales that were regrown.

The scales were placed into a plastic Petri dish. The scientists poured soapy water inside the Petri dish and let the scales soak for 12-24 hours. This was done to wipe off potential slime and pigmented tissue. Then, they took the scales out of the dish with a forceps and dried them with a paper towel. The scales were sandwiched between two microscope slides to prevent curling, with tape placed around the slides to keep them together.

The Schultz lab at UCONN imaged the scales under a microscope using the MicroPublisher 6 Q-Imaging and the Ocular software. A cord was plugged from the wall outlet to the top of the camera, and another cord was plugged from the top to a computer USB port. The switch was flipped to I. The light source (set to the 2nd largest dot) and overhead lab lights were turned on, and the Ocular USB key was plugged into a computer. Then, the scientists would open the Ocular application and click the "Live View" button on the top left, revealing a preview of the photo. They increased the focus and quality of the picture by zooming and calibrating the frame so that a zoomed in annuli can be seen clearly. Sticky notes were placed on the stage of the microscope to level it, and a ruler was placed to be visible on the left edge of the photograph. Camera settings were double checked before they clicked the "Publish the Folder" button to snap a picture. The camera settings were as follows: there was a 50 ms exposure time, no binning, a pre-exposure clearing mode, the output was in color, the calibration was halogen, and the field of view was a full frame.

IRB approval was obtained for research, including a Collaborative Institutional Training Initiative (CITI) Social/Behavioral certification affiliated with the University of Connecticut. Permission was obtained from Rebecca Colby to use a subset of her imaged scales. Experts in the Schultz lab in the University of Connecticut (UCONN) Storrs campus have determined the established ages for the Alewives using prepared scales. Scales were chosen of Alewives that were estimated to be 2-6 years old, and that were imaged between the years of 2010 and 2015, excluding 2011. They were arranged in four batches randomly, with each batch containing five scales. 28 participants were invited from the student body of UCONN during Spring 2021, the Southern New England Chapter of the American Fisheries Society, and anglers from the Fish and Aquatic Conservation, as well as any referrals from the participants themselves. The invitations were issued on March 9, 2021, followed by the invitations closing on March 17.

Each participant who was willing to participate was given a separate Google Drive folder via email. The contents of the folder contained five prepared scale images from alewives in their own folders, as well as a questionnaire and a labelled instruction set. The randomized instruction set had 2 pre-determined difficulties: either simple or having demonstrations. This was done to test whether or not word description was enough of an explanation or if the inclusion of diagrams was beneficial or even necessary to help them complete the process. The simple instructions consisted of an overview summarizing what was required of the participant, background information with a detailed protocol on how to count annuli to determine a fish's age, and an aging protocol stating how to age the fish and report their results. The other set of instructions had the same text, along with four images of Alewife scales, with each of them showing an aspect of fish aging. The first image pointed out an annulus/annuli, the second pointed out transverse grooves, the third one pointed out a false annulus, and the last showed a counting of a five-year-old Alewife.

The participants aged the fish by counting the annuli on the scales based on the instructions that were given to them. In the questionnaire, they put the answers to five demographic questions (which included a conditional "if" question), guesses of ages of fish that they counted, and their confidence score for each guess. The participants were welcome to withdraw from the experiment at any time for any reason. They were also allowed to skip any questions they did not feel comfortable answering. They were told to send an email when they were finished stating that they had completed the assignment. The due date for all data to be collected was March 31.

The data was recorded in a Google Sheets data file that listed the Participant and Scale IDs, estimated age, confidence score, and instruction set used. SAS software was used to analyze the whole set. Using the NPAR1WAY procedure, the software conducted a Wilcoxon Two-Sample Test to evaluate the difference between the medians of the participants that had the simple instructions and the participants that had the detailed instructions. Using the general linear model (GLM) procedure, a non-parametric two-way ANOVA was conducted for three variables to analyze the instruction sets and the effect on efficiently determining the alewife fish age. The three variables were familiarity with fish biology, education, and prior aging. Accuracy was quantified in terms of absolute values. Due to the effects of pseudoreplication, and because of each individual making multiple age estimates, the ANOVAs were created with the number of participants as the observations rather than the total number of data points.

Results

Out of 28 invited participants, 22 completed the study with 110 observations to evaluate. Of these 22 participants, five of them graduated high school, seven graduated from college, and nine had an advanced degree. 7 participants had substantial familiarity with fish biology, 9 people had moderate, 4 people had a little, and 1 person had none. 8 people have aged fish prior to this study, and 12 people have not. A total of 41 answers were correct. 6 participants had no answers correct, while on the other side 4 participants had 4 answers correct. The highest deviation from the actual age of an Alewife was 8 years, and the range of error was from -2 to 8 years.

