CITIZEN SCIENCE: IS IT WORTH YOUR TIME?

by

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ABSTRACT OF DISSERTATION

This dissertation investigated citizen science, a tool that connects the public to the scientific community through research-based projects and education campaigns. Benefits include volunteers adding data to long-term data sets and improved scientific literacy among the public. Oftentimes, there is trepidation among scientists, managers, and decision makers when it comes to citizen science. These concerns include the integrity of volunteer data and whether citizen science projects are promoting scientific literacy. To investigate these concerns, this dissertation focused on three major areas: [1] the integrity of long-term water quality data produced by volunteers of the Albemarle-Pamlico National Estuary Partnership's Citizens' Monitoring Network (APNEP-CMN) when compared to acquired water quality data from government projects, [2] using cultural consensus theory to estimate cultural beliefs of water quality among different cultural groups (citizen science volunteers that focused on water quality monitoring, water quality professionals, water quality educators, fishers, and individuals with no experience in water quality), and [3] application of social theories, education tools, and communication models to improve the design

and implementation of education campaigns. Results suggested [1] significant differences (P-value < 0.05) in water quality data for most variables (water temperature, water depth, secchi depth, dissolved oxygen, pH, and salinity) among monitoring sites within a similar region (lower, middle, or upper) and the same season (fall, spring, summer, or winter) in the Tar-Pamlico and Albemarle regions. These results were not in support of my first hypothesis, which stated that water quality data among monitoring sites within the same region will produce similar results (P-value > 0.05) although significant differences (P-value < 0.05) were expected for dissolved oxygen and salinity due to more involved measuring protocols. The only exception was the 1991-1993 block of the Albemarle region. My second hypothesis stated that APNEP-CMN volunteers with monitoring sites in close proximity to one another will produce similar water quality data (P-value > 0.05); results were not in support of this hypothesis. Differences among volunteer and government data were perhaps a result of different monitoring equipment, geographic location, local precipitation, and volunteer training protocols. [2] Results from the cultural consensus analysis suggested there was agreement within and across the cultural groups after surveying 285 respondents on a variety of water quality topics. Volunteers of citizen science and water quality educators had the strongest consensus within their groups while water quality professionals had the least. Mean cultural competencies were also greater among volunteers and educators. No significant differences were found among the mean cultural competencies between the groups; the only exception was among educators and individuals with no experience in water quality. Results suggested that volunteers may be receiving their information primarily from educators who are commonly involved with citizen science projects. Discrepancies among the other groups may have been associated with differences in education and professional backgrounds in water quality. There was 92 percent accordance among the cultural groups and survey statements. Eight percent discordance was

observed for the following survey topics: (a) time of day fluctuations, (b) water quality appearance, (c) pH, and (d) storm events. Overall, it remains unclear whether citizen science is promoting scientific literacy based on these results. Improved volunteer training and education campaigns were mentioned as recommendations to strengthen the integrity of volunteer data and knowledge of water quality. [3] These recommendations introduced the third area of this dissertation, which focused on the application of social theories, education tools, and communication models found in the primary literature to improve education campaigns. Successful campaigns are dependent on the careful framework of planning, implementation, and evaluation; each of these framework components were discussed. The potential for citizen science to change how the public perceives water quality and other environmental issues continues to grow. With increasing human population and the continued strain on our natural resources, it is imperative that educators and scientists begin to ruminate how citizen science might benefit their community.

CITIZEN SCIENCE: IS IT WORTH YOUR TIME?

A Dissertation

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Doctorate of Philosophy, Coastal Resources Management

Primary Concentration in Coastal and Estuarine Ecology

Secondary Concentration in Coastal Geosciences, Social Science, and Coastal Policy

by

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CHAPTER 1

Introduction to dissertation

"I am constantly amazed at the resiliency and life cycles of the wetlands. The area is always changing with varying conditions in weather and tides. It is rewarding to take it all in and know that I am contributing a piece to a larger puzzle of research."

- Michael Halminski
  Citizen science volunteer

For the past ten years, Bill Dunn would get up during the early morning hours on the first and second Tuesdays of the month to visit the community clubhouse along Arrowhead Beach in Chowan County, North Carolina. He would join other members of his environmental team and enjoy conversation with a cup of coffee before grabbing the sampling buckets and heading to the outside pier to collect water from the Chowan River. Bill and his team would measure water quality variables such as dissolved oxygen, pH, and salinity to gauge water quality from their water samples at their specific location. Bill previously worked in water and waste while living in Virginia. When he moved to Chowan County, the presence of a dye plant located on the Chowan River caught his attention. His motivation to join a citizen science project was the curiosity to whether the outflow from the nearby dye plant was impacting the health of the river. After ten years with the citizen science project, Bill concedes to having a better understanding of water quality and can easily interpret the data that his team collects, which is useful in case of environmental emergencies. However, Bill has not stopped there. He is now involved in joint management efforts with the North Carolina Division of Water Resources to safely control the invasive aquatic plant, Hydrilla *(Hydrilla verticillata)*, which is negatively impacting areas of the Chowan River. Without citizen science, Bill and his team might not have had the opportunity to be involved with water quality monitoring and the scientific community. Their contributions

include both long-term water quality data and a public eye's view on current and important environmental issues.

What is citizen science?

Citizen science is a tool that connects the public to the scientific community with the goal of expanding scientific knowledge and literacy (Bonney et al. 2009). Many state, federal, and non-profit groups have implemented citizen science projects into their annual work plans and budgets. These projects involve volunteers who contribute scientific data that focuses on the program's interest or mission such as water quality monitoring, bird watching, invasive species, and species presence or absence.

In addition to data collection, most citizen science projects have an education component. This component involves the design and implementation of education campaigns to various interest groups. Not only do these educational campaigns help project coordinators recruit volunteers but they can also be used to gauge public perceptions concerning environmental issues and improve scientific literacy. These education campaigns may include formal PowerPoint presentations, hands-on activities, discussion groups, or activities from published curriculum guides that carry specific learning outcomes such as water quality.

Citizen science provides the opportunity for scientists to seek assistance from the public by actively collecting data towards real scientific investigations. With limited time and money, scientists cannot always collect data across a wide geographic range. In return, volunteers help fill in potential data gaps for geographic regions not routinely monitored by scientists. Volunteers also have the opportunity to learn more about the scientific process, communicate with scientists, and connect with nature. Michael Halminski from Dare County, North Carolina became involved in citizen science projects through network connections made from his time working as an oyster

gardener. For the past ten years, Michael has monitored water quality in Pamlico Sound near Cape Hatteras. His motivation to stay involved with these projects was to maintain a connection with the environment and the opportunity to assist scientists and learn from them. He described his walks through the salt marsh to his monitoring location very peaceful and relaxing.

Statement of problem

While citizen science offers many benefits to both scientists and volunteers, there are some problems that should be addressed. In 2009, the United States Environmental Protection Agency identified over 900 citizen science projects in the United States (Loperfido et. al. 2010). Despite huge investments to fund these projects and the time put forth by volunteers, there is hesitation to use volunteer data for science-based decisions. This hesitancy creates two problems: (1) data that are collected from volunteers will carry no extended value and (2) reluctance can lower motivation from volunteers if it becomes known to them. Most volunteers join these projects because they have vested interests in the environment and want to contribute their time and efforts to help. By not using volunteer data for its intended purpose, it creates a disservice to the volunteers. Research efforts were needed to better understand the integrity of volunteer data in order to identify areas of weakness for the improvement of volunteer training protocols.

Another concern is whether citizen science projects promote scientific literacy through volunteer efforts and education campaigns. If volunteers are not properly trained to measure and interpret water quality data, then it can potentially lead to erroneous data. Project coordinators should be encouraged to analyze volunteer data on a routine basis to identify potential errors and investigate why they might be occurring. For education campaigns aimed to recruit volunteers or educate the public, communication skills, education tools, and social theories should be explored and incorporated into the campaign design to help improve learning outcomes. Research efforts

were needed to better understand what a population or region might know about a certain environmental issue. These efforts helped identify areas of weakness that should be better integrated in volunteer training and learning objectives of education campaigns.

From my own personal experiences leading a citizen science project for five years, external forces such as budgetary restraints can also pose problems for citizen science projects. If project costs outweigh the benefits, then the likelihood for that project to be removed from the annual budget or work plan is heightened. By removing projects that aim at collecting long-term data, it negates invested time, efforts, and costs. Volunteer data that are being utilized by the scientific community along with evidence that supports scientific literacy among volunteers and the public can help improve project visibility to those who might decide their fate.

Although there are a number of concerns associated with citizen science projects, there are successful cases. A recent study (Loperfido et. al. 2010) showed that nutrient data (nitrogen and phosphorous) collected from volunteers met water quality criteria of the United States Environmental Protection Agency when these data were adjusted for errors and biases, thus proving the potential of volunteer data.

The Cornell Lab of Ornithology (CLO) has used citizen science to assist with their research for decades. Bonney et al. (2009) listed ten active citizen science projects from CLO. Data from these projects have been featured in several media outlets in addition to being used by managers and policy makers as decision support tools. Bonney et al. (2009) has described CLO's model for developing and implementing a citizen science project, which begins with choosing a scientific question, forming an interdisciplinary team to run the project, recruiting/training volunteers, disseminating analyzed data, and measuring outcomes. CLO has encouraged using this model for developing and maintaining citizen science projects.

The overarching goal of this dissertation was to investigate the integrity of volunteer data and to provide evidence whether citizen science is promoting scientific literacy among volunteers and the public. Citizen science has the potential to be seen as valuable additions to government and non-profit programs by offering long-term data that can contribute to multiple scientific investigations and foster scientific literacy. The following sections introduces my research questions and briefly describes the subsequent chapters of this dissertation.

RESEARCH QUESTIONS

Chapter two

1. How similar are water quality data when measured by APNEP-CMN volunteers and water quality professionals from government projects?
2. Do APNEP-CMN volunteers with sites in close proximity to each other produce similar results in water quality data?
3. What factors might contribute to any observed discrepancies in water quality data among the sites?

Chapter three

4. What are the cultural beliefs concerning water quality for citizen science volunteers that conduct water quality monitoring and how might their beliefs be similar, or different, to other cultural groups such as water quality professionals, water quality educators, fishers (commercial and recreational), and individuals with no experience in water quality?
5. Is there consensus among the individuals of each cultural group? Does this change when cultural groups are combined?

6. Are cultural competencies among the different cultural groups significant?
7. Was there evidence that citizen science promotes scientific literacy among volunteers?

Chapter four

8. What social theories, education tools, and communication models could be used to improve education campaigns?

CHAPTER OVERVIEW AND BROADER IMPACTS

Chapter two

To investigate data integrity, the Albemarle-Pamlico National Estuary Partnership's Citizens' Monitoring Network (APNEP-CMN) was used as a case study. APNEP-CMN is a long-running citizen science project that focuses on water quality monitoring in the Albemarle-Pamlico (A-P) estuarine system.

Volunteer data can be useful towards pilot studies, scientific investigations, and decision-making by managers and policy-makers. Volunteer data in select regions of the A-P estuary were compared to water quality data measured by professionals that belonged to various government projects. Two hypotheses were investigated: (1) water quality data among monitoring sites within the same region will produce similar results (P-value > 0.05) although significant differences (P-value < 0.05) are expected for dissolved oxygen and salinity due to more involved measuring protocols; and (2) APNEP-CMN volunteers with monitoring sites in close proximity to one another will produce similar water quality data (P-value > 0.05). Various statistical methods such as the one-way ANOVA, Kruskal-Wallis, and Mann-Whitney U tests were conducted to investigate these hypotheses.

Identified strengths and weaknesses for measured water quality variables were described to assist in the improvement of volunteer training protocols and methodologies. Monitoring equipment was also investigated using separate water quality data from East Carolina University to better understand how different equipment might influence differences in water quality data.

Chapter three

Cultural consensus theory was used to estimate cultural beliefs, or knowledge, of water quality among different cultural groups. Water quality knowledge is defined as the general characteristics and behaviors of water quality variables and how it affects aquatic life and the surrounding environment; mechanics on how each water quality variable is measured were not included. Data were collected through an online survey that included statements on various water quality topics. Respondents of the survey identified with one of the following cultural groups: (1) citizen science volunteers that focused on water quality monitoring, (2) water quality educators, (3) water quality professionals, (4) fishers [commercial and recreational], and (5) individuals with no experience in water quality. In addition, questions that related to demographics, previous experiences, and expertise in water quality were included in the survey.

Cultural consensus analysis and one-way ANOVAs were used to investigate three hypotheses: (1) each cultural group will display consensus; when all cultural groups are combined into one group, there will be no consensus; (2) volunteers of citizen science that focus on water quality monitoring will display a stronger consensus when compared to the cultural group that has no experience with water quality; and (3) there will be significant differences among the mean cultural competencies of the cultural groups. Cultural consensus analysis provided cultural competencies and whether there was consensus within, and across, the cultural groups (Weller 2007). The one-way ANOVA was used to determine if there were significant differences among

the mean cultural competencies of the cultural groups. By using multiple cultural groups with different cultural beliefs of water quality, results determined if citizen science played a role in improving scientific literacy. Results were also able to identify discordance among the different cultural groups and certain water quality survey topics. This information helped identify which water quality topics needed to be discussed during volunteer training and education campaigns. In addition, survey results also provided a glimpse towards public perceptions of water quality that could be beneficial to government, education, and non-profit programs.

Chapter four

In addition to data collection, citizen science typically includes an education component, which involves the design and implementation of education campaigns that help recruit volunteers as well as educate the public. The previous chapters of this dissertation focused on two main areas, (1) the integrity of volunteer data and (2) cultural beliefs of water quality among different cultural groups. Recommendations from these two chapters included improved volunteer training and education campaigns. The purpose of this chapter was to introduce different social theories, education tools, and communication models from the primary literature towards the enhancement of education campaigns. Information mined from the literature should assist scientists, water quality educators, and project coordinators of citizen science. Recommendations based on the literature will aid in promoting environmental stewardship, scientific literacy, recruitment of citizen science volunteers, and integrity of volunteer data.

"Educating the public" is a common phrase heard among scientists when it comes to promoting scientific literacy among the public. A successful campaign is dependent on the careful framework of planning, implementation, and evaluation. Cognitive and social development theories, including knowledge of various learning types, are important in finding target audiences

(Jacobson 1999). Bloom's Taxonomy is a common tool used among educators to develop learning objectives that target certain cognitive abilities (Bloom et al. 1956). Communication models such as the Elaboration Likelihood Model of Persuasion are contingent on the cognitive abilities and motivation of the audience in order to shift attitudes, thus influencing behaviors (Petty and Cacioppo 1981; 1986). These different strategies to improve education campaigns were discussed in the chapter.

Chapter five

The final chapter of this dissertation summarized the results from these different investigations along with listed conclusions and recommendations. Future directions of this dissertation research was also included.

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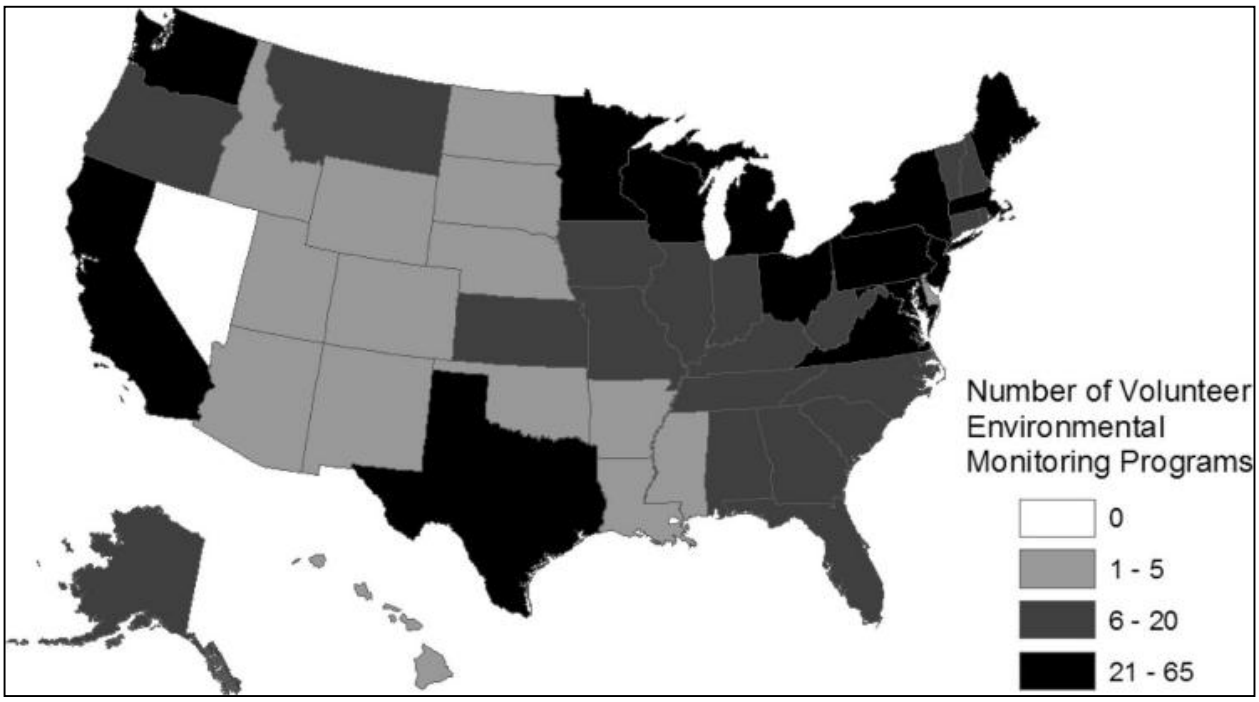
LIST OF FIGURES

Figure 1.


Number of Volunteer Environmental Monitoring Programs
0
1 - 5
6 - 20
21 - 65

CHAPTER 2

Volunteer and the professional: A comparative investigation of data integrity among citizen science and government water quality monitoring projects in the Albemarle-Pamlico estuary

ABSTRACT

Citizen science is a tool that connects the public to the scientific community, which results in contributions to long-term volunteer data sets and improvement in scientific literacy. Often times, there is trepidation concerning the integrity of these data, which consequently makes it nonviable for its intended use. This study investigated the integrity of a long-term water quality data set produced by volunteers of the Albemarle-Pamlico National Estuary Partnership's Citizens' Monitoring Network (APNEP-CMN), a water quality monitoring project initiated in 1988. Using various statistical methods, these volunteer data were compared to multiple government water quality projects managed by professionals in the Tar-Pamlico and Albemarle regions of eastern North Carolina. In some cases, volunteer data were compared to other volunteer data within APNEP-CMN. Two hypotheses were investigated: (1) water quality data among monitoring sites within the same region will produce similar results (P-value > 0.05) although significant differences (P-value < 0.05) were expected for dissolved oxygen and salinity due to more involved measuring protocols; and (2) APNEP-CMN volunteers with monitoring sites in close proximity to one another will produce similar water quality data (P-value > 0.05). Various statistical methods such as the one-way ANOVA, Kruskal-Wallis, and Mann-Whitney U tests were used to investigate differences among volunteer and government data. Results suggested significant differences (P-value < 0.05) in water quality data for most variables (water temperature, water depth, secchi depth, dissolved oxygen, pH, and salinity) among monitoring sites within a similar region (lower, middle, or upper) and the same season (fall, spring, summer, or winter) in the Tar-Pamlico and Albemarle regions. These results were not in support of my first hypothesis although significant differences (P-value < 0.05) were detected for dissolved oxygen and salinity. The only exception was the 1991-1993 block of the Albemarle region, which supported the first hypothesis. Only two

block comparisons in the Albemarle region investigated my second hypothesis – results were not in support of this hypothesis. Differences among volunteer and government data were perhaps a result of different monitoring equipment, geographic location, local precipitation, and volunteer training. Using unpublished water quality data provided by East Carolina University, an independent t-test and one-way ANOVA were conducted to investigate whether different monitoring equipment influenced differences in water quality when measured side-by-side at one location. Results detected no significant differences (Independent t-test, P-value = 0.07, df = 7) among the means for dissolved oxygen when collected by the YSI Model 85 Water Quality Meter and the dissolved oxygen titration/chemical kit manufactured by the LaMotte Company. For pH, results detected significant differences (ANOVA, P-value < 0.01, df = 11) among the means for pH when measured using three types of monitoring equipment: (1) pH colorimetric test kit manufactured by the LaMotte Company, (2) pH Pen Model EX60, and (3) Hydrion pH paper. Recommendations to improve data integrity of volunteer data such as the development of project quality assurance/quality control plans, volunteer training protocols, and project transparency were also discussed.

INTRODUCTION

Millions of dollars are spent each year on citizen science projects. These projects can be described as "a process where concerned citizens, government agencies, industry, academia, community groups, and local institutions collaborate to voluntarily monitor, track, and respond to issues of common environmental concerns" (Whitelaw et al. 2003). In 2009, the United States Environmental Protection Agency identified over 900 of these projects in the United States (Loperfido et al. 2010). Most of these projects have two focus areas: data collection and educational campaigns.

Despite huge investments to fund these projects and the time put forth by volunteers, regulators are hesitant when actually using volunteer data for science-based decisions, thus eliminating its influence on management and policy decisions (Gillett et al. 2011). In addition to data collection, these projects also prove to be a valuable asset for furthering public understanding of general science and increasing environmental awareness through changes in attitudes and behaviors. These ideas can be used to make informed management and policy decisions that may affect their personal lives, community well-being, and national issues (e.g., overfishing, habitat degradation, climate change) (National Science Board 2002). Environmental policy such as the Clean Water and Endangered Species Acts are largely influenced by scientific data and public response to a given concern. Since citizen science projects focus on both data collection and increasing public understanding of environmental issues, this further solidifies the importance of these projects to decision makers if managed successfully.

Citizen science projects focus on a variety of interest areas such as water quality, seagrasses, bird nesting, and sea turtles. For example, the Cornell Lab of Ornithology (CLO) has managed multiple citizen science projects that are related to birds. These projects have brought in

tens of millions of observations made by citizens each year (Bonney et al. 2009). Citizen science projects may focus on one or more interest areas depending on its size, budget, and scope. Most of these projects are housed within federal and state government programs, and also non-profit groups. A coordinator is typically assigned to run these projects. Alternatively, staff members of government agencies or non-profit groups may share responsibilities.

Costs associated with managing citizen science projects can be a challenge. CLO's budget surpasses one million dollars to manage their multiple projects each year. Grants through the National Science Foundation have been a large supporter of CLO's projects. While not all projects come close to a million-dollar budget, sustaining long-term projects is still a challenge since the project itself does not bring in funds to support itself. To combat this, CLO stated they have projects that come with a fee to participate or access to data (Bonney et al. 2009). Apart from CLO, Wiggins et al. (2011) surveyed staff from multiple projects (n = 43) and discovered that expenses were covered mainly from grants, in-kind contributions, and private donations.

Costs aside, there could be other problem areas that threaten these projects such as lack of staff or general disinterest (i.e., not enough volunteers to justify project costs). There is also the critical issue that lies within the regulators: who or what determines whether these projects continue each fiscal year? These projects will be prioritized alongside other programs and research, which is an essential part of budgetary planning but does not necessarily rule out personal opinions. Some may view these projects as purely educational and do not see the potential value from volunteer data. If regulators disregard volunteer data, then this may reduce the probability that the project will receive continued funding. While most regulators agree that education is important for increasing public knowledge of science, some may eliminate education or say that educational methods are not implemented effectively. Some may argue that education is not cost effective

since other programs may present the same information, thus making the additional cost of citizen science projects unjustifiable.

Successful cases

Significant efforts are made by volunteers of citizen science projects to collect data that could be helpful or used in making management and policy decisions but there is uncertainty from regulators to use these data for these purposes. On the contrary, there are successful cases where volunteer data from these projects have been valuable to the scientific community and the environment.

To measure the integrity of volunteer data from an Iowa-based citizen science project, Loperfido et al. (2010) analyzed water quality measurements to test for errors and biases. Water samples of known nitrate and phosphate concentrations were prepared in a lab and distributed to volunteers for comparisons. Results from the study revealed that volunteer measurements of nitrate were significantly lower than concentrations determined through standard methods in both laboratory-prepared and environmental samples. Phosphorus concentrations showed the opposite and were similar among volunteer measurements and laboratory-prepared and environmental samples. Volunteers identified waters in their study area that were in violation of the United States Environmental Protection Agency water quality criteria for total nitrogen and phosphorus when their data were adjusted for errors and biases. This understanding has allowed regulators to incorporate volunteer data into total nutrient loading reports (Loperfido et al. 2010), which may help lead to stricter practices regarding the use of silt screens and agricultural fertilizers and discharge from point-source polluters.

Volunteers of the *Citizen Science Initiative: Marine Invasive Species Monitoring Organization* was successful at identifying the presence of invasive and native crabs within the

intertidal zones of 52 sites that ranged from New Jersey to Maine. Data collected from over 1,000 volunteers were added to a large-scale, standardized database that could fill in gaps not monitored by professionals as well as increase the knowledge of marine systems. Volunteers ranged from age 3 to 78 and had various education backgrounds (pre-school to Ph.D.). Prior to identifying crab species, gender, and measuring carapace width, they took part in a one-hour training session and received several identification field guides. An on-site research team was able to test the accuracy of volunteer data and concluded that education level played a big role in correctly identifying the species and gender of a crab. For third graders, there was 80 percent accuracy when noting whether a crab was native or invasive; accuracy was 95 percent for seventh graders. Gender classification of crabs proved more difficult for the younger volunteers, thus requiring at least a seventh grade education. Volunteers that had at least two years of university education produced data that had an accuracy level above 95 percent (Delaney et al. 2008).

By incorporating an eligibility requirement for volunteer participation, the accuracy of the database was improved and could be used by biologists and the government for early detection of invasive species so they could be eradicated from the site area (US Congress OTA 1993; Myers et al. 2000; Lodge et al. 2006). A key factor in this project's success was that they chose measurable variables that could be obtained easily (e.g., species identification, gender, carapace width) so eligibility criteria were low. Additionally, volunteer data were readily available to managers, which were accomplished through web publishing and geographic information systems for data entry and sharing. With some degree of database standardization and eligibility criteria, the invasive species information could be forwarded to stakeholders that included researchers, policy makers, educators, and the general public (Delaney et al. 2008). This information was important

to regulators since invasive species can disrupt ecosystems such as trophic dynamics, reproduction, and resource competition.

Data quality mechanisms

These were just a couple successful cases of citizen science projects using different data quality control mechanisms. Each project is different and it is up to the coordinator to have knowledge of potential data inconsistencies. For example, water quality monitoring that involves titration/chemical test kits may present data inconsistencies among volunteers because of intensive protocols. To help the coordinator, Wiggins et al. (2011) provided a framework of options for data quality that provided project staff with multiple mechanisms for monitoring data quality. Additionally, it provided information to when each mechanism should be used during the project (i.e., before, during, after) as well as identifying the source of potential error (i.e., protocol or volunteer).

Listed first in the framework was a quality assurance/quality control plan, which is a document that is completed before commencing the project and lists the procedural and quality aspects of the data that are to be collected from the project. Specifically, it describes how these data were collected, how it will be used, and how it was monitored or modified for error. With this document in place, it makes these data more accessible for other purposes such as management, policy, publication, or data reuse. Projects funded by the United States Environmental Protection Agency require a plan while other funding sources may or may not have this requirement. For projects without a plan, Wiggins et al. (2011) provided other data quality mechanisms that can be explored during the project, or after it has ended. For example, data triangulation was listed in the framework for quality control after the project has ended and examines error from both data collection protocols and the volunteers. Triangulation involves using more than one approach

towards the investigation of a research question to ensure certainty in findings. Specifically, data triangulation involves gathering data through different sampling strategies from different times and sources (Denzin 1970). This chapter centered on data triangulation and is further discussed in the subsequent sections.

STUDY AREA AND BACKGROUND

Water quality data collected from volunteers of the Albemarle-Pamlico National Estuary Partnership's Citizens' Monitoring Network (APNEP-CMN) were used for this study. APNEP-CMN is a network of private citizens who keep track of ambient, surface water quality in the Albemarle-Pamlico estuary and its tributaries. It began in 1988 as an initiative by the Pamlico-Tar River Foundation and was limited to monitoring areas in the Tar-Pamlico River watershed. In 1991, the monitoring project was transferred to the Albemarle-Pamlico National Estuary Program (former program name) to gather essential data and focus additional public attention on the quality of the fragile water resources of the entire Albemarle-Pamlico estuary. This monitoring project has two main components: (1) water quality monitoring and (2) educational campaigns that focus on the themes of water quality, pollution, and aquatic ecology. Regional environmental groups/agencies and education campaigns help APNEP-CMN identify projects, recruit volunteers, and serve as advocates for these data.

APNEP-CMN volunteers monitor the water quality of the estuary after an initial training session from the project coordinator. Specifically, volunteers monitor dissolved oxygen, pH, salinity, temperature, depth, and clarity to gauge the general health or quality of the waters in the estuary. Volunteers use titration/chemical water quality kits and other equipment manufactured by the LaMotte Company to analyze water samples. They also observe qualitative factors such as

weather conditions, wind speed, and other visual indicators, and record their results. The field data sheet that volunteers used to record these measurements is illustrated in Figures 1a and 1b. All data collected are forwarded to the project office (Institute for Coastal Science and Policy, East Carolina University) where the project coordinator organizes the information into a database for citizen and government agency use. Often, these monitoring efforts serve as useful supplements to existing governmental activities and databases when requested.

Personal involvement with APNEP-CMN

I served as project coordinator for APNEP-CMN from August 28, 2006, through September 30, 2011. Responsibilities specific to APNEP-CMN included: (1) outreach efforts towards the recruitment of volunteers, (2) volunteer training, (3) data manager, (4) APNEP-CMN newsletter editor, and (5) educator for a variety of education campaigns related to water quality and environmental awareness. APNEP-CMN ended as a result of budgetary cutbacks that all National Estuary Programs were experiencing at the time in addition to the development of a new work plan. APNEP staff were encouraged to reinstate APNEP-CMN as a new entity that would adopt a more ecosystem-based management approach at lower annual cost through established partnerships. Since APNEP-CMN ended in late 2011, its status has remained stationary with the exception of maintaining current volunteers through management of incoming water quality data and refreshing chemical supplies and equipment. I have volunteered my time to take on these limited tasks under the support of the Institute of Coastal Science and Policy and APNEP through the end of my dissertation research.

What is water quality monitoring and why is it important?

Water quality monitoring is the repetitive measurement or observation of a water body over time (USGS 2013). Water quality is collected repetitively to detect changes and trends in water

conditions that occur due to natural events and/or pollution. Typically, one or two years of data will not show major trends in water quality and will not pinpoint sources of pollution. Therefore, monitoring is a long-term effort (Meals et al. 2012). Carefully obtained, quality assured, objective monitoring is valuable in developing information about a water body's baseline conditions. Trained analysts use these data to identify trends and changes in aquatic systems. By not relying on subjective information, monitoring can provide more objective, quantified measures of the past (APNEP 2013a).

What is the Albemarle-Pamlico estuary and why should it be monitored?

The United States Environmental Protection Agency (USEPA) defines an estuary as a partially enclosed area where freshwater from the inland rivers mixes with salty water from the Ocean (USEPA 2013). The Albemarle-Pamlico (A-P) estuary is considered one of North Carolina's most important natural resource treasures and was designated as an "estuary of national significance" by United States Congress in 1987 (APNEP 2013b). The estuary is home to a wide diversity of unique habitats and wildlife, including anadromous fish species such as river herring (*Alosa spp.*) and striped bass (*Morone saxatilis*) (Smith and Rulifson 2015). Historically, the estuary has also supported many important northeastern North Carolina industries such as commercial fishing, seafood, recreation, and tourism. Not only do we extract resources from the estuary but we also depend on its aesthetic and cultural viability to attract interest and tourism (APNEP 2013b).

The A-P estuary is the largest lagoonal system, and the second largest estuary in the United States (Cooper et al. 2004) with Chesapeake Bay being the largest. Geologically, Albemarle Sound is considered a "drowned river valley" estuary that flooded and filled empty valleys as a result of sea level rise during the Holocene epoch (Riggs et al. 1992, Sager and Riggs 1998). In contrast,

Pamlico Sound is a bar-built estuary (Pritchard 1952, Dyer 1997), which is categorized by shallow depth and reduced tidal influences in the areas farthest from the barrier island inlets (Giffin and Corbett 2003). Regarding estuary circulation, Albemarle Sound is classified as a salt wedge estuary due to higher freshwater inputs. Pamlico Sound is described as a partially mixed estuary since the inlets allow salt water to enter the Sound.

The six major river basins included in the A-P estuary are: (1) Chowan, (2) Neuse, (3) Pasquotank, (4) Roanoke, (5) Tar-Pamlico, and (6) White Oak. The Chowan, Pasquotank, and Roanoke watersheds flow into Albemarle Sound. The Neuse and Tar-Pamlico watersheds discharge into Pamlico Sound. There are also a number of smaller watersheds that discharge into Albemarle and Pamlico Sounds. The White Oak watershed flows into Core and Bogue Sounds. The other Sounds of the estuary are the Croatan, Currituck, and Roanoke. Albemarle and Pamlico Sounds are connected to the Atlantic Ocean through small inlets in the barrier island system (North Carolina Outer Banks). These barrier islands lessen the impacts of lunar ocean tides except near the inlets. Wind driven tides dominate in Albemarle and Pamlico Sounds, including the nearby tributaries (Cooper et al. 2004).

Estuaries are also known to be highly productive areas due to high production of organic matter (USEPA 2013). Geologically, the A-P estuary is unique due to diversity in sediment size and mineralogy. Sediments are derived from river input, shoreline erosion, the continental shelf, and biogenic production. Sediments that enter through the rivers (within the estuary) are silt and clay. Sand is limited or absent due to low flow velocities that cannot support sand transport and upstream impoundments that capture most of the coarser sediments. The major source of coarse sediment is through shoreline erosion by direct wave attacks and inlets, which accounts for approximately half of the medium-grained sand in the system (Meade and Trimble 1974). Estuary

dynamics, including tidal, climatic, retention time, and nutrient loading conditions sensitize the watersheds. Due to excessive levels of nutrients resulting in massive algal blooms and fish kills, the entire Tar-Pamlico watershed was designated as "Nutrient Sensitive Water" in 1989 by the North Carolina Environmental Management Commission (DNR 1989).

The A-P estuary is a large and diverse region and is too big to adequately monitor with government resources. Because the estuary is so large and the impacts are so diverse, assistance is needed to monitor the estuary. The wide expanse of waters that makes up the estuary is often more accessible to local citizens who live near it. The help of citizens fills in the gaps left open by limited government resources and funds. This led to the establishment of APNEP-CMN in 1988 and its further expansion to the entire Albemarle-Pamlico estuary in 1991.

RESEARCH QUESTIONS AND HYPOTHESES

The goal of this study was to determine whether water quality data gathered by trained citizen science volunteers were as reliable as data gathered by government resource staff and therefore usable for science-based decisions by resource managers. Specifically, water quality data collected by volunteers of the Albemarle-Pamlico National Estuary Partnership's Citizens' Monitoring Network (APNEP-CMN) were compared to data collected by professionals from government projects within close geographic proximity. These government projects included data from the North Carolina Division of Marine Fisheries, United States Geological Survey, and East Carolina University. Water quality data among APNEP-CMN volunteers in similar geographic regions were also investigated for consistency. Results from this investigation provided insight towards the reliability of the APNEP-CMN dataset. Detected problems and strategies were addressed and discussed for the benefit of other related citizen science projects.

Research questions

1. How similar are water quality data when measured by APNEP-CMN volunteers and water quality professionals from government projects?
2. Do APNEP-CMN volunteers with sites in close proximity to each other produce similar results in water quality data?
3. What factors might contribute to any observed discrepancies in water quality data among the sites?

Hypotheses

1. Water quality data among monitoring sites within the same region will produce similar results (P-value > 0.05) although significant differences (P-value < 0.05) are expected for dissolved oxygen and salinity due to more involved measuring protocols.
2. APNEP-CMN volunteers with monitoring sites in close proximity to one another will produce similar water quality data (P-value > 0.05).

