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PREFACE:

The Geoscience Information Society (GSIS) was established in 1965 as an independent nonprofit professional society. Members include librarians, information specialists, publishers, and scientists concerned with all aspects of geosciences information. Members are based in the United States, Canada, Australia, Sweden, Taiwan and the United Kingdom.

GSIS is a member society of the American Geosciences Institute and is an associated society of the Geological Society of America. The GSIS annual meeting is held in conjunction with the annual GSA meeting, and the papers, posters, and forums presented are a part of the GSA program.

Papers and Posters provided in these proceedings were given at the 2017 Annual Meeting of the Geological Society of America held in Seattle, Washington, October 22-25, 2017. Papers are arranged in the same order as the presentations. Where the entire paper is not available, the abstract is provided with the permission of GSA. Papers were provided in session and posters were presented all day with the authors available during a two-hour session. The theme of these sessions were on geoscience data and information resources and co-sponsored with the Geoinformatics Division of the GSA.

The proceedings in this volume are divided into two parts:

1. Papers presented at the GSA Oral Session No. 313: Discovery and Preservation of Geoscience Data and Information Resources and posters presented at the GSA Poster Session No. 264: Use of Geoscience Data and Information Resources in Education and Research.
2. GSIS Meeting Supplemental Materials

Thank you to all our poster presenters, the leadership of GSIS, and to the session conveners'/proceedings editors who have preceded us for their hard work in the name of the Society and their contributions to our profession.

Christopher A. Badurek
GSIS Technical Session Convener 2017

A CITIZEN SCIENCE APPROACH TO GROUNDWATER MONITORING: THE IMPACTS OF PARTICIPATION ON KNOWLEDGE AND ATTITUDES, AND IMPLICATIONS FOR MANAGEMENT

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Abstract—Citizen science is the participation of non-scientists in the collection of scientific data and other aspects of the scientific process. While public participation in science is not new, this approach to research has become increasingly common in the past two decades. Despite the increasing popularity of this approach, due to the technologically complex and expensive techniques typically required to take hydrological measurements, its use in water related sciences has been primarily limited to monitoring of surface water quality or measurement of precipitation amounts. In this paper, we present the results of a study that involved citizen scientists in the monitoring of groundwater levels and subsequent characterization of the water table on Bogue Banks, North Carolina. The data and results presented here aim to fill the gap in the literature regarding relationships between citizen science, scientific knowledge, and environmental attitudes in a hydrogeological context. Specifically, we use a pretest-posttest survey design to assess the effects of participation in a citizen science groundwater monitoring project on participants' knowledge of hydrologic concepts, and attitudes toward science and the environment. Further, by examining participants' perceptions regarding causes of and impacts from localized stormwater flooding as well as climate change more generally, we explore the potential ways that citizen science can contribute to improved management of water resources. We found that participation in the citizen science project increased knowledge of hydrological concepts, but did not change attitudes toward science and the environment.

1. INTRODUCTION

Citizen science is the participation of non-scientists in the collection of scientific data and other aspects of the scientific process, such as developing research questions and analyzing data. While the participation of members of the public in science projects is not new, this approach to research has become increasingly common in the past two decades (Crain et al., 2014; Dickinson et al., 2012; McKinley et al., 2017). This increase reflects growing concern for environmental issues and awareness of human impacts on ecosystems (Bonney et al., 2014; Johnson et al., 2014), and falling public spending on the environment (Conrad and Hilchey, 2011). Although questions remain regarding the reliability of data collected by citizen scientists and the extent to which citizen science facilitates greater scientific knowledge and understanding, researchers highlight the important role citizen science plays in linking members of the public to environmental management (Jordan et al., 2011; McKinley et al., 2017). Participation in citizen science projects can expose volunteers to local environmental conditions, increasing awareness of associated problems and the related potential management or policy options. This, in turn, can lead to increased engagement in management, either directly by providing input to policymakers, or indirectly by sharing information and encouraging others to get involved (Dunlap, 1992; Marcinkowski, 1993; McKinley, 2017). Dickinson et al. (2012) emphasize how participation in citizen science projects creates authentic learning experiences, providing opportunities for scientists to engage directly with community members, often regarding critical issues of scientific concern. This can lead to increased public support for science and policies that promote environmental sustainability.

Not all citizen science projects employ the same format. For example, Bonney et al. (2009) describe three types of citizen science projects: contributory projects, collaborative projects, and co-created projects. Contributory projects, which can be either active or passive in nature, are those in which volunteers' primary role is to collect data. These are the most common (Price and Lee, 2013) and have been used in a variety of fields, including ornithology (Brossard et al., 2005), environmental education (Mannion et al., 2013), astronomy (Percy, 1999), and risk communication (Kar, 2016). In collaborative projects, volunteers collect data but may also contribute to additional aspects of the scientific process, such as helping to develop the project goals or scientific objectives, analyzing data, or disseminating findings. One of the better-known projects of this type is the Galaxy Zoo astronomy project, which resulted in one citizen scientist discovering a new astronomical structure in the course of the study (Cardamore et al., 2009; Price and Lee, 2013). Collaborative projects are also common in water quality (Cunha et al., 2017) and ornithology (Brossard et al., 2005) studies. In co-created projects, all aspects of the research design and process are co-designed by scientists and volunteers. This type of citizen science project is the least utilized at present (Price and Lee, 2013). The three formats of projects therefore provide a myriad of opportunities for the public to participate in citizen science, allowing for different deliverables, commitments and benefits.