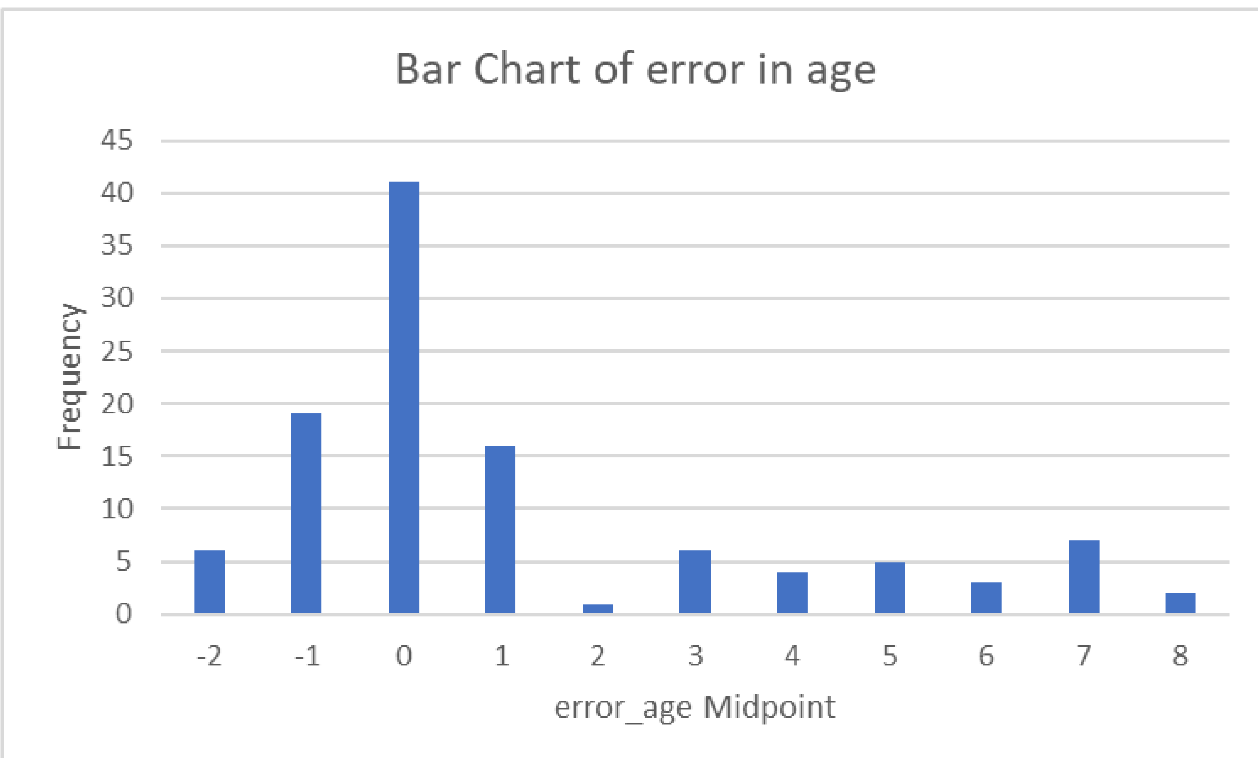

Figure 1. Bar chart of error in age. Note that the error is recorded by the numerical offset and direction, rather than the absolute value.

The results were placed in a table that showed the total number of observations, the mean, standard deviation, minimum, and maximum (Table 1). They were also placed in a histogram (Figure 1) showing the frequency of how far off each guess was. A box and whisker plot shows the distribution of absolute error in the age of the Alewife fish for each instruction set (Figure 2). A second box and whisker plot shows the distribution of Wilcoxon scores for absolute error (Figure 3). The error_age plot points were skewed towards the right, which violates one of the assumptions of a t-test as the data would not be normally distributed. Data shows a smaller interquartile range and deviation in the B instructor set than in the A instructor set. The Wilcoxon score figure shows the probability of getting a value for Z less than -3. Since the first null hypothesis was that the values of error should be the same or greater with the instruction set, the alternative is that the values of error would be less. The P of getting that Z score of -3 to minus infinity observed under the null hypothesis was 0.0011. The alternative hypothesis is therefore chosen over the null hypothesis.