METHODS

Acquiring data

Water quality data collected by volunteers of the Albemarle-Pamlico National Estuary Partnership's Citizens' Monitoring Network (APNEP-CMN) were organized into one master dataset that ranged from 1988 to 2013. These data were pieced together through multiple archived electronic datasets that were left behind by previous APNEP-CMN project coordinators from 1988 through August 2006. The dataset included volunteer and site information (e.g., volunteer name, geographic coordinates of sites, basin, and county) and the following water quality variables: [1]

air and water temperatures (degrees Celsius), [2] water and secchi depths (meters), [3] dissolved oxygen (milligrams per liter), [4] pH, and [5] salinity (parts per thousand) (Figure 1a). Site observations were recorded based on provided responses that were included in the field data sheet (Figure 1b). These observations included: [1] wind direction, [2] wind speed, [3] water surface, [4] lunar tide, [5] direction of current, [6] speed of current, [7] water color, [8] other signs (e.g., dead fish, sea nettles, oil slick, debris, etc.), [9] algal index (only applicable to volunteers who conduct algae watch), [10] weather, [11] frequency of local rainfall for past week of monitoring, [12] last date of local rainfall, and [13] weekly sum of daily rainfall for past week of monitoring (inches, measured from provided rain gauge). A comment section was provided at the end of the field data sheet and responses were recorded into the dataset (Figure 1b). Date and time of data collection were also recorded.

Government data were acquired from multiple projects within The North Carolina Division of Marine Fisheries (NCDMF), United States Geological Survey (USGS), and East Carolina University (ECU). Data from these projects were selected based on their similarities to APNEP-CMN through water quality measurements and the timeframe to which these data were collected (late 1980s through 2013). Each government project is summarized in the following paragraphs.

The North Carolina Division of Marine Fisheries (NCDMF) contributed data from *Project 909*. This project involved monitoring water quality in Albemarle Sound and its tributaries. The purpose of this project was to get a better understanding of essential habitat for multiple commercial and recreational fisheries. Fifteen monitoring sites were selected based on the seasonal spawning habits and life stages of river herring (*Alosa spp.).* Water quality data were collected using an YSI 600 XLM V2 multi-parameter sondes with an YSI 6150 ROX optical dissolved oxygen (milligrams per liter) probe, YSI 6561 pH probe, and an YSI 6560 conductivity

(microsiemens) and temperature (degrees Celsius) probe. All data were downloaded directly from the sondes to the computer. No standardized data sheets were used throughout the project. Project data ranged from August 6, 2008 through December 31, 2010 with measurements taken every hour of the 24-hour day.

Data from the United States Geological Survey (USGS) were obtained from the Water Quality Portal located on their website (www.waterqualitydata.us). Site USGS-0204387900 was selected for data download. Water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), and salinity (parts per thousand) were the only water quality variables measured at this location. Project data were collected once per day starting in January 1991 through July 1993. Time of day when data were collected was not recorded.

Water quality data from East Carolina University (ECU) stems from two projects, *PCS Phosphate* and *Striped Bass Otolith Study*. The currently active *PCS Phosphate* project originated in the late 1980s with collaboration between ECU and the PCS Phosphate Company Incorporated in Aurora, North Carolina. The purpose of this collaboration was to observe water health of the Pamlico River surrounding the PCS Phosphate facility, which produces primary crop nutrients (e.g., potash, nitrogen, and phosphate). The project involves ECU researchers collecting water quality at 20 sites along the Pamlico River and taking water samples back to the laboratory for nutrient testing. Water quality variables used from this project included: [1] water temperature (degrees Celsius), [2] dissolved oxygen (milligrams per liter), [3] pH, and [4] salinity (parts per thousand). Measurements were recorded at every half-meter increment in depth using an YSI Model 85 Water Quality Meter and an Oakton pH meter. Project data used for this study ranged from January 29, 1987 through December 21, 2013. The frequency of data collection varied between once or twice per month. Time of day when data were collected was not recorded.

The *Striped Bass Otolith Study* is part of a continuing research project in the Roger Rulifson laboratory at ECU. Prime interest of this study is to observe the origins of striped bass (*Morone saxatilis*) populations in the Albemarle Sound by using otolith microchemistry techniques. As part of this project, water quality was collected at 19 monitoring sites within the river basins of Albemarle Sound. Water quality variables of interest were similar to the *PCS Phosphate* project. Project data ranged from May 5, 2011 through February 27, 2012. The frequency of data collection was once per month at each site.

APNEP-CMN data selection

There were two issues with APNEP-CMN data that needed to be resolved prior to analyses. These included short-term data collection from monitoring sites and frequent data gaps. To adjust for these potential data biases, criteria were developed for identifying monitoring sites for analysis. Selection of sites using these criteria was done subjectively as opposed to selection based on algorithmic design. These criteria were:

1. Monitoring sites that have been in existence for over one year, which ensured a time series long enough for statistical analysis.
2. Monitoring sites that have consistent data. This included data that were collected on a weekly to biweekly basis with equal spread (i.e., uniform collection rather than clumped).
3. Monitoring sites that have a high number of missing data were not used. Those sites with a high number of missing data were deleted from analysis.

Creating the master datasets

APNEP-CMN data were entered by hand into Microsoft Excel from standardized field data sheets that were mailed in by volunteers. Prior to August 2006, previous project coordinators

entered any received data. Since these data were spread across multiple spreadsheets and media types, I had to standardize all files and then compile them into one data spreadsheet for analysis. Acquired data from the government projects were also organized into separate spreadsheets.

Each row represented data for one location by date. Columns represented: (1) project name, (2) season, (3) date, (4) location number, (5) region, (6) position, (7) geographic coordinates [decimal degrees], (8) location description, (9) time, (10) water temperature, (11) water depth, (12) secchi depth, (13) dissolved oxygen, (14) pH, and (15) salinity. Season was defined as winter (January-March), spring (April-June), summer (July-September), or fall (October-December). Region was defined as lower, middle, or upper portions of the study area. Position was the sequential numbering of sites from downstream (lower) to upstream (upper).

Some of the government projects used in this study collected water quality data at depth increments for each station. In this scenario, only data collected just below the surface were imported into the master datasets since APNEP-CMN volunteers collected data from the surface. For government projects that collected data every hour of the 24-hour day, only one hour of data per day were included in the master dataset. This one-hour of data was selected based on the average time of day (e.g., morning, afternoon, evening) of data collection from APNEP-CMN volunteers. In addition, not all government projects collected the entire list of water quality variables mentioned above. In that case, the cells in that column were left empty.

Error spot-checking

The "Filter" function in Excel was used to spot-check the master datasets for common errors associated with data entry. These errors were lack of decimals or extra decimals. Corrections to these datasets were only made if the error could be traced back to a simple typing error from the data manager. For example, a water temperature reading may have been typed as 248°C. By

looking at the temperatures on the surrounding dates or the date (e.g., July), it was assumed that the real value was 24.8°C. If the error seemed ambiguous, then it was left alone. Another error was the mix-up between water and secchi depths. This was simple to detect since secchi depth is less or equal to water depth. If observed, the error was corrected in the master dataset.

Grouping of the sites

Google Maps and ArcGIS, Version 13.1 were used to map latitudinal and longitudinal coordinates of both APNEP-CMN and government monitored sites. Unfortunately, there were some missing coordinate data for several of the APNEP-CMN monitoring sites. This was perhaps a result of the variability among the electronic spreadsheets left behind by previous project coordinators. If sites with missing coordinate data had enough site information (e.g., location name, basin, and county), then coordinates were created based on that information using Google Maps. Any ambiguous sites with missing coordinates remained unchanged. Luckily, those sites were short-lived (≤ 1 year), which violated the first criterion. All coordinates were imported into Google Maps for error spot-checking. Any coordinates that appeared erroneous were adjusted using the method previously described. The advantage to using Google Maps was being able to view all sites in a user-friendly, interactive format. This made it easier to group APNEP-CMN and government monitored sites based on their proximities to one another for later analysis.

With over 100 combined sites (both volunteer and government) distributed throughout the Albemarle-Pamlico estuary, it was difficult to include all of them for this study. The two major groups selected for analysis were the Tar-Pamlico and Albemarle regions. Since these two groups covered a large study area, they were further broken down into three smaller regions: (a) lower, (b) middle, and (c) upper. Sites from all data sources were also sequentially numbered from downstream (lower) to upstream (upper) regions. For the Tar-Pamlico region, APNEP-CMN

monitoring sites were compared to PCS Phosphate data for the entire time span (1987-2013) of available data (Figure 2). Since there were multiple government projects in the Albemarle region for different years, the region was broken into five blocks: (1) 1989-1992, (2) 1991-1993, (3) 2002-2005, (4) 2008-2010, and (5) 2011-2012 (Figure 3). Blocks one and three compared data among APNEP-CMN volunteers in the same geographic regions. Blocks two, four, and five compared APNEP-CMN data to USGS, NCDMF, and ECU, respectively. Once the sites were selected and grouped accordingly for analysis, geographic coordinates for the sites were imported into ArcGIS, Version 13.1 for mapping. Figures 4 and 5 illustrate all sites within the Tar-Pamlico and Albemarle regions, respectively. Figures 6-10 illustrates each block within the Albemarle region. Geographic coordinates for sites in the Tar-Pamlico and Albemarle regions are provided in Tables 1 and 2, respectively. The names of each site are the original names used in their respective projects. This was done to preserve the integrity of these sites.

Analysis preparation

The two master datasets for the Tar-Pamlico and Albemarle regions were imported into multiple statistical programs for analysis. Beforehand, the Albemarle dataset was split into multiple spreadsheets for each block described in the previous section. The following sections described all statistical methods used for analysis. Depending on the project and region/block, water quality variables and use of statistical methods varied due to missing data or not enough monitoring sites.

Descriptive statistics

JMP®, Version 12 Pro was used to gain an initial description of data from each spreadsheet. Tables were generated to showcase the sample size, mean, and standard deviation of each water quality variable used in analysis and separated by project, region, and season.

Additional tables were generated to include the information described above but for each monitoring site.

One-way ANOVA, Kruskal-Wallis, and Mann-Whitney U tests

A one-way analysis of variance (ANOVA) using SYSTAT®, Version 12 compared the means among three or more samples. Specifically, one-way ANOVAs were conducted for each water quality variable by region and factored separately by project and season. For season, two one-way ANOVAs were produced – one for each project. Output included degrees of freedom, mean squares, F-ratio, and the P-value. Before performing the one-way ANOVAs, rows that contained missing data for the water quality variable being tested were removed prior to running the one-way ANOVAs. Since one-way ANOVAs cannot provide specific details about mean differences among individual sites, post-hoc pairwise comparisons were also conducted.

In addition to the one-way ANOVAs, Shapiro-Wilk tests for normality were also conducted on the datasets used for the ANOVAs. Since one-way ANOVAs require a normal distribution, this presented a potential problem. To offer a similar non-parametric option, Kruskal-Wallis tests were also conducted, which uses the median instead of the mean. Importantly, the distributions do not have to be normal to conduct a Kruskal-Wallis test. Output for the Kruskal-Wallis test included the P-value and was reported alongside the one-way ANOVA results. The hypotheses for the one-way ANOVA and Kruskal-Wallis are:

$$H_o: \mu_1 = \mu_2 = ... = \mu_k$$

$$H_a: \text{Not } H_o$$

A Mann-Whitney U test was conducted when comparing two sites to each other. This test is viewed as the non-parametric alternative to the independent t-test. The hypotheses for the Mann-Whitney U test are provided below:

$$H_o: \mu_1 = \mu_2$$

$$H_a: \text{Not } H_o$$

Post-hoc pairwise comparisons maps and matrices

Output from the post-hoc pairwise comparisons were transformed into site matrices. These matrices contained the mean differences among all possible site combinations for each available water quality variable by region. Mean differences that were significant at the 0.05 alpha level were shaded grey in the matrices; sites that contained missing data were shaded black.

For visual representation, maps were produced using ArcGIS, Version 13.1 for each matrix. Site markers on the maps were size dependent based on the number of site differences. In other words, the bigger the site marker, the bigger the number of different sites.

Principal components analysis

Principal components analysis (PCA) is a common multivariate technique used in a variety of environmental studies, including water quality analysis (Bengraine and Marhaba 2003; Ouyang 2005; Bu et al. 2009; Olsen et al. 2012). PCA uses a correlation framework among multiple constituents to create new variables, or principal components, while preserving most of the original data (Olsen et al. 2012). In other words, it has the capability to reduce large datasets into fewer variable combinations, thus making it easier to identify spatial patterns, or for other exploratory purposes. These new principal components are equal to the number of variables used in the dataset (Ouyang 2005). Each component provides an eigenvalue that explains the variability of the data

(as a percentage), which eventually reaches a cumulative 100 percent (Olsen et al. 2012). Typically, the first few components are used for interpretation, or whenever the explained variability reaches between 60 and 70 percent. Each component also produces a loading matrix that better explains the correlation strength among the data variables. From this matrix, information as to which water quality variable is best explaining variability of that component is identified.

For analysis, all available water quality variables were included in the original PCA model. Variables were then removed if there were lack of data or it produced a weaker model. The model that best explained data variability within the first three principal components was used. Three PCA models were conducted for each project separated by region or individual site. Output included a biplot of the first two principal components, loading matrix, and eigenvalues. PCA was used to determine if volunteer and government data were identifying similar spatial patterns.

Non-metric multidimensional scaling

Non-metric multidimensional scaling (MDS) was conducted to analyze how available water quality variables among monitoring sites differed spatially. MDS visualizes the relationships among objects in multidimensional space (Mugavin 2008). These objects are plotted with new variables as axes. The relationship among these objects provides insight to their similarities and dissimilarities from one another (Giguère 2006; Tsogo et al. 2000).

The scaling is based on the rank order of the dissimilarities, which makes it non-metric (Shepard 1962; Kruskal 1964). Non-metric MDS plots were generated using R Statistical Software for each region/block and separated by water quality variable, project (using geometric shapes), and region (color/patterns of geometric shapes).

These plots visualized the similarities and dissimilarities among available water quality variables and the monitoring sites of different projects. Objects plotted close to one another were considered similar; dissimilarities were indicated by objects being plotted further apart.

Additional statistics

Spatial/Temporal distributions and slopes

Using JMP®, Version 12 Pro, scatter plots were generated for each available water quality variable by site (positioned from downstream to upstream) and separated by region (lower, middle, or upper) and season (fall, spring summer, or winter). Fit lines were also added to estimate slope for each available water quality variable by position and separated by project and region. Output included the intercept, slope, P-value, and adjusted R-squared. The P-value was based on the slope of the fit line at the 0.05 alpha level. For interpretation of the P-values, the following hypotheses were used:

$$H_o: B_1 = 0$$

$$H_a: B_1 \neq 0$$

A P-value below 0.05 indicates that the slope does not equal zero and suggests there is a linear relationship among the water quality variable (y) and position (x). For temporal distribution, the same protocols described above were used. The only difference was using time (years) in place of position.

Distance plots

ArcGIS, Version 13.1 was used to provide distance estimates (kilometers) among monitoring sites. Specifically, a drawing tool was used to connect distance lines from site to site

using the maps previously generated in ArcGIS. SYSTAT®, Version 12 statistical software was used to perform post-hoc pairwise comparisons (from the one-way analysis of variance) among the monitoring sites for each available water quality variable separated by region; projects were not separated. Output included mean site differences among all possible combinations of the monitoring sites. These site differences were tagged with the measured distance among sites, which were used to generate the distance plots. The purpose behind these plots was to visualize water quality variability using distance among sites within the lower, middle, and upper regions of the Tar-Pamlico and Albemarle. No further statistical analysis was used for these plots.

Time series: Seasonal Mann-Kendall

Environmental data are often described as "messy" due to the high potential of containing missing observations, the presence of outliers, and a non-normal distribution. Seasonal patterns are also expected in environmental data, thus making it difficult to identify trends. In other words, seasonality may have an effect on the Y-variable (e.g., water temperature, dissolved oxygen). These seasonal effects may disrupt analysis by hiding trends in the Y-variable over time. To account for these problems, the seasonal Mann-Kendall test (Hirsch et al. 1982) was applied. The hypotheses for this test are listed below:

H_o: There is no trend in the series.

H_a: There is a trend in the series.

This seasonal Mann-Kendall test looks for a monotonic trend in a time series that displays seasonality. A monotonic trend is defined as a gradual change over time that has a consistent direction. Unlike time series analysis, the seasonal Mann-Kendall test accommodates for time series even if there are missing data observations and the display of a non-normal distribution

(Antonopoulos et al. 2001), which makes this statistical test popular with environmental studies (Helsel et al. 2006). SYSTAT®, Version 12 was used to conduct the seasonal Mann-Kendall test for each available water quality variable separated by project. Prior to conducting the test, seasons were broken down into 12 months. Output from these tests returned a Kendall's tau coefficient and P-value, which determined if the null hypothesis is accepted (no trend) or rejected (monotonic trend is present) (Mann 1945; Helsel and Hirsch 2002).

Monitoring equipment comparisons

Independent t-test and one-way ANOVA

To investigate whether monitoring equipment are driving potential differences in water quality measurements, unpublished data were acquired from students enrolled in a Fisheries Techniques course led by Roger Rulifson (2015). These students used different monitoring equipment to measure water quality at a canal that flows into Lake Mattamuskeet (Hyde County, North Carolina, geographic coordinates in decimal degrees: 35.517373 latitude, -76.061160 longitude). Dissolved oxygen (milligrams per liter) and pH were measured during morning, afternoon, and evening hours on March 20-22, 2015 using the following monitoring equipment: (1) titration/chemical test kits manufactured by the LaMotte Company, (2) pH Pen Model EX60, (3) Hydrion pH paper, and (4) the YSI Model 85 Water Quality Meter.

To investigate monitoring equipment used to measure dissolved oxygen, an independent t-test and one-way analysis of variance (ANOVA) were conducted to determine if there were significant differences among the means. The same applied for pH with the exception of using a one-way ANOVA since three types of monitoring equipment were used to measure pH.

RESULTS

Tar-Pamlico region

APNEP-CMN and PCS Phosphate

For the entire Tar-Pamlico region, water quality data collected from 20 APNEP-CMN and 20 PCS Phosphate monitoring sites between 1987 and 2013 were compared to each other (Table 1, Figure 4). Water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) were the analyzed variables. Since PCS Phosphate measured water quality variables at half-meter increments, only the surface data (0.0-meter depth) were used for analysis. Time of data collection was either the afternoon or varied throughout the day. To better account for geographic differences, all monitoring sites in the Tar-Pamlico region were split into lower, middle, or upper regions. Table 3 lists the distances (kilometers) among all sites in the Tar-Pamlico region. Descriptive statistics are provided in Appendices A1-A5.

Results from the one-way ANOVA and Kruskal-Wallis (KW) tests when factored by project (APNEP-CMN and PCS Phosphate) revealed significant differences (KW P-value < 0.01) for all water quality variables among monitoring sites within a similar region. The only exception was water temperature among sites in the upper region (KW P-value = 0.14) and salinity in the lower (KW P-value = 0.75) and middle (KW P-value = 0.34) regions (Table 5). When factored by season, there were significant differences among water temperature, dissolved oxygen (lower and middle regions), pH, and salinity among APNEP-CMN sites within all three regions (KW P-value < 0.01); the only exception was dissolved oxygen in the upper region (KW P-value = 0.07) (Table 6a). PCS Phosphate data suggested seasonal differences for all water quality variables among monitoring sites within all three regions (KW P-value < 0.01) with the exception of pH in the upper region (KW P-value = 0.35) (Table 6b). Results from the post-hoc pairwise comparisons for

each water quality variable among monitoring sites within all three regions are provided in Appendices A6-A17. The grey shaded area represents site pair mean differences that are significant at the 0.05 alpha level.

The following variables were included for principal components analysis: (1) water temperature, (2) dissolved oxygen, (3) pH, and (4) salinity. For APNEP-CMN data in the lower Tar-Pamlico region, 98 percent of the variability were explained in the first three principal components. Results of APNEP-CMN data suggested that as water temperature decreased, dissolved oxygen increased; pH also increased. Salinity did not seem to influence data variability (Figure 11a). PCS Phosphate followed a similar result pattern to APNEP-CMN. However, only 93 percent of data variability were explained within the first three principal components (Figure 11b).

In the middle region of the Tar-Pamlico, APNEP-CMN (Figure 12a) and PCS Phosphate (Figure 12b) revealed similar result patterns within the first three principal components. For instance, as water temperature decreased, pH increased. Salinity had little influence on data variability for the first principal component.

For both APNEP-CMN (Figure 13a) and PCS Phosphate (Figure 13b) data in the upper region, 93 to 94 percent of the variability were explained within the first three principal components, respectively. Results for both APNEP-CMN and PCS Phosphate visualized similar water quality axes from the biplots. For example, pH increased when dissolved oxygen increased.

Results from the non-metric multidimensional scaling suggested some variability with water temperature among sites in the lower, middle, and upper regions of the Tar-Pamlico. Four clusters were identified; three of these clusters either contained one or two sites. Each of these three separate clusters contained APNEP-CMN sites in the lower and upper regions (Figure 14).

For dissolved oxygen, two clusters were identified. One of these clusters contained one APNEP-CMN site in the middle region. Based on the distance points, PCS Phosphate data had less variability than APNEP-CMN (Figure 15).

pH revealed a similar result pattern to dissolved oxygen. Two clusters were identified; one of these clusters was an APNEP-CMN site in the upper region. APNEP-CMN data seemed to have greater variability as opposed to PCS Phosphate; APNEP-CMN sites in the upper region seemed to be influencing this variability based on the dissimilarity of the distance points (Figure 16).

For salinity, two clusters were identified. One of these clusters belonged to one APNEP-CMN site in the upper region. The remaining APNEP-CMN and PCS Phosphate sites were grouped according to their respected regions (Figure 17).

Additional analyses were conducted to further explore APNEP-CMN and PCS Phosphate data in the Tar-Pamlico region. Statistical methods included: (1) spatial slope estimates, (2) distance plots, (3) temporal slope estimates, and the (4) seasonal Mann-Kendall test. Output from these methods are provided in Appendices A18-25.

Albemarle region

Table 2 lists and describes all sites in the Albemarle region before being split into five blocks (Figure 5). For each block (Figures 6-10), water quality data from APNEP-CMN sites were either compared to government or APNEP-CMN sites. Distances (kilometers) among the sites are provided in Table 4.

1989-1992 block: APNEP-CMN volunteers

Water quality data from four APNEP-CMN monitoring sites in the upper portion of the Albemarle region were compared to one another. All fours sites were concurrently active from

1988 through 1992 (Figure 6). Water quality variables used for analysis included water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). Descriptive statistics are provided in Appendices B1 and B2.

Results from the one-way ANOVA and Kruskal-Wallis (KW) tests when factored by site revealed significant differences (KW P-value < 0.01) among the four APNEP-CMN sites (Table 7). The post-hoc pairwise comparisons for each water quality variable are provided in Appendices B3-B6. The grey shaded area represents site pair mean differences that are significant at the 0.05 alpha level.

For principal components analysis, the following variables were included for analysis: (1) water depth, (2) secchi depth, (3) dissolved oxygen, (4) pH, and (5) salinity. The first three principal components explained 80 to 86 percent of data variability. Sites 01C (Figure 18) and 06C (Figure 19) lacked sufficient data for proper interpretation. Sites 04C (Figure 20) and 05C (Figure 21) revealed similar water quality axes on the biplots. For instance, when salinity increased, dissolved oxygen decreased; other observed patterns were increased secchi depth with increased water depth.

Additional analyses were conducted to further explore APNEP-CMN data among volunteers in the upper Albemarle region. Statistical methods included: (1) spatial slope estimates, (2) distance plots, (3) temporal slope estimates, and the (4) seasonal Mann-Kendall test. Output from these methods are provided in Appendices B7-B13.

1991-1993 block: APNEP-CMN and USGS

Water quality data from five APNEP-CMN monitoring sites in the lower and middle regions of the Albemarle were compared to a single site from the United States Geological Survey (USGS) site from 1991 through 1993 (Figure 7). Water quality variables used for analysis included

water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), and salinity (parts per thousand). Descriptive statistics are provided in Appendices C1 and C2.

Results from the one-way ANOVA and Kruskal-Wallis (KW) tests when factored by project (APNEP-CMN and USGS) revealed no significant differences among water temperature (KW P-value = 0.55); there were significant differences for dissolved oxygen and salinity (KW P-value < 0.01) (Table 8). When factored by season for APNEP-CMN sites, there were significant differences for water temperature, dissolved oxygen, pH, and salinity (KW P-value < 0.01) (Table 9a). These results were repeated for the USGS site; pH data were not available for the USGS site (Table 9b). Results from the post-hoc pairwise comparisons for each water quality variable are provided in Appendices C3-C6. The grey shaded area represents site pair mean differences that are significant at the 0.05 alpha level.

The following variables were included for principal components analysis: (1) water temperature, (2) dissolved oxygen, and (3) salinity. For the first two principal components, 88 to 97 percent of data variability were explained. Water temperature and dissolved oxygen shared similar patterns among APNEP-CMN and UGGS sites. However, salinity and dissolved oxygen had different patterns. For instance, APNEP-CMN data suggested that as salinity increased, dissolved oxygen would also increase; USGS data suggested that dissolved oxygen decreased as salinity increased (Figure 22).

Additional analyses were conducted to further explore APNEP-CMN and USGS data in the lower and middle Albemarle regions. Statistical methods included: (1) spatial slope estimates, (2) distance plots, (3) temporal slope estimates, and the (4) seasonal Mann-Kendall test. Output from these methods are provided in Appendices C7-C13.

2002-2005 block: APNEP-CMN volunteers

Two APNEP-CMN sites were compared to each other using water quality data collected between 2002 and 2005 in the upper region of the Albemarle region (Figure 8). Water temperature (degrees Celsius), water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), and pH were the variables used for analysis. Descriptive statistics are provided in Appendices D1 and D2.

Results from the Mann-Whitney U tests (MW) suggested significant differences for water depth, secchi depth, and dissolved oxygen (MW P-value < 0.01) among the two APNEP-CMN sites; no significant differences were suggested for water temperature (MW P-value = 0.35) and pH (MW P-value = 0.09) (Table 10). When factored by season using the one-way ANOVA and Kruskal-Wallis (KW) tests, there were significant differences among water temperature, water depth, secchi depth, and dissolved oxygen (KW P-value < 0.01). There were no significant seasonal differences for pH at APNEP-CMN site 22C (KW P-value = 1.00) (Table 11a); APNEP-CMN site 23C was significant (KW P-value = 0.02) (Table 11b).

For principal components analysis, the following variables were included: (1) water temperature, (2) water depth, (3) dissolved oxygen, and (4) pH. The first three principal components explained 96 to 97 percent of data variability. Water temperature and dissolved oxygen were driving the first two principal components. Based on the biplots, there were dissimilar patterns between water depth and water temperature among the two APNEP-CMN sites. Specifically, APNEP-CMN site 22C data suggested that as water depth increased, there was an increase in water temperature; for site 23C data, increased water depth would result in lower water temperature (Figure 23).

Additional analyses were conducted to further explore APNEP-CMN data among volunteers in the upper Albemarle region. Statistical methods included temporal slope estimates and the seasonal Mann-Kendall test. Output from these methods are provided in Appendices D3-D6.

2008-2010 block: APNEP-CMN and NCDMF

This was the largest block analyzed for the entire Albemarle region. Seven APNEP-CMN sites were compared to thirteen sites monitored by the North Carolina Division of Marine Fisheries (NCDMF) from 2008 through 2010 (Figure 9). Water temperature (degrees Celsius), water depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) were the variables used for analysis. Descriptive statistics are provided in Appendices E1 and E2.

Results from the one-way ANOVA and Kruskal-Wallis (KW) tests when factored by project (APNEP-CMN and NCDMF) suggested significant differences among monitoring sites for water temperature in the middle region (KW P-value < 0.01), water depth within all three regions (KW P-value < 0.01), dissolved oxygen in the middle and upper regions (KW P-value < 0.01), pH in the lower region (KW P-value = 0.02), and salinity within all three regions (KW P-value < 0.01). No significant differences were suggested among monitoring sites within similar regions when factored by project for water temperature in the lower (KW P-value = 0.80) and upper (KW P-value = 0.67) regions; dissolved oxygen in the lower region (KW P-value = 0.36); and pH in the middle (KW P-value = 0.66) and upper (KW P-value = 0.74) regions (Table 12). When APNEP-CMN data within a similar region were factored by season, results suggested significant differences for water temperature among sites within all three regions (KW P-value < 0.01); water depth in the lower region (KW P-value = 0.04); dissolved oxygen within all three regions (KW P-value < 0.01); pH within all three regions (KW P-value < 0.03); and salinity in the lower and

middle regions (KW P-value < 0.01) (Table 13a). For NCDMF data factored by season, there were significant differences for water temperature, water depth, dissolved oxygen, pH, and salinity among sites within all three regions (KW P-value < 0.01) (Table 13b). Results from the post-hoc pairwise comparisons for each water quality variable among monitoring sites within all three regions are provided in Appendices E3-E17. The grey shaded area represents site pair mean differences that are significant at the 0.05 alpha level.

The following variables were included for principal components analysis: (1) water temperature, water depth, dissolved oxygen, pH, and salinity. For the lower region, 83 to 92 percent data variability were explained within the first three principal components. Results suggested that water temperature and dissolved oxygen were driving variability for both APNEP-CMN and NCDMF data followed by pH and salinity (Figure 24). In the middle region, the first three principal components explained 87 to 89 percent of data variability. Both APNEP-CMN and NCDMF data revealed similar patterns based on the water quality axes of the biplots (Figure 25). For the upper region, 80 to 81 percent data variability were explained within the first three principal components. There were some differences among the first two principal components for water depth and salinity. APNEP-CMN data suggested that as water depth decreased, salinity also decreased. NCDMF data suggested the opposite – as water depth increased, salinity also increased; this pattern was also observed for water depth and dissolved oxygen (Figure 26).

Results from the non-metric multidimensional scaling suggested data variability with water temperature among sites in the middle and upper regions of the Albemarle. Five clusters were identified; three of these clusters each contained one APNEP-CMN site in the middle and upper regions. APNEP-CMN and NCDMF sites in the lower region suggested less data variability (i.e., similar) due to closer distance points (Figure 27). For water depth, there were four clusters. One

of these clusters contained three NCDMF sites in the middle and upper regions. Another cluster contained one APNEP-CMN site in the upper region (Figure 28). For dissolved oxygen, three clusters were identified; two of these clusters each contained two sites. APNEP-CMN and NCDMF sites in the lower region suggested less data variability in contrast to the lower and middle regions (Figure 29). Four clusters were identified for pH; three of these clusters each contained one site. Data variability in the upper region appeared to be greater based on the spread of the distance points (i.e., dissimilar) (Figure 30). For salinity, three clusters were identified. There seemed to be some variability among sites in the lower, middle, and upper regions. APNEP-CMN and NCDMF sites in the lower and upper regions were clustered together; there was one APNEP-CMN site in the middle region that represented one cluster (Figure 31).

Additional analyses were conducted to further explore APNEP-CMN and NCDMF data in the Albemarle region. Statistical methods included: (1) spatial slope estimates, (2) distance plots, (3) temporal slope estimates, and the (4) seasonal Mann-Kendall test. Output from these methods are provided in Appendices E18-25.

2011-2012 block: APNEP-CMN and ECU

One APNEP-CMN site was compared to a site monitored by researchers and students at East Carolina University (ECU) within the upper region of the Albemarle during 2011 and 2012 (Figure 10). Water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) were the variables analyzed. Descriptive statistics are provided in Appendices F1 and F2.

The Mann-Whitney U test (MW) results suggested significant differences among APNEP-CMN and ECU sites for pH and salinity (MW P-value < 0.01); no significant differences were suggested for water temperature (MW P-value $= 0.62$) and dissolved oxygen (MW P-value $= 0.76$)

(Table 14). There were no significant differences among APNEP-CMN and ECU data when factored by season (KW P-value > 0.05) (Table 15a-b); the only exception was water temperature for APNEP-CMN data (KW P-value < 0.01) (Table 15a).

The following variables were included for principal components analysis: (1) water temperature, (2) dissolved oxygen, (3) pH, and (4) salinity. Within the first three principal components, 93 to 95 percent of data variability were explained. There were notable differences among the different principal components. For instance, data from the APNEP-CMN site suggested an increase in dissolved oxygen as water temperature decreased. However, ECU data suggested a different story – dissolved oxygen increased as water temperature increased. Salinity seemed to influence ECU data, which suggested that water temperature, dissolved oxygen, and pH increased as salinity decreased (Figure 32).

Additional analyses were conducted to further explore APNEP-CMN and ECU data within the upper Albemarle region. Statistical methods included temporal slope estimates and the seasonal Mann-Kendall test. Output from these methods are provided in Appendices F3-F6.

Summary: Kruskal-Wallis and Mann-Whitney U Tests

Table 16 summarizes results (P-values) from the Kruskal-Wallis and Mann-Whitney U tests when factored by project/site for each water quality variable within a similar region (when applicable). Table 17a summarizes results from the same tests but factored by season for APNEP-CMN data; Table 17b summarizes results from government and other APNEP-CMN data.

Monitoring equipment

For dissolved oxygen, the YSI Model 85 Water Quality Meter produced a mean (and standard deviation) of 10.27 (± 1.57) milligrams per liter (mg/L) whereas the dissolved oxygen

titration/chemical kit manufactured by the LaMotte Company produced a lower mean of 7.94 (± 1.62) mg/L. Results from the independent t-test (IT) revealed no significant differences among these means produced by the different monitoring equipment (IT P-value = 0.07, df = 7).

Three types of monitoring equipment were used to measure pH: (1) pH Pen Model EX60, (2) pH colorimetric test kit manufactured by the LaMotte Company, and (3) Hydrion pH paper. The means (and standard deviation) varied among the equipment, 8.14 (± 0.84), 7.00 (± 0.00), and 6.40 (± 0.00), respectively. Using a one-way ANOVA, the means among the different equipment were significantly different (ANOVA P-value < 0.01, df = 11).

DISCUSSION

Region block comparisons

Citizen science is a tool that interconnects the public and the scientific community. Not only does citizen science promote scientific literacy but it also supports the scientific community by contributing potentially valuable information to long-term datasets. Criticism is often related to the integrity of data being collected by volunteers of citizen science projects (Gillett et al. 2011). While project coordinators typically include volunteer training as a requirement, is that enough to alleviate the criticism? The focus of this study was to investigate the integrity of volunteer water quality data from a citizen science project and compare these data to other government projects. The caveat to comparing water quality data among different sources is the expected natural variability of water quality from one site to the next, plus differences in collection methods (i.e., monitoring equipment). To accommodate, sites were grouped based on their geographic proximity to each other and available water quality data. Various statistical methods described in the "methods" section were used to analyze both volunteer and government data.

My first hypothesis stated that water quality data among monitoring sites within a similar region will produce similar results (P-value > 0.05) although significant differences (P-value < 0.05) were expected for dissolved oxygen and salinity due to more involved measuring protocols. The second hypothesis stated that APNEP-CMN volunteers with monitoring sites in close proximity to one another will produce similar results. Whether results from each region/block supported these hypotheses will be discussed in the following sections.

Tar-Pamlico region

Based on the results from the Kruskal-Wallis tests (KW), there were significant differences among monitoring sites within a similar region when factored by project (APNEP-CMN and PCS Phosphate) for water temperature in the lower (KW P-value = 0.01) and middle regions (KW P-value = 0.04); there were no significant differences in the upper region (KW P-value = 0.14). Data for dissolved oxygen and pH were also significantly different among sites within a similar region (KW P-value < 0.01). For salinity, the upper region was significant among sites (KW P-value < 0.01) (Table 16). When factored by season, data from both projects detected seasonal differences (KW P-value < 0.05) with a couple exceptions: (1) dissolved oxygen in the upper region for APNEP-CMN data (KW P-value = 0.07) (Table 17a) and (2) pH in the upper region for PCS Phosphate data (KW P-value = 0.35). Post-hoc pairwise comparisons further examined these differences among individual sites and tested for significance (Appendices A6-A17). There were not enough data for interpretation of water and secchi depths. Overall, results were not in support of my first hypothesis. However, results did support my prediction that dissolved oxygen and salinity would produce significant differences among monitoring sites within a similar region due to measuring protocols.

Albemarle region: 1989-1992 block

Results from the Kruskal-Wallis tests suggested significant differences among the APNEP-CMN sites for water depth, secchi depth, dissolved oxygen, and salinity (KW P-value < 0.01) (Table 16). Post-hoc pairwise comparisons further examined these differences among individual sites and tested for significance (Appendices B3-B6). Results were not in support of my first and second hypotheses.

Albemarle region: 1991-1993 block

There were significant differences among APNEP-CMN and USGS project data for dissolved oxygen and salinity (KW P-value < 0.01); there was no significant difference among project data for water temperature (KW P-value = 0.55) (Table 16). Both projects detected seasonal differences (KW P-value < 0.01) (Table 17a-b). Post-hoc pairwise comparisons further examined these differences among individual sites and tested for significance (Appendices C3-C6). There were not enough data for interpretation of water depth, secchi depth, and pH. Results were in support of my first hypothesis.