A broad range of benefits have been attributed to a citizen science approach. Involving citizen scientists in data collection can allow for large increases in sample sizes and the total number of observations that can be recorded. Importantly, these data may be collected from locations that are not accessible to the scientists themselves due to geographical and/or funding limitations (Brudney, 1999; Cooper et al., 2007; Danielsen et al., 2014; Johnson et al., 2014). Such efforts contribute to the establishment of ecological or environmental baselines, assist in long-term monitoring of organisms or environmental conditions, facilitate documenting shifts associated with global phenomena such as climate change, and assist responses to crises such as oil spills (Dickinson et al., 2012; Fuccillo et al., 2015; McCormick, 2012; Sullivan et al., 2009; Thomas et al., 2016). While questions remain regarding the validity of data collected by citizen scientists, several studies have shown that with proper training, these data can be reliable and useful (e.g., Little et al., 2015; Lowry et al., 2013).

Researchers have also focused on how citizen science contributes to increased scientific knowledge and understanding of the scientific process (Crall et al., 2012; Evans et al., 2005; Jordan et al., 2011). While this is often put forth as a potential benefit of citizen science in general and as a goal of specific studies, the relationship between participation in citizen science projects and increases in scientific knowledge is not well-documented. Experts suggest that it is challenging to demonstrate increases in knowledge due to the lack of established metrics and techniques to do so, and the expense involved in proper evaluation (Bonney et al., 2016; Phillips et al., 2012). However, a small number of studies have demonstrated increases in scientific knowledge related to the specific topic being examined, such as bird biology (Brossard et al., 2005) or invasive species (Crall et al., 2012; Jordan et al., 2011).

Although research projects involving a citizen science approach have increased dramatically over the past two decades, the use of the approach in water related sciences has been limited (Buytaert et al., 2014). Further, those projects involving citizen scientists in hydrologic research primarily involve water quality monitoring (e.g., Macknick and Enders, 2012; EarthEcho Water Challenge, 2017) or precipitation measurement (e.g., Cifelli et al., 2005; Community Collaborative Rain, Hail and Snow [CoCoRaHS] Network, 2017), likely due to the relative ease with which those parameters can be measured. Many hydrological measurements, however, rely on technologically complex and expensive techniques, and meaningful analysis of data associated with the water cycle often requires data collected over long temporal and large spatial scales, which contributes to the limited adoption of citizen science approaches in hydrologic research (Buytaert et al., 2016). While technological advances have led to the development of low-cost, high quality hydrological equipment, as well as new ways for volunteers to record and submit data via cell phones and other personal devices, only a small number of projects have attempted to involve citizen scientists in studies addressing more complex hydrological questions. For example, Mazzoleni et al. (2017) demonstrated that citizen scientists' streamflow observations can be integrated into hydrological models to improve flood predictions, and Turner and Richter (2011) showed how citizen scientists' wet/dry mapping observations contributed to improved understanding of hydrologic systems at the watershed scale. To our knowledge, however, these and similar studies focused primarily on determining the reliability and utility of citizen scientist collected data, and did not examine the impacts of participation in hydrological projects on participants' scientific knowledge and attitudes toward the environment, as we do here.

This research study aims to fill a gap in the literature regarding relationships between citizen science, scientific knowledge, and environmental attitudes in a hydrological context. Specifically, we assess whether participation in a citizen science groundwater monitoring project affects participants' knowledge of hydrologic concepts, and attitudes toward science and the environment. Second, we examine whether and how participants' perceptions of threats and impacts from flooding and climate change are altered by their participation. Lastly, we evaluate whether participation in a hydrologic citizen science project increases the understanding of relationships among coastal flooding, sea-level rise (SLR), and climate change. To the authors' knowledge, this study is one of the first to evaluate how citizen scientists' perceptions about climate change may evolve due to participation in a hydrologic study. By examining participants' perceptions regarding causes of and impacts from localized stormwater flooding as well as climate change more generally, we explore the potential ways that citizen science can contribute to improved management of water resources. Further, by using standardized survey instruments to measure attitudes, we contribute to Brossard et al.'s (2005) call for citizen science studies to use such scales to improve the capacity for valid comparisons of results across studies.

2. METHODS

2.1 Study site description

The citizen science project was conducted on Bogue Banks, a ~28 km^2 barrier island comprised of the communities of Emerald Isle, Pine Knoll Shores, Atlantic Beach, Salter Path, and Indian Beach (Figure 1). Situated off the coast of North Carolina, the island is located in Carteret County, and is a popular destination for vacationers and retirees. In 2015, Bogue Banks had a permanent population of 7,413, reflecting a 7.5% increase from 2010 (US Census Bureau, 2017). The seasonal influx of visitors to Carteret County generates over $350 million in tourism revenues each year and supports nearly 3,500 jobs (EDPNC, 2017).

The topography on the island is characterized by a series of shoreline parallel dunes and swales, with elevation ranging from approximately 1m below sea-level to 17m above sea-level. The southeastern portion of the island is home to the largest dunes, while the ground surface in the northern portion of the island generally slopes gently into Bogue Sound. Lautier (2001) characterizes the hydrogeologic framework of the North Carolina Coastal Plain aquifer system as a wedge of formations that dip and thicken to the east. The surficial or water table aquifer (relevant to this study) is an unconfined, Quaternary aquifer composed mainly of sandy material with some beds of mud and clay that is present throughout the North Carolina Coastal Plain (Lautier, 2001). The predominant source of recharge for the surficial aquifer is precipitation. The water table is typically close to the ground surface in the surficial aquifer. On Bogue Banks, the water table may vary from being above the ground surface in depressional areas, to several meters below the surface on top of large dunes.