The non-parametric two-way ANOVAs (Figures 4-6) showed that there was a significance with prior aging and education, and no significance with familiarity with fish biology. There was a general decreasing trend in the rank for the prior aging variable. In other words, the rank was generally higher for participants who have not aged fish prior to the experiment. For the ANOVA of familiarity, there was an increasing trend in the rank, and then it decreased at the last x value. In the education ANOVA, the trend was generally increasing. These trends occurred regardless of the instruction set, and in all three ANOVAS, the rank was lower for instruction set B.

The ANOVAs also generated mean squares that represented the deviation from the mean divided by the degrees of freedom in each variable. The mean squares, rounded to the nearest hundredth, are lowest in education (46.72), followed by familiarity (201.69) and prior aging

(513.51). The F values that result from that, rounded to the nearest hundredth, are 0.66 for education, 3.33 for familiarity, and 3.03 for prior aging. The respective Pr > F variables, rounded to the nearest hundredth, were 0.53, 0.05, and 0.1. Since the P values were small for the education and the prior aging variables, the alternative hypothesis is therefore chosen over the second null hypothesis.

One significant point is that the participants with the simple set of instructions had more deviant estimates from the ages than the participants that had the demonstration set of instructions. Both the highest deviation and the most frequent significant deviations were recorded from participants that had the simple set of instructions. Another significant point is that the parallel lines of the Figure 4 graph observing familiarity are additive, so further predictions are possible.

Table 1. Critical variables in the error of determination of age in the Alewife.

Analysis Variable: error_age				
N	Mean	Std Dev	Minimum	Maximum
110	1.17273	2.59449	-2	8