Albemarle region: 2002-2005 block

Results from the Mann-Whitney U test (MW) suggested significant differences for water depth, secchi depth, and dissolved oxygen (MW P-value < 0.01) among the two APNEP-CMN sites; no significant differences were reported for water temperature (MW P-value = 0.35) and pH (MW P-value = 0.09) (Table 16). Each of the two APNEP-CMN sites detected seasonal differences for water temperature, water depth, secchi depth, and dissolved oxygen (MW P-value < 0.02) (Table 17a-b); one APNEP-CMN site detected no seasonal differences with pH (MW P-value = 1.00) (Table 17a). There were not enough salinity data for interpretation. Results were not in support of my first and second hypotheses.

Albemarle region: 2008-2010 block

In the lower region, there were significant differences among project data (APNEP-CMN and NCDMF) for water depth, pH, and salinity (KW P-value < 0.02). For sites in the middle region, there were significant differences among project data for water temperature, water depth, dissolved oxygen, and salinity (KW P-value < 0.01); pH was not significant (KW P-value = 0.66). For sites in the upper region, there were significant differences among water depth, dissolved oxygen, and salinity (KW P-value < 0.01); water temperature (KW P-value = 0.67) and pH (KW P-value = 0.74) were not significant (Table 16). APNEP-CMN data suggested seasonal differences for water temperature, dissolved oxygen, and pH within all three regions (KW P-value < 0.05); there were no seasonal differences for water depth in the middle (KW P-value = 0.14) and upper (KW P-value = 0.21) regions; and salinity in the upper region (KW P-value = 0.89) (Table 17a). NCDMF data suggested seasonal differences for all water quality variables within each region (Table 17b). The post-hoc pairwise comparisons further examined these differences among individual sites and tested for significance (Appendices E3-E17). There were not enough data for interpretation of secchi depth. Overall, results were not in support of my first hypothesis although significant differences were detected for dissolved oxygen in the middle and upper regions.

Albemarle region: 2011-2012 block

The only significant differences among project data (APNEP-CMN and ECU) were pH and salinity (MW P-value < 0.01); no significant differences were reported for water temperature (MW P-value = 0.62) and dissolved oxygen (MW P-value = 0.76) (Table 16). For APNEP-CMN data, there were no seasonal differences for dissolved oxygen (MW P-value = 0.95), pH (MW P-value = 0.58), and salinity (MW P-value = 0.89); there was a seasonal difference for water temperature (MW P-value < 0.01) (Table 17a). ECU data detected no seasonal differences for all

water quality variables (MW P-value > 0.05) (Table 17b). There were not enough data for interpretation of water and secchi depths. Results were not in support of my first hypothesis; however, salinity data were significantly different among the two sites.

Water quality variables

The following sections discusses each water quality variable and reported differences among APNEP-CMN and government data.

Water temperature

Out of all the water quality variables investigated for this study, water temperature was perhaps the easiest to measure due to simpler protocol. APNEP-CMN volunteers collected water temperature using a handheld thermometer manufactured by the LaMotte Company whereas government sources used probed instruments or receivers to measure temperature. During my tenure as APNEP-CMN project coordinator, volunteers were advised during their training sessions to collect water temperature measurements soon after bringing their water sample buckets on dock. This would prevent faulty measurements as a result from direct sunlight, which may heat up the water in the sample bucket at a faster rate; this could also throw off other measurements for other water quality variables that are influenced by temperature. Based on the non-metric multidimensional scaling plot for the Tar-Pamlico region, APNEP-CMN and PCS Phosphate sites were grouped together with the exception of four sites in the lower and upper regions – three of these four were APNEP-CMN sites (Figure 14). A similar pattern was suggested for the 2008-2010 block of the Albemarle region with the exception of water temperature in the middle and upper regions (Figure 27).

Water depth

Water depth was only measured at half of the analyzed regions/blocks. There were no depth measurements analyzed in the Tar-Pamlico region due to missing data. The 2002-2005 block of the Albemarle region contained two APNEP-CMN sites that were situated in Bennett's Creek, a tributary of the Chowan River with depths less than two meters (Figure 8). Volunteers measured water depth by using a secchi disk with a rope calibrated at tenths of a meter. Discrepancies in water depth data among the sites (Tables 10 and 16) were not surprising since depth is largely dependent on geographic location and local precipitation. For example, volunteers typically collected measurements along the shoreline or a dock where depth is typically low as opposed to the deeper channels. There are also geological differences in river morphology that may be driving these differences.

Secchi depth

Secchi depth was another variable that was seldom measured. Volunteers measured secchi depth using the secchi disk with calibrated rope – the same tool that was used to measure water depth. During the training sessions, volunteers were advised to measure secchi depth with their backs to the sun to avoid a glare when lowering the secchi disk into the water column. A common mistake was that volunteers would mix up the depth readings on the field data sheet, which may eventually make it to the master dataset if not detected by the data manager and corrected. Like water depth, secchi depth is dependent on geographic location. Sites that are typically shallow and clear of suspended sediments and/or tannins should imply 100 percent clarity, thus making secchi depth easy to measure. Discrepancies in secchi depth data could also be influenced by local precipitation. For the 2002-2005 block, results from the Mann-Whitney U test (MW) indicated seasonal differences among two APNEP-CMN sites for secchi depth (MW P-value < 0.01) (Tables

10 and 16), which may reinforce differences due to precipitation. For the 1989-1992 block, results from the post-hoc pairwise comparisons indicated that APNEP-CMN site 06C was driving observed differences among the other three APNEP-CMN sites (Appendix B4). Unlike the other three sites, 06C also had average water and secchi depths that exceeded two meters (Appendix B1).

Dissolved oxygen

Dissolved oxygen was perhaps the most involved water quality variable measured by APNEP-CMN volunteers. For instance, volunteers used titration/chemical kits manufactured by the LaMotte Company containing protocols that involved titrations and non-contamination from atmospheric oxygen. Titration is a technique that involves adding a substance of known concentration into another solution of unknown concentration. The reaction is often complete after observing a color change in the solution of unknown concentration. Volunteers were advised to add the known solution into their prepared sample drop-by-drop using the titrator until they observed the color change. In this case, one drop can complete the reaction – this is considered volumetric analysis. To counteract any discrepancies in measurements, volunteers were asked to repeat the test for dissolved oxygen. If the measurement difference was greater than 0.6 milligrams per liter (mg/L), a third test was advised before taking the average for the final recorded measurement.

Dissolved oxygen concentrations vary throughout the day and season (Smith and Rulifson 2015). During the hours of no sunlight, oxygen is not being produced by sunlight through photosynthesis. During this time, available oxygen is being consumed by aquatic organisms; it is not until the daylight hours when oxygen concentrations can be replenished. If volunteers are monitoring mostly in the morning, then dissolved oxygen measurements may be lower when

compared to sites monitored during the afternoon. With this natural variability, differences were expected among the sites.

The 1991-1993 block of the lower and middle regions of the Albemarle compared five APNEP-CMN sites to a site monitored by the United States Geological Survey (USGS). Results from the Kruskal-Wallis tests (KW) suggested significant differences among APNEP-CMN and USGS monitoring sites (KW P-value < 0.01) (Tables 8 and 16). A closer look at the post-hoc pairwise comparisons (Appendix C4) revealed that mean differences among the sites varied from -0.05 to -6.13 milligrams per liter (mg/L). Only one APNEP-CMN site (05A) was similar to USGS. In addition, nearly all APNEP-CMN sites were dissimilar to each other. These dissimilarities may be a result of geographic distance among the sites. For instance, sites that were 25 and 60 kilometers (km) apart had mean differences in dissolved oxygen around -6.00 mg/L; however, there were also sites over 60 km from each other that had smaller differences between -3.00 and -4.00 mg/L (Appendix C9).

pH

APNEP-CMN volunteers measured pH using a colorimetric kit manufactured by the LaMotte Company. The protocol involved adding an indicator solution to the collected water sample. Volunteers then compared the color of their sample solution to a color octet comparator to get their final pH measurement. Since volunteers may see colors differently, this test can be considered subjective. In addition, each color in the octet comparator represents one pH measurement (e.g., 6.5, 7.0), which caused some volunteers to extrapolate the measurement if the colors did not match exactly with their sample solution.

A pH range between 6 and 9 is suitable for aquatic life, which was observed in all regions/blocks for the Tar-Pamlico and Albemarle with a few measurements that may have extended outside this range. These outliers could have represented real or faulty pH measurements.

From the post-hoc pairwise comparison results, significant mean differences among sites were sometimes small; for example, a 0.20 mean difference in pH between two sites (Appendix D12). In this case, some reported differences might not warrant concern about pH differences in volunteer and government data, particularly those within suitable range.

Salinity

APNEP-CMN volunteers measured salinity using two different techniques manufactured by the LaMotte Company: (1) titration/chemical test kit, and (2) hydrometer kit. During my tenure as project coordinator, APNEP-CMN volunteers were instructed to use the hydrometer kit to measure salinity since the protocol was simpler. Similar to dissolved oxygen, the titration/chemical test kit for salinity required titrations and demineralized water. The methods using the hydrometer kit involved filling a graduated cylinder with sample water before placing the hydrometer into the cylinder. Once the hydrometer was motionless, volunteers recorded the specific gravity along the surface of the sample water using the graduated scale on the hydrometer. Afterwards, volunteers used a provided chart to determine the salinity measurement using their gravity reading and water temperature. Thus, the salinity measurement was dependent on the water temperature measurement. If volunteers are leaving the thermometer in the graduated cylinder for an extended amount of time while they measured other water quality variables, then water temperature may change, thus impacting both water temperature and salinity measurements.

Salinity was also expected to vary among the sites. Grouping of these sites into lower, middle, or upper regions was a tactic to reduce these predicted differences. It can be assumed that

sites in the lower region, which are closest to the Albemarle-Pamlico estuary may be more susceptible to tidal influences or coastal storms, which may cause more saline water to be pushed upstream. Results from the post-hoc pairwise comparisons did detect variability in salinity among all three regions of the Tar-Pamlico (Appendices A15-A17). As expected, sites closest to Pamlico Sound had salinity differences between -0.60 and 7.24 parts per thousand (ppt) (Appendix A15). However, there were also differences in the other regions although the mean site differences were a lot smaller, particularly in the upper regions (Appendix 17), where salinity is typically lower.

How does volunteer data measure up to government data?

The impetus of this study was to describe the integrity of volunteer data when compared to government data that are grouped by region/block. Water and secchi depths lacked sufficient data to offer any solid interpretation. My first hypothesis stated that water quality data among sites within the same region would be similar although differences were expected for dissolved oxygen and salinity due to measuring protocols. The 1991-1993 block of the lower and middle Albemarle regions was the only comparison that supported this hypothesis. However, the Tar-Pamlico region reported significant differences for dissolved oxygen among sites within each of the three regions; salinity in the upper region. Significant differences were also reported among APNEP-CMN sites for dissolved oxygen and salinity in the 1989-1992 block of the Albemarle region; dissolved oxygen for the 2002-2005 block. Significant differences among sites within the middle and upper regions of the 2008-2010 block of the Albemarle were also reported for dissolved oxygen and salinity. For the 2011-2012 block of the Albemarle region, significant differences were reported for salinity data among the two sites.

A similar study conducted in freshwater streams of Nova Scotia discovered that volunteer data were similar to government, or professional, data when measured side-by-side for the

following variables: water temperature, pH, conductivity, and discharge. Similarities of these data were based on whether volunteer data were within accuracy requirements of mechanical and government criteria. The only significant difference was with dissolved oxygen. Recommendations from this study suggested modification of volunteer training protocols to improve calibration techniques and field methods (Shelton 2013).

How does volunteer data compare to other volunteer data?

There were two blocks in the Albemarle region that investigated how well water quality data from multiple APNEP-CMN sites compared to each other. The 1989-1992 block investigated four APNEP-CMN sites in the upper Chowan River. The longest distance among the sites was 2.5 kilometers. All four sites did not collect water temperature data. The 2002-2005 block compared two sites that were 6.6 kilometers apart in a tributary of the upper Chowan River. Both sites did not collect salinity data. My second hypothesis stated that APNEP-CMN volunteers with monitoring sites in close proximity to one another would produce similar results. Results from both comparison blocks were not in support of my second hypothesis.

Is monitoring equipment driving differences in water quality data?

APNEP-CMN volunteers used titration/chemical water quality test kits and other equipment manufactured by the LaMotte Company whereas government data were measured using more "modern" equipment such as probed water quality instruments and submerged data receivers. While titration/chemical test kits prove effective in measuring water quality if protocols are followed correctly, one limitation is that it is often labor intensive and subjective, which increases the potential for user error. There is also the issue of chemical expiration and storage requirements, which may influence measurements if unchecked. The advantage to using modern equipment such as probed instruments is that it allows the user to collect multiple water quality variables in a single

take over little time, thus making it more efficient. For this reason, this equipment has become an important and widely used tool for evaluating water quality on larger temporal and spatial scales (Glasgow et al. 2004). However, this equipment does present shortcomings, which includes cost, maintenance, and calibration techniques.

Citizen science projects are less likely to have a budget that allows the purchase of this type of monitoring equipment for each volunteer. Instead, the titration/chemical test kits and more "less technological" equipment are more economical. This does introduce the question to whether there are significant differences among using different types of equipment. If so, perhaps this could explain some of the differences in volunteer data observed in this study.

Results from unpublished water quality data collected from students enrolled in a Fisheries Techniques course led by Roger Rulifson (2015) at East Carolina University detected differences among some water quality variables when using different monitoring equipment. Specifically, results detected no significant differences (Independent t-test, P-value = 0.07, df = 7) among the means for dissolved oxygen when collected by the YSI Model 85 Water Quality Meter and the dissolved oxygen titration/chemical kit manufactured by the LaMotte Company. For pH, students detected significant differences (ANOVA, P-value < 0.01, df = 11) among the means for pH when measured using three types of monitoring equipment: (1) pH colorimetric test kit manufactured by the LaMotte Company, (2) pH Pen Model EX60, and (3) Hydrion pH paper. However, it should be noted that these students were being trained to measure water quality using different equipment when collecting these data, thus heightening the risk of human error.

While government data used for this study included different types of equipment, results from this investigation (Rulifson 2015) may suggest that different monitoring equipment can

produce water quality measurements that are not precise. The question to which method is accurate is up for debate and warrants further scientific investigation.

Limitations

A limitation of this study is that both volunteer and government data were not originally measured with the intent to be later compared to each other. This was the biggest challenge when designing and selecting data for this study. Differences in water quality were expected due to natural variability and the surrounding physical environment. The question that remained was the magnitude of these differences. If water quality were measured side-by-side between a volunteer and professional (Shelton 2013), determining data precision and/or accuracy might have been simpler.

There is also the expectation, or assumption, that government data collected by professionals are accurate – especially when compared to data collected by volunteers. However, does that mean that government data are free from errors? A water quality professional can be described as someone who receives monetary compensation for performing water quality monitoring to which they may have received previous training and education from a university or other institution. On the opposite side, you have volunteers who may or may not have previous education background in water quality monitoring aside from initial training by the project coordinator, or other necessary requirements. The question to whether government data are free from errors cannot be answered specifically, thus leaving the assumption that it is accurate. For clarity, professionals do follow a quality assurance/quality control plan, which drives how data are collected and managed. In some cases, water quality data from submerged data receivers would lack involvement from human interaction once the receivers were properly calibrated and made active. Data from these receivers were often collected hourly and uploaded directly from the

receiver or wirelessly for the professional to manage as seen by the United States Geological Survey data that were used in this study.

Recommendations

For new citizen science projects, a quality assurance/quality control plan should be first developed and followed for the duration of the project (Wiggins et al. 2011). In fact, it is required for all citizen science projects that are listed and supported by the United States Environmental Protection Agency (USEPA). Volunteers and participants of the project should receive copies of the plan so they have a clear understanding to what they are doing, why it is important, and how collected data will be managed. For existing projects that do not have a plan, the USEPA website provides a document that contains the necessary components for building a plan (USEPA 2013). Importantly, volunteers should be properly trained before collecting data. Training should include discussion to what each water quality variable represents and what the measurements mean. This will allow the volunteer to determine if their measurements appear erroneous so the protocol can be repeated to see how subsequent measurements compare. While volunteers should receive a copy of the plan containing important information about the project, the project coordinator should still devote time to explain each water quality variable being tested. If volunteers are only trained in how to take the measurements, then how well do volunteers understand the full scope to what they are doing? The coordinator, or trainer, should not assume that volunteers already know this information despite some volunteers mentioning they have previous water quality experience. The duration or frequency of training should also be considered. Is one training session enough? Should new volunteers be placed on a probationary period? These are the type of questions that the coordinator should deliberate when designing or modifying their training protocols based on the meticulousness of water quality variables being measured.

Following training, project coordinators should conduct site visits on occasion for each volunteer to reevaluate protocols being used. Over time, volunteers may develop their own system for improved monitoring efficiency. This developed system may or may not impact their measurements. For instance, volunteers may collect their water sample in a five-gallon bucket and place it in direct sunlight on the dock. If volunteers place the thermometer in the bucket and leave it for an extended length of time while they collect other data, the temperature measurement may not be true. If they use this temperature measurement to measure salinity using the hydrometer kit, this will also impact the salinity measurement. Volunteers may need to be advised whether or not their monitoring system is negatively impacting their data measurements.

Project coordinators should maintain transparency within the project so volunteers feel connected to the inner workings of the project. Lack of communication among project staff and volunteers can become a problem. Volunteers often join these projects because they have vested interest in the objectives of the project, thus they want to feel like what they are doing is important or sustaining the project. APNEP-CMN would keep volunteers abreast of information through quarterly newsletters that included local news concerning water quality, volunteer spotlights, and data reports. When volunteer data are requested for different research projects, volunteers should become aware. During my time as project coordinator for APNEP-CMN, this was the most common question asked by volunteers. They want to know how data are being used and that it carries value to the scientific community. With social media becoming mainstream in today's technology, this is an easy and affordable outlet for project coordinators to disseminate this type of information to volunteers and subscribers. Social media can also be used as a strategy for volunteer recruitment.

Results from this study suggested significant differences in water quality data for most variables among monitoring sites within a similar region and the same season (Tables 16 and 17a-b). Citizen science project coordinators should investigate monitoring equipment that is economical to the project budget but also eliminates multiple protocol steps. Protocols for both water temperature and pH are simpler in comparison to dissolved oxygen and salinity. Simpler protocols may contribute to lesser human error. For example, would dissolved oxygen data be more reliable if volunteers were using a probed instrument designed to measure pH? For dissolved oxygen, results from Rulifson (2015) revealed no significant differences when measured side-by-side using the titration/chemical kit manufactured by the LaMotte Company and YSI Model 85 Water Quality Meter. The difference between the two means was estimated at 2.3 milligrams per liter (mg/L) with the titration/chemical kit manufactured by the LaMotte Company having the lower mean. Interestingly, this pattern was also observed in the Tar-Pamlico and Albemarle regions. While the mean differences are not always exact, however, dissolved oxygen tends to be underestimated when measured using the titration/chemical test kit over the probed instruments or submerged data receivers. Although more data and investigation are needed to better understand these differences, coordinators should consider how different monitoring equipment may impact volunteer data.

Final words

Citizen science is an important tool for making a connection among the public and the scientific community. Without citizen science, long-term data sets such as the one produced by APNEP-CMN volunteers would not exist. These long-term data sets can help answer many questions about aquatic ecosystem health such as hurricane impacts and recovery, suitable habitats for commercially and recreationally important fisheries, as well as pollutant impacts from nearby

point-source polluters. Meanwhile, volunteers are becoming more educated about water quality health and its interconnectedness to everything around us. Volunteers can use their newfound knowledge to become more publicly involved in the processes that may govern environmental procedures, policy, and management. For instance, APNEP-CMN volunteer, Bill Dunn, has been featured in the local news speaking about the invasive aquatic plant, Hydrilla *(Hydrilla verticillata),* which is negatively impacting the Chowan River. Collaborative efforts between the volunteer and the North Carolina Division of Water Resources has helped establish methods to safely control this invasive species while not disrupting overall ecosystem health.

While water quality data produced by volunteers should be routinely monitored under the accordance of a quality assurance/quality control plan, project coordinators should make concerted efforts to sustain the project by making sure that volunteer data are made available to all that would benefit from it. The benefits of citizen should be known to the scientific community so that it can continue to be supported. Without citizen science, the public becomes disconnected, which has been a growing concern among scientists in the battle of environmental issues happening around the globe.

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Figure 2. Water quality data collection timeline for the Tar-Pamlico region. Sites are ordered from downstream to upstream.

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Figure 6. Map of APNEP-CMN sites for the 1989-1992 block of the upper Albemarle region. See Table 6 for site and geographic information.

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Figure 16. Non-metric multidimensional scaling plot of the Tar-Pamlico region for pH by project. Circles represent APNEP-CMN sites; triangles represent PCS Phosphate sites. Black = lower region; striped = middle region; and gray = upper region.

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Figure 27. Non-metric multidimensional scaling plot of the 2008-2010 block of the Albemarle region for water temperature (degrees Celsius) by project. Circles = APNEP-CMN sites. Triangles = NCDMF sites. Black = lower region; striped = middle region; and gray = upper region.

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Figure 32. Principal components analysis output for (a) APNEP-CMN site 05C and (b) ECU site CB of the 2011-2012 block of the upper Albemarle region. Output includes biplot, loading matrix, and eigenvalues.

Table 1.

Project	Position	Region	Site	Description	Latitude	Longitude	Years Monitored	Average Collection Time
PCS Phosphate	1	Lower	1	Between Pamlico Point and Rose Bay	35.35000000	-76.48333300	1987-1988, 1990-2013	Varied
PCS Phosphate	2	Lower	1A	Between Abel Bay and Cedar Island	35.35833300	-76.52500000	1987, 1990-2013	Varied
APNEP-CMN	3	Lower	17P	Pungo Shores	35.46666667	-76.60138889	1988-1990	Varied
APNEP-CMN	4	Lower	19P	Vale Creek	35.51748690	-76.64798500	1988-1993	Varied
PCS Phosphate	5	Lower	2	Lighted marker "1" at Goose Creek	35.33944400	-76.59638900	1988, 1992	Varied
PCS Phosphate	6	Lower	3	Lighted marker "3" off Indian Island	35.37305600	-76.64638900	1987-2013	Varied
PCS Phosphate	7	Lower	4S	Lighted marker "4" off South Creek	35.35777800	-76.67722200	1987, 1990-1996	Varied
PCS Phosphate	8	Lower	4N	Lighted marker "1" off North Creek	35.41277800	-76.66916700	1987, 1990-1996	Varied
PCS Phosphate	9	Lower	4P	Day marker "7" in South Creek	35.35111100	-76.72833300	1987, 1990-1996	Varied
APNEP-CMN	10	Lower	15P	South Creek	35.36666667	-76.71666667	1988-1992	Varied
PCS Phosphate	11	Lower	5S	Lighted marker "1" at Ferry Terminal	35.38138900	-76.74638900	1987, 1990-1996	Varied
PCS Phosphate	12	Lower	5	Between 5N and 5S	35.40027800	-76.73833300	1987, 1989-2013	Varied
PCS Phosphate	13	Lower	5N	Lighted marker "1" in Gaylord Bay	35.42194400	-76.73611100	1987, 1990-1996	Varied
PCS Phosphate	14	Lower	6	TGC Outfall	35.38666700	-76.76861100	1987, 1990-2013	Varied
APNEP-CMN	15	Lower	57P	Mixon Creek	35.43166667	-76.77277778	2003-2006	Afternoon
APNEP-CMN	16	Middle	25N	Bonnerton Bridge	35.35944444	-76.86555556	1995-1996	Varied
PCS Phosphate	17	Middle	7S	Day marker "2" at Durham Creek	35.39944400	-76.81777800	1987, 1990-2013	Varied
APNEP-CMN	18	Middle	11P	Hunter's Bridge, Bath Creek	35.52250000	-76.81000000	1988-1993	Afternoon
APNEP-CMN	19	Middle	13P	Bath Creek	35.47305556	-76.81305556	1988-2001	Varied
PCS Phosphate	20	Middle	7N	Lighted marker "1" at Bath Creek	35.45222200	-76.82083300	1987, 1990-1996	Varied
PCS Phosphate	21	Middle	7	Lighted marker "5" off Core Point	35.43055600	-76.84166700	1987, 1990-2013	Varied
PCS Phosphate	22	Middle	8	Lighted marker "7" at Mauls Point	35.45277800	-76.91944400	1987, 1990-2013	Varied
APNEP-CMN	23	Middle	20P	Blount's Creek, Eastside	35.38805556	-76.97277778	1994-1997	Afternoon
PCS Phosphate	24	Middle	9S	South Blounts Bay	35.45111100	-76.95888900	1987-1996	Varied
APNEP-CMN	25	Middle	65P	Broad Creek	35.48955500	-76.95121600	2012-2013	Afternoon
APNEP-CMN	26	Middle	07P	Pamlico Plantation	35.47722222	-76.95472222	1988-1990	Varied
PCS Phosphate	27	Middle	9N	Lighted marker "1" at Broad Creek	35.48055600	-76.95666700	1987, 1990-1996	Varied
APNEP-CMN	28	Middle	03P	Hills Point	35.46666667	-76.98305556	1988-1989	Varied
PCS Phosphate	29	Middle	10	Lighted marker "12" at Camp Hardee	35.48194400	-76.98750000	1987, 1990-2013	Varied
APNEP-CMN	30	Upper	10P	Mouth of Chocowinity Bay	35.48527778	-77.03416667	1990-1993	Varied
APNEP-CMN	31	Upper	50P	Cypress Landing, Pamlico River	35.49722222	-77.03916667	2000-2007	Afternoon
APNEP-CMN	32	Upper	05P	Chocowinity Bay	35.49822800	-77.03060000	1988-1990	Varied
PCS Phosphate	33	Upper	11	Mouth of Chocowinity Bay	35.49750000	-77.02722200	1987, 1990-1996	Varied
APNEP-CMN	34	Upper	06P	River Acres	35.50510300	-77.00405700	1989-1990	Varied
PCS Phosphate	35	Upper	12	Railroad Bridge	35.53111100	-77.04861100	1987, 1990-2013	Varied
APNEP-CMN	36	Upper	01P	NC Estuarium, Pamlico River	35.54277778	-77.05972222	1988-2004	Varied
APNEP-CMN	37	Upper	09T	Tranters Creek	35.57111111	-77.10750000	1988-1990	Varied
APNEP-CMN	38	Upper	07T	Chicod Creek	35.58500000	-77.20361111	1988-1993	Varied
APNEP-CMN	39	Upper	06T	Tar River, Near Grimesland	35.60888889	-77.22750000	1988-1989	Varied
APNEP-CMN	40	Upper	05T	Tar River, Near Greenville Town Common	35.61777778	-77.37722222	1988-1991	Varied

Table 2.

Project	Position	Region	Site	Latitude	Longitude	Description	Dates	Avg. Time
APNEP-CMN	1	Lower	18A	36.053056	-75.692222	Kitty Hawk Bay	1989-1996	Varies
APNEP-CMN	2	Lower	11CS	36.193056	-75.884722	Fisher Landing, North River	1990-1991, 1994-1995	Varies
NCDMF	3	Lower	9	35.904910	-76.007780	Alligator River, US 64 Bridge	2008-2010	Afternoon
NCDMF	4	Lower	10	35.672333	-76.081800	Alligator River, Grassy Point (Marker #49)	2008-2010	Afternoon
USGS	5	Lower	USGS	36.151667	-76.021667	USGS Station, Pasquotank, Hydrologic Unit 03010205	1991-1993	N/A
APNEP-CMN	6	Lower	35A	36.258889	-76.145000	Pasquotank River, Brickhouse Pt., SE of Davis Bay	2003-2009	Afternoon
NCDMF	7	Lower	8	36.288950	-76.188630	Pasquotank River, Cobb Point (Marker #7)	2008-2010	Afternoon
APNEP-CMN	8	Lower	02A	36.300000	-76.216667	Knobbs Creek	1989-1994	Varies
APNEP-CMN	9	Lower	01A	36.336111	-76.219222	Above WWTP	1989-1994, 1996	Varies
APNEP-CMN	10	Middle	05A	36.135139	-76.332889	Perquimans River	1989-1993	Varies
APNEP-CMN	11	Middle	36A	36.160980	-76.428270	Perquimans River	2006-2012	Afternoon
NCDMF	12	Middle	5	36.194167	-76.461700	Perquimans River, S-Bridge (Marker #9)	2008-2010	Afternoon
NCDMF	13	Middle	6	35.925070	-76.281115	Scuppernong River, Marker #5	2008-2010	Afternoon
NCDMF	14	Middle	12	35.861649	-76.384312	Scuppernong River, SR 1142 (Main Street)	2008-2010	Afternoon
APNEP-CMN	15	Middle	32A	36.108611	-76.421944	Yeopim Creek	2002, 2004-2009	Afternoon
NCDMF	16	Middle	4	35.915190	-76.723010	Roanoke River, US 45 Bridge	2008-2010	Afternoon
APNEP-CMN	17	Middle	25C	36.015435	-76.586051	Cape Colony, Albemarle Sound	2007-2009	Afternoon
NCDMF	18	Middle	14	36.040861	-76.703833	Chowan River Bridge Seine Site (#46S)	2008-2010	Afternoon
NCDMF	19	Middle	1	36.096900	-76.724600	Chowan River, Rocky Hock (Marker #3)	2008-2010	Afternoon
APNEP-CMN	20	Upper	06C	36.213056	-76.715556	Chowan Beach	1989-1994	Morning
APNEP-CMN	21	Upper	04C	36.224611	-76.708694	Tyner	1989-1992	Varies
APNEP-CMN	22	Upper	01C	36.234667	-76.706917	Kelly's Beach	1989-1991	Varies
APNEP-CMN	23	Upper	05C	36.227050	-76.706551	Arrowhead Beach, Chowan River	1989-1997, 2000-2013	Morning
ECU	24	Upper	CB	36.269300	-76.682171	Chowan River B	2011-2012	N/A
NCDMF	25	Upper	2	36.294400	-76.697300	Chowan River, Holiday Island (Marker #13)	2008-2010	Afternoon
NCDMF	26	Upper	11	36.314010	-76.656780	Catherine's Creek, SR 1232 (Catherine Creek Road)	2008-2010	Afternoon
APNEP-CMN	27	Upper	22C	36.398889	-76.750833	Bennett's Creek at Highway 37 Bridge	2002-2008	Morning
APNEP-CMN	28	Upper	23C	36.431389	-76.698889	Bennett's Creek (just below Merchant's Millpond dam)	2002-2005	Morning
NCDMF	29	Upper	3	36.402100	-76.935100	Chowan River, US 13 Bridge	2008-2010	Afternoon
APNEP-CMN	30	Upper	21C	36.530833	-76.925833	Chowan River at Riddick's Landing	2002-2008	Afternoon
NCDMF	31	Upper	13	36.543837	-76.916505	Blackwater River, NC/VA Line	2008-2010	Afternoon

Table 3.

(a) Lower region

Region	Site	1	1A	17P	19P	2	3	4S	4N	4P	15P	5S	5	5N	6	57P
Lower	1		4.00	16.81	25.60	10.34	15.04	17.64	18.27	22.27	21.29	24.16	23.83	24.31	26.24	27.81
	1A	4.00		13.88	22.55	6.82	11.15	13.84	14.42	18.50	17.44	20.28	19.94	20.44	22.36	23.94
	17P	16.81	13.88		8.79	15.34	17.00	20.45	20.78	25.34	23.82	26.96	25.64	26.44	28.43	29.91
	19P	25.60	22.55	8.79		23.45	26.48	29.22	28.73	33.03	32.48	34.66	34.68	34.44	36.55	37.26
	2	10.34	6.82	15.34	23.45		5.88	7.62	10.48	12.41	11.34	14.41	14.56	15.65	16.51	19.01
	3	15.04	11.15	17.00	26.48	5.88		3.27	4.87	7.84	6.43	9.13	8.88	9.79	11.21	13.19
	4S	17.64	13.84	20.45	29.22	7.62	3.27		6.15	4.70	3.72	6.81	7.28	8.91	8.90	11.94
	4N	18.27	14.42	20.78	28.73	10.48	4.87	6.15		8.70	6.69	7.83	6.43	6.16	9.49	9.64
	4P	22.27	18.50	25.34	33.03	12.41	7.84	4.70	8.70		2.03	10.32	11.99	13.61	13.61	16.77
	15P	21.29	17.44	23.82	32.48	11.34	6.43	3.72	6.69	2.03		3.16	4.22	6.38	5.22	8.83
	5S	24.16	20.28	26.96	34.66	14.41	9.13	6.81	7.83	10.32	3.16		2.22	4.60	2.10	6.07
	5	23.83	19.94	25.64	34.68	14.56	8.88	7.28	6.43	11.99	4.22	2.22		2.41	3.14	4.68
	5N	24.31	20.44	26.44	34.44	15.65	9.79	8.91	6.16	13.61	6.38	4.60	2.41		4.90	3.50
	6	26.24	22.36	28.43	36.55	16.51	11.21	8.90	9.49	13.61	5.22	2.10	3.14	4.90		5.01
	57P	27.81	23.94	29.91	37.26	19.01	13.19	11.94	9.64	16.77	8.83	6.07	4.68	3.50	5.01	

(b) Middle region

Region	Site	25N	7S	11P	13P	7N	7	8	20P	9S	65P	07P	9N	03P	10
Middle	25N		7.05	21.35	15.46	13.02	11.23	18.86	30.36	22.30	24.30	23.27	23.24	24.66	25.89
	7S	7.05		14.11	8.28	5.86	4.08	11.56	23.01	15.14	17.16	16.15	16.13	17.53	18.53
	11P	21.35	14.11		6.27	8.72	11.69	17.68	30.33	21.08	23.52	23.00	22.96	24.55	25.36
	13P	15.46	8.28	6.27		2.42	5.48	11.37	23.63	15.77	17.29	16.57	16.28	18.16	18.93
	7N	13.02	5.86	8.72	2.42		3.06	9.62	21.55	13.18	15.41	14.24	13.98	15.69	16.49
	7	11.23	4.08	11.69	5.48	3.06		7.48	18.93	11.07	13.08	11.93	12.05	13.46	14.41
	8	18.86	11.56	17.68	11.37	9.62	7.48		12.13	3.59	5.60	4.48	4.57	5.98	6.97
	20P	30.36	23.01	30.33	23.63	21.55	18.93	12.13		8.52	12.23	10.81	11.30	11.03	11.98
	9S	22.30	15.14	21.08	15.77	13.18	11.07	3.59	8.52		4.32	2.15	3.27	2.79	4.29
	65P	24.30	17.16	23.52	17.29	15.41	13.08	5.60	12.23	4.32		2.49	1.11	3.85	4.43
	07P	23.27	16.15	23.00	16.57	14.24	11.93	4.48	10.81	2.15	2.49		1.31	1.82	2.53
	9N	23.24	16.13	22.96	16.28	13.98	12.05	4.57	11.30	3.27	1.11	1.31		2.85	2.80
	03P	24.66	17.53	24.55	18.16	15.69	13.46	5.98	11.03	2.79	3.85	1.82	2.85		1.74
	10	25.89	18.53	25.36	18.93	16.49	14.41	6.97	11.98	4.29	4.43	2.53	2.80	1.74	

(c) Upper region

Region	Site	10P	50P	05P	11	06P	12	01P	09T	07T	06T	05T
Upper	10P		1.40	1.10	1.50	3.51	8.12	9.73	16.08	24.08	27.14	42.50
	50P	1.40		1.53	1.08	3.42	7.34	9.14	16.66	23.95	27.37	43.20
	05P	1.23	1.53		0.71	2.18	6.85	8.38	15.55	22.47	25.48	40.10
	11	1.50	1.08	0.71		2.26	5.53	7.15	14.74	22.06	25.30	40.35
	06P	3.51	3.42	2.18	2.26		4.97	6.55	13.00	20.85	24.24	38.56
	12	8.12	7.34	6.85	5.53	4.97		1.64	8.18	16.17	19.08	33.89
	01P	9.73	9.14	8.38	7.15	6.55	1.64		6.72	14.08	17.33	32.20
	09T	16.08	16.66	15.55	14.74	13.00	8.18	6.72		10.63	13.23	28.35
	07T	24.08	23.95	22.47	22.06	20.85	16.17	14.08	10.63		4.64	19.66
	06T	27.14	27.37	25.48	25.30	24.24	19.08	17.33	13.23	4.64		14.96
	05T	42.50	43.20	40.10	40.35	38.56	33.89	32.20	28.35	19.66	14.96	

Table 4.