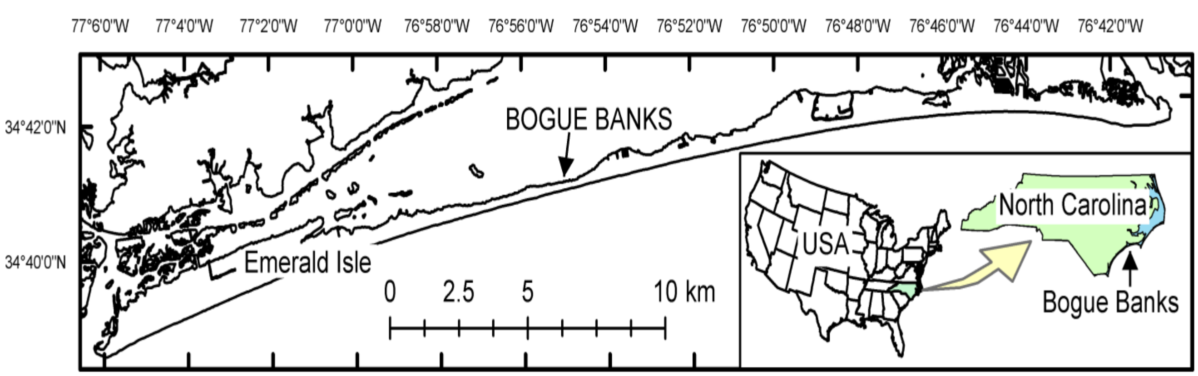

Figure 1. Location of Bogue Banks off the coast of North Carolina.

Bogue Banks was selected as the study site because it represents a coastal community that is at risk from climate change and SLR, similar to many other regions across the globe (e.g., Nicholls and Cazenave, 2010; Green et al., 2011; Taylor et al., 2013). Global projections of SLRs of 0.2 m to >1 m by the end of this century (Jevrejeva et al., 2012; NRC, 2012; Rahmstorf et al., 2012; Horton et al., 2014) will cause major water resources problems of marine inundation (where previously dry land is occupied by sea water) and saline water intrusion (where saltwater replaces freshwater in aquifers) in coastal regions (Cooper et al., 2013). Additionally, future SLR may cause groundwater inundation (where groundwater tables reach the land surface leading to localized flooding) in low-lying coastal areas (e.g., Mastersen et al., 2013; Rotzoll and Fletcher, 2012; Manda et al., 2014).

Stormwater flooding events are of great concern to residents on Bogue Banks. Town managers on the island are therefore intent on employing engineering solutions to alleviate the frequency and intensity of stormwater flooding events. However, engineering solutions may be inadequate if the drivers of the flooding are not entirely understood. Since the island is dominated by dunes and swales, the low-lying areas may be prone to flooding where the water table rises above the ground surface, thereby contributing to stormwater flooding. To characterize the island's water table and assess the proportion of land on Bogue Banks impacted by groundwater inundation, and to assess the reliability of water level measurements taken by citizen scientists, 29 shallow groundwater monitoring wells were installed on Bogue Banks, and a pilot study with seven volunteer citizen scientists was conducted on Bogue Banks in 2015. Based on the researchers' experiences during the pilot study and feedback from those participants, the research design was expanded to attract more citizen scientists, to collect data from a greater number of wells over a longer time period, and to assess the impacts of participation in hydrological citizen science projects on participants' scientific knowledge and attitudes toward the environment.

2.2 Data collection

Participants were recruited by putting up flyers in frequently visited locations on Bogue Banks, publishing announcements in local newsletters, and soliciting volunteers from local organizations (e.g., aquariums and environmental non-governmental organizations). Two informational sessions were held in February 2017, attracting a total of 31 participants. During these sessions, the researchers introduced the project and described the responsibilities of citizen scientists in the project, which included: participating in a workshop and training session to learn about groundwater systems and how to properly take water level measurements in shallow groundwater monitoring wells; measuring and recording groundwater levels at assigned wells at least once a week over a three-month period; submitting those data to researchers via a dedicated website (https://coastalwater.org/cgsw/); completing pretest and posttest surveys; and participating in occasional meetings or email discussions with researchers and other citizen scientists during the research period. At the end of the informational sessions, all 31 participants agreed to volunteer as citizen scientists, completed the informed consent process and pretest survey (approved by East Carolina University's Institutional Review Board), and participated in the workshop and training session. During the workshop, citizen scientists manipulated and interacted with physical groundwater models in small groups. The authors also led them through a hypothesis-testing process in which they tested hypotheses about groundwater flow directions and water level variations in monitoring wells. The citizen scientists then received hands-on, one-on-one instruction at one of the installed groundwater wells to ensure proper water level measurement. Before leaving the workshop and training session, each participant was given a water level meter, keys to the wells, data recording sheets, and laminated copies of instructions for accessing wells, taking measurements, and submitting groundwater level data.