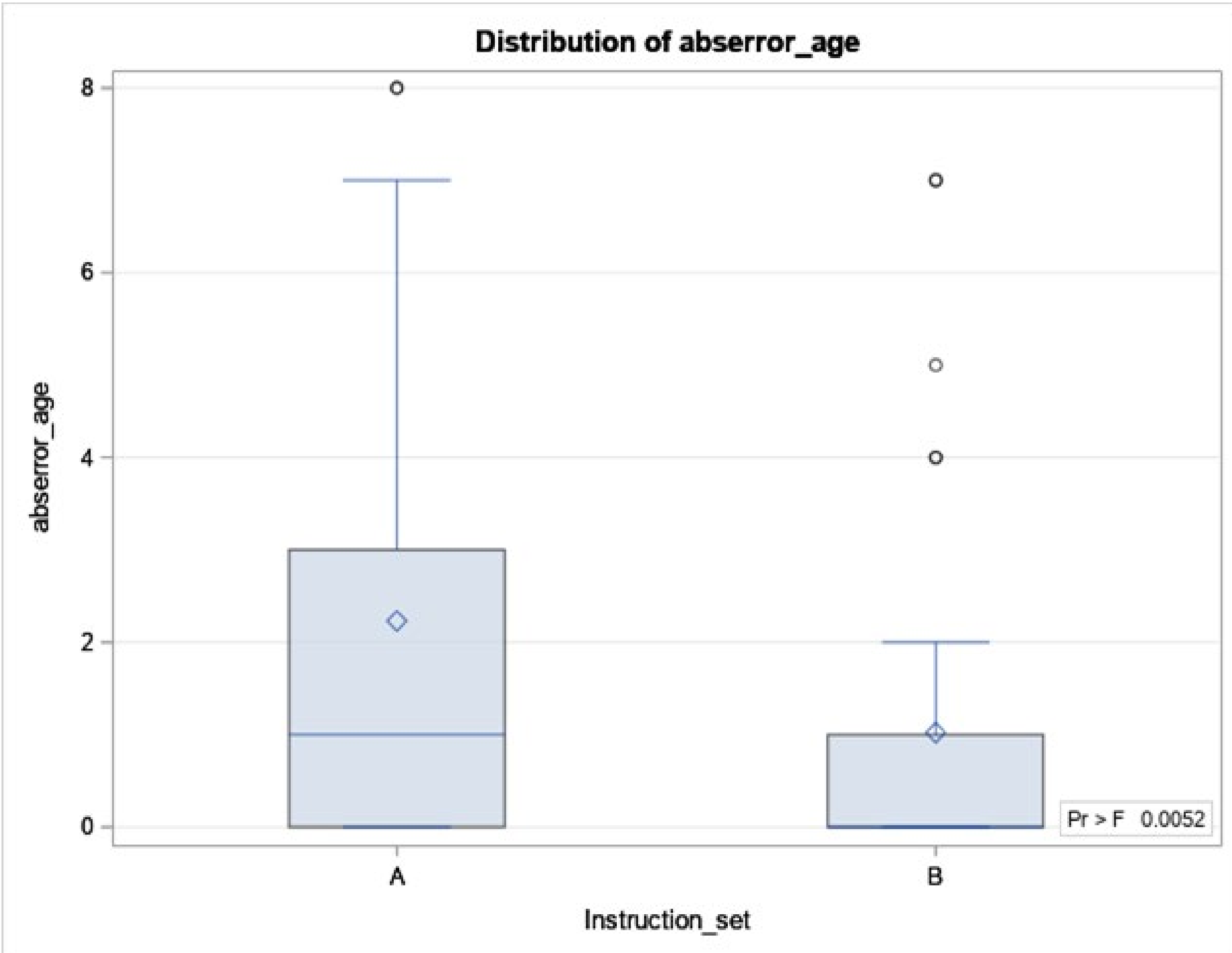

Figure 2. Distribution of Absolute Error in the age of the Alewife fish.

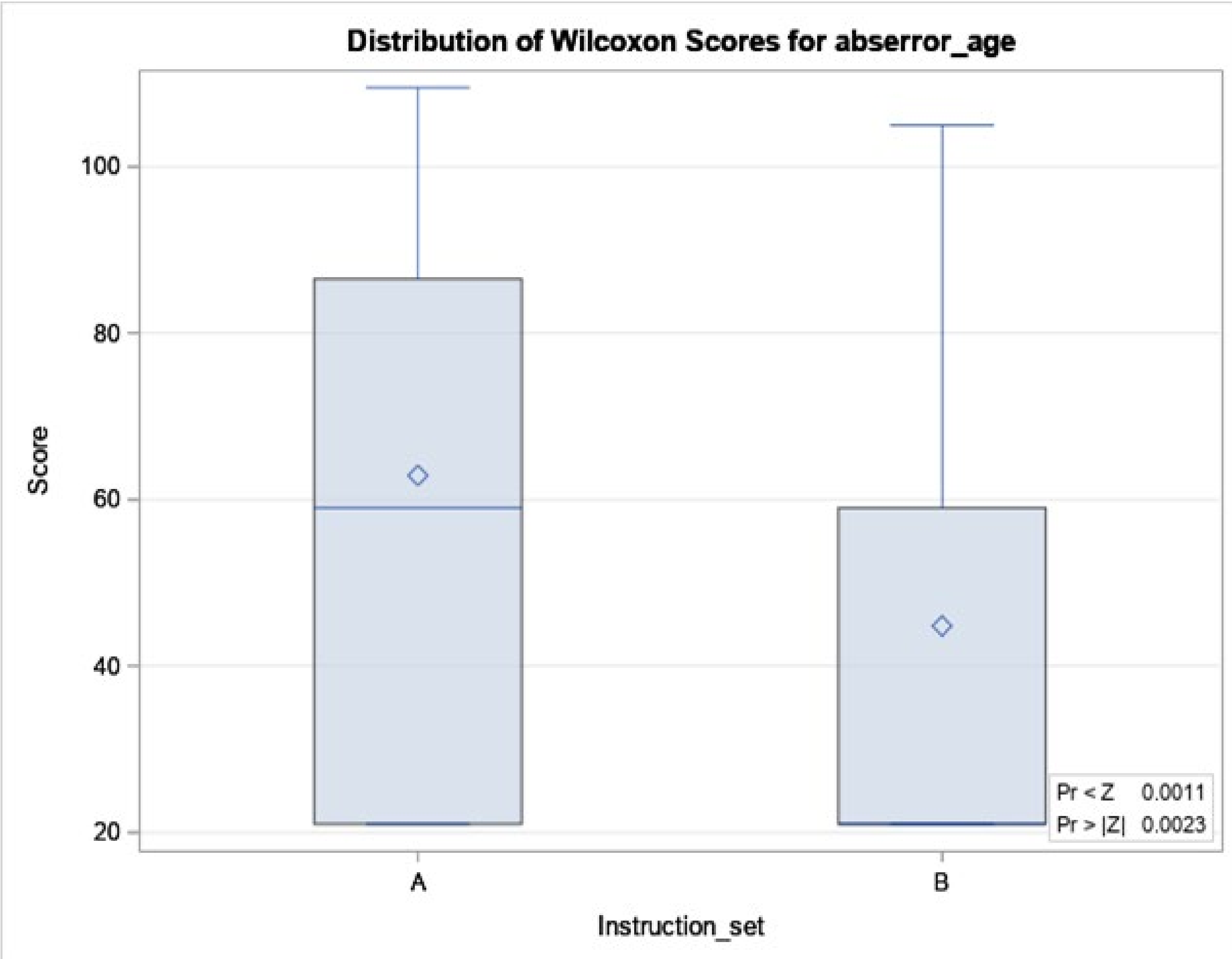

Figure 3. Distribution of Wilcoxon Scores for Absolute Error Age. This figure shows a comparison of medians and the normal approximation of the data.