(a) Lower region

Region	Site	18A	11CS	9	10	USGS	35A	8	02A	01A
Lower	18A		30.11	34.87	67.02	34.60	50.65	55.68	58.27	62.62
	11CS	30.11		33.84	65.37	13.94	31.99	35.91	38.02	42.17
	9	34.87	33.84		31.06	27.41	43.67	48.82	51.62	55.64
	10	67.02	65.37	31.06		59.14	74.99	80.17	82.57	89.18
	USGS	34.60	13.94	27.41	59.14		16.27	21.41	24.21	28.23
	35A	50.65	31.99	43.67	74.99	16.27		5.15	7.95	11.96
	8	55.68	35.91	48.82	80.17	21.41	5.15		2.80	6.81
	02A	58.27	38.02	51.62	82.57	24.21	7.95	2.80		4.01
	01A	62.62	42.17	55.64	89.18	28.23	11.96	6.81	4.01	

(b) Middle region

Region	Site	05A	36A	5	6	12	32A	4	25C	14	1
Middle	05A		9.05	13.80	24.73	48.19	22.85	51.92	38.29	49.28	54.62
	36A	9.05		4.75	37.71	56.77	30.67	59.72	45.61	57.13	62.94
	5	13.80	4.75		41.72	61.48	34.89	63.97	49.60	60.98	66.81
	6	24.73	37.71	41.72		17.42	25.07	44.90	45.02	43.73	50.25
	12	48.19	56.77	61.48	17.42		43.58	65.41	49.06	63.87	68.21
	32A	22.85	30.67	34.89	25.07	43.58		40.12	37.68	37.16	43.76
	4	51.92	59.72	63.97	44.90	65.41	40.12		16.67	16.00	22.49
	25C	38.29	45.61	49.60	45.02	49.06	37.68	16.67		10.98	17.48
	14	49.28	57.13	60.98	43.73	63.87	37.16	16.00	10.98		6.49
	1	54.62	62.94	66.81	50.25	68.21	43.76	22.49	17.48	6.49	

(c) Upper region

Region	Site	06C	04C	01C	05C	CB	2	11	22C	23C	3	21C	13
Upper	06C		1.42	2.52	1.75	6.96	9.35	15.17	47.31	36.00	36.01	53.56	57.26
	04C	1.42		1.13	0.90	5.50	7.91	13.15	27.73	34.79	33.24	52.54	53.02
	01C	2.52	1.13		0.85	4.44	6.84	12.65	27.22	33.48	32.67	51.01	57.85
	05C	1.75	0.90	0.85		5.18	7.59	13.38	28.60	35.08	33.98	53.62	60.27
	CB	6.96	5.50	4.44	5.18		3.10	8.33	21.25	27.88	28.49	47.65	53.69
	2	9.35	7.91	6.84	7.59	3.10		6.30	21.67	28.56	25.60	44.64	51.09
	11	15.17	13.15	12.65	13.38	8.33	6.30		27.09	34.34	31.84	49.96	56.10
	22C	47.31	27.73	27.22	28.60	21.25	21.67	27.09		6.59	43.93	62.21	66.54
	23C	36.00	34.79	33.48	35.08	27.88	28.56	34.34	6.59		51.00	70.73	76.86
	3	36.01	33.24	32.67	33.98	28.49	25.60	31.84	43.93	51.00		18.47	24.58
	21C	53.56	52.54	51.01	53.62	47.65	44.64	49.96	62.21	70.73	18.47		7.90
	13	57.26	53.02	57.85	60.27	53.69	51.09	56.10	66.54	76.86	24.58	7.90	

Table 5.

Factor	Dependent variables	Region	df	Mean squares	F-ratio	P, ANOVA	P, Kruskal Wallis
Project	Water temperature	Lower	1	336.51	5.61	0.018	0.014
		Middle	1	312.95	5.03	0.025	0.038
		Upper	1	132.27	2.06	0.152	0.137
	Dissolved oxygen	Lower	1	896.59	151.60	< 0.01	< 0.01
		Middle	1	4546.31	704.95	< 0.01	< 0.01
		Upper	1	892.56	141.54	< 0.01	< 0.01
	pH	Lower	1	36.31	121.55	< 0.01	< 0.01
		Middle	1	214.30	395.03	< 0.01	< 0.01
		Upper	1	38.504	67.26	< 0.01	< 0.01
	Salinity	Lower	1	3.424	0.18	0.674	0.747
		Middle	1	15.329	0.73	0.392	0.336
		Upper	1	150.414	16.73	< 0.01	< 0.01

Table 6.

(a) APNEP-CMN

Factor	Dependent variables	Region	df	Mean squares	F-ratio	P, ANOVA	P, Kruskal Wallis
Season	Water temperature	Lower	3	1214.452	67.73	< 0.01	< 0.01
		Middle	3	6145.48	394.72	< 0.01	< 0.01
		Upper	3	4099.08	194.03	< 0.01	< 0.01
	Dissolved oxygen	Lower	3	443.31	112.86	< 0.01	< 0.01
		Middle	3	615.31	95.87	< 0.01	< 0.01
		Upper	3	558.43	128.60	< 0.01	< 0.01
	pH	Lower	3	2.65	6.65	< 0.01	< 0.01
		Middle	3	5.05	7.52	< 0.01	< 0.01
		Upper	3	1.362	2.19	0.087	0.074
	Salinity	Lower	3	1360.415	75.47	< 0.01	< 0.01
		Middle	3	1862.938	97.68	< 0.01	< 0.01
		Upper	3	211.61	24.91	< 0.01	< 0.01

(b) PCS Phosphate

Factor	Dependent variables	Region	df	Mean squares	F-ratio	P, ANOVA	P, Kruskal Wallis
Season	Water temperature	Lower	3	33198.872	1280.33	< 0.01	< 0.01
		Middle	3	30348.29	1123.73	< 0.01	< 0.01
		Upper	3	8298.24	317.54	< 0.01	< 0.01
	Dissolved oxygen	Lower	3	1179.28	251.88	< 0.01	< 0.01
		Middle	3	1040.19	230.07	< 0.01	< 0.01
		Upper	3	278.61	51.50	< 0.01	< 0.01
	pH	Lower	3	1.34	7.79	< 0.01	< 0.01
		Middle	3	3.22	12.22	< 0.01	< 0.01
		Upper	3	0.421	1.25	0.294	0.349
	Salinity	Lower	3	1434.728	79.00	< 0.01	< 0.01
		Middle	3	1392.102	72.45	< 0.01	< 0.01
		Upper	3	246.6	26.72	< 0.01	< 0.01

Table 7.

Factor	Dependent variables	Region	df	Mean squares	F-ratio	P, ANOVA	P, Kruskal Wallis
Site	Water depth	Upper	3	90.821	552.00	< 0.01	< 0.01
	Secchi depth	Upper	3	27.01	129.66	< 0.01	< 0.01
	Dissolved oxygen	Upper	3	18.35	6.28	< 0.01	< 0.01
	pH	Upper	3	3.33	18.18	< 0.01	< 0.01
	Salinity	Upper	1	4.64	4.17	0.046	N/A

Table 8.

Factor	Dependent variables	Region	df	Mean squares	F-ratio	P, ANOVA	P, Kruskal Wallis
Project	Water temperature	Lower, Middle	1	35.601	0.61	0.436	0.551
	Dissolved oxygen	Lower, Middle	1	1765.61	265.86	< 0.01	< 0.01
	Salinity	Lower, Middle	1	50.24	15.07	< 0.01	< 0.01

Table 9.

(a) APNEP-CMN

Factor	Dependent variables	Region	df	Mean squares	F-ratio	P, ANOVA	P, Kruskal Wallis
Season	Water temperature	Lower, Middle	3	18798.885	1413.94	< 0.01	< 0.01
	Dissolved oxygen	Lower, Middle	3	612.82	93.21	< 0.01	< 0.01
	pH	Lower, Middle	3	3.41	3.89	0.009	0.012
	Salinity	Lower, Middle	3	94.35	30.44	< 0.01	< 0.01

(b) USGS

Factor	Dependent variables	Region	df	Mean squares	F-ratio	P, ANOVA	P, Kruskal Wallis
Season	Water temperature	Lower, Middle	3	11477.161	1025.18	< 0.01	< 0.01
	Dissolved oxygen	Lower, Middle	3	314.43	323.78	< 0.01	< 0.01
	Salinity	Lower, Middle	3	149.35	93.87	< 0.01	< 0.01

Table 10.

Factor	Dependent variables	Region	df	Difference in Means	P, Two-sample t-test	P, Mann-Whitney U-Test
Site	Water temperature	Upper	227	0.723	0.476	0.353
	Water depth	Upper	228	1.356	< 0.01	< 0.01
	Secchi depth	Upper	228	0.33	< 0.01	< 0.01
	Dissolved oxygen	Upper	226	-1.67	< 0.01	< 0.01
	pH	Upper	N/A	N/A	N/A	0.088

Table 11.

(a) 22C

Factor	Dependent variables	Region	df	Mean Squares	F-ratio	P, ANOVA	P, Kruskal-Wallis
Season	Water temperature	Upper	3	1991.568	130.011	< 0.01	< 0.01
	Water depth	Upper	3	0.227	5.559	0.001	0.003
	Secchi depth	Upper	3	0.314	7.166	< 0.01	0.014
	Dissolved oxygen	Upper	3	278.449	75.744	< 0.01	< 0.01
	pH	Upper	N/A	N/A	N/A	N/A	1.000

(b) 23C

Factor	Dependent variables	Region	df	Mean Squares	F-ratio	P, ANOVA	P, Kruskal-Wallis
Season	Water temperature	Upper	3	1189.596	99.723	< 0.01	< 0.01
	Water depth	Upper	3	0.650	11.805	< 0.01	< 0.01
	Secchi depth	Upper	3	0.450	19.789	< 0.01	< 0.01
	Dissolved oxygen	Upper	3	174.026	59.476	< 0.01	< 0.01
	pH	Upper	3	0.014	2.372	0.076	0.019

Table 12.

Factor	Dependent variables	Region	df	Mean squares	F-ratio	P, ANOVA	P, Kruskal Wallis
Project	Water temperature	Lower	1	0.93	0.02	0.904	0.795
		Middle	1	1584.67	23.37	< 0.01	< 0.01
		Upper	1	0.09	0.00	0.974	0.674
	Water depth	Lower	1	102.35	2591.16	< 0.01	< 0.01
		Middle	1	1587.13	519.40	< 0.01	< 0.01
		Upper	1	853.22	388.28	< 0.01	< 0.01
	Dissolved oxygen	Lower	1	0.89	0.22	0.637	0.358
		Middle	1	524.64	59.87	< 0.01	< 0.01
		Upper	1	127.52	14.17	< 0.01	< 0.01
	pH	Lower	1	2.88	4.20	0.041	0.016
		Middle	1	0.11	0.24	0.623	0.664
		Upper	1	0.92	2.37	0.124	0.738
	Salinity	Lower	1	3.03	0.79	0.374	0.003
		Middle	1	2142.65	1998.51	< 0.01	< 0.01
		Upper	1	0.41	2.15	0.143	< 0.01

Table 13.

(a) APNEP-CMN

Factor	Dependent variables	Region	df	Mean squares	F-ratio	P, ANOVA	P, Kruskal Wallis
Season	Water temperature	Lower	3	454.86	28.76	< 0.01	< 0.01
		Middle	3	3138.13	151.07	< 0.01	< 0.01
		Upper	3	1064.65	76.70	< 0.01	< 0.01
	Water depth	Lower	3	0.16	2.96	0.052	0.037
		Middle	3	0.23	0.51	0.673	0.141
		Upper	3	0.13	2.47	0.069	0.213
	Dissolved oxygen	Lower	3	21.84	26.62	< 0.01	< 0.01
		Middle	3	75.61	34.13	< 0.01	< 0.01
		Upper	3	73.72	11.00	< 0.01	< 0.01
	pH	Lower	3	2.07	4.38	0.014	0.033
		Middle	3	2.43	4.16	0.007	< 0.01
		Upper	3	0.51	2.81	0.045	0.022
	Salinity	Lower	3	6.87	17.47	< 0.01	0.004
		Middle	3	30.79	6.46	< 0.01	0.008
		Upper	3	0.39	1.03	0.388	0.224

(b) NCDMF

Factor	Dependent variables	Region	df	Mean squares	F-ratio	P, ANOVA	P, Kruskal Wallis
Season	Water temperature	Lower	3	22656.88	1608.14	< 0.01	< 0.01
		Middle	3	38567.32	2210.78	< 0.01	< 0.01
		Upper	3	29812.38	1585.12	< 0.01	< 0.01
	Water depth	Lower	3	1.24	34.20	< 0.01	< 0.01
		Middle	3	47.04	14.52	< 0.01	< 0.01
		Upper	3	54.95	25.02	< 0.01	< 0.01
	Dissolved oxygen	Lower	3	835.66	384.12	< 0.01	< 0.01
		Middle	3	2529.34	425.07	< 0.01	< 0.01
		Upper	3	2281.86	570.47	< 0.01	< 0.01
	pH	Lower	3	54.84	101.77	< 0.01	< 0.01
		Middle	3	4.98	11.52	< 0.01	< 0.01
		Upper	3	6.52	16.92	< 0.01	< 0.01
	Salinity	Lower	3	435.02	148.64	< 0.01	< 0.01
		Middle	3	40.57	53.59	< 0.01	< 0.01
		Upper	3	7.11	42.14	< 0.01	< 0.01

Table 14.

Factor	Dependent variables	Region	df	Difference in Means	P, Two-sample t-test	P, Mann-Whitney U-Test
Project	Water temperature	Upper	52	-1.430	0.609	0.616
	Dissolved oxygen	Upper	35	-1.533	0.443	0.758
	pH	Upper	53	-1.546	< 0.01	< 0.01
	Salinity	Upper	43	-0.778	0.001	< 0.01

Table 15.

(a) 05C, APNEP-CMN

Factor	Dependent variables	Region	df	Mean Squares	F-ratio	P, ANOVA	P, Kruskal-Wallis
Season	Water temperature	Upper	3	558.181	22.476	< 0.01	< 0.01
	Dissolved oxygen	Upper	3	1.412	0.109	0.954	0.952
	pH	Upper	3	0.031	0.511	0.677	0.580
	Salinity	Upper	3	0.102	0.235	0.872	0.885

(b) CB, ECU

Factor	Dependent variables	Region	df	Mean Squares	F-ratio	P, ANOVA	P, Kruskal-Wallis
Season	Water temperature	Upper	3	167.961	9.128	0.012	0.069
	Dissolved oxygen	Upper	3	78.736	1.030	0.444	0.381
	pH	Upper	3	0.030	0.303	0.823	0.549
	Salinity	Upper	3	0.086	4.843	0.061	0.314

Table 16.

Comparison	Factor	Region/Block	Water quality variable					
			Water temperature	Water depth	Secchi depth	Dissolved oxygen	pH	Salinity
V-G	Project	**Tar-Pamlico**						
		Lower	0.010	N/A	N/A	< 0.01	< 0.01	0.747
		Middle	0.038	N/A	N/A	< 0.01	< 0.01	0.336
		Upper	0.137	N/A	N/A	< 0.01	< 0.01	< 0.01
		Albemarle						
V-V	Site	1989-1992 block	N/A	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
V-G	Project	1991-1993 block	0.551	N/A	N/A	< 0.01	N/A	< 0.01
V-V	Site	2002-2005 block	0.353	< 0.01	< 0.01	< 0.01	0.088	N/A
V-G	Project	2008-2010 block						
		Lower	0.795	< 0.01	N/A	0.358	0.016	0.003
		Middle	< 0.01	< 0.01	N/A	< 0.01	0.664	< 0.01
		Upper	0.674	< 0.01	N/A	< 0.01	0.738	< 0.01
V-G	Project	2011-2012 block	0.616	N/A	N/A	0.758	< 0.01	< 0.01

Table 17.

(a) APNEP-CMN

Project	Factor	Region/Block	Water quality variable					
			Water temperature	Water depth	Secchi depth	Dissolved oxygen	pH	Salinity
		Tar-Pamlico						
APNEP-CMN	Season	*Lower*	< 0.01	N/A	N/A	< 0.01	< 0.01	< 0.01
		Middle	< 0.01	N/A	N/A	< 0.01	< 0.01	< 0.01
		Upper	< 0.01	N/A	N/A	0.074	< 0.01	< 0.01
		Albemarle						
APNEP-CMN	Season	1989-1992 block	N/A	N/A	N/A	N/A	N/A	N/A
		1991-1993 block	< 0.01	N/A	N/A	< 0.01	0.012	< 0.01
		2002-2005 block	< 0.01	0.003	0.014	< 0.01	1.000	N/A
		2008-2010 block						
		Lower	< 0.01	0.037	N/A	< 0.01	0.033	0.004
		Middle	< 0.01	0.141	N/A	< 0.01	< 0.01	0.008
		Upper	< 0.01	0.213	N/A	< 0.01	0.022	0.224
		2011-2012 block	< 0.01	N/A	N/A	0.952	0.580	0.885

(b) Government and APNEP-CMN

Project	Factor	Region/Block	Water quality variable					
			Water temperature	Water depth	Secchi depth	Dissolved oxygen	pH	Salinity
		Tar-Pamlico						
PCS Phosphate	Season	*Lower*	< 0.01	N/A	N/A	< 0.01	< 0.01	< 0.01
		Middle	< 0.01	N/A	N/A	< 0.01	< 0.01	< 0.01
		Upper	< 0.01	N/A	N/A	< 0.01	0.349	< 0.01
		Albemarle						
APNEP-CMN	Season	1989-1992 block	N/A	N/A	N/A	N/A	N/A	N/A
USGS		1991-1993 block	< 0.01	N/A	N/A	< 0.01	N/A	< 0.01
APNEP-CMN		2002-2005 block	< 0.01	< 0.01	< 0.01	< 0.01	0.019	N/A
NCDMF		2008-2010 block						
		Lower	< 0.01	< 0.01	N/A	< 0.01	< 0.01	< 0.01
		Middle	< 0.01	< 0.01	N/A	< 0.01	< 0.01	< 0.01
		Upper	< 0.01	< 0.01	N/A	< 0.01	< 0.01	< 0.01
ECU		2011-2012 block	0.069	N/A	N/A	0.381	0.549	0.314

Figure 1a.

APNEP CITIZENS' MONITORING NETWORK
ICSP / 250 Flanagan Building / East Carolina University / Greenville, NC 27858-4353
Phone: (252) 328-1747 / Fax: (252) 328-4265

DATA REPORT

Numbered items denote Data Base Information
S = # Denotes Sensitivity of Measurement

---------- ***Section A - General Information*** ---------- **CROSS OUT IF NO DATA** ----------

(1) Site Code: (Number and Letter)..... **(1)** ___ ___ ___ ___ ___

(2) Monitor Name: **Please Print Here** _____ **(2)** **Monitor #:** ___ ___ ___

(3) Collection Date: ..... **(3)** **Year** __ __**Month** __ __**Day** __ __

(4) Time of Day (Military Time): ..... **(4)** **Hours** __ __ : **Minutes** __ __

(5) Air Temperature: ..... **(5)** ___ ___ . ___ **Degrees Celsius**

(6) Bucket Sample Water Temperature: ..... **(6)** ___ ___ . ___ **Degrees Celsius**

---------- ***Section B - Turbidity*** ----------

(7) Secchi Depth: [S = 0.05 M] **(7)** ___ ___ . ___ ___ **Meters**
(if secchi depth > water depth, enter water depth for #7 and #8)

(8) Water Depth: [S = 0.05 M] (water depth must be ≥ secchi depth)..... **(8)** ___ ___ . ___ ___ **Meters**

---------- ***Section C - pH & Dissolved Oxygen*** ----------

(9) pH: ..... **(9)** ___ ___ . ___ **Standard Units**

Begin Dissolved Oxygen Tests
Test 1 (T1) [S = 0.1 mg/l for a tests] __ ___ . ___ mg/L

Test 2 (T2) & difference of T1-T2 (Conduct third test if difference is > 0.6) ___ ___ . ___ mg/L Diff. = 0. ___

Test 3 - (If Needed) (Resample and retest if difference is > 0.6) ___ ___ . ___ mg/L Diff. = 0. ___

(10) Final (Average) DO Reading: (Average two tests with difference < 0.6).....**(10)** ___ ___ . ___ **mg/L**

---------- ***Section D - Salinity*** ----------

(11) Please Circle Method Used
Direct Hydrometer Reading: (Observed Density): (leave blank if < 1.0000) **(11A)** _____
or Conductivity Meter reading (Testr 3 or Testr 4) **(11B)** _____

(12) Hydrometer Cylinder Temperature / Water Temp.....**(12)** ___ ___ . ___ **Degrees Celsius**

(13) Salinity (use LaMotte Table for hydrometer or Conductivity Chart for meter) **(13)** ___ ___ . ___ **0/00 or ppt**

Figure 1b.

---------- *Section E - General Observations* ----------

(14) Wind Direction:	1-N 2-NE 3-NW 4-S 5-SE 6-SW 7-E 8-W	**(14)**	_____
(15) Wind Speed: Beaufort Wind Scale:	0-calm, 1-Light Air, 2-Light Breeze, 3-Gentle Breeze, 4-Moderate Breeze, 5-Fresh Breeze, 6-Strong Breeze, 7-Near Gale, 8-Gale, 9-Strong Gale, 10-Storm, 11-Violent Storm, 12-Hurricane	**(15)**	_____
(16) Water Surface:	1-Stagnant, 2-Calm, 3-Ripple, 4-Waves, 5-White Caps	**(16)**	_____
(17) Lunar Tide:	1-No Lunar/Ocean Tide Applicable, 2-Incoming [High] Tide, 3-Outgoing [Low] Tide	**(17)**	_____
(18) Direction of Current:	1-None, 2-Upstream (*Due to Wind or Lunar Tide*), 3-Downstream	**(18)**	_____
(19) Speed of Current:	1-None, 2-Visible Flow, 3-Rapid (*Due to Rain Runoff*)	**(19)**	_____
(20) Water Color:	1-Normal, 2-Abnormal (See comment section below)	**(20)**	_____
(21) Other Signs:	1-Sea nettles, 2-Dead Fish, 3-Dead Crabs, 4-SAV, 5-Oil Slick, 6-Ice, 7-Debris, 8-Erosion, 9-Foam, 10-Bubbles, 11-Odor	**(21)**	_____
(22) Algal Index:	**(For monitors who conduct algae watch only)** 0-2 Clear, 3-4 Present, 5-6 Visible, 7-8 Scattered, 9-10 Extensive Surface Blooms	**(22)**	_____
(23) Weather:	1-Clear, 2-Partly Cloudy, 3-Overcast, 4-Fog/Haze, 5-Drizzle, 6-Intermittent Rain, 7-Rain, 8-Snow	**(23)**	_____
(24) Frequency of Local Rainfall for Past Week:	1-None, 2-Scattered Showers, 3-Showers, 4-Thunderstorms, 5-Hurricane Conditions	**(24)**	_____
(25)Last Date of Rainfall:	1-Today, 2-Yesterday, 3-Day Before Yesterday, 4- Earlier in Week	**(25)**	_____
(26) Weekly Sum of Daily Rainfall Readings for Past Week (Inches):		**(26)**	_____

Comments / Observations (If water color is abnormal, describe how the abnormal water color is different from normal water color.)

_____

_____

_____

This data was collected according to APNEP-CMN standards:

Signed: _____

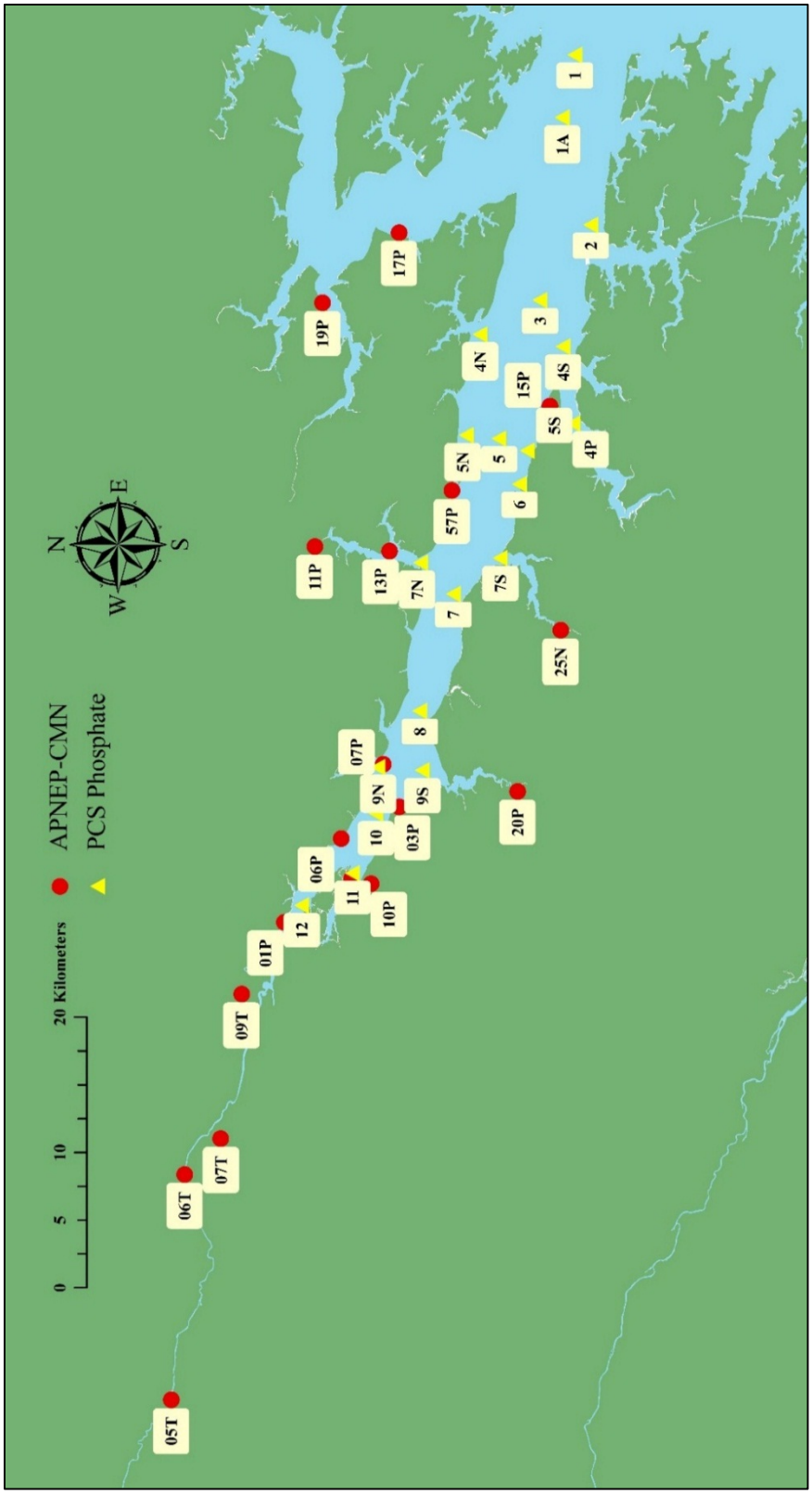
Figure 2.

Project	Site	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
PCS Phosphate	1	****	****		****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
PCS Phosphate	1A	****			****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
APNEP-CMN	17P		****	****	****																							
APNEP-CMN	19P		****	****	****	****	****	****																				
PCS Phosphate	2		****				****																					
PCS Phosphate	3	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
PCS Phosphate	4S	****			****	****	****	****	****	****	****																	
PCS Phosphate	4N	****			****	****	****	****	****	****	****																	
PCS Phosphate	4P	****			****	****	****	****	****	****	****																	
APNEP-CMN	15P		****	****	****	****	****																					
PCS Phosphate	5S	****			****	****	****	****	****	****	****																	
PCS Phosphate	5	****		****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
PCS Phosphate	5N	****			****	****	****	****	****	****	****																	
PCS Phosphate	6	****			****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
APNEP-CMN	57P																	****	****	****	****							
APNEP-CMN	25N									****	****																	
PCS Phosphate	7S	****			****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
APNEP-CMN	11P		****	****	****	****	****	****																				
APNEP-CMN	13P		****	****	****	****	****	****	****	****	****	****	****	****	****	****												
PCS Phosphate	7N	****			****	****	****	****	****	****	****																	
PCS Phosphate	7	****			****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
PCS Phosphate	8	****			****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
APNEP-CMN	20P								****	****	****	****																
PCS Phosphate	9S	****	****	****	****	****	****	****	****	****	****																	
APNEP-CMN	65P																										****	****
APNEP-CMN	07P		****	****	****																							
PCS Phosphate	9N	****			****	****	****	****	****	****	****																	
APNEP-CMN	03P		****	****																								
PCS Phosphate	10	****			****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
APNEP-CMN	10P				****	****	****	****																				
APNEP-CMN	50P														****	****	****	****	****	****	****	****						
APNEP-CMN	05P		****	****	****																							
PCS Phosphate	11	****			****	****	****	****	****	****	****																	
APNEP-CMN	06P			****	****																							
PCS Phosphate	12	****			****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
APNEP-CMN	01P		****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****									
APNEP-CMN	09T		****	****	****																							
APNEP-CMN	07T		****	****	****	****	****	****																				
APNEP-CMN	06T		****	****																								
APNEP-CMN	05T		****	****	****	****																						

Figure 3.

Project	Site	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
APNEP-CMN	18A		*****	*****	*****	*****	*****	*****	*****	*****																	
APNEP-CMN	11CS			*****	*****			*****	*****																		
NCDMF	9																					*****	*****	*****			
NCDMF	10																					*****	*****	*****			
USGS	USGS				*****	*****	*****																				
APNEP-CMN	35A																*****	*****	*****	*****	*****	*****	*****				
NCDMF	8																					*****	*****	*****			
APNEP-CMN	02A		*****	*****	*****	*****	*****	*****																			
APNEP-CMN	01A		*****	*****	*****	*****	*****	*****		*****																	
APNEP-CMN	05A		*****	*****	*****	*****	*****																				
APNEP-CMN	36A																			*****	*****	*****	*****	*****	*****	*****	
NCDMF	5																					*****	*****	*****			
NCDMF	6																					*****	*****	*****			
NCDMF	12																					*****	*****	*****			
APNEP-CMN	32A															*****		*****	*****	*****	*****	*****	*****				
NCDMF	4																					*****	*****	*****			
APNEP-CMN	25C																				*****	*****	*****				
NCDMF	14																					*****	*****	*****			
NCDMF	1																					*****	*****	*****			
APNEP-CMN	06C		*****	*****	*****	*****	*****	*****																			
APNEP-CMN	04C		*****	*****	*****	*****																					
APNEP-CMN	01C		*****	*****	*****																						
APNEP-CMN	05C		*****	*****	*****	*****	*****	*****	*****	*****	*****			*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
ECU	CB																								*****	*****	
NCDMF	2																					*****	*****	*****			
NCDMF	11																					*****	*****	*****			
APNEP-CMN	22C															*****	*****	*****	*****	*****	*****	*****					
APNEP-CMN	23C															*****	*****	*****	*****	*****							
NCDMF	3																					*****	*****	*****			
APNEP-CMN	21C															*****	*****	*****	*****	*****	*****	*****					
NCDMF	13																					*****	*****	*****			

Figure 4.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5
10
20 Kilometers
APNEP-CMN
PCS Phosphate
N
E
S
W
05T
06T
07T
09T
01P
12
06P
11
10P
10
03P
9N
9S
07P
8
11P
13P
7N
7
57P
5N
5
6
7S
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19P
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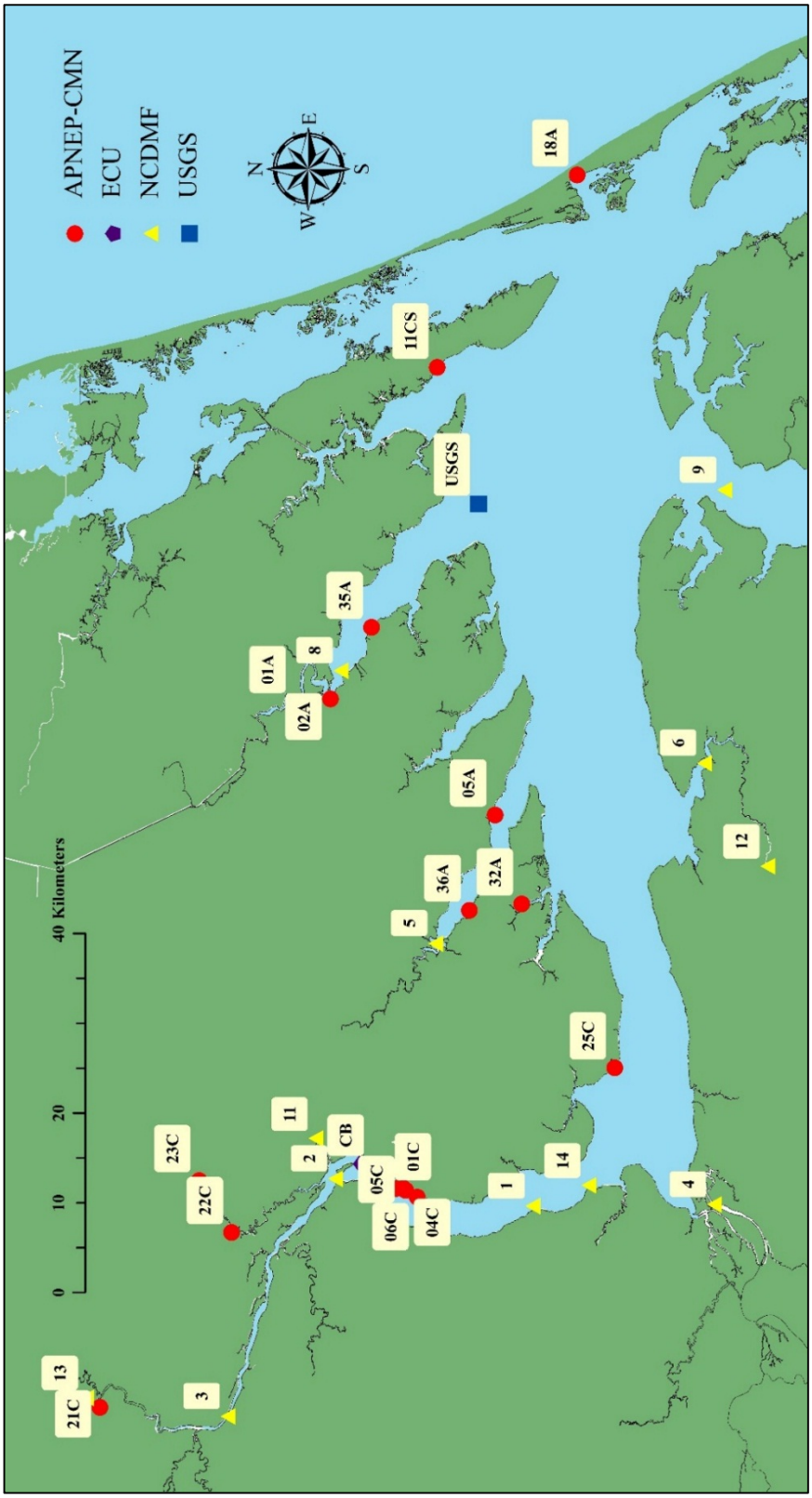
4N
15P
5S
4S
4P
3
2
1A
1

Figure 5.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ECU
NCDMF
USGS
N
E
S
W
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10
20
40 Kilometers
21C
13
3
23C
22C
11
2
CB
05C
06C
01C
04C
1
14
25C
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36A
32A
05A
01A
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02A
35A
USGS
11CS
18A
9
6
12
4

Figure 6.