Throughout the three-month monitoring period, researchers were in continued communication with the citizen scientists, primarily via email, to assist with any issues or concerns that arose. A meeting was held half-way through the data collection period (March 2017) during which researchers presented the data collected up until that point and facilitated a discussion with the participants ($n = 9$) who attended. At the end of the three-month data collection period, final meetings were held on two different occasions (in May 2017) to debrief the participants. The citizen scientists were encouraged to attend the event to return their equipment, complete the posttest survey, provide feedback to the researchers regarding their experiences with the project, and participate in discussions regarding how the data will be analyzed and results disseminated. A total of twelve citizen scientists participated in the final meetings. The discussions at these meetings included examining time-series graphs of data collected by the citizen scientists, comparing groundwater levels to rainfall data, and evaluating groundwater contour maps developed from the citizen scientists' data.

2.3 Survey instruments

As with many citizen science projects, the participants in this study were volunteers; as such, the number of potential participants was limited. For this reason, it was not possible to create a directly comparable control group, and so we used a pretest-posttest design (Bernard, 2011). Two surveys were administered to participants. The pretest was administered at the start of the project during the first group meeting (February 2017), after the citizen scientists had agreed to participate but prior to receiving in-depth instruction on groundwater concepts. The posttest was administered at the conclusion of the project, once all data had been collected and turned in to the project scientists (May 2017). All the participants completed the pretest during the initial meeting, but because several participants were not able or willing to attend the final meeting, some of the posttests were administered and returned by email or the regular postal service.

Other researchers have emphasized the importance of using standardized and widely used survey instruments that will allow for comparison of data collected in various citizen science studies as well as national survey efforts (Brossard et al., 2005; Dickinson and Bonney, 2012). While the authors agree with Brossard et al. (2005: p.1103) that survey instruments designed for national random samples may not be completely suitable for a project such as this in which participants are volunteers and, therefore, self-selected, the authors wanted to contribute to efforts to produce comparable data. For this reason, two widely-used instruments to measure participants' attitudes toward science and attitudes toward the environment were employed in the pretest and posttest surveys (MATOSS and NEP scales, see below). Other sections of the surveys were developed specifically for this study.

Knowledge of hydrologic concepts was assessed with 21 multiple choice questions (Supplementary materials, Table SM1) that were developed collectively by the study's lead scientists and pilot tested with a small sample of students ($n = 10$) at East Carolina University.

This section of the survey was designed to measure participants' knowledge of hydrology in general, stormwater management practices, the potential effects of SLR, and their knowledge of groundwater systems specific to Bogue Banks. The knowledge test questions were the same on the pretest and posttest, and they all addressed concepts or facts that were presented to participants during the project's initial training workshop and reinforced via in-person meetings or other communications throughout the project's duration.

Attitude toward science was assessed with a modified version of the National Science Foundation's attitude toward organized science scale (ATOSS) (National Science Board, 1996). Previous citizen science studies have used a modified version of this scale (MATOSS) (Brossard et al., 2005; Crall et al., 2012), and the authors calculated participants' overall MATOSS scores in a similar manner. However, because the survey developed for this study included six items from the ATOSS (Supplementary materials, Table SM2), MATOSS scores for the participants in this study range from -12 (strong negative attitude toward science) to 12 (strong positive attitude toward science). Identical items were used on the pretest and the posttest.

Attitude toward the environment were assessed using a subset of the new environmental paradigm scale (Supplementary materials, Table SM3), originally developed in 1978 (Dunlap and Van Liere, 1978) and revised as the new ecological paradigm (NEP) scale (Dunlap et al., 2000). It is one of the most commonly used scales to measure environmental attitudes, and has previously been used in other citizen science studies (e.g., Brossard et al., 2005; Crall et al., 2012). The survey developed for this study included 8 items from this scale and, following common practice of the use of this scale, participants' overall scores range from 1 to 5, reflecting the mean of their responses to each item (Hawcroft and Milfont, 2010). Higher NEP scores indicate an ecocentric orientation reflecting commitment to the preservation of natural resources, and lower NEP scores indicate an anthropocentric orientation reflecting commitment to exploitation of natural resources. Identical items were used on the pretest and the posttest.

Additional questions on the survey asked participants about their perceptions of and beliefs about flooding on Bogue Banks and climate change more generally. These questions varied in format, including both closed- and open-ended questions. Again, the same questions were included on the pretest and posttest (Tables 2 – 4). The pretest also contained items that were not part of the posttest, including questions about demographics and other participant characteristics, such as place of residence, previous participation in a citizen science project, and motivations for volunteering. The posttest also included items that were not on the pretest, including questions for evaluating the project and soliciting feedback from participants regarding their experiences as citizen scientists.

2.4 Data analysis

Survey responses were statistically analyzed using either a paired t-test or the Wilcoxon signed-rank test (depending on data characteristics, such as distribution normality) in the commercially available SPSS software package. Because this study is focused on evaluating the extent to which participation in the citizen science project impacted knowledge and attitudes, those analyses are limited to the number of participants who completed both the pretest and posttest (n = 20).[1] Since small sample sizes and participant drop-out is common in pretest-posttest designs, including those involving citizen scientists (Druschke and Seltzer, 2012; Johnson et al., 2014), data was also collected via focus groups during the final project meeting. Focus groups were recorded, then analyzed for themes. These results are used to augment the results from the survey data.

3. RESULTS

3.1 Response rates and participant characteristics

A total of 31 citizen scientists participated at least partially in the study by attending one of the groundwater monitoring training workshops, taking water level measurements, and completing the pretest survey. However, as mentioned previously, because only 20 participants completed the posttest survey (64.5% response rate), the results reported here are limited to that sample.