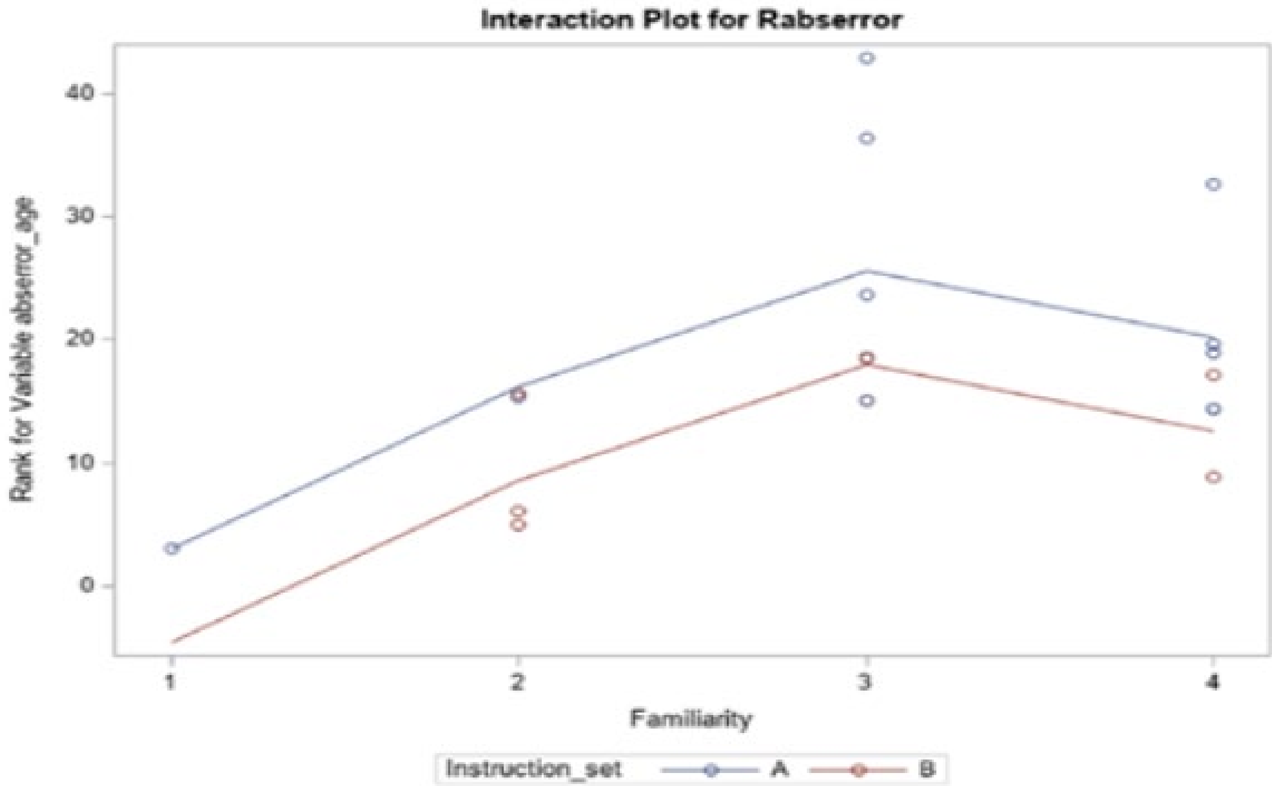

Figure 4. Non-parametric two-way ANOVA with variable of familiarity with fish biology. The non-parametric aspect is due to some of the assumptions for a two-way ANOVA not being met, such as the sample sizes being equal and the population being normally distributed.