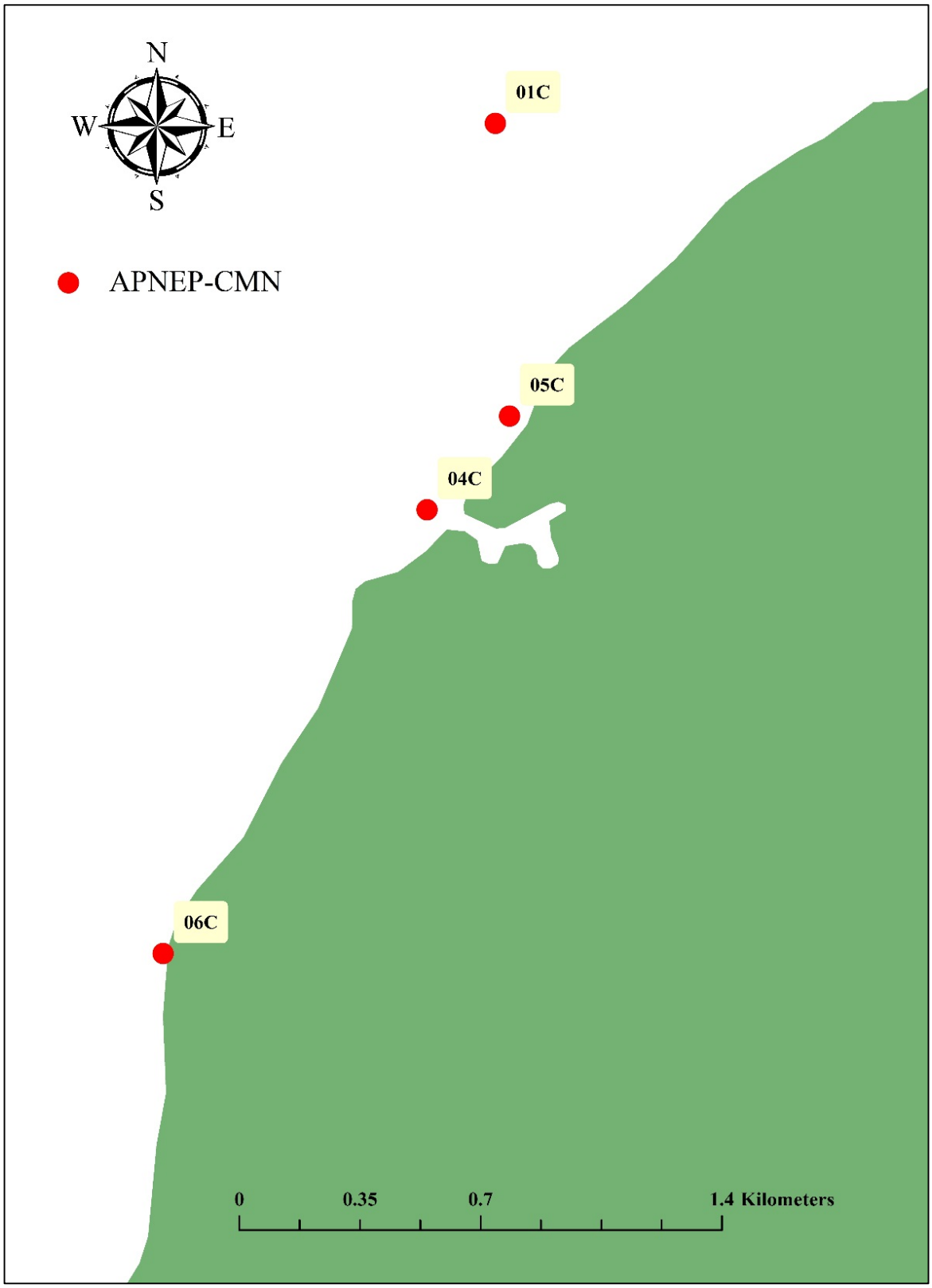


Figure 7.

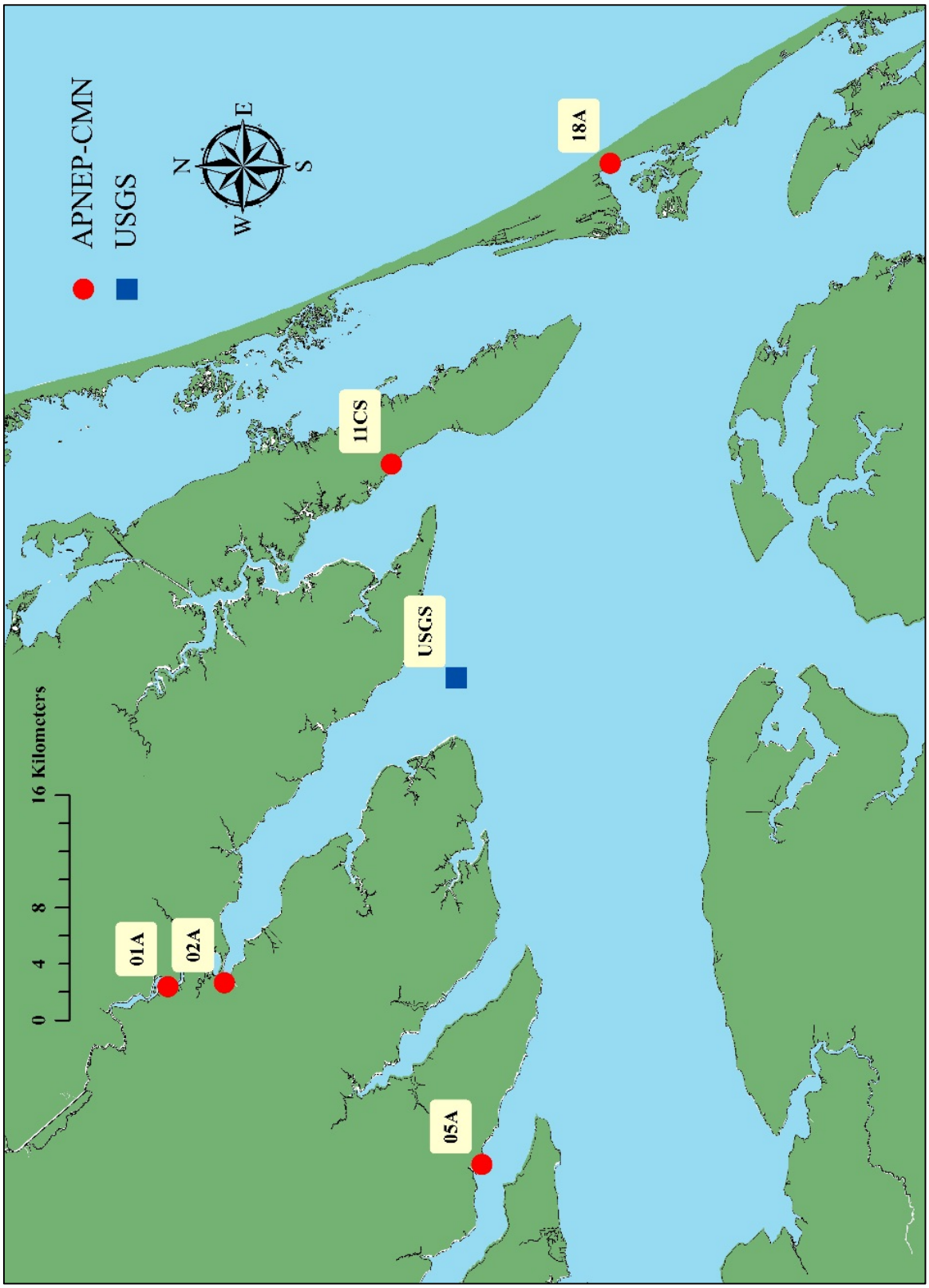

APNEP-CMN
USGS
N
E
S
W
0 4 8 16 Kilometers
01A
02A
05A
11CS
USGS
18A

Figure 8.

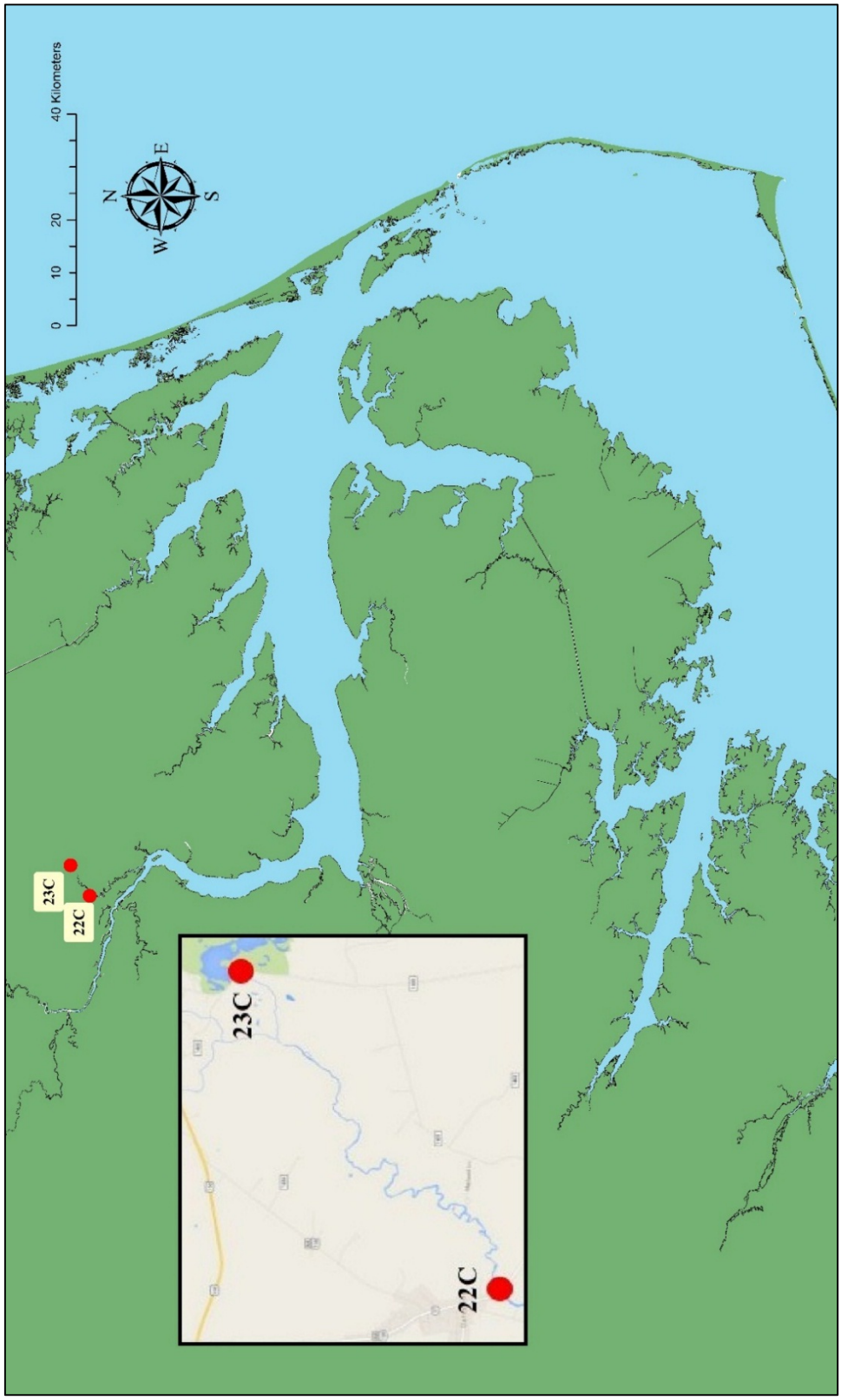


Figure 9.

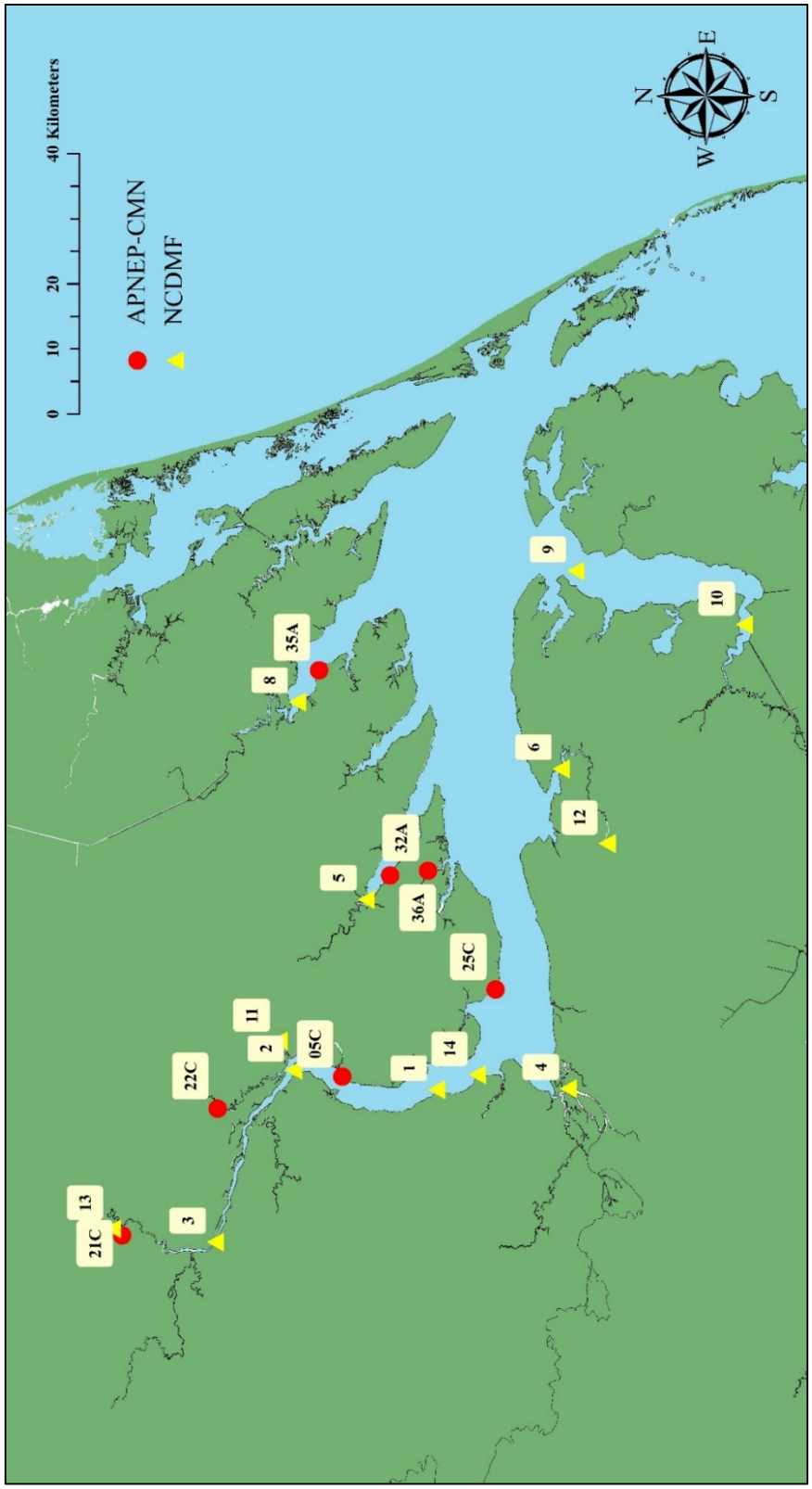

0
10
20
40 Kilometers
APNEP-CMN
NCDMF
N
E
S
W
13
21C
3
22C
11
2
05C
35A
8
5
32A
36A
25C
1
14
4
9
10
6
12

Figure 10.

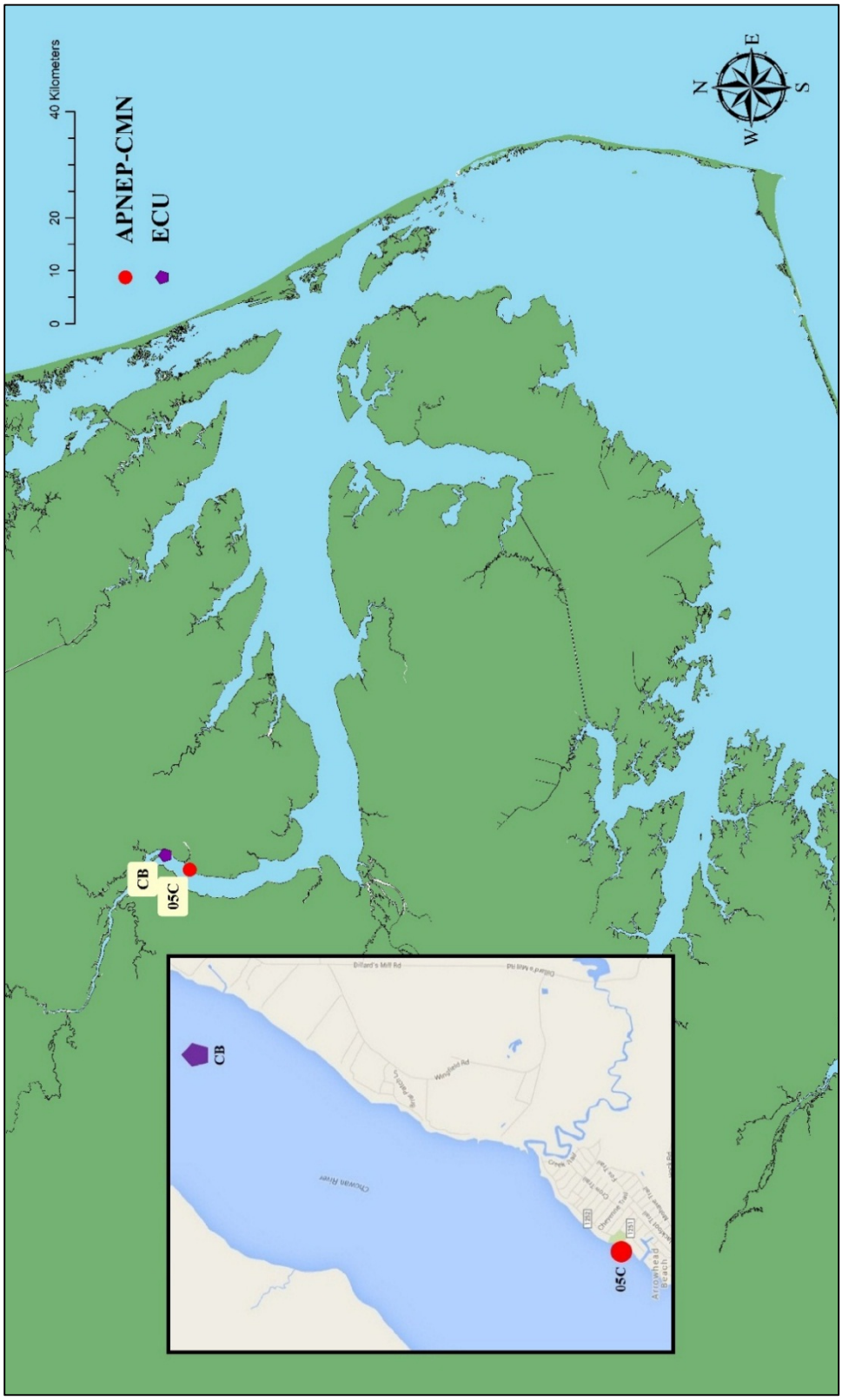
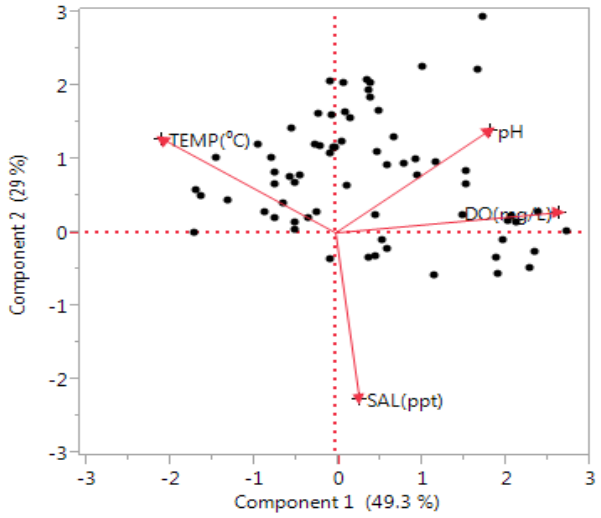
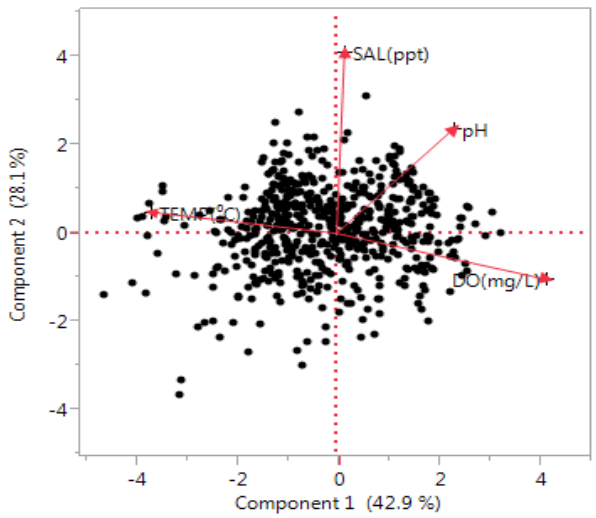

0
10
20
40 Kilometers
APNEP-CMN
ECU
N
E
S
W
CB
05C
Crowan River
Dillard's Mill Rd
Wayfield Rd
Blue Points Ln
Creek Trail
Cherrytree Trail
Fox Trail
Cherrytree Trail
Arrowhead Beach
Blackfoot Trail
Beaver Trail
1253
1253

Figure 11.

(a) Lower, APNEP-CMN



(b) Lower, PCS Phosphate

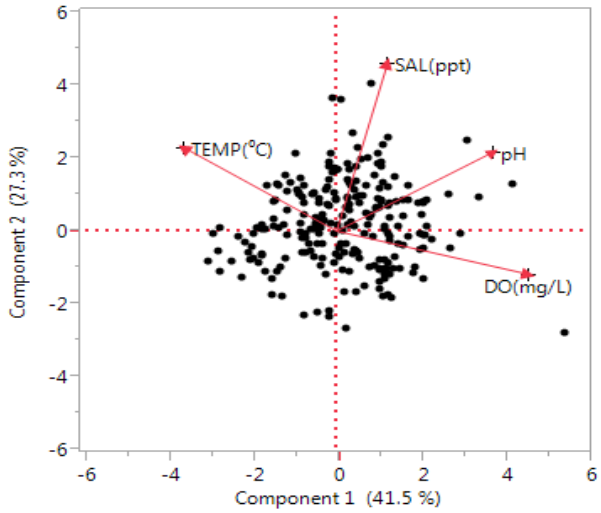


Lower region	Component			
	1	2	3	4
Water temperature	-0.76	0.47	0.43	0.15
Dissolved oxygen	0.97	0.10	-0.09	0.20
pH	0.79	0.51	0.53	-0.13
Salinity	0.08	-0.82	0.56	0.03
Eigenvalue	1.97	1.16	0.79	0.08
Percent	49.25	28.98	19.72	2.05
Cumulative percent	49.25	78.23	97.95	100.00

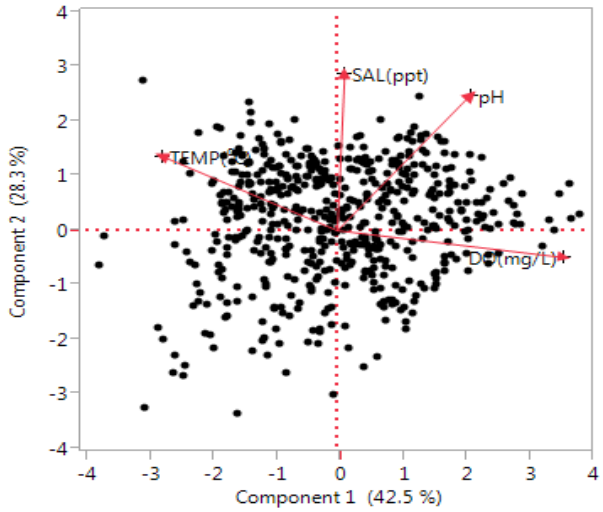
Lower region	Component			
	1	2	3	4
Water temperature	-0.80	0.10	0.52	0.29
Dissolved oxygen	0.91	-0.23	0.10	0.34
pH	0.50	0.51	0.67	-0.17
Salinity	0.03	0.89	-0.42	0.15
Eigenvalue	1.72	1.12	0.91	0.25
Percent	42.88	28.10	22.70	6.32
Cumulative percent	42.88	70.98	93.68	100.00

Figure 12.

(a) Middle, APNEP-CMN



(b) Middle, PCS Phosphate

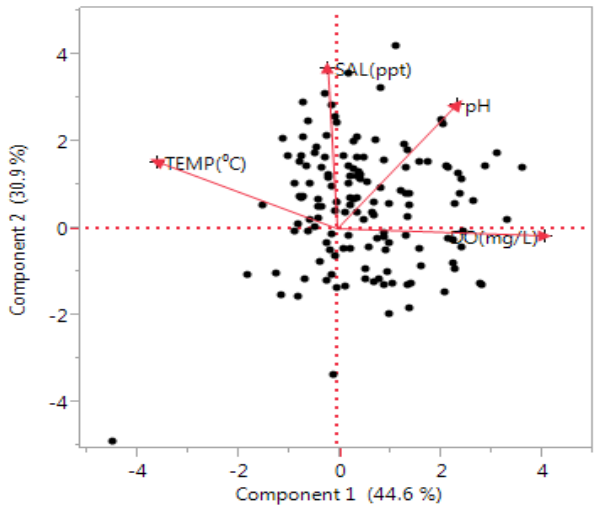


Middle region	Component			
	1	2	3	4
Water temperature	-0.67	0.42	0.53	0.31
Dissolved oxygen	0.84	-0.22	0.13	0.49
pH	0.69	0.40	0.51	-0.33
Salinity	0.22	0.84	-0.47	0.13
Eigenvalue	1.66	1.09	0.79	0.46
Percent	41.47	27.33	19.64	11.56
Cumulative percent	41.47	68.80	88.44	100.00

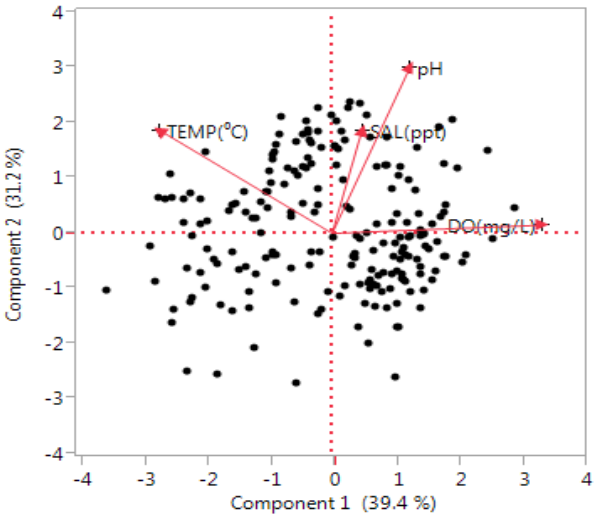
Middle region	Component			
	1	2	3	4
Water temperature	-0.73	0.36	0.54	0.23
Dissolved oxygen	0.93	-0.13	0.15	0.30
pH	0.55	0.65	0.49	-0.20
Salinity	0.03	0.75	-0.65	0.11
Eigenvalue	1.70	1.13	0.97	0.20
Percent	42.52	28.27	24.24	4.96
Cumulative percent	42.52	70.80	95.04	100.00

Figure 13.

(a) Upper, APNEP-CMN



(b) Upper, PCS Phosphate



Upper region	Component			
	1	2	3	4
Water temperature	-0.80	0.35	0.38	0.31
Dissolved oxygen	0.92	-0.04	0.01	0.38
pH	0.54	0.65	0.51	-0.19
Salinity	0.28	0.83	-0.55	0.04
Eigenvalue	1.78	1.24	0.70	0.28
Percent	44.60	30.88	17.51	7.00
Cumulative percent	44.60	75.48	93.00	100.00

Upper region	Component			
	1	2	3	4
Water temperature	-0.76	0.52	-0.26	0.29
Dissolved oxygen	0.93	0.04	-0.20	0.31
pH	0.34	0.84	-0.35	-0.23
Salinity	0.13	0.52	0.84	0.07
Eigenvalue	1.58	1.25	0.94	0.24
Percent	39.43	31.19	23.46	5.92
Cumulative percent	39.43	70.62	94.08	100.00

Figure 14.

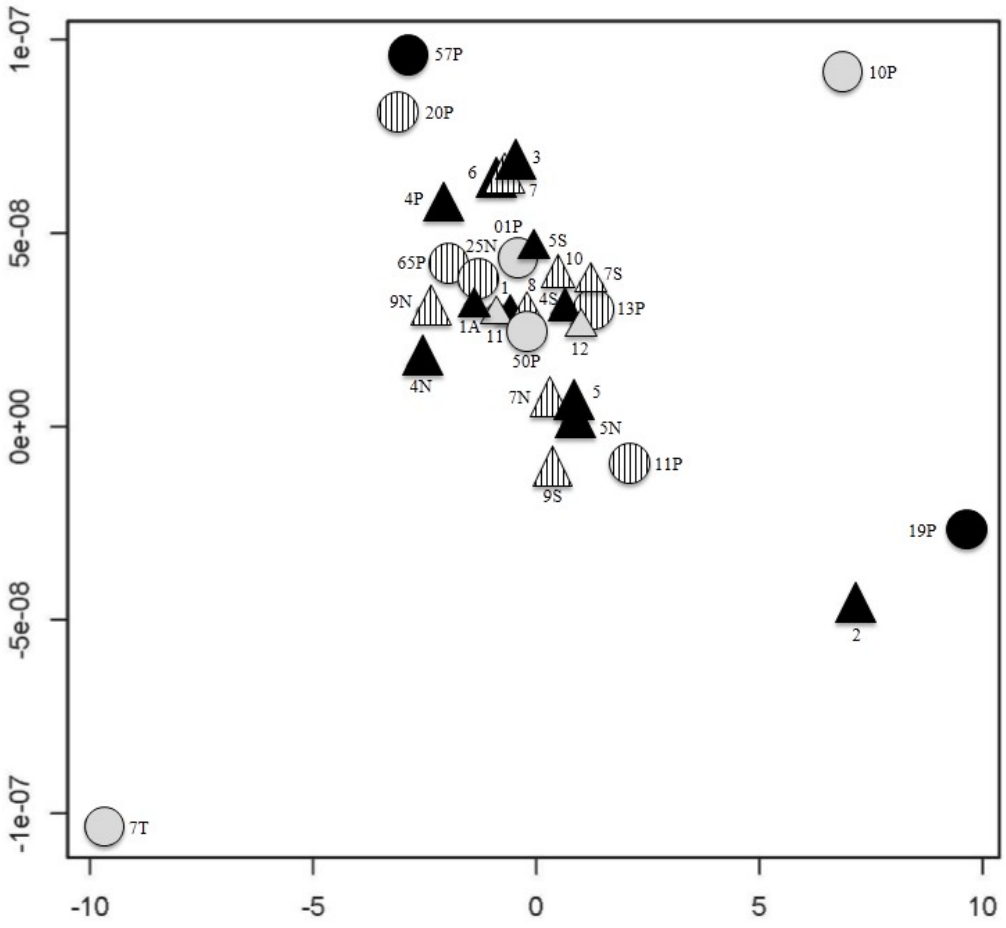

1e-07
5e-08
0e+00
-5e-08
-1e-07
-10
-5
0
5
10
57P
10P
20P
3
6
7
4P
01P
5S
25N
65P
10
7S
8
9N
1
4S
13P
1A
11
12
50P
4N
7N
5
5N
11P
9S
19P
2
7T

Figure 15.

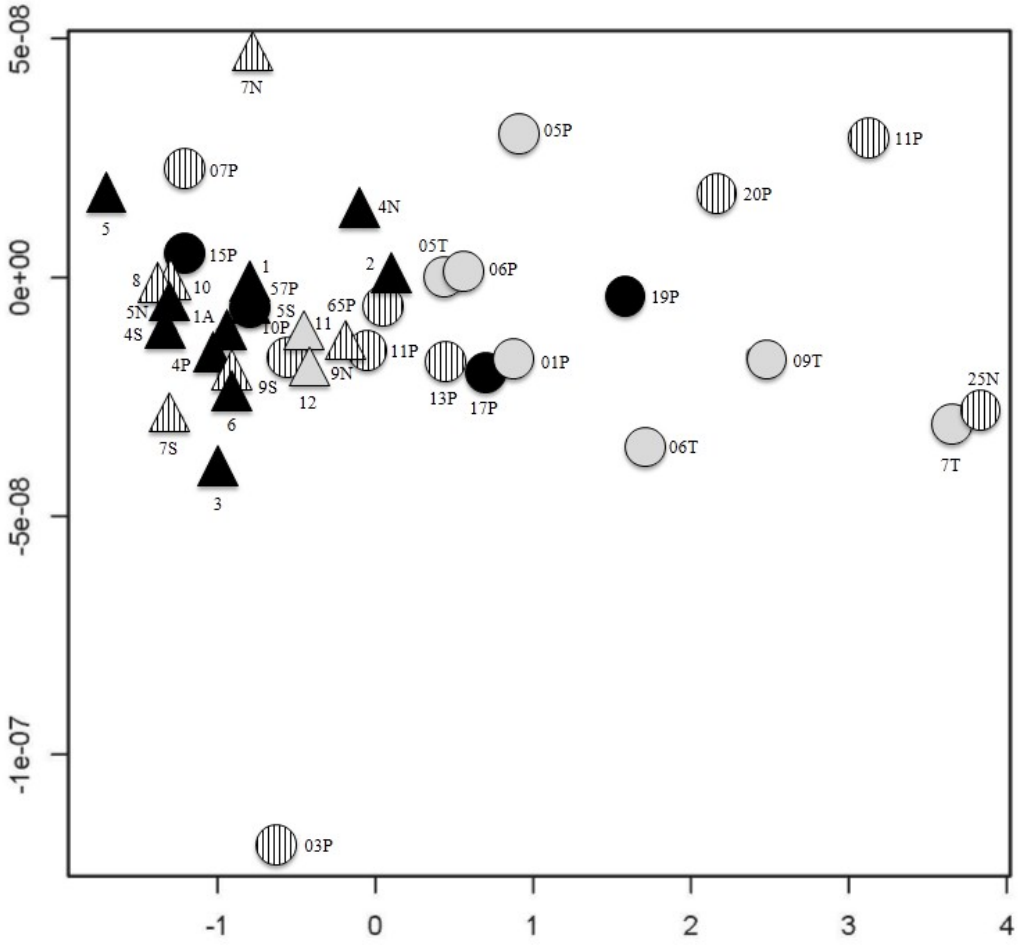

5e-08
0e+00
-5e-08
-1e-07
-1
0
1
2
3
4
7N
05P
11P
07P
20P
5
4N
15P
05T
06P
8
10
1
57P
2
19P
5N
1A
5S
65P
4S
10P
11
11P
01P
09T
4P
9N
9S
12
13P
17P
25N
6
7S
06T
7T
3
03P

Figure 16.

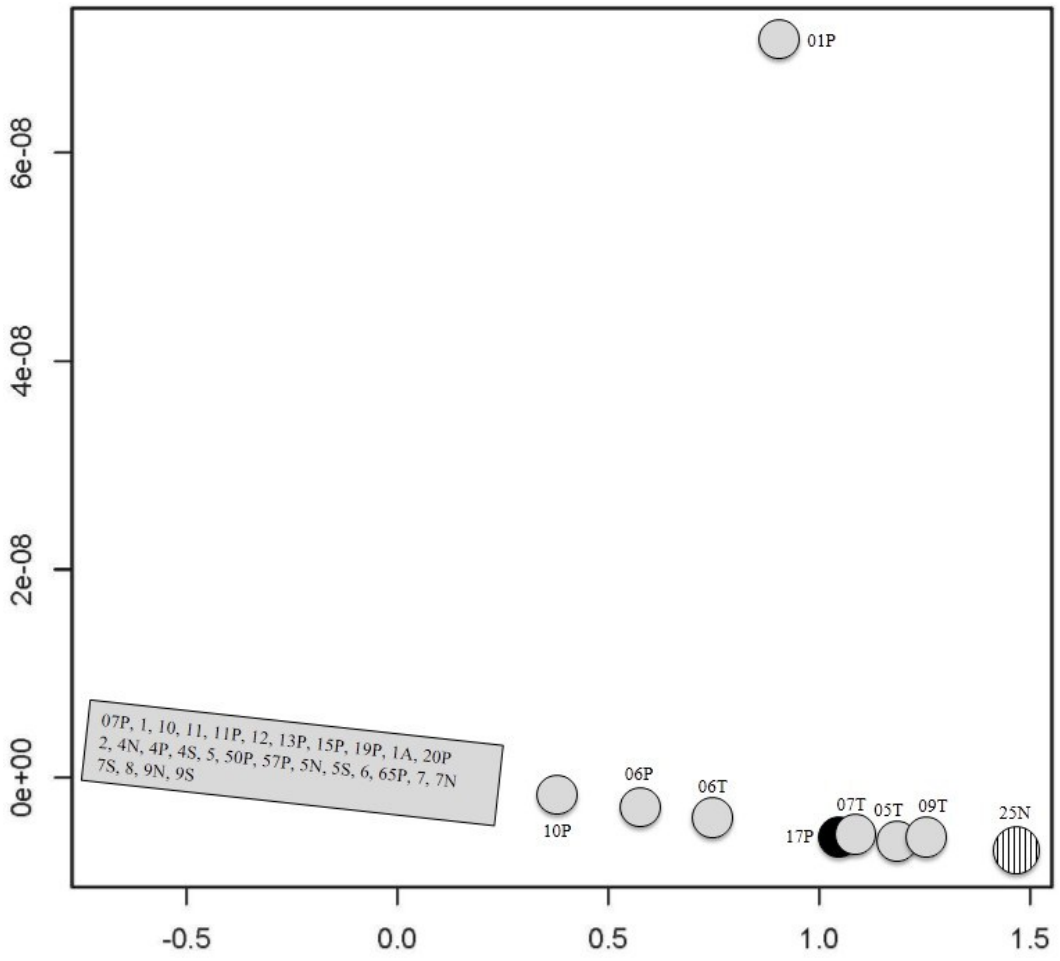

01P
6e-08
4e-08
2e-08
0e+00
07P, 1, 10, 11, 11P, 12, 13P, 15P, 19P, 1A, 20P
2, 4N, 4P, 4S, 5, 50P, 57P, 5N, 5S, 6, 65P, 7, 7N
7S, 8, 9N, 9S
10P
06P
06T
17P
07T
05T
09T
25N
-0.5
0.0
0.5
1.0
1.5

Figure 17.