Participants represented a wide range of ages; 35% of participants were under the age of 30, 20% were between the ages of 31 and 50, and 40% were aged 51 and older (5% did not answer this question). About two thirds of the citizen scientists who completed the project were female. An overwhelming majority of the participants reported their ethnicity as white (95 percent), while the remaining five percent identified as Black/African American. The participants were also highly educated, with 80 percent reporting a credential beyond a high school diploma or General Education Diploma. When asked if they had been involved with environmental groups in any capacity, 40% of the citizen scientists reported that they had.

Given the seasonal shifts in population on Bogue Banks, the residency pattern of the citizen scientists was evaluated. The majority (65%) of participants were full-time residents of Bogue Banks; however, given the seasonality of Bogue Banks' population, 15% were part-time residents and 20% traveled from surrounding areas to participate in the project. Participants were also asked about their employment status, and a significant number of the citizen scientists were retirees (40%), while the second largest group reported being employed full-time (30%).

3.2 Knowledge of hydrologic concepts

On the pretest knowledge questions, participants answered an average of 14.55 questions correctly out of 21 (about 69.3%). On the posttest, the mean score increased to 16.50 (about 78.6%) (Table 1). A paired t-test indicated this difference in mean scores was statistically significant (Table 1). These results suggest that participants did increase their knowledge of hydrologic concepts by participating in the project.

[1] Although it is not described in detail in this manuscript, we did look for potential differences between those participants who completed both the pretest and posttest (n=20) and those who only completed the pretest (n=11). Non-parametric tests did not find statistically significant differences in terms of gender (p=.449), age (p=1.000), residency (p=.405), MATOSS score (p=.341), or NEP score (p=.845).

3.3 Attitudes toward science

MATOSS scores for the participants in this study could range from -12 (strong negative attitude toward science) to 12 (strong positive attitude toward science). On the pretest, the mean score was 5.85, indicating a fairly positive attitude toward science. On the posttest, the mean score was 5.70, and a paired t-test indicated this difference was not statistically significant (Table 1). This suggests that participants' attitudes toward science did not change by participating in the project.

3.4 Attitudes toward the environment

Participants' mean NEP score on the pretest was 3.52 and 3.43 on the posttest, indicating a slightly ecocentric orientation. Although there was a slight decrease in the mean score, a paired t-test indicated this difference was not significant (Table 1). This suggests that participants' attitudes toward the environment did not change by participating in the project.

3.5 Perceptions of threats of and impacts from flooding on Bogue Banks

The results of Wilcoxon signed-ranks tests comparing participant responses on the pretest and posttest for each item indicate that there was little change in participants' perceptions of threats from flooding on Bogue Banks from the pretest to the posttest, and none of the changes were statistically significant (Table 2).[2] Nearly 90% of participants believed that the flood intensity and frequency on Bogue Banks would increase in the next 50-100 years. Although a large proportion of participants (85%) responded that they were concerned about flooding on Bogue Banks, smaller percentages reported that flooding impacts their physical and/or mental health (20%) or that it impacts them financially (30%). Much larger percentages of respondents felt that flooding has negative economic impacts on Bogue Banks (75%), and negative environmental impacts (70%).

3.6 Perceptions of climate change

The results of Wilcoxon signed-ranks tests comparing participant responses on the pretest and posttest for each item also indicate that there was little change in participants' perceptions of climate change from the pretest to the posttest, and none of the changes were statistically significant (Table 3).[3] Two-thirds of participants responded that the issue of climate change is important to them personally, and 75% reported they were at least "somewhat worried" about climate change. While all participants indicated that they knew at least "a little" about climate change, only 10% reported that they knew "a lot." Regarding the extent of consensus among scientists regarding climate change, 70% reported they felt that "most scientists think climate change is happening," while 20% believe that there is "a lot of disagreement among scientists."

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[2] Because none of the changes were found to be statistically significant, for clarity, the results described here reflect pretest responses. For the posttest results, see Table 2.
[3] Because none of the changes were found to be statistically significant, for clarity, the results described here reflect pretest responses. For the posttest results, see Table 3.

The majority of participants (70%) reported that they think climate change is “caused mostly by human activities” (as opposed to natural changes in the environment), and most (70%) believe that while humans could reduce climate change, it is unclear at this point if we will do so. Participants were also asked a series of questions regarding the extent to which they believed climate change will be a problem in the future at various scales (i.e., the world, Bogue Banks, you and your family) if nothing is done to reduce it. While 90% reported they felt it is a serious problem (i.e., “somewhat serious” or “very serious”) for the world, smaller percentages reported they felt it is a serious problem for Bogue Banks, or for them and their families (85% and 70%, respectively).

3.7 Perceptions of relationship among flooding, sea-level rise, and climate change

Participants were asked to indicate whether they agreed or disagreed with a series of statements about relationships among flooding on Bogue Banks, SLR, and climate change (Table 4). Comparison of pretest and posttest responses to these items reveals that for each statement, a slightly larger percentage of participants agreed after participating in the project than before. These differences, however, were not found to be statistically significant using Wilcoxon signed-ranks tests.