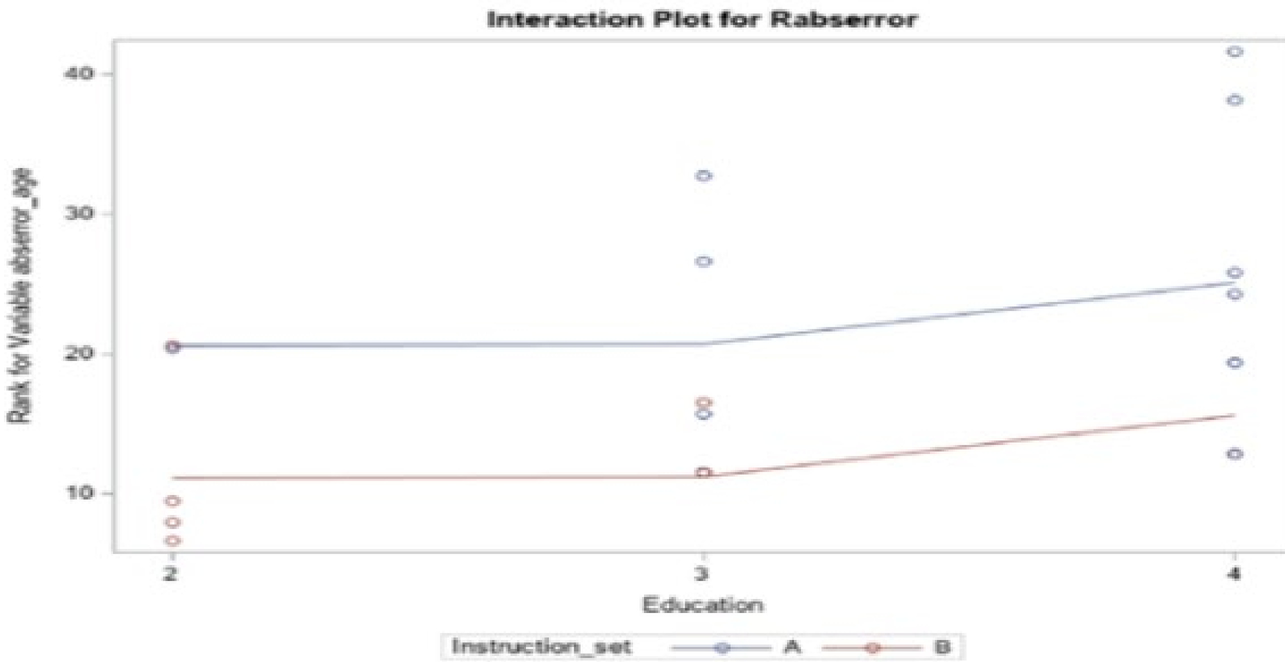

Figure 5. Non-parametric two-way ANOVA with variable of education.

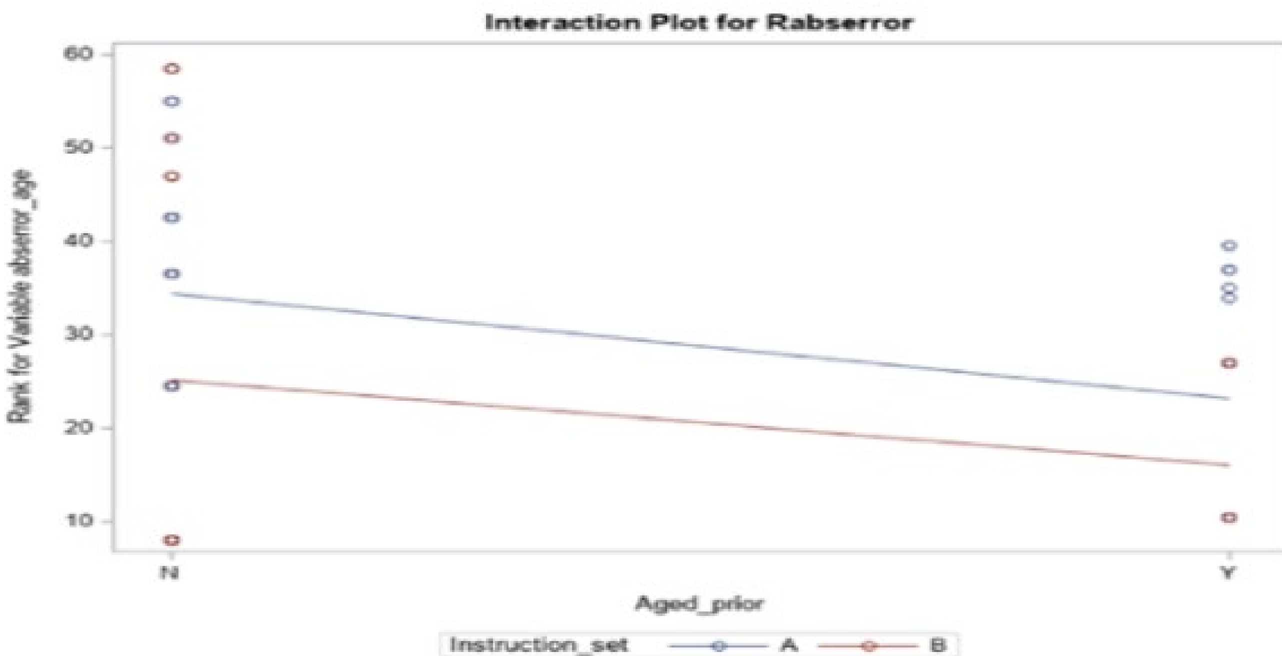

Figure 6. Non-parametric two-way ANOVA with variable of prior aging of fish.