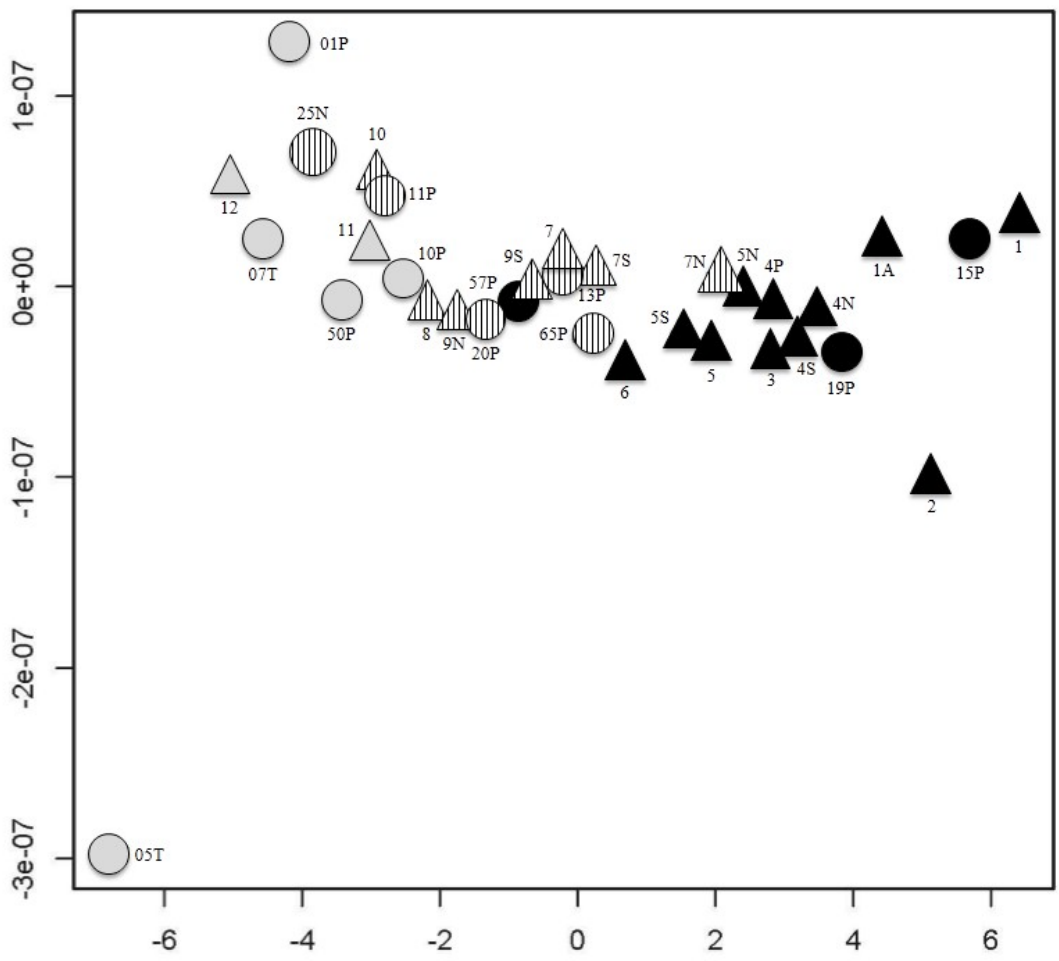
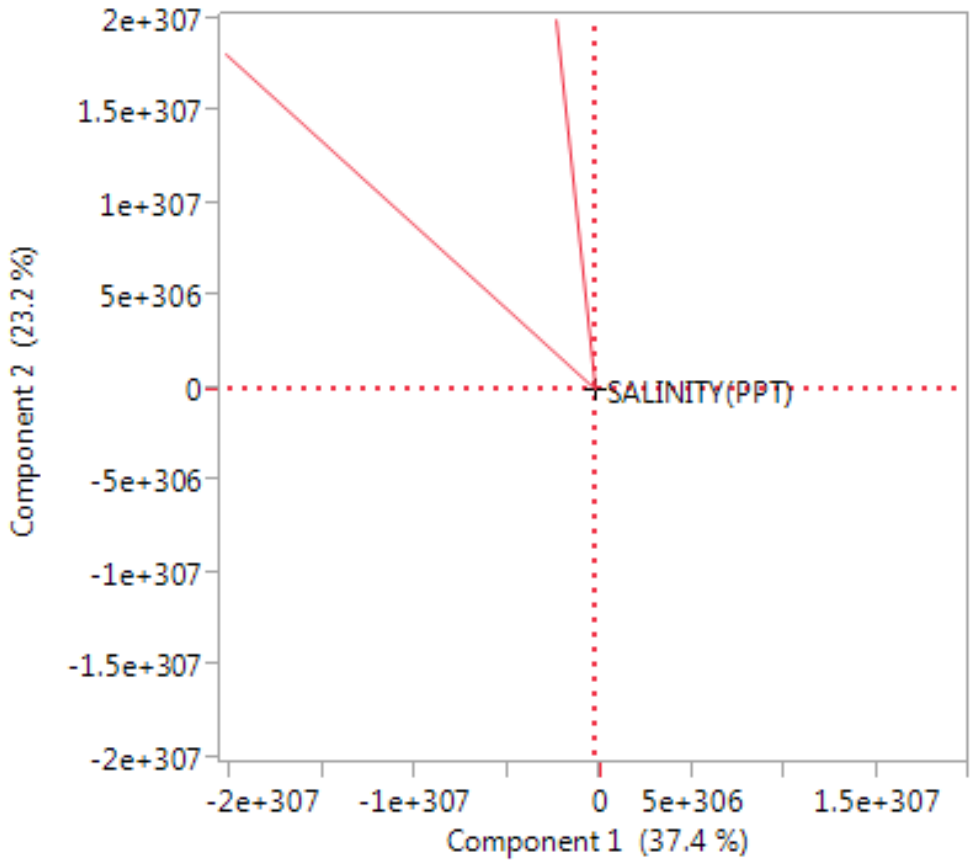
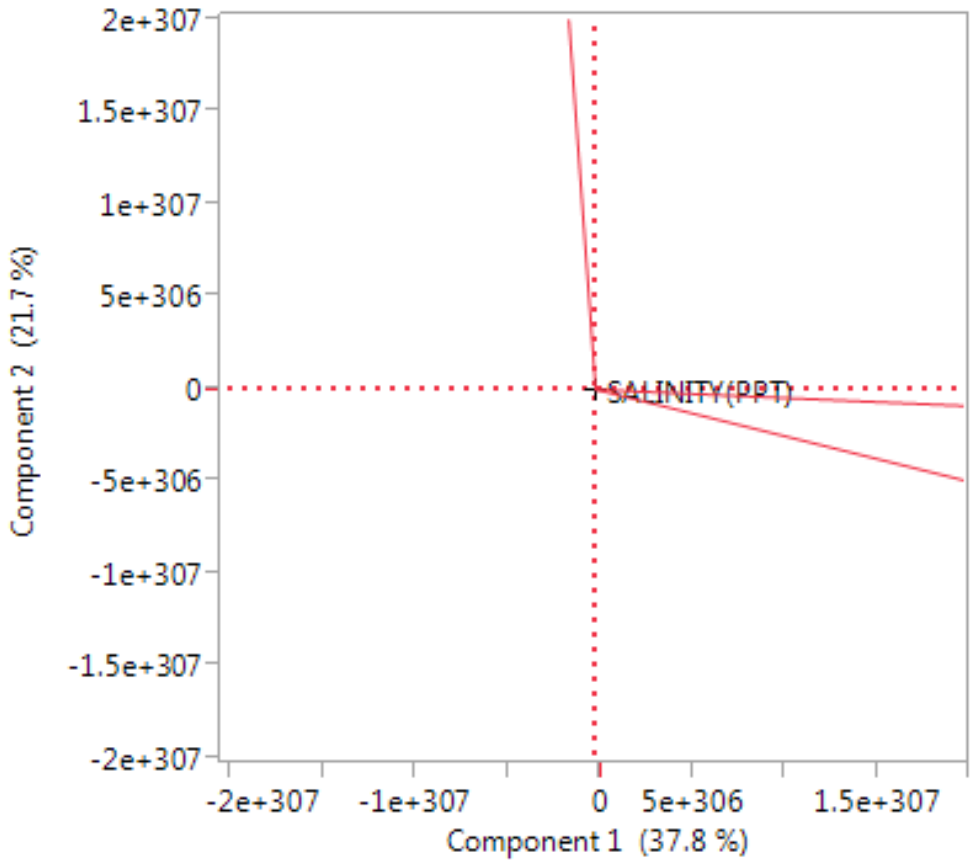

01P
25N
10
11P
12
07T
11
10P
50P
57P
9S
7
7S
13P
8
9N
20P
65P
6
5S
5
7N
5N
4P
3
4S
4N
19P
1A
15P
1
2
05T
1e-07
0e+00
-1e-07
-2e-07
-3e-07
-6
-4
-2
0
2
4
6

Figure 18.



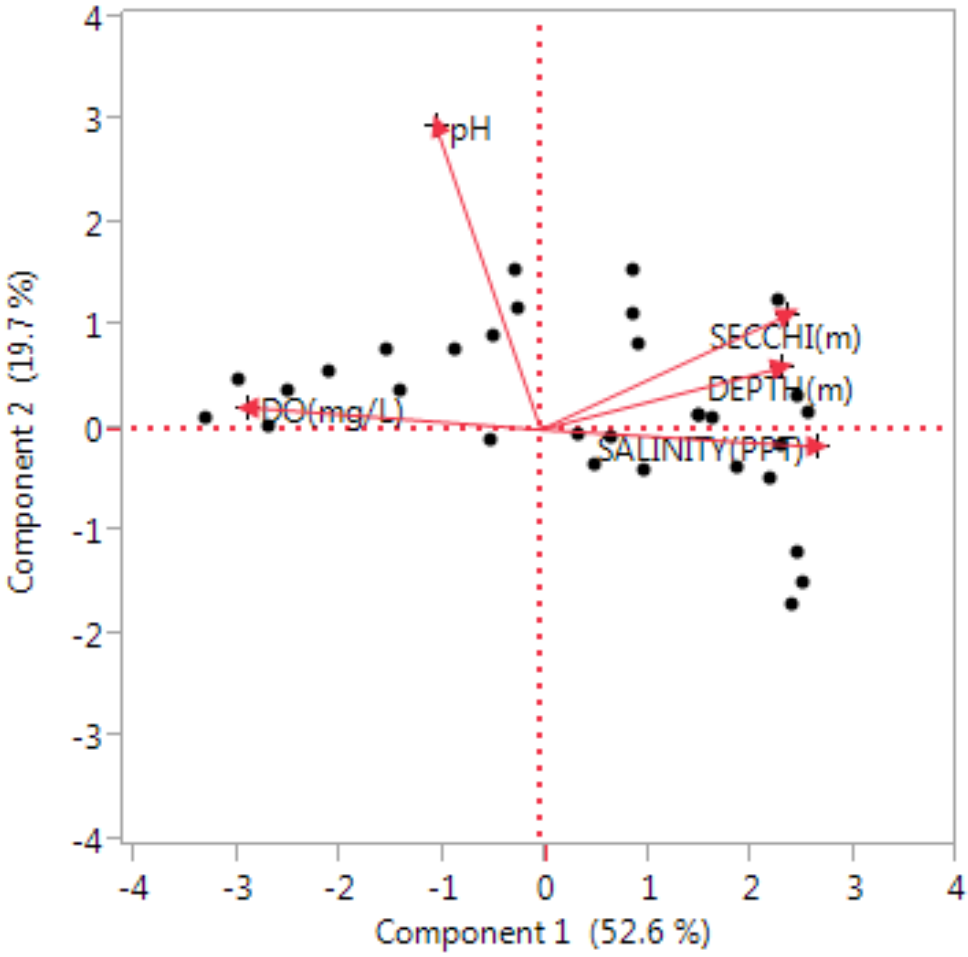
	Component				
	1	**2**	**3**	**4**	**5**
Water depth	0.82	0.27	0.00	0.43	-0.27
Secchi depth	1.16	0.20	0.00	-0.06	0.34
Dissolved oxygen	1.00	0.54	0.00	0.57	0.16
pH	0.74	0.87	0.00	-0.48	-0.09
Salinity	0.22	0.00	1.00	0.00	0.00
Eigenvalue	1.87	1.16	1.00	0.74	0.22
Percent	37.45	23.19	20.00	14.88	4.48
Cumulative percent	37.45	60.64	80.64	95.52	100.00

Figure 19.



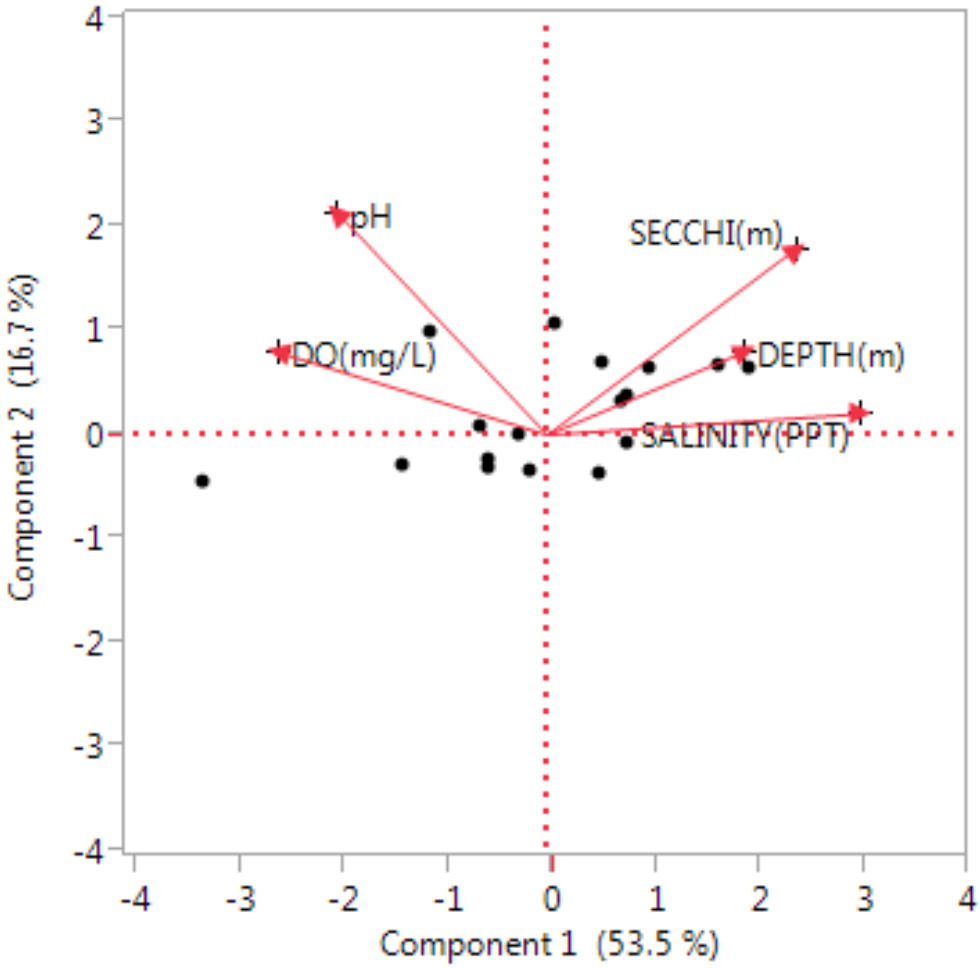
	Component				
	1	**2**	**3**	**4**	**5**
Water depth	0.90	-0.04	0.00	0.16	-0.40
Secchi depth	0.85	-0.21	0.00	0.32	0.36
Dissolved oxygen	-0.07	0.91	0.00	0.42	0.02
pH	0.59	0.47	0.00	-0.65	0.09
Salinity	0.00	0.00	1.00	0.00	0.00
Eigenvalue	1.89	1.08	1.00	0.73	0.29
Percent	37.84	21.70	20.00	14.59	5.87
Cumulative percent	37.84	59.54	79.54	94.13	100.00

Figure 20.



	Component				
	1	2	3	4	5
Water depth	0.72	0.19	0.56	-0.34	0.11
Secchi depth	0.74	0.34	0.17	0.55	-0.04
Dissolved oxygen	-0.88	0.07	0.24	0.20	0.35
pH	-0.31	0.91	-0.22	-0.16	-0.01
Salinity	0.83	-0.05	-0.46	-0.04	0.31
Eigenvalue	2.63	0.99	0.66	0.49	0.23
Percent	52.55	19.74	13.28	9.78	4.65
Cumulative percent	52.55	72.29	85.57	95.35	100.00

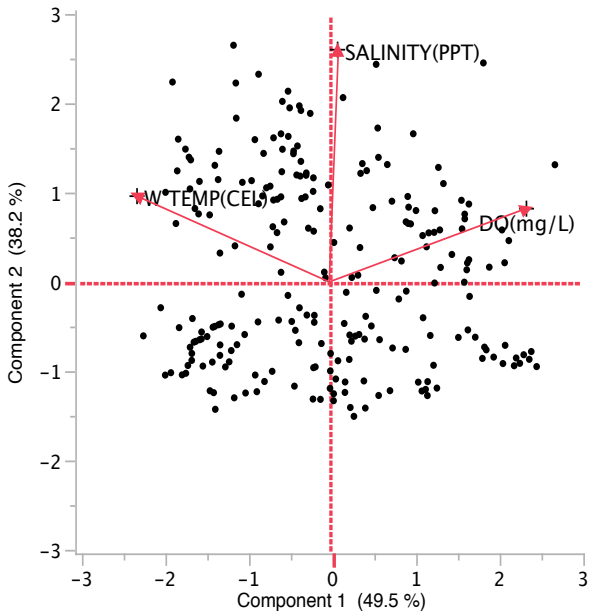
Figure 21.



	Component				
	1	2	3	4	5
Water depth	0.57	0.24	0.77	-0.16	0.03
Secchi depth	0.73	0.54	-0.19	0.34	-0.17
Dissolved oxygen	-0.78	0.24	0.21	0.50	0.17
pH	-0.61	0.65	-0.18	-0.41	0.04
Salinity	0.91	0.06	-0.27	-0.01	0.30
Eigenvalue	2.67	0.83	0.78	0.56	0.15
Percent	53.49	16.66	15.59	11.26	3.00
Cumulative percent	53.49	70.15	85.74	97.00	100.00

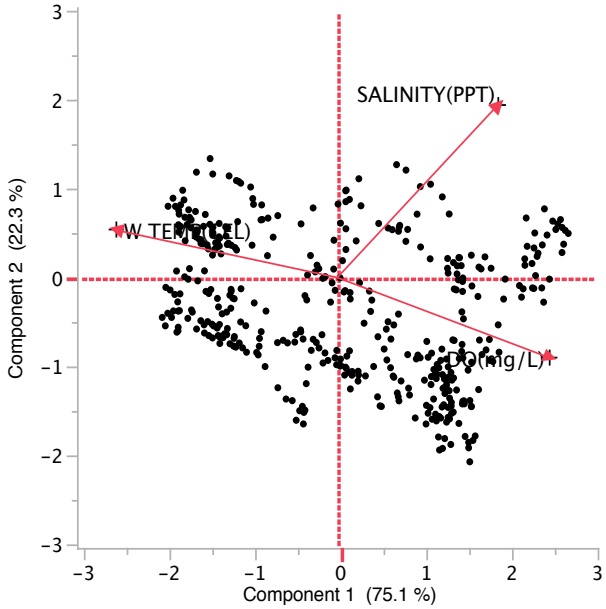
Figure 22.

(a) APNEP-CMN



	Component		
	1	2	3
Water temperature	-0.85	0.36	0.38
Dissolved oxygen	0.87	0.30	0.39
Salinity	0.04	0.96	-0.26
Eigenvalue	1.49	1.15	0.37
Percent	49.50	38.24	12.26
Cumulative percent	49.50	87.74	100.00

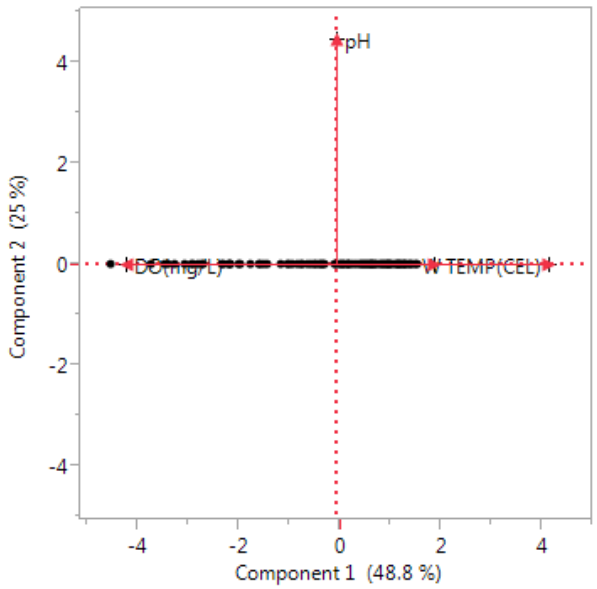
(b) USGS



	Component		
	1	2	3
Water temperature	-0.96	0.20	0.21
Dissolved oxygen	0.92	-0.34	0.19
Salinity	0.69	0.72	0.03
Eigenvalue	2.25	0.67	0.08
Percent	75.05	22.28	2.67
Cumulative percent	75.05	97.33	100.00

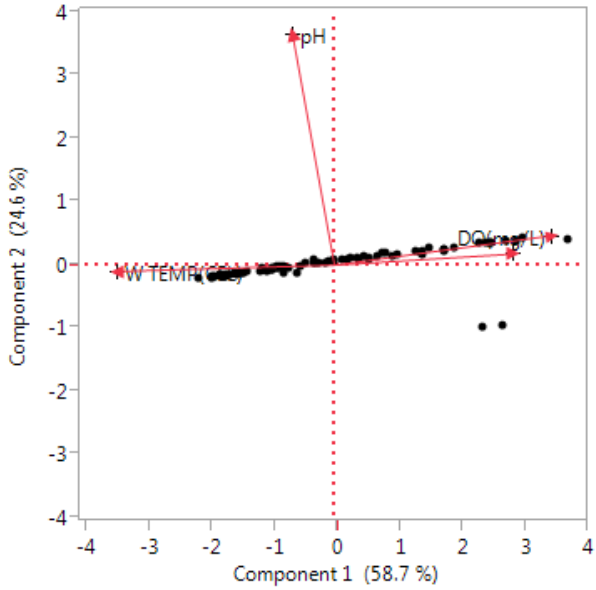
Figure 23.

(a) 22C, APNEP-CMN



	Component			
	1	2	3	4
Water temperature	0.95	0.00	-0.18	0.27
Water depth	0.43	0.00	0.90	-0.02
Dissolved oxygen	-0.93	0.00	0.24	0.27
pH	0.00	1.00	0.00	0.00
Eigenvalue	1.95	1.00	0.90	0.15
Percent	48.81	25.00	22.50	3.68
Cumulative percent	48.81	73.81	96.32	100.00

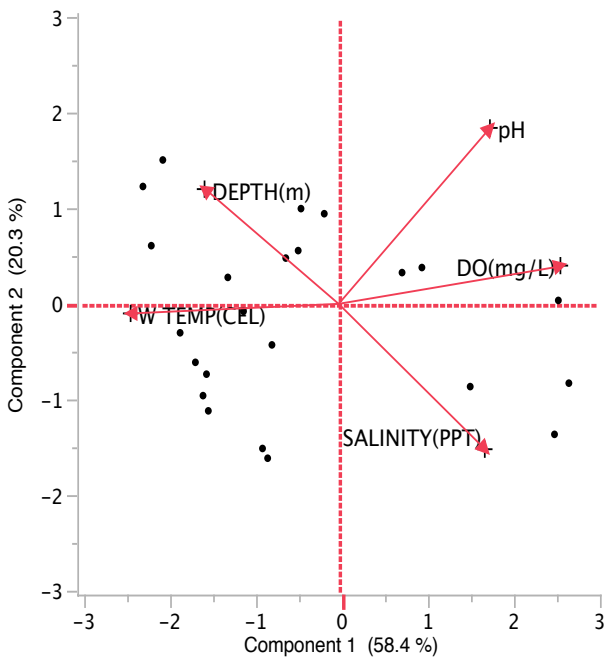
(b) 23C, APNEP-CMN



	Component			
	1	2	3	4
Water temperature	-0.93	-0.03	0.28	0.25
Water depth	0.77	0.05	0.64	-0.01
Dissolved oxygen	0.93	0.12	-0.25	0.25
pH	-0.18	0.98	0.01	-0.02
Eigenvalue	2.35	0.99	0.55	0.12
Percent	58.67	24.64	13.64	3.06
Cumulative percent	58.67	83.30	96.94	100.00

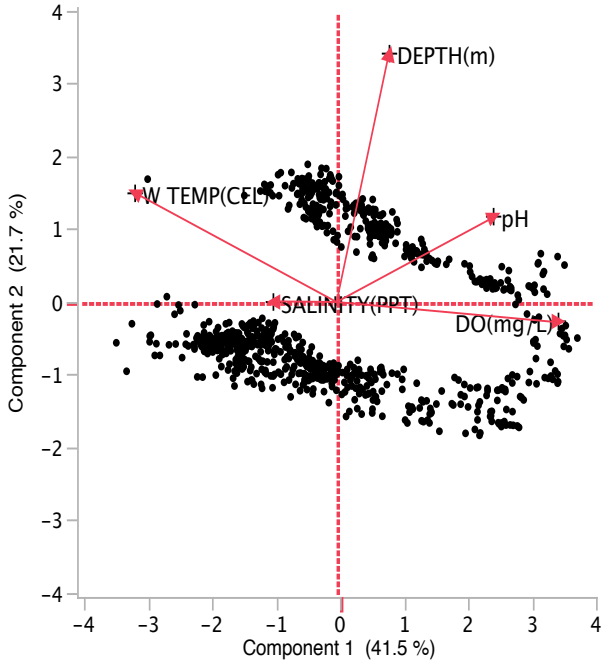
Figure 24.

(a) Lower, APNEP-CMN



Lower region	Component				
	1	2	3	4	5
Water temperature	-0.91	-0.04	-0.15	0.37	0.13
Water depth	-0.58	0.45	0.68	-0.05	0.03
Dissolved oxygen	0.96	0.15	0.04	-0.06	0.21
pH	0.65	0.68	-0.10	0.30	-0.08
Salinity	0.64	-0.57	0.44	0.28	-0.03
Eigenvalue	2.92	1.02	0.69	0.31	0.07
Percent	58.37	20.32	13.71	6.20	1.40
Cumulative percent	58.37	78.69	92.40	98.60	100.00

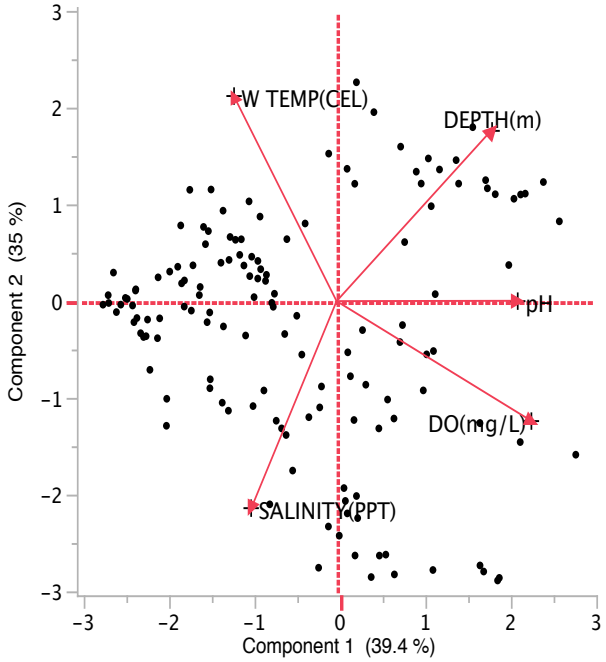
(b) Lower, NCDMF



Lower region	Component				
	1	2	3	4	5
Water temperature	-0.83	0.40	-0.19	0.18	0.28
Water depth	0.22	0.91	0.08	-0.33	-0.09
Dissolved oxygen	0.92	-0.07	0.07	-0.23	0.30
pH	0.65	0.31	0.02	0.69	-0.02
Salinity	-0.26	0.00	0.96	0.07	0.04
Eigenvalue	2.07	1.09	0.97	0.68	0.18
Percent	41.53	21.71	19.48	13.62	3.66
Cumulative percent	41.53	63.25	82.72	96.34	100.00

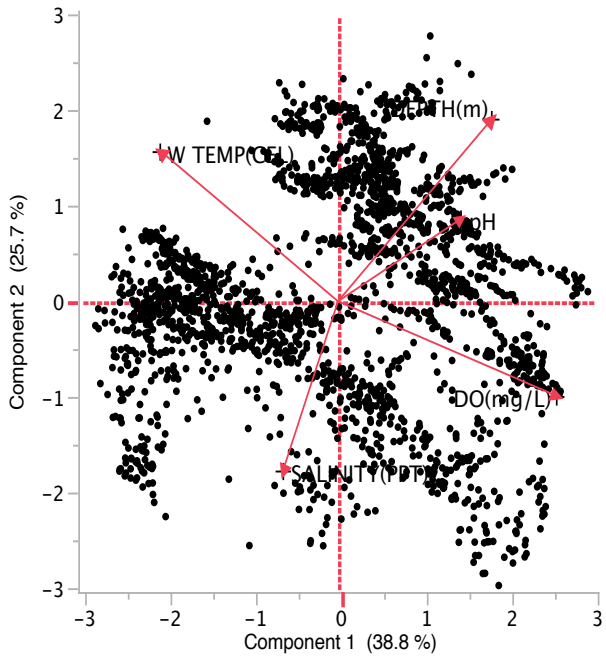
Figure 25.

(a) Middle, APNEP-CMN



Middle region	Component				
	1	2	3	4	5
Water temperature	-0.43	0.76	0.40	-0.16	0.25
Water depth	0.65	0.63	-0.05	0.42	0.09
Dissolved oxygen	0.81	-0.44	-0.13	-0.19	0.30
pH	0.76	0.00	0.61	-0.10	-0.19
Salinity	-0.36	-0.77	0.42	0.29	0.15
Eigenvalue	1.97	1.75	0.74	0.33	0.22
Percent	39.37	34.97	14.70	6.66	4.30
Cumulative percent	39.37	74.34	89.04	95.70	100.00

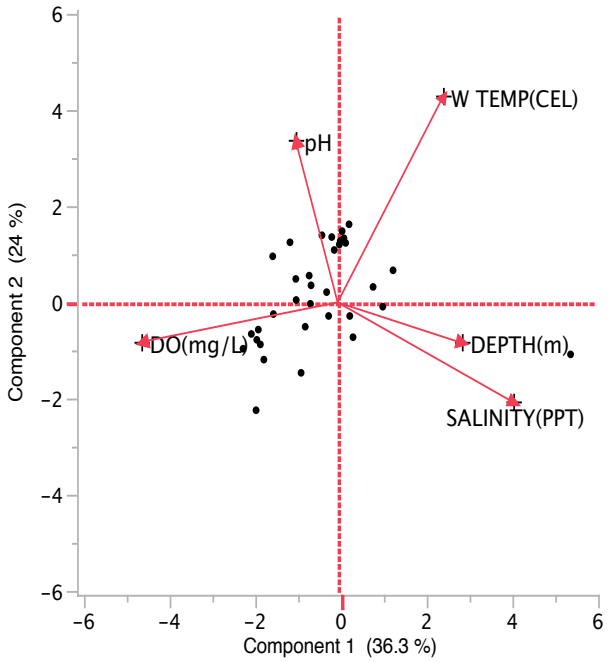
(b) Middle, NCDMF



Middle region	Component				
	1	2	3	4	5
Water temperature	-0.71	0.54	0.35	0.06	0.30
Water depth	0.61	0.65	0.03	0.44	-0.08
Dissolved oxygen	0.88	-0.34	0.02	0.02	0.34
pH	0.49	0.29	0.73	-0.36	-0.09
Salinity	-0.22	-0.61	0.68	0.34	-0.06
Eigenvalue	1.94	1.28	1.12	0.44	0.22
Percent	38.75	25.65	22.37	8.81	4.42
Cumulative percent	38.75	64.40	86.77	95.58	100.00

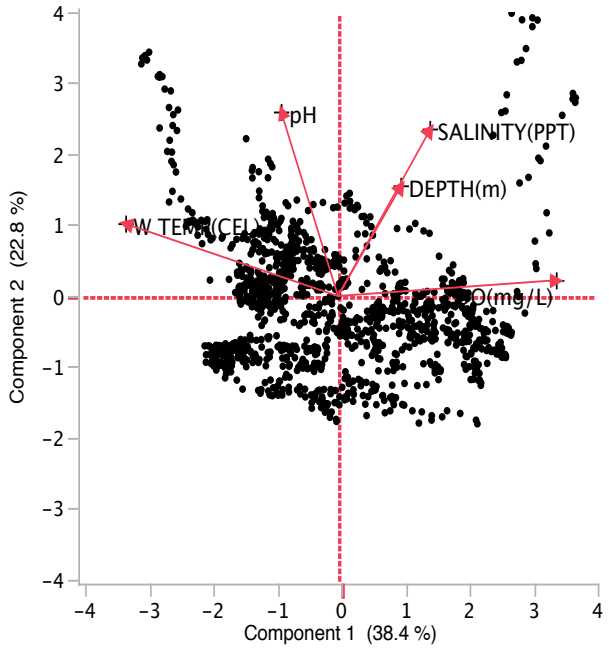
Figure 26.

(a) Upper, APNEP-CMN



Upper region	Component				
	1	2	3	4	5
Water temperature	0.45	0.79	-0.19	0.30	0.22
Water depth	0.53	-0.16	0.63	0.53	-0.12
Dissolved oxygen	-0.84	-0.15	0.36	0.23	0.29
pH	-0.18	0.62	0.62	-0.44	-0.08
Salinity	0.76	-0.39	0.22	-0.40	0.25
Eigenvalue	1.81	1.20	1.00	0.77	0.21
Percent	36.25	24.02	20.01	15.44	4.24
Cumulative percent	36.25	60.28	80.29	95.73	100.00

(b) Upper, NCDMF



Upper region	Component				
	1	2	3	4	5
Water temperature	-0.89	0.27	0.24	-0.06	0.26
Water depth	0.26	0.41	0.84	0.22	-0.09
Dissolved oxygen	0.92	0.06	-0.08	0.28	0.26
pH	-0.24	0.70	-0.48	0.47	-0.07
Salinity	0.39	0.63	-0.11	-0.66	0.00
Eigenvalue	1.92	1.14	1.01	0.78	0.15
Percent	38.40	22.83	20.22	15.60	2.95
Cumulative percent	38.40	61.23	81.45	97.05	100.00

Figure 27.