4. DISCUSSION

Results of the study suggest that participation in the Bogue Banks Coastal Groundwater and Stormwater Watch citizen science project increased knowledge of hydrological concepts. Because the scientific content involved in this study was quite complex (e.g., hydrogeology and the water cycle), this significant increase in knowledge is promising, particularly for water-related fields. Whereas previous studies documenting knowledge increases have examined knowledge changes regarding the biology and behavior of specific species (Brossard et al., 2005; Evans et al., 2005) and species identification (Jordan et al., 2011; Lentijo and Hostetler, 2013), results of this study indicate that participation in citizen science can also increase knowledge of complex physical processes such as groundwater-surface water interactions.

This is also encouraging in that the time the citizen scientists spent on learning hydrologic concepts and how to take water level measurements in wells was relatively short, occurring during a two-hour period. As described above, during the workshop and training session, however, citizen scientists manipulated and interacted with physical groundwater models in small groups, and were led through a related hypothesis-testing process by the authors. Additionally, the citizen scientists received hands-on, one-on-one instruction at one of the installed groundwater wells to ensure proper water level measurement. This experiential approach to learning, followed by the three-month data collection period during which they used and refined their newly acquired measurement skills and reinforced the underlying knowledge, likely contributed to increased scores on the knowledge test.

Similar to Brossard et al. (2005), results of this study do not indicate a significant change in participants’ MATOSS or NEP scores as a result of participating in the citizen science project. The citizen scientists’ mean MATOSS scores (5.85 on pretest, 5.70 on posttest) indicate a positive attitude toward science, and their average NEP scores (3.52 on the pretest and 3.43 on the posttest) indicate an ecocentric orientation. These scores are not surprising, as previous research has demonstrated that science volunteers tend to already hold pro-science and pro-environment beliefs (Price and Lee, 2013). Nevertheless, these results may have important implications for water management in that individuals with an ecocentric orientation may be more likely to support practices that mimic nature, such as the use of rain gardens or wetland restoration, whereas those with an anthropocentric orientation may be more supportive of practices that utilize manmade technological solution, such as installing pumps to lower the water table.

The results of this study also do not indicate significant changes in participants' perceptions of climate change between the pretest and the posttest. When compared with national surveys of the general American public (NSB, 2016; RFF, 2015), however, the study participants reported greater concern for climate change and the associated impacts. For example, while 60% of this study's participants responded that climate change was either "extremely important" or "very important" when asked its importance to them personally, results from a nationally representative survey conducted by the Yale Program on Climate Change Communication found that only 26% of respondents reported the same level of importance (Leiserowitz et al., 2016). Another representative sample study, Stanford University's 2015 National Global Warming Study, found that 45% of respondents indicated that they felt the issue was extremely or very important (RFF, 2015).[4] The participants of the current study also reported being more worried about climate change than a nationally representative sample. While 75% of the current study's participants responded that they were "very worried" or "somewhat worried" about climate change, only 58% of respondents to the Yale study reported the same level of concern (Leiserowitz et al., 2016). It is also interesting to note that a much greater percentage of respondents from this study perceived that most scientists think climate change is happening (70% in this study and 48% in Leiserowitz et al., 2016), and a greater percentage also believe climate change is caused mostly by human activities as opposed to natural environmental changes (70% and 20% in this study, respectively; 53% and 34% in Leiserowitz et al., 2016). Although these data are not directly comparable, they do suggest that those individuals who volunteered for this citizen science project were already highly concerned about climate change and the associated impacts prior to their participation in the study.

The results from this study do not indicate significant changes in participants' perceptions about relationships among flooding on Bogue Banks, SLR, and climate change; however, it should be noted that the authors purposefully did not emphasize the project's applicability to climate change related issues. Because of the political and controversial nature of the topic in North Carolina, and the desire to recruit as many citizen scientist volunteers as possible, the project's foci on characterizing the island's water table, assessing the proportion of land on Bogue Banks impacted by groundwater and marine inundation, and assessing the reliability of water level measurements taken by citizen scientists were emphasized. Additional studies that include specific instruction on the relationships among these phenomena could result in participants' increased understanding.

Importantly, the study results support claims that citizen science plays an important role in linking members of the public to environmental management by exposing them to local

[4] Question wording was slightly different in that the current study asked about perceptions of "climate change," whereas the 2015 National Global Warming Study asked about "global warming."

environmental conditions and increasing awareness of associated problems and the related potential management or policy options (Jordan et al., 2011; McKinley et al., 2017). Discussion among the authors and this study's citizen scientists frequently focused on how the data collected could be transmitted to local policymakers and used to inform management decisions. Additionally, the results highlight the relationship between participation in citizen science projects and the dissemination of information related to the topic of study. During focus group interviews, the majority of study participants described how they used a variety of methods to share their experiences as citizen scientists with friends and family, acquaintances, and fellow community members, including the use of social media as well as more traditional means of communication, such as face-to-face conversation. Many described they discussed not only *what* they were doing (i.e., taking water level measurements), but also *why* they had volunteered to participate.

Results also suggest that the public is interested in participating in hydrologic studies in their communities, but the project must be relevant to the citizen scientists to generate significant interest. The citizen scientists who were the most engaged and active in the project (e.g., took additional measurements beyond what they were asked) indicated during focus groups that they participated because they were personally concerned with the issues of flooding, SLR, and climate change, on both a local and global scale. They felt that by participating in the project, they were able to actively contribute to the scientific and management efforts geared toward increasing understanding of these issues and how to adapt to these environmental changes. Water managers and professional scientists could therefore leverage this resource to meet the challenges of providing long term groundwater data over large spatial scales. However, participants also emphasized the need for scientists to continually engage with citizen scientists and active community members after studies end, and/or between research efforts. They indicated that such continued engagement is critical for citizen scientists and volunteers to feel connected to the researchers, the topic of study, and the long-term implications of their involvement.