Discussion

Results showed a trend of people who gave answers that were usually off by 2 or less. The participants that were chosen came from a range of backgrounds. This occurred regardless of the confidence score, which showed the effectiveness of instructions. The other interesting thing with the effectiveness of instructions concerns the range of the observations. The observations were skewed towards the right of 0, and there were no guesses that were lower than -2. Considering that the ages of the Alewives ranged from 2 to 6, there was an understanding that the Alewife ages were to be positive numbers.

The first hypothesis was supported since participants who had a demonstration set of instructions generally gave more correct guesses. The results suggest a correlation between a visual picture to help clarify the concepts in the instruction set and the performance in guessing the ages of Alewife fish. It can be reasoned, therefore, that clarity and visual aid can be helpful in being able to not only make people understand the description, but to even keep them interested in the subject matter. With enhanced and sometimes tailored instruction, people with little background in the respective scientific field of the experiment can still show promising results. The second hypothesis was supported since the increasing familiarity and education correlated with an increasing rank, as shown by the non-parametric two-way ANOVAS.

One of the shortcomings in our experiment was the fact that the instructions were not carried out by every participant in the same exact manner. Rather than doing the Google Doc directly, some participants downloaded it as a Microsoft Word document and sent it by email. It also was not pointed out that the folders were for the invited single participants only, and that no one else except the testers and the participant should have access to that folder. This further stresses how citizen science requires scientists to consider all of the factors so that the experiment is both seamless and generative of valuable data.

With more studies being carried out collectively by citizens, data can generally be generated at a faster rate. There is also the advantage of local citizens being in places that scientists cannot access without legal permission, although permission may still be required for commencing scientific studies. There are, however, certain cultural and social considerations to consider when people are engaging in scientific matters, as the bias of a group of people in a certain lifestyle could affect the generation of results. For some participants, the demographic questions were not always fully answered, but they always guessed all the ages of the Alewife fish provided to them, regardless of the batch. It demonstrates how certain data that scientists ask for could potentially be a cause of friction for participants.

As a solution to the aforementioned issue, there is often much to be gained in receiving feedback about a scientific experiment from participants. To get people involved or persuade them to do something requires procedures that can be further refined with experience and the overall collective thought on the matter. The experiment conducted did not dive too deeply in this other than giving people a chance to put a confidence score. If a confidence score had a written reason to back it up, there could be more substantive feedback on how to better engage people in science.

Sometimes, it can also be about the way scientists approach potential people with experiments. Certain morals and beliefs may have to be respected, and the presentation itself should have a relatively attractive and reasonable approach. Furthermore, this approach should be tailored to fit the knowledge of the people group being persuaded, as some groups can be put off by things Further research may be done in showing how the presentation of instructions affects people's productivity and willingness to perform the experiment. Issues that attain to the grade vocabulary of words, any potential offenses, and the accessibility of instructions in terms of retrieving and reading them are things that should be addressed in future studies.

Fisheries can really benefit from citizen science, and some of the activities available to fisheries citizen scientists include gathering abundance, distribution, and habitat preferences, supplementing existing catch data, and collecting biological and environmental data. Some fisheries have already utilized this method, as was the case when volunteer anglers worked with scientists on genetic samples from Canary rockfish (*Sebastes pinniger*) in Puget Sound, Washington. People should conduct research on how to adapt it to the fisheries field, as citizen science is meant to be an adaptive tool to existing data sources rather than a replacement for existing science projects. And implementing and maintaining citizen science programs will require the trust of people from all over the board - scientists, government agencies, fishers, and the public (Bonney 2021).

Citizen science can also be used for a wide range of scientific subjects outside the scope of this study, but there should also be future study on observing what type of science citizen scientists are most comfortable with. This study fell under the category of natural science, where participants were observing the body parts of an Alewife to generate information about the species. Most present studies that involve citizen science are used in the natural sciences field, and mostly concerning solving problems. But little to no citizen science is used in formal sciences such as logic and mathematics, as well as social sciences like economics and sociology. According to a survey of citizen science projects in Europe, 80% is confined to life and natural sciences and only 11% to the social sciences (Tauginienė 2020). Part of the reasoning for this could be to the longstanding bond between citizen science and the natural sciences.