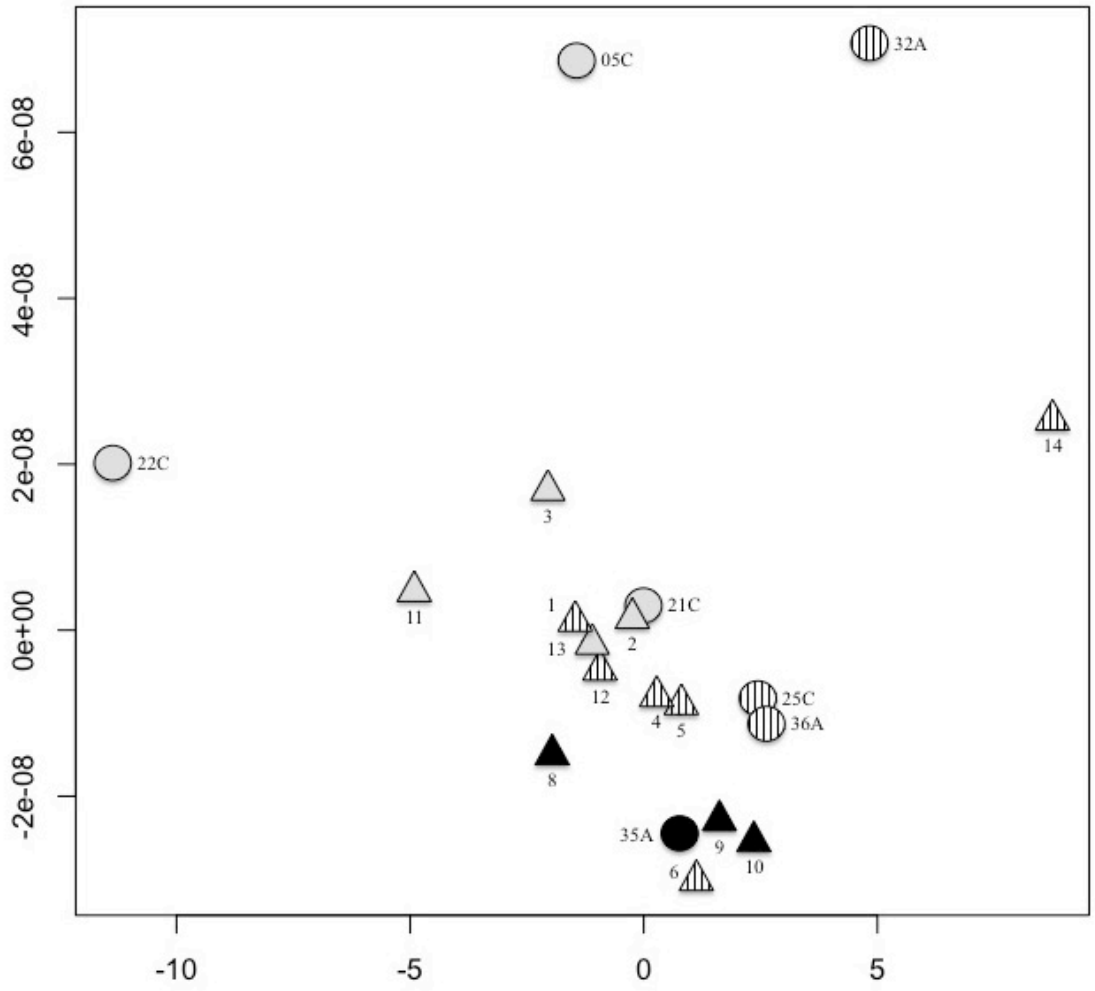

6e-08
4e-08
2e-08
0e+00
-2e-08
-10
-5
0
5
05C
32A
22C
14
3
11
1
21C
13
2
12
4
5
25C
36A
8
35A
9
10
6

Figure 28.

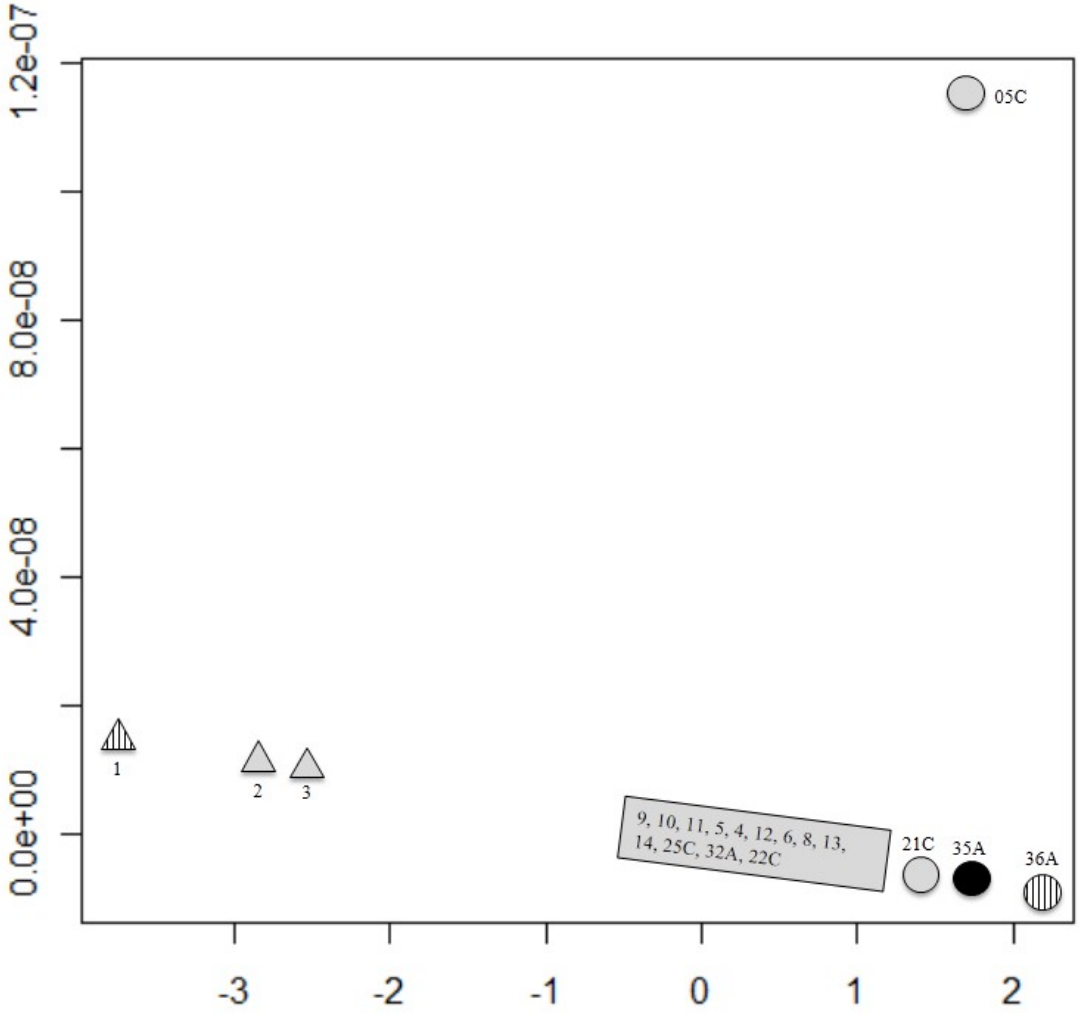

1.2e-07
8.0e-08
4.0e-08
0.0e+00
-3
-2
-1
0
1
2
05C
1
2
3
9, 10, 11, 5, 4, 12, 6, 8, 13,
14, 25C, 32A, 22C
21C
35A
36A

Figure 29.

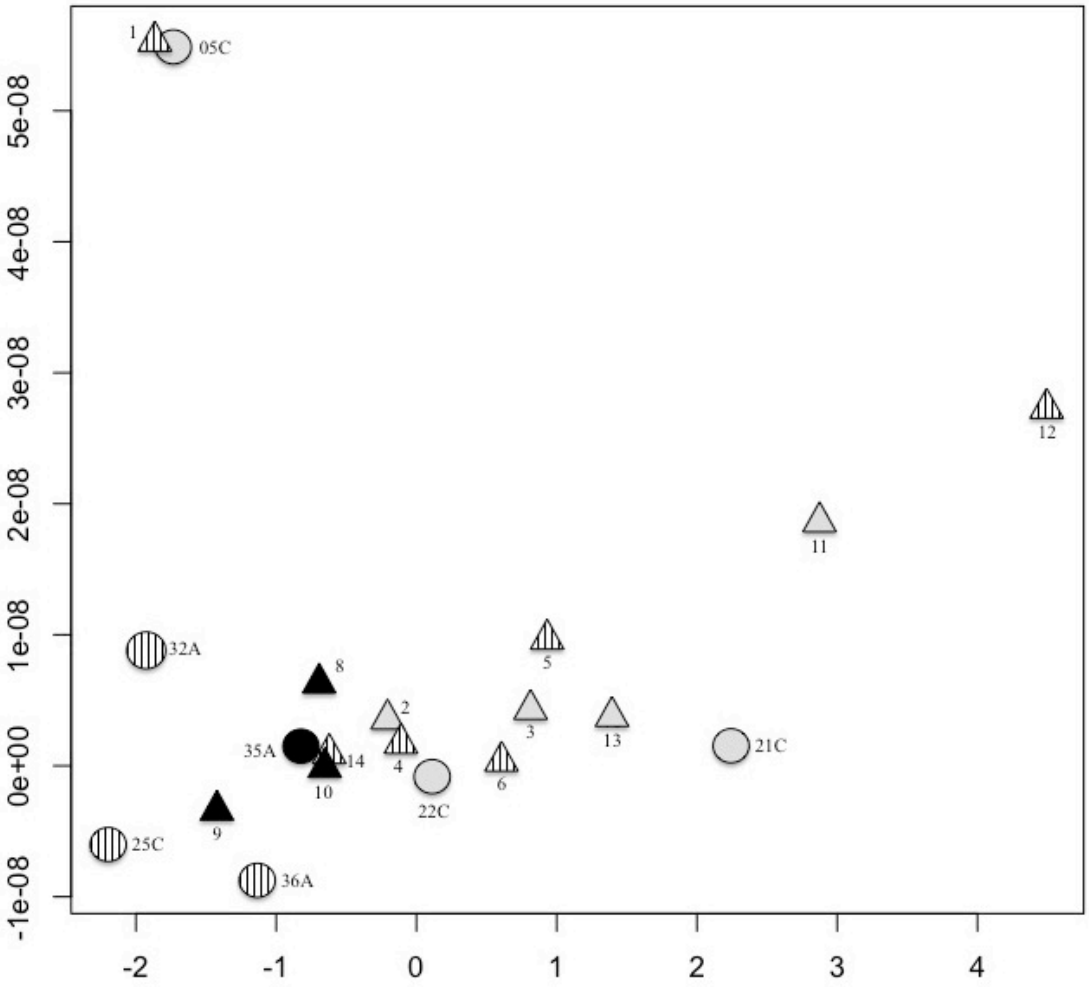
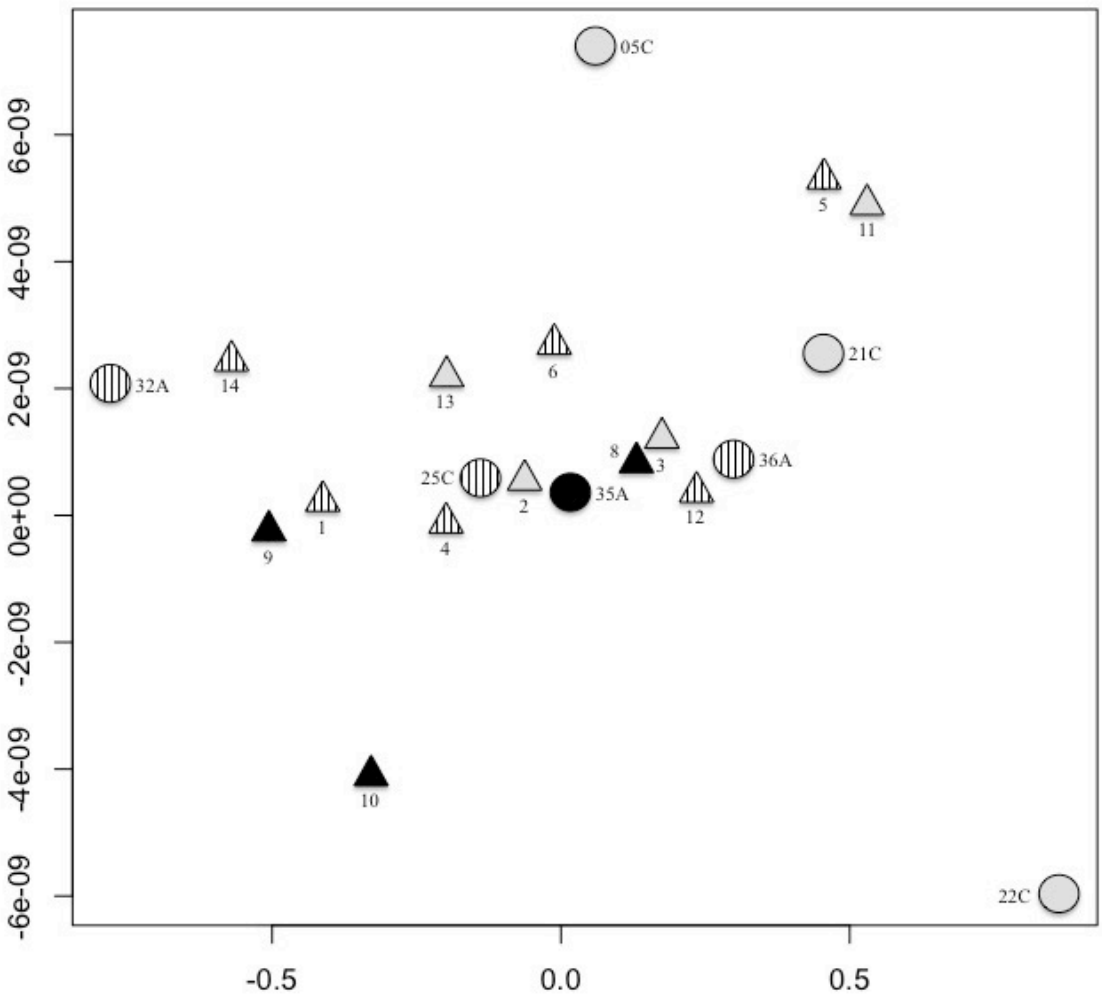

1
05C
12
11
32A
8
5
2
3
13
21C
35A
14
4
10
6
22C
9
25C
36A
5e-08
4e-08
3e-08
2e-08
1e-08
0e+00
-1e-08
-2
-1
0
1
2
3
4

Figure 30.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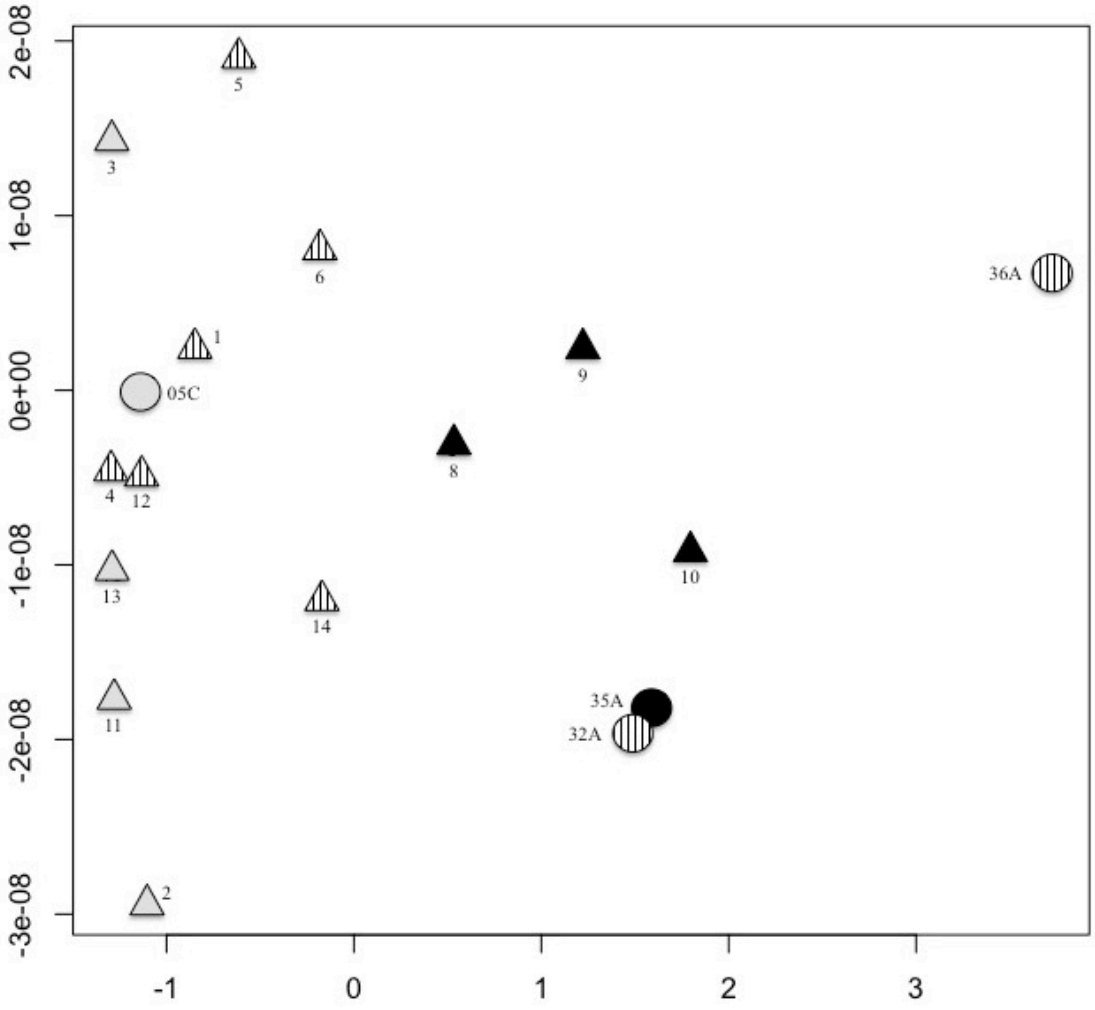
5
11
21C
32A
14
13
6
8
3
36A
25C
2
35A
12
1
4
9
10
22C
6e-09
4e-09
2e-09
0e+00
-2e-09
-4e-09
-6e-09
-0.5
0.0
0.5

Figure 31.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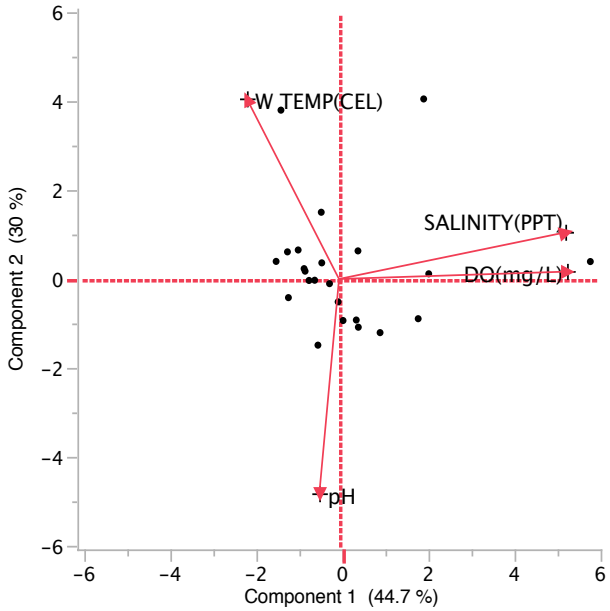
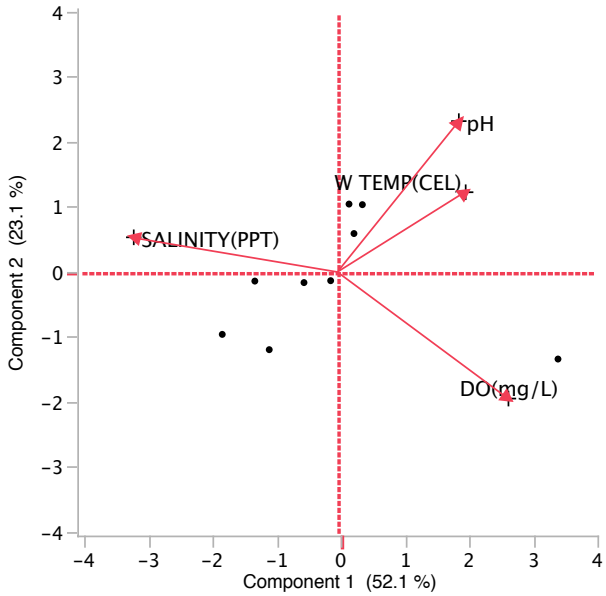
1e-08
0e+00
-1e-08
-2e-08
-3e-08
-1
0
1
2
3
5
3
6
36A
1
9
05C
8
4
12
10
13
14
35A
32A
11
2

Figure 32.





	Component			
	1	2	3	4
Water temperature	-0.37	0.69	0.62	-0.02
Dissolved oxygen	0.91	0.03	0.18	-0.37
pH	-0.08	-0.83	0.55	0.05
Salinity	0.90	0.18	0.12	0.37
Eigenvalue	1.79	1.20	0.74	0.28
Percent	44.68	29.99	18.41	6.93
Cumulative percent	44.68	74.66	93.07	100.00

	Component			
	1	2	3	4
Water temperature	0.58	0.36	0.73	0.06
Dissolved oxygen	0.77	-0.57	-0.08	0.28
pH	0.55	0.67	-0.48	0.12
Salinity	-0.92	0.15	0.10	0.34
Eigenvalue	2.08	0.92	0.78	0.21
Percent	52.08	23.09	19.50	5.34
Cumulative percent	52.08	75.16	94.66	100.00

Appendix A1. Descriptive statistics of available water quality data for the Tar-Pamlico region separated by project and region. Water quality variables include: water temperature (degrees Celsius), water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). Region = lower, middle, and upper. N = number of monitoring sessions. Std. Dev. = standard deviation.

	Lower			Middle			Upper		
Project	**Water temperature (°C)**			**Water temperature (°C)**			**Water temperature (°C)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	74	21.8	8.2	408	20.0	7.8	257	19.4	8.3
PCS Phosphate	2934	19.6	7.7	2568	19.1	7.9	683	18.6	7.9
	Water depth (m)			**Water depth (m)**			**Water depth (m)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	648	0.9	0.4	1036	1.7	0.9	806	1.8	1.8
PCS Phosphate	0			0			0		
	Secchi depth (m)			**Secchi depth (m)**			**Secchi depth (m)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	576	0.7	0.4	1022	0.9	0.6	800	0.7	0.4
PCS Phosphate	0			0			0		
	Dissolved oxygen (mg/L)			**Dissolved oxygen (mg/L)**			**Dissolved oxygen (mg/L)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	643	7.8	2.4	1011	6.8	2.9	958	7.0	2.5
PCS Phosphate	2895	9.1	2.4	2544	9.3	2.4	673	8.5	2.6
	pH			**pH**			**pH**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	653	7.7	0.6	1035	7.3	0.8	963	7.0	0.8
PCS Phosphate	596	8.0	0.4	558	8.0	0.5	209	7.5	0.6
	Salinity (ppt)			**Salinity (ppt)**			**Salinity (ppt)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	192	9.6	3.9	417	5.7	4.6	265	3.3	2.4
PCS Phosphate	2936	9.7	4.4	2568	5.9	4.6	683	2.4	3.2

Appendix A2. Descriptive statistics of water temperature (degrees Celsius) for the Tar-Pamlico region separated by project and site. Project = APNEP-CMN, PCS Phosphate. Position = numbered from downstream to upstream. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 1 for site information and Table 3 for distances (kilometers) among sites.

			Winter			Spring			Summer			Fall		
Project	**Position**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
PCS Phosphate	1	1	55	10.82	4.82	64	22.40	4.20	75	27.03	4.00	70	16.18	4.91
PCS Phosphate	2	1A	62	11.45	5.99	78	22.80	4.44	91	27.69	2.28	82	17.12	5.79
APNEP-CMN	3	17P	0			0			0			0		
APNEP-CMN	4	19P	1	9.50		0			0			0		
PCS Phosphate	5	2	1	12.00		0			0			0		
PCS Phosphate	6	3	110	10.81	5.27	141	22.75	4.30	132	27.23	3.22	124	16.43	5.77
PCS Phosphate	7	4S	30	11.30	5.34	50	20.94	5.16	46	24.33	6.31	43	14.45	4.43
PCS Phosphate	8	4N	30	13.06	8.04	45	24.40	5.10	43	28.17	1.69	39	18.19	6.92
PCS Phosphate	9	4P	31	12.40	7.39	50	23.72	4.46	47	27.54	1.89	43	17.79	6.87
APNEP-CMN	10	15P	0			0			0			0		
PCS Phosphate	11	5S	31	10.94	5.20	50	21.64	3.97	46	25.82	3.48	43	15.90	4.86
PCS Phosphate	12	5	109	9.66	3.46	141	21.24	6.05	131	25.68	6.75	124	14.61	5.09
PCS Phosphate	13	5N	30	10.07	3.64	45	20.37	5.70	43	24.80	6.12	40	15.02	4.24
PCS Phosphate	14	6	114	11.34	5.83	143	22.98	4.39	135	27.31	3.05	127	16.69	6.11
APNEP-CMN	15	57P	14	10.52	3.59	19	23.72	4.46	25	29.37	2.78	15	18.05	6.23
APNEP-CMN	16	25N	7	9.77	3.30	19	20.71	4.95	16	26.00	4.22	6	17.10	5.96
PCS Phosphate	17	7S	114	9.61	3.44	143	20.59	6.47	135	25.50	6.96	128	14.15	5.08
APNEP-CMN	18	11P	4	8.38	1.11	0			4	25.68	2.08	0		
APNEP-CMN	19	13P	58	10.38	4.17	33	21.95	3.53	42	26.85	2.73	35	15.73	3.95
PCS Phosphate	20	7N	30	10.94	4.25	44	21.75	4.99	41	25.37	5.77	43	14.97	4.38
PCS Phosphate	21	7	113	10.99	5.57	143	23.01	4.33	136	27.49	3.07	128	16.40	5.94
PCS Phosphate	22	8	112	10.58	4.48	143	22.11	4.64	134	26.84	4.70	128	15.67	5.32
APNEP-CMN	23	20P	32	11.84	3.26	58	25.09	3.78	40	29.63	2.78	26	16.92	4.66
PCS Phosphate	24	9S	31	10.62	5.39	47	21.49	4.18	45	25.16	5.03	43	14.81	4.78
APNEP-CMN	25	65P	6	10.38	1.35	5	21.00	4.90	11	28.90	2.81	6	17.25	5.71
APNEP-CMN	26	07P	0			0			0			0		
PCS Phosphate	27	9N	30	12.69	7.85	50	23.99	4.63	48	27.99	1.89	43	17.50	6.95
APNEP-CMN	28	03P	0			0			0			0		
PCS Phosphate	29	10	114	10.16	3.85	140	21.65	5.63	136	26.10	5.58	126	14.99	5.39
APNEP-CMN	30	10P	2	12.25	2.47	0			0			0		
APNEP-CMN	31	50P	52	10.36	4.44	49	22.92	5.04	51	28.54	3.26	44	15.32	5.58
APNEP-CMN	32	05P	0			0			0			0		
PCS Phosphate	33	11	31	11.60	6.59	48	22.57	4.08	47	26.44	2.92	43	16.23	6.03
APNEP-CMN	34	06P	0			0			0			0		
PCS Phosphate	35	12	114	9.54	3.54	140	21.28	5.83	133	25.88	5.70	127	14.27	4.89
APNEP-CMN	36	01P	12	10.33	3.98	19	21.77	5.29	13	27.77	2.24	12	16.29	6.46
APNEP-CMN	37	09T	0			0			0			0		
APNEP-CMN	38	07T	0			0			3	28.83	0.76	0		
APNEP-CMN	39	06T	0			0			0			0		
APNEP-CMN	40	05T	0			0			0			0		
Sum, Mean			**1480**	**10.81**		**1907**	**22.26**		**1849**	**26.93**		**1688**	**16.08**	

Appendix A3. Descriptive statistics of dissolved oxygen (milligrams per liter) for the Tar-Pamlico region separated by project and site. Project = APNEP-CMN, PCS Phosphate. Position = numbered from downstream to upstream. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 1 for site information and Table 3 for distances (kilometers) among sites.

			Winter			Spring			Summer			Fall		
Project	**Position**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
PCS Phosphate	1	1	55	10.78	2.10	64	8.10	1.48	75	7.69	2.34	70	9.42	1.92
PCS Phosphate	2	1A	61	10.88	2.20	78	8.28	1.45	87	8.05	1.92	79	9.42	2.09
APNEP-CMN	3	17P	24	9.81	0.89	38	6.82	2.00	40	5.76	1.76	22	8.60	1.62
APNEP-CMN	4	19P	50	9.35	1.58	65	5.68	1.37	64	4.24	1.20	59	7.42	1.72
PCS Phosphate	5	2	1	8.00		0			0			0		
PCS Phosphate	6	3	107	11.11	2.19	139	8.30	1.75	131	8.03	1.83	124	9.37	2.31
PCS Phosphate	7	4S	27	11.41	2.29	50	8.73	1.98	46	8.78	2.50	43	9.64	2.43
PCS Phosphate	8	4N	26	9.79	2.39	45	7.52	2.21	43	7.52	2.75	39	8.66	2.22
PCS Phosphate	9	4P	28	11.45	2.71	50	7.94	3.00	47	8.34	2.94	43	9.79	2.04
APNEP-CMN	10	15P	48	10.93	1.49	57	9.05	1.27	56	7.84	1.41	46	9.65	1.42
PCS Phosphate	11	5S	28	10.91	2.84	50	8.24	1.69	46	8.13	1.82	43	9.13	2.04
PCS Phosphate	12	5	107	11.59	1.95	140	9.06	1.87	131	8.61	2.17	124	10.40	2.20
PCS Phosphate	13	5N	27	11.04	1.75	45	8.67	1.95	43	8.70	2.20	40	9.83	1.85
PCS Phosphate	14	6	111	10.91	2.73	141	8.26	2.00	134	7.73	1.97	127	9.44	2.34
APNEP-CMN	15	57P	14	10.95	1.47	19	7.76	1.35	26	8.51	1.69	15	9.08	1.51
APNEP-CMN	16	25N	4	9.10	0.86	19	3.04	2.23	16	2.97	1.02	6	8.47	12.54
PCS Phosphate	17	7S	111	11.37	2.13	141	8.65	1.97	134	8.10	2.05	128	9.78	1.97
APNEP-CMN	18	11P	62	8.35	1.97	77	4.48	2.03	69	2.82	1.21	66	4.65	2.55
APNEP-CMN	19	13P	99	9.21	1.75	93	6.90	1.34	86	6.08	0.97	77	8.32	1.46
PCS Phosphate	20	7N	26	10.50	2.91	44	8.39	1.68	41	8.00	1.63	43	9.17	2.16
PCS Phosphate	21	7	111	11.37	2.41	142	8.68	2.07	135	8.11	2.27	128	9.74	2.41
PCS Phosphate	22	8	110	11.33	2.07	142	8.82	1.77	132	8.17	1.96	128	9.77	2.18
APNEP-CMN	23	20P	32	8.01	1.17	60	5.99	0.96	34	4.84	1.71	26	4.60	2.05
PCS Phosphate	24	9S	29	10.57	1.88	47	8.63	1.43	45	7.97	1.95	43	9.47	2.13
APNEP-CMN	25	65P	6	8.42	5.51	5	7.86	1.38	11	7.93	1.50	6	7.99	2.28
APNEP-CMN	26	07P	21	10.55	2.04	29	8.81	1.09	31	8.38	2.00	21	10.05	1.76
PCS Phosphate	27	9N	30	9.79	2.99	50	7.85	2.22	48	7.35	1.89	43	8.69	2.76
APNEP-CMN	28	03P	12	10.39	1.18	23	8.60	1.70	14	6.99	1.64	6	9.83	2.62
PCS Phosphate	29	10	113	10.94	2.09	139	8.86	1.83	135	8.13	2.23	126	9.90	2.33
APNEP-CMN	30	10P	32	10.31	1.04	24	8.08	1.70	15	6.35	0.97	21	8.43	1.35
APNEP-CMN	31	50P	52	9.86	1.87	47	7.21	1.86	51	7.17	1.21	44	8.41	1.96
APNEP-CMN	32	05P	17	8.74	2.03	26	7.22	1.59	25	6.88	2.53	16	8.06	2.38
PCS Phosphate	33	11	29	10.18	2.73	48	8.09	2.54	47	7.36	3.21	38	9.45	2.79
APNEP-CMN	34	06P	9	8.69	0.20	20	6.96	1.50	17	5.55	1.04	12	8.74	1.74
PCS Phosphate	35	12	112	10.29	1.87	139	7.79	1.81	133	7.29	2.62	127	9.02	2.17
APNEP-CMN	36	01P	59	9.05	1.08	57	6.48	1.13	60	5.70	1.65	49	7.71	1.78
APNEP-CMN	37	09T	13	8.45	1.66	22	4.66	1.54	17	4.14	1.90	13	6.34	2.38
APNEP-CMN	38	07T	39	6.85	2.55	38	4.24	1.75	42	2.93	1.35	27	3.51	1.73
APNEP-CMN	39	06T	9	9.12	1.00	12	5.52	0.83	18	5.06	0.68	8	7.54	1.67
APNEP-CMN	40	05T	20	9.14	1.05	10	6.04	1.12	9	5.70	0.38	8	8.09	1.30
Sum, Mean			**1871**	**9.99**		**2435**	**7.44**		**2334**	**6.87**		**2084**	**8.60**	

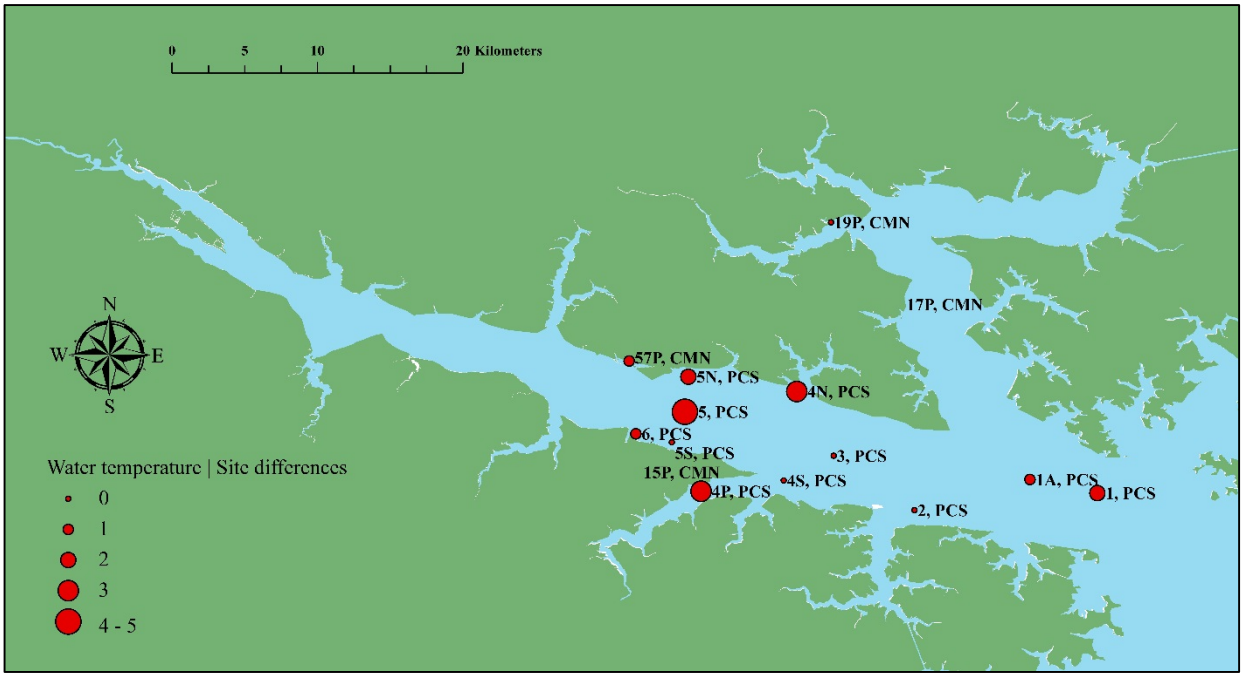
Appendix A4. Descriptive statistics of pH for the Tar-Pamlico region separated by project and site. Project = APNEP-CMN, PCS Phosphate. Position = numbered from downstream to upstream. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 1 for site information and Table 3 for distances (kilometers) among sites.