5. SUMMARY AND CONCLUSIONS

This paper presents the results of a study that involved citizen scientists in the monitoring of groundwater levels and subsequent characterization of the water table on Bogue Banks, North Carolina. The data and results aim to fill the gap in the literature regarding relationships between citizen science, scientific knowledge, and environmental attitudes in a hydrological context. The results suggest that participation in the citizen science project increased knowledge of hydrological concepts, which is particularly promising since this is the first study to examine this connection in regards to physical processes such as groundwater-surface water interactions. Further these results emphasize the importance of the hands-on, experiential learning opportunities that citizen science projects often provide.

Although significant changes in participants' attitudes toward science or the environment were not found, the results support those from previous studies (e.g., Price and Lee, 2013) which demonstrate that science volunteers tend to already hold pro-science and pro-environment beliefs. These results may have important implications for the types of water management strategies citizen scientists are likely to support. Similarly, while this study's results do not indicate significant changes in participants' perceptions of climate change as a result of participation in the citizen science groundwater study, when the data are compared with those from nationally representative samples, they indicate that those individuals who volunteered for this citizen science project were already highly concerned about climate change and the associated impacts prior to their participation.

The results suggest that citizen science projects can play an important role in increasing participants' knowledge of hydrological concepts, but that long-term participation by volunteers is a significant challenge. The most committed, active, and engaged citizen scientists in this study were those individuals who were concerned about flooding, SLR, and climate change prior to their involvement, and who viewed their participation as a way to make an important contribution to the related scientific and management concerns. Moreover, these individuals expressed strong interest in continuing their engagement with scientists, and helping to translate results into locally-relevant policy recommendations. Water resources scientists and managers interested in developing management solutions supported by local level observations and supported by community members should, therefore, consider using a citizen science approach as a first step toward increasing knowledge of hydrological concepts, increasing awareness of water management issues and solutions, and identifying highly-committed community members interested in cultivating long-term working relationships with researchers.

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TABLES

	Pretest mean	**Posttest mean**	***t***	***p***
Knowledge test	14.55	16.5	4.33	0.000
MATOSS	5.85	5.7	0.269	0.791
NEP	3.52	3.43	1.2	0.245

Table 1. Comparison (via paired t-tests) of mean scores for knowledge test, MATOSS, and NEP on pretest and posttest (n = 20).

Question	Response	Pretest (%)	Posttest (%)	*p*
In the next 50-100 years, how do you think flood intensity and frequency on Bogue Banks will change?	It will become worse; Bogue Banks will flood more frequently and the flooding will become more significant	89.5	85.0	0.317
	It will stay the same	0.0	5.0	
	It will improve; Bogue Banks will flood less frequently and the flooding will be less significant	10.5	10.0	
I am concerned about flooding on Bogue Banks.	Disagree	5.0	5.0	0.527
	Neither agree nor disagree	10.0	20.0	
	Agree	85.0	75.0	
Flooding impacts my physical and/or mental health.	Disagree	55.0	55.0	0.792
	Neither agree nor disagree	25.0	20.0	
	Agree	20.0	25.0	
Flooding impacts me financially.	Disagree	50.0	40.0	0.450
	Neither agree nor disagree	20.0	25.0	
	Agree	30.0	35.0	
Flooding has negative economic impacts on the Bogue Banks community.	Disagree	5.0	0.0	0.705
	Neither agree nor disagree	20.0	25.0	
	Agree	75.0	75.0	
	Disagree	5.0	5.0	0.705

Flooding has negative environmental impacts on Bogue Banks.	Neither agree nor disagree	25.0	30.0
	Agree	70.0	65.0

Table 2. Comparison (via Wilcoxon signed-ranks tests) of mean ranks on pretest and posttest questions regarding perceptions of threats from flooding on Bogue Banks (n = 20).

Question		**Pretest (%)**	**Posttest (%)**	***p***
How important is the issue of climate change to you personally?	Extremely important	40.0	40.0	0.414
	Very important	20.0	10.0	
	Somewhat important	30.0	40.0	
	Not too important	10.0	10.0	
	Not at all important	0.0	0.0	
How worried are you about climate change?	Very worried	45.0	50.0	0.083
	Somewhat worried	30.0	35.0	
	Not very worried	25.0	15.0	
	Not all all worried	0.0	0.0	
How much do you feel you know about climate change?	A lot	10.0	10.0	0.705
	A moderate amount	60.0	55.0	
	A little	30.0	35.0	
	Nothing	0.0	0.0	
Which is closest to your view?	Most scientists think climate change is happening	70.0	68.4	0.705
	There is a lot of disagreement among scientists	20.0	15.8	
	Most scientists think climate change is not happening	0.0	0.0	