The study suggests that although there is accuracy regardless of the person's background, better accuracy is generated when a participant has some prior familiarity with the scientific subject. Therefore, it is possible that future citizen science projects could benefit from putting interested participants in a screening to evaluate how able they are to get the job done. By doing this, scientists would have people who are better suited to the scientific material due to their location, familiarity, and/or age.

Citations

Abecasis et al. 2007. Ageing seabreams: A comparative study between scales and otoliths *Fisheries Research* 89: 37-48. https://doi.org/10.1016/j.fishres.2007.08.013

Bean, T. 2002. Introduced Species Summary Project (Alewife (*Alosa pseudoharengus*)) Columbia. Retrieved from http://www.columbia.edu/itc/cerc/danoff-burg/invasion_bio/inv_spp_summ/alewife.html

Bonney et al. 2014. Next Steps for Citizen Science *Science* 343: 1436-1437. doi.org/10.1126/science.1251554

Bonney et al. 2021. Sea Change: Using Citizen Science to Inform Fisheries Management *BioScience*. https://doi.org/10.1093/biosci/biab016

Duszynski et al. 2003. Coccidia (Eimeriidae) of Clupeiformes. Kansas State University.

Retrieved from https://www.k-state.edu/parasitology/worldcoccidia/CLUPEIFORMES

Garling, D. 2016. Determining the Age of Fish (E1774). Michigan State University. Retrieved from https://www.canr.msu.edu/resources/determining_the_age_of_fish_e1774

Grunberg, R. 2019. Divergence in Alewife Alosa pseudoharengus (Actinopterygii, Clupeidae), life history alters parasite communities. SpringerLink. Retrieved from https://link-springer-com.ezproxy.lib.uconn.edu/article/10.1007/s10750-018-3743-4

Irwin, A. 2018. No PhDs needed: how citizen science is transforming research. Nature. Retrieved from https://www.nature.com/articles/d41586-018-07106-5

McGrouther, M. 2019. Fish scales. Australian Museum. Retrieved from https://australian.museum/learn/animals/fishes/fish-scales/

Miehls, A. 2020. Tiny Bones Tell Big Stories: How Fish Ear Bones Inform Great Lakes Fishery Science & Management. USGS. Retrieved from https://www.usgs.gov/center-news/tiny-bones-tell-big-stories-how-fish-ear-bones-inform-great-lakes-fishery-science

Myers et al. 2020. An efficient protocol and data set for automated otolith image analysis *Geoscience Data Journal* 7: 80-88. http://dx.doi.org.ezproxy.lib.uconn.edu/10.1002/gdj3.86

O'Gorman, R. 2010. Alosa pseudoharengus (alewife). CABI. Retrieved from https://www.cabi.org/isc/datasheet/94217

Piesing, M. 2020. The rise of citizen science: can the public help solve our biggest problems? TheGuardian. Retrieved from https://www.theguardian.com/education/2020/nov/16/the-rise-of-citizen-science-can-the-public-help-solve-our-biggest-problems

Sharma, B. 2020. What Are The Different Types Of Fish Scales? ScienceABC. Retrieved from https://www.scienceabc.com/nature/animals/what-are-the-different-types-of-fish-scales.html

Stuby, L. 2007. What is Age Validation and How Does it Relate to Fortune Cookies? Alaska Department of Fish and Game. Retrieved from http://www.adfg.alaska.gov/index.cfm?adfg=wildlifenews.view_article&articles_id=285

Taft, D. 2017. The Stubborn Staying Power of the Alewife Herring. The New York Times. Retrieved from https://www.nytimes.com/2017/03/16/nyregion/alewife-herring.html

Tanner, H. 2019. Alewife *Something Spectacular: My Great Lakes Salmon Story* 120-123. https://doi-org.ezproxy.lib.uconn.edu/10.14321/j.ctv65sxrf.20

Tauginienė et al. 2020. Citizen science in the social sciences and humanities: the power of interdisciplinarity. *Palgrave Commun* 6. https://doi.org/10.1057/s41599-020-0471-y

Tobias, V. 2004. *Alosa pseudoharengus*. Animal Diversity Web. Retrieved from https://animaldiversity.org/accounts/Alosa_pseudoharengus/

Ullrich, C. 2012. Citizen science. National Geographic. Retrieved from https://www.nationalgeographic.org/encyclopedia/citizen-science/

Vitale et al. 2019. Handbook of fish age estimation protocols and validation methods. *ICES Cooperative Research* 346: 1. http://doi.org/10.17895/ices.pub.5221