	Don't know enough to say	10.0	15.8	
Assuming climate change is happening, do you think it is:	Caused mostly by human activities	70.0	63.2	0.655
	Caused mostly by natural changes in the environment	20.0	31.6	
	Neither, because climate change isn't happening	0.0	0.0	
	Other	10.0	5.3	
Which is closest to your view?	Humans can reduce climate change, and we are going to do so successfully	10.0	5.6	0.317
	Humans could reduce climate change, but its unclear at this point whether we will do what's needed	70.0	83.3	
	Humans could reduce climate change, but people aren't willing to change their behavior, so we're not going to	10.0	5.6	
	Humans can't reduce climate change, even if it is happening	10.0	5.6	
	Climate change isn't happening	0.0	0.0	
If nothing is done to reduce climate change in the future, how serious of a problem do you think it will be for the world?	Very serious	65.0	52.6	0.564
	Somewhat serious	25.0	42.1	
	Not so serious	10.0	5.3	
	Not serious at all	0.0	0.0	

If nothing is done to reduce climate change in the future, how serious of a problem do you think it will be for Bogue Banks?	Very serious	55.0	57.9	0.180
	Somewhat serious	30.0	36.8	
	Not so serious	15.0	5.3	
	Not serious at all	0.0	0.0	
If nothing is done to reduce climate change in the future, how serious of a problem do you think it will be for you and your family?	Very serious	45.0	36.8	0.257
	Somewhat serious	25.0	47.4	
	Not so serious	25.0	15.8	
	Not serious at all	5.0	0.0	

Table 3. Comparison (via Wilcoxon signed-ranks tests) of mean ranks on pretest and posttest questions regarding perceptions of climate change (n = 20).

Question		Pretest (%)	Posttest (%)	*p*
Climate change contributes to flooding experienced on Bogue Banks	Disagree	0.0	5.0	0.564
	Not sure	63.2	55.0	
	Agree	36.8	40.0	
	Climate change is not happening	0.0	0.0	
Climate change is related to sea level rise.	Disagree	0.0	0.0	0.157
	Not sure	36.8	25.0	
	Agree	63.2	75.0	
	Climate change is not happening	0.0	0.0	
Sea level rise is related to coastal flooding.	Disagree	0.0	0.0	1.000
	Not sure	16.7	15.8	
	Agree	83.3	84.2	
	Climate change is not happening	0.0	0.0	
Climate change is a threat to Bogue Banks.	Disagree	0.0	0.0	1.000
	Not sure	31.6	30.0	
	Agree	68.4	70.0	
	Climate change is not happening	0.0	0.0	

Table 4. Comparison (via Wilcoxon signed-ranks tests) of mean ranks on pretest and posttest questions regarding perceptions of relationships among flooding, sea level rise, and climate change (n = 20).

SUPPLEMENTARY MATERIAL

Knowledge Question	% Correct (Pretest)	% Correct (Posttest)
Layers of rock or sediment that transmit groundwater in sufficient quantities to meet demand are called __________.	70.0	95.0
Which of the following reservoirs contains the most water?	55.0	65.0
Which of the following combinations make for the best groundwater reservoir?	40.0	30.0
The boundary between the saturated zone and the unsaturated zone is called the _____________.	80.0	80.0
What percentage of Earth's liquid freshwater is in the form of groundwater?	10.0	30.0
Which of the following is not a factor that will influence infiltration of groundwater?	55.0	95.0
How will the water table of an aquifer close to the earth's surface respond during a wet spring season?	85.0	95.0
When there is a drought, how will the depth to the water table respond over time?	60.0	70.0
What is porosity?	75.0	85.0
What is permeability?	75.0	90.0
Which environmental issue will most commonly affect aquifers in coastal or island areas?	50.0	65.0
What is infiltration?	85.0	85.0
The ___________ describes the path water takes as it moves between the land, the ocean, and the atmosphere.	95.0	90.0
How would sea level rise impact the elevation of the water table in an aquifer near the earth's surface?	75.0	85.0
What is the major source of drinkable water on Bogue Banks?	40.0	65.0
Which of the following removes water from roads and the nearby ground surface?	80.0	80.0

How would paving over a natural area where grass once grew impact stormwater runoff?	85.0	90.0
It is reasonable to expect that stormwater flooding during extreme events, such as hurricanes, ________________.	90.0	95.0
It is reasonable to expect that stormwater flooding during events that occur many times per year, such as summer afternoon thunderstorms, ________________.	70.0	70.0
Which of the following practices can be used to reduce the potential of stormwater flooding?	80.0	95.0
What impact would sea level rise have on stormwater flooding due to seawater beginning to fill stormwater pipes?	100.0	95.0

Table SM1. Correct responses to hydrogeologic concepts knowledge test multiple choice questions (*n* = 20).

Because of science and technology, there will be more opportunities for the next generation.
Science makes our way of life change too fast.
Science and technology are making our lives healthier, easier, and more comfortable.
Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the federal government.
Science is too concerned with theory and speculation to be of much use in making concrete government policy decisions that will affect the way we live.
The benefits of scientific research are greater than any harmful effects.

Table SM2. Items included in the MATOSS scale. Response options were: strongly disagree, disagree, neither agree or disagree, agree, strongly agree.

When humans interfere with nature it often produces disastrous consequences.
Humans have the right to modify the natural environment to suit their needs.
Human ingenuity will insure that we do not make the Earth unlivable.
The Earth has plenty of natural resources if we just learn how to develop them.
Despite our special abilities, humans are still subject to the laws of nature.
The so-called "ecological crisis" facing humankind has been greatly exaggerated.
The Earth is like a spaceship with very limited room and resources.
If things continue on their present course, we will soon experience a major ecological catastrophe.

Table SM3. Items included in the NEP scale. Response options were: strongly disagree, disagree, neither agree or disagree, agree, strongly agree.