			Winter			Spring			Summer			Fall		
Project	**Position**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
PCS Phosphate	1	1	16	8.11	0.27	18	8.12	0.22	15	8.35	0.28	16	8.21	0.27
PCS Phosphate	2	1A	18	7.93	0.58	29	7.93	0.39	26	8.08	0.48	26	7.88	0.47
APNEP-CMN	3	17P	25	7.72	0.46	38	7.37	0.49	40	7.74	0.44	26	7.65	0.49
APNEP-CMN	4	19P	52	7.52	0.45	65	7.05	0.29	63	7.02	0.31	59	7.22	0.39
PCS Phosphate	5	2	0			0			0			0		
PCS Phosphate	6	3	25	8.16	0.34	34	8.02	0.50	32	8.21	0.39	27	8.03	0.37
PCS Phosphate	7	4S	4	8.48	0.41	0			3	8.20	0.10	5	7.96	0.24
PCS Phosphate	8	4N	1	7.70		3	7.60	0.26	5	7.50	0.12	3	7.80	0.20
PCS Phosphate	9	4P	3	7.60	0.26	5	7.42	0.47	1	7.60		7	7.97	0.23
APNEP-CMN	10	15P	48	8.29	0.40	58	8.30	0.40	60	8.24	0.42	45	8.17	0.30
PCS Phosphate	11	5S	1	7.70		8	7.50	0.14	2	7.55	0.07	1	7.10	
PCS Phosphate	12	5	26	8.17	0.39	38	8.03	0.42	30	8.29	0.45	25	8.12	0.27
PCS Phosphate	13	5N	2	7.95	0.07	4	7.58	0.54	2	7.75	0.21	4	7.83	0.55
PCS Phosphate	14	6	29	8.12	0.41	39	7.99	0.34	32	8.15	0.39	31	7.99	0.46
APNEP-CMN	15	57P	14	7.98	0.24	19	7.46	0.55	26	8.47	0.64	15	7.95	0.35
APNEP-CMN	16	25N	7	5.64	0.38	19	6.03	0.42	16	6.31	0.73	6	6.33	0.68
PCS Phosphate	17	7S	27	8.29	0.42	36	7.92	0.35	35	8.18	0.49	27	8.06	0.53
APNEP-CMN	18	11P	62	6.46	0.26	77	6.42	0.29	67	6.49	0.24	66	6.60	0.33
APNEP-CMN	19	13P	108	7.77	0.88	99	7.40	0.91	92	7.78	0.54	85	7.65	0.47
PCS Phosphate	20	7N	1	8.00		5	7.72	0.41	2	8.00	0.00	7	7.99	0.09
PCS Phosphate	21	7	23	8.35	0.37	40	7.91	0.42	31	8.25	0.47	28	7.92	0.51
PCS Phosphate	22	8	26	8.28	0.41	35	8.04	0.40	31	8.33	0.56	27	8.07	0.60
APNEP-CMN	23	20P	32	8.01	0.32	58	7.36	0.50	32	7.66	0.35	26	7.67	0.52
PCS Phosphate	24	9S	1	8.00		4	8.23	0.13	3	8.07	0.06	4	7.75	0.13
APNEP-CMN	25	65P	6	8.20	0.51	5	7.90	0.42	11	8.27	0.28	6	7.78	0.94
APNEP-CMN	26	07P	20	7.40	0.60	29	7.52	0.54	30	7.68	0.64	20	8.03	0.44
PCS Phosphate	27	9N	2	8.20	0.42	2	7.45	0.21	2	7.55	0.07	1	8.20	
APNEP-CMN	28	03P	12	7.54	0.72	24	7.52	0.81	14	7.61	0.59	6	7.92	0.20
PCS Phosphate	29	10	32	7.91	0.56	47	7.69	0.59	43	8.03	0.64	36	8.05	0.65
APNEP-CMN	30	10P	33	7.31	0.63	24	7.60	0.63	15	7.33	0.49	21	7.53	0.47
APNEP-CMN	31	50P	54	7.91	0.86	49	7.54	1.21	51	7.86	0.56	42	7.62	0.74
APNEP-CMN	32	05P	17	7.62	0.76	24	7.67	0.50	20	7.95	0.56	10	8.00	0.47
PCS Phosphate	33	11	6	7.42	0.59	14	7.61	0.49	13	7.36	0.53	11	7.55	0.18
APNEP-CMN	34	06P	11	6.91	0.20	20	7.00	0.36	17	7.06	0.56	12	6.96	0.33
PCS Phosphate	35	12	32	7.54	0.47	48	7.29	0.60	45	7.60	0.66	40	7.50	0.63
APNEP-CMN	36	01P	61	6.55	0.41	58	6.61	0.46	61	6.78	0.63	51	6.69	0.43
APNEP-CMN	37	09T	14	6.39	0.40	22	6.14	0.28	17	6.29	0.36	14	6.61	0.71
APNEP-CMN	38	07T	37	6.46	0.32	42	6.43	0.32	38	6.59	0.28	24	6.54	0.25
APNEP-CMN	39	06T	8	6.69	0.37	20	6.73	0.30	17	6.94	0.17	7	6.93	0.19
APNEP-CMN	40	05T	22	6.46	0.41	11	6.18	0.40	9	6.28	0.44	10	6.50	0.41
Sum, Mean			**918**	**7.61**		**1170**	**7.43**		**1049**	**7.63**		**877**	**7.60**	

Appendix A5. Descriptive statistics of salinity (parts per thousand) for the Tar-Pamlico region separated by project and site. Project = APNEP-CMN, PCS Phosphate. Position = numbered from downstream to upstream. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 1 for site information and Table 3 for distances (kilometers) among sites.

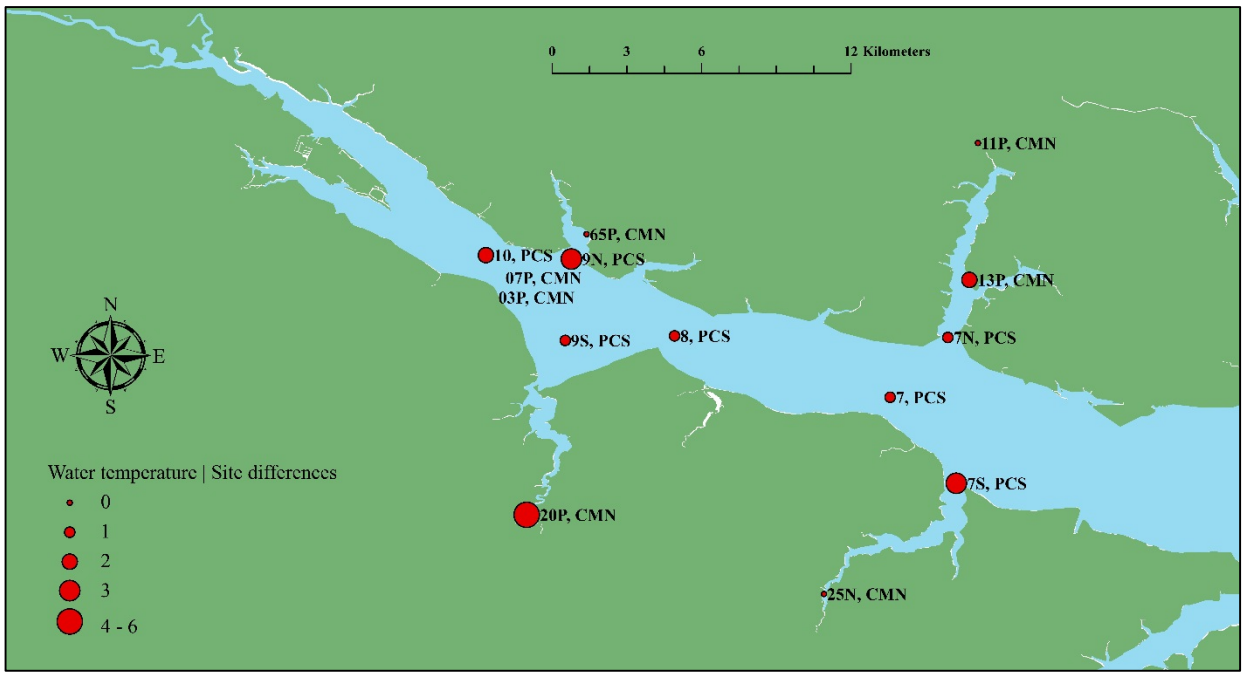
			Winter			Spring			Summer			Fall		
Project	**Position**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
PCS Phosphate	1	1	55	13.03	3.78	64	11.99	3.45	76	14.20	4.54	70	14.01	5.02
PCS Phosphate	2	1A	62	11.39	4.24	78	9.99	3.35	92	11.75	4.30	82	12.36	4.86
APNEP-CMN	3	17P	0			0			0			0		
APNEP-CMN	4	19P	12	13.48	2.73	23	9.90	2.07	22	10.32	2.34	2	10.05	1.34
PCS Phosphate	5	2	1	12.10		0			0			0		
PCS Phosphate	6	3	110	9.61	4.21	141	8.05	3.23	132	10.31	3.80	124	11.31	5.02
PCS Phosphate	7	4S	30	9.08	4.05	50	8.81	3.53	46	10.77	2.98	43	11.75	3.64
PCS Phosphate	8	4N	30	10.78	4.18	45	8.54	2.66	43	9.82	3.32	39	12.93	3.83
PCS Phosphate	9	4P	31	8.95	3.53	50	8.33	2.57	47	10.21	3.38	43	11.68	3.10
APNEP-CMN	10	15P	12	14.08	1.08	22	11.36	0.79	21	12.39	1.94	4	17.00	0.82
PCS Phosphate	11	5S	31	8.21	4.49	50	6.58	2.57	46	8.76	2.64	43	10.75	4.52
PCS Phosphate	12	5	109	8.31	4.56	141	7.32	3.55	132	9.47	3.67	124	10.62	4.92
PCS Phosphate	13	5N	30	10.44	4.42	45	7.28	2.87	43	9.21	3.32	40	11.09	5.02
PCS Phosphate	14	6	114	7.22	4.31	142	6.06	3.27	135	8.33	3.80	127	9.00	4.65
APNEP-CMN	15	57P	14	8.20	2.37	19	5.07	2.37	26	5.78	3.01	15	6.15	3.59
APNEP-CMN	16	25N	7	0.49	0.23	18	2.91	1.82	14	4.61	2.93	6	3.43	2.76
PCS Phosphate	17	7S	114	6.73	4.35	143	5.57	3.06	135	7.80	3.88	128	8.92	4.85
APNEP-CMN	18	11P	15	2.17	0.78	23	4.53	2.39	16	5.48	2.23	1	5.30	
APNEP-CMN	19	13P	59	6.65	4.17	49	4.58	2.42	45	7.15	4.04	28	10.15	4.47
PCS Phosphate	20	7N	30	8.22	4.44	44	7.64	4.96	41	9.09	3.32	43	11.09	3.71
PCS Phosphate	21	7	113	6.05	4.37	143	5.30	3.86	136	7.54	3.87	128	8.33	4.93
PCS Phosphate	22	8	112	4.11	3.42	143	3.12	2.67	134	5.55	3.80	128	6.38	4.84
APNEP-CMN	23	20P	28	3.84	6.12	40	2.85	1.97	24	5.70	3.10	26	11.75	8.29
PCS Phosphate	24	9S	31	5.20	5.64	47	4.82	4.85	45	6.78	4.44	43	8.27	5.24
APNEP-CMN	25	65P	1	14.90		4	3.93	0.78	11	7.15	1.46	2	10.10	0.71
APNEP-CMN	26	07P	0			0			0			0		
PCS Phosphate	27	9N	31	4.55	3.79	50	3.61	2.75	48	5.21	2.79	43	7.81	4.25
APNEP-CMN	28	03P	0			0			0			0		
PCS Phosphate	29	10	114	2.86	3.89	140	2.79	4.15	136	4.86	4.72	125	5.62	4.89
APNEP-CMN	30	10P	15	4.65	1.44	11	4.02	1.76	9	5.13	1.99	5	3.58	2.17
APNEP-CMN	31	50P	29	3.25	3.11	27	2.67	2.24	32	4.00	2.36	30	4.27	3.27
APNEP-CMN	32	05P	0			0			0			0		
PCS Phosphate	33	11	30	2.64	3.33	48	2.87	3.63	47	3.99	3.28	43	6.11	4.37
APNEP-CMN	34	06P	0			0			0			0		
PCS Phosphate	35	12	114	1.10	1.97	140	1.09	2.03	134	2.22	2.81	127	3.32	3.38
APNEP-CMN	36	01P	15	0.96	0.71	13	3.19	1.75	18	4.94	1.71	14	1.74	1.38
APNEP-CMN	37	09T	0			0			0			0		
APNEP-CMN	38	07T	18	1.97	0.88	10	2.83	1.30	6	3.35	1.30	12	2.25	0.75
APNEP-CMN	39	06T	0			0			0			0		
APNEP-CMN	40	05T	1	0.20		0			0			0		
Sum, Mean			**1518**	**6.83**		**1963**	**5.73**		**1892**	**7.48**		**1688**	**8.62**	

Appendix A6. Post-hoc pairwise comparison matrix for sites in the lower Tar-Pamlico region using combined water temperature (degrees Celsius) data from APNEP-CMN and PCS Phosphate. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. Black pattern shaded areas denotes missing data. The map plots these sites (red circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 1 for site information and Table 3 for distances (kilometers) among sites.



Water temperature	Site	1	1A	17P	19P	2	3	4S	4N	4P	15P	5S	5	5N	6	57P
Lower region	1		-0.83		10.16	7.66	-0.12	1.16	-2.07	-1.57		0.29	1.39	1.39	-0.35	-2.30
	1A	-0.83			-10.99	8.49	0.71	1.99	-1.24	-0.74		1.12	2.22	2.22	0.48	-1.47
	17P															
	19P	10.16	-10.99			-2.50	-10.28	-9.00	-12.22	-11.73		-9.87	-8.76	-8.76	-10.51	-12.46
	2	7.66	8.49		-2.50		-7.78	-6.50	-9.72	-9.23		-7.37	-6.26	-6.26	-8.01	-9.96
	3	-0.12	0.71		-10.28	-7.78		1.28	-1.94	-1.45		0.41	1.52	1.52	-0.23	-2.18
	4S	1.16	1.99		-9.00	-6.50	1.28		2.73	0.49		-0.87	0.24	0.24	-1.51	-3.46
	4N	-2.07	-1.24		-12.22	-9.72	-1.94	2.73		0.49		2.36	3.46	3.46	1.71	-0.24
	4P	-1.57	-0.74		-11.73	-9.23	-1.45	0.49	0.49			1.86	2.97	2.97	1.22	-0.73
	15P															
	5S	0.29	1.12		-9.87	-7.37	0.41	-0.87	2.36	1.86			-1.10	-1.10	-0.64	2.59
	5	1.39	2.22		-8.76	-6.26	1.52	0.24	3.46	2.97		-1.10		0.00	-1.75	-3.69
	5N	1.39	2.22		-8.76	-6.26	1.52	0.24	3.46	2.97		-1.10	0.00		-1.75	3.69
	6	-0.35	0.48		-10.51	-8.01	-0.23	-1.51	1.71	1.22		-0.64	-1.75	-1.75		1.95
	57P	-2.30	-1.47		-12.46	-9.96	-2.18	-3.46	-0.24	-0.73		2.59	-3.69	3.69	1.95	

Appendix A7. Post-hoc pairwise comparison matrix for sites in the middle Tar-Pamlico region using combined water temperature (degrees Celsius) data from APNEP-CMN and PCS Phosphate. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. Black pattern shaded areas denotes missing data. The map plots these sites (red circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 1 for site information and Table 3 for distances (kilometers) among sites.

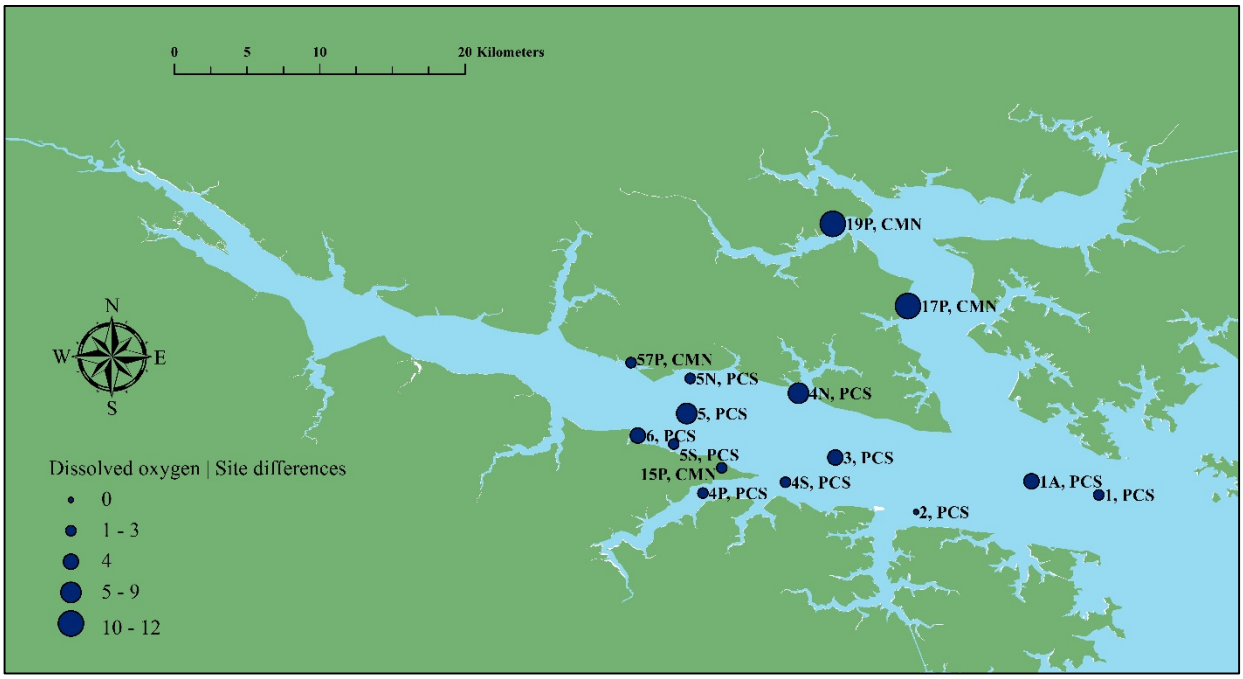


Water temperature	Site	25N	7S	11P	13P	7N	7	8	20P	9S	65P	07P	9N	03P	10
Middle region	25N		2.55	-3.4	-2.54	1.64	0.48	1.18	1.75	1.7	-0.6		-1.07		-1.77
	7S	2.551		-0.85	0.01	0.92	2.07	-1.37	4.3	-0.85	3.15		-3.63		0.78
	11P	-3.4	-0.85		-0.86	-1.77	-2.92	-2.22	-5.15	-1.7	-4		-4.47		1.63
	13P	-2.54	0.01	-0.86		-0.91	-2.06	-1.36	-4.29	-0.84	-3.14		-3.62		0.77
	7N	1.635	0.916	-1.77	-0.91		1.16	-0.45	3.38	0.06	2.24		-2.71		-0.14
	7	0.481	2.07	-2.92	-2.06	1.155		0.7	2.23	1.22	1.08		-1.56		-1.29
	8	1.182	-1.37	-2.22	-1.36	-0.45	0.701		2.93	0.52	1.78		-2.26		-0.59
	20P	1.748	4.299	-5.15	-4.29	3.383	2.229	2.93		3.45	1.15		0.67		-3.52
	9S	1.699	-0.85	-1.7	-0.84	0.064	1.219	0.518	3.447		2.3		2.77		-0.07
	65P	-0.6	3.151	-4	-3.14	2.235	1.081	1.782	1.148	2.299			-0.47		-2.37
	07P														
	9N	-1.07	-3.63	-4.47	-3.62	-2.71	-1.56	-2.26	0.674	2.774	-0.47				-2.84
	03P														
	10	-1.77	0.781	1.63	0.771	-0.14	-1.29	-0.59	-3.52	-0.07	-2.37		-2.84		

Appendix A8. Post-hoc pairwise comparison matrix for sites in the upper Tar-Pamlico region using combined water temperature (degrees Celsius) data from APNEP-CMN and PCS Phosphate. Values represent mean differences among sites. All site comparisons were non-significant at the 0.05 alpha level. Black pattern shaded areas denotes missing data. See Table 1 for site information and Table 3 for distances (kilometers) among sites.

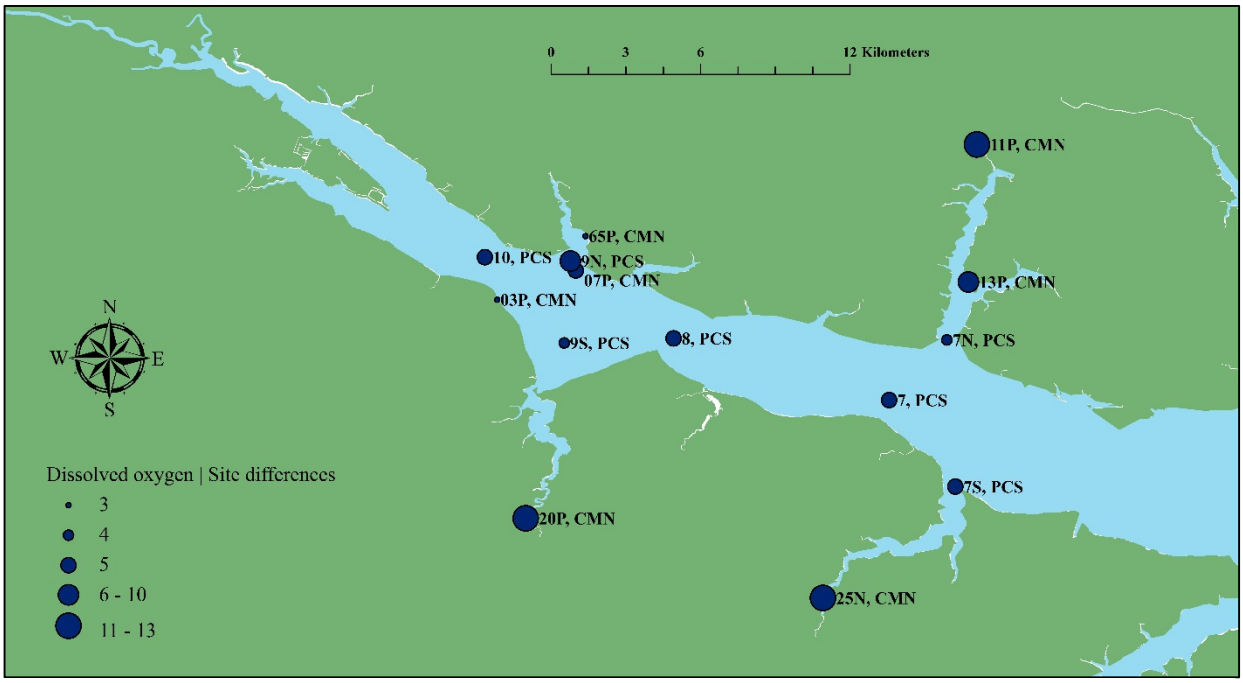
Water temperature	Site	10P	50P	05P	11	06P	12	01P	09T	07T	06T	05T
Upper region	**10P**		-7.1		-7.77		-5.89	7.289		16.58		
	50P	-7.1			0.673		-1.21	0.194		9.488		
	05P											
	11	-7.77	0.673				1.883	-0.48		8.815		
	06P											
	12	-5.89	-1.21		1.883			1.404		10.7		
	01P	7.289	0.194		-0.48		1.404			-9.29		
	09T											
	07T	16.58	9.488		8.815		10.7	-9.29				
	06T											
	05T											

Appendix A9. Post-hoc pairwise comparison matrix for sites in the lower Tar-Pamlico region using combined dissolved oxygen (milligrams per liter) data from APNEP-CMN and PCS Phosphate. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (blue circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 1 for site information and Table 3 for distances (kilometers) among sites.



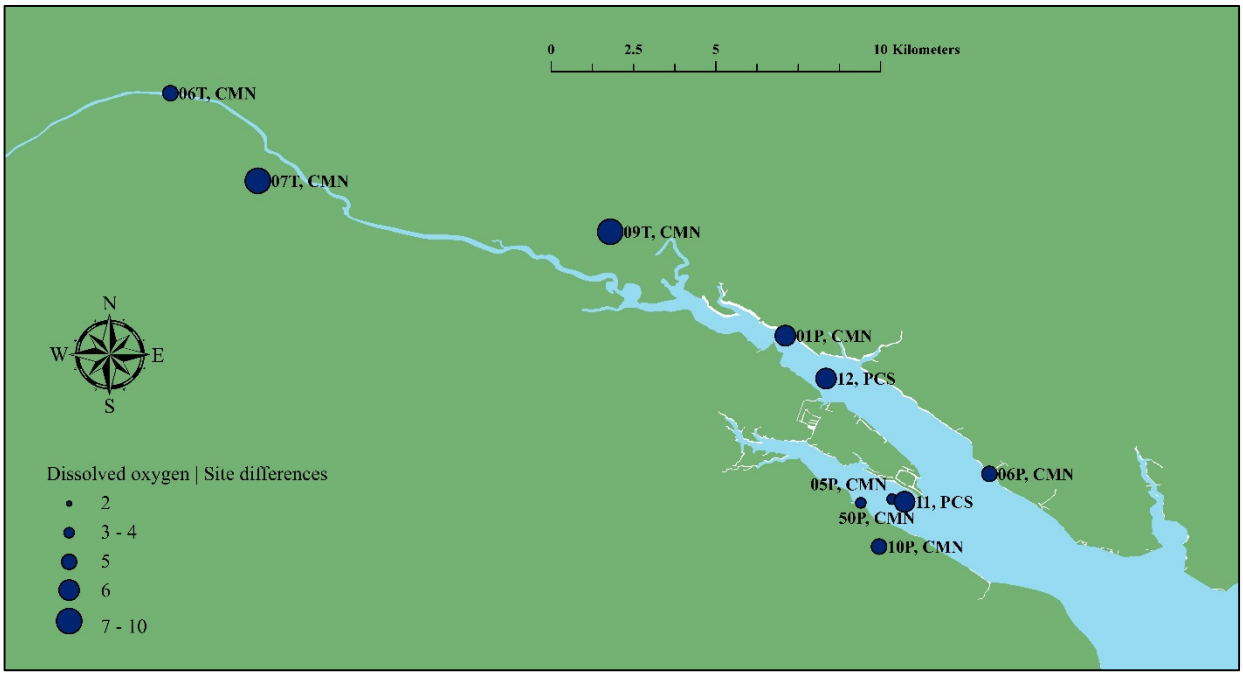
Dissolved oxygen	Site	1	1A	17P	19P	2	3	4S	4N	4P	15P	5S	5	5N	6	57P
Lower region	**1**		-0.14	1.52	2.39	0.89	-0.21	-0.53	0.69	-0.22	-0.41	0.01	-0.92	-0.50	-0.09	-0.01
	1A	-0.14		-1.66	-2.53	1.03	-0.06	-0.38	0.83	-0.08	0.26	0.15	-0.78	-0.36	0.05	0.14
	17P	1.52	-1.66		0.87	-0.63	-1.72	-2.04	-0.83	-1.74	1.92	-1.51	-2.44	-2.01	-1.61	-1.52
	19P	2.39	-2.53	0.87		-1.50	-2.60	-2.92	-1.70	-2.61	2.80	-2.38	-3.31	-2.89	-2.49	-2.40
	2	0.89	1.03	-0.63	-1.50		-1.09	-1.41	-0.20	-1.11	1.29	-0.88	-1.81	-1.39	-0.98	-0.90
	3	-0.21	-0.06	-1.72	-2.60	-1.09		-0.32	0.90	-0.02	0.20	0.21	-0.72	-0.29	0.11	0.20
	4S	-0.53	-0.38	-2.04	-2.92	-1.41	-0.32		-1.22	-0.30	-0.12	0.53	-0.40	0.03	0.43	0.52
	4N	0.69	0.83	-0.83	-1.70	-0.20	0.90	-1.22		-0.92	1.10	-0.68	-1.61	-1.19	-0.79	-0.70
	4P	-0.22	-0.08	-1.74	-2.61	-1.11	-0.02	-0.30	-0.92		0.18	0.23	-0.70	-0.27	0.13	0.22
	15P	-0.41	0.26	1.92	2.80	1.29	0.20	-0.12	1.10	0.18		0.41	-0.52	-0.09	0.31	0.40
	5S	0.01	0.15	-1.51	-2.38	-0.88	0.21	0.53	-0.68	0.23	0.41		0.93	0.51	-0.10	0.01
	5	-0.92	-0.78	-2.44	-3.31	-1.81	-0.72	-0.40	-1.61	-0.70	-0.52	0.93		0.42	0.83	0.91
	5N	-0.50	-0.36	-2.01	-2.89	-1.39	-0.29	0.03	-1.19	-0.27	-0.09	0.51	0.42		0.40	-0.49
	6	-0.09	0.05	-1.61	-2.49	-0.98	0.11	0.43	-0.79	0.13	0.31	-0.10	0.83	0.40		-0.09
	57P	-0.01	0.14	-1.52	-2.40	-0.90	0.20	0.52	-0.70	0.22	0.40	0.01	0.91	-0.49	-0.09	

Appendix A10. Post-hoc pairwise comparison matrix for sites in the middle Tar-Pamlico region using combined dissolved oxygen (milligrams per liter) data from APNEP-CMN and PCS Phosphate. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (blue circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 1 for site information and Table 3 for distances (kilometers) among sites.



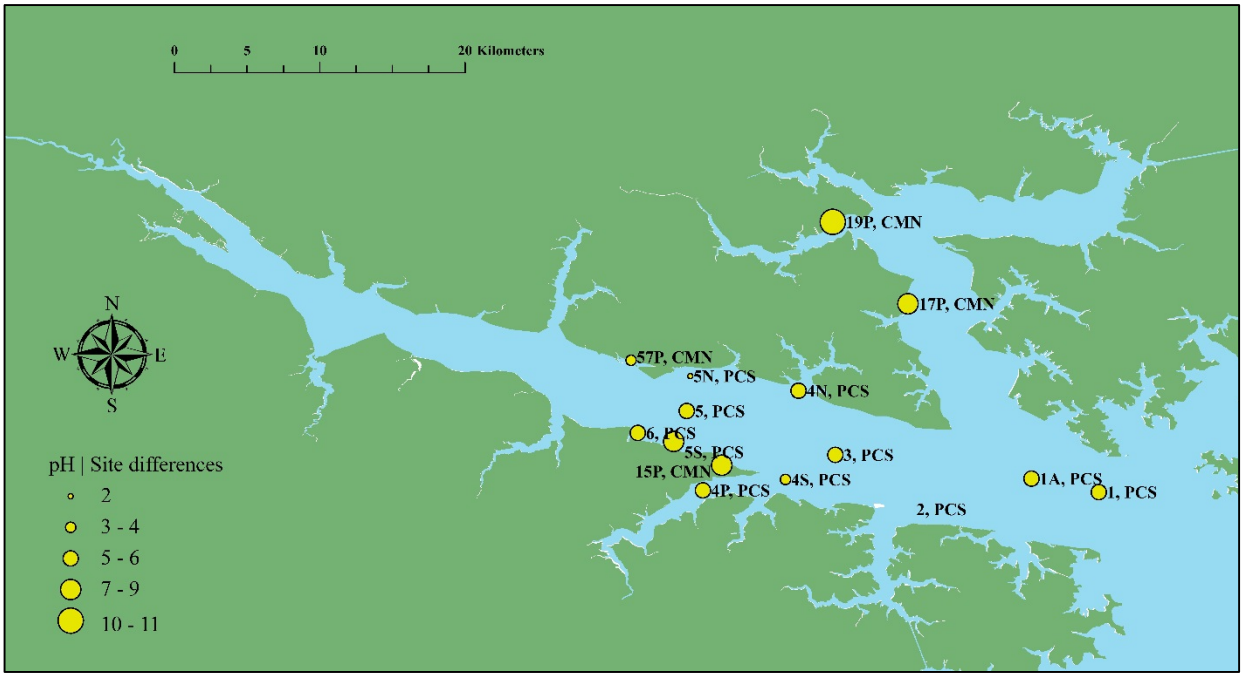
Dissolved oxygen	Site	25N	7S	11P	13P	7N	7	8	20P	9S	65P	07P	9N	03P	10
Middle region	**25N**		-5.10	0.70	3.38	-4.58	-5.10	-5.15	1.65	-4.73	-3.76	5.02	-3.98	4.44	5.11
	7S	-5.10		-4.40	-1.72	-0.52	0.00	-0.05	-3.46	0.37	-1.34	-0.08	1.12	-0.66	0.01
	11P	0.70	-4.40		-2.68	-3.88	-4.40	-4.45	-0.94	-4.03	-3.06	4.32	-3.28	3.74	4.41
	13P	3.38	-1.72	-2.68		-1.21	-1.72	-1.78	1.73	-1.36	-0.38	1.64	-0.61	1.06	1.73
	7N	-4.58	-0.52	-3.88	-1.21		0.51	-0.57	-2.94	-0.15	-0.83	0.43	0.60	-0.14	0.52
	7	-5.10	0.00	-4.40	-1.72	0.51		-0.06	-3.45	0.36	-1.34	-0.08	1.11	-0.66	0.01
	8	-5.15	-0.05	-4.45	-1.78	-0.57	-0.06		-3.51	0.42	-1.40	-0.14	1.17	-0.72	-0.05
	20P	1.65	-3.46	-0.94	1.73	-2.94	-3.45	-3.51		-3.09	-2.11	3.37	-2.34	2.80	3.46
	9S	-4.73	0.37	-4.03	-1.36	-0.15	0.36	0.42	-3.09		-0.97	0.28	-0.75	-0.29	0.37
	65P	-3.76	-1.34	-3.06	-0.38	-0.83	-1.34	-1.40	-2.11	-0.97		1.26	-0.22	0.68	1.35
	07P	5.02	-0.08	4.32	1.64	0.43	-0.08	-0.14	3.37	0.28	1.26		1.03	-0.58	-0.09
	9N	-3.98	1.12	-3.28	-0.61	0.60	1.11	1.17	-2.34	-0.75	-0.22	1.03		0.46	1.13
	03P	4.44	-0.66	3.74	1.06	-0.14	-0.66	-0.72	2.80	-0.29	0.68	-0.58	0.46		-0.67
	10	5.11	0.01	4.41	1.73	0.52	0.01	-0.05	3.46	0.37	1.35	-0.09	1.13	-0.67	

Appendix A11. Post-hoc pairwise comparison matrix for sites in the upper Tar-Pamlico region using combined dissolved oxygen (milligrams per liter) data from APNEP-CMN and PCS Phosphate. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (blue circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 1 for site information and Table 3 for distances (kilometers) among sites.



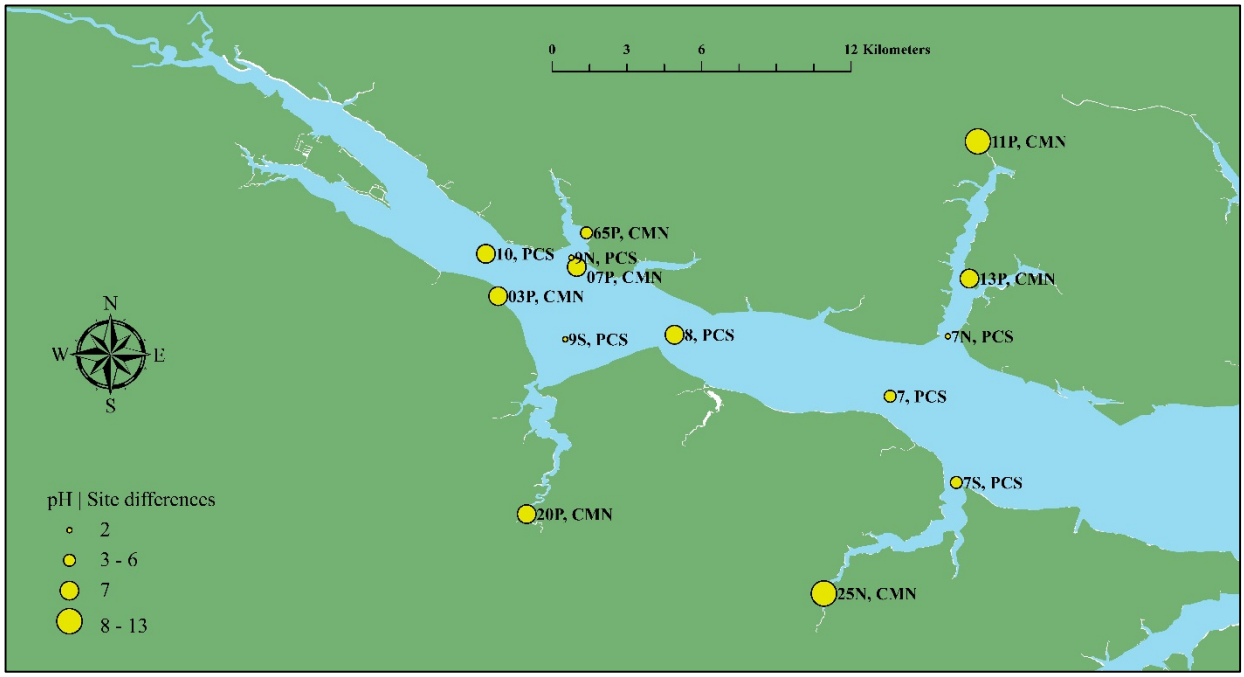
Dissolved oxygen	Site	10P	50P	05P	11	06P	12	01P	09T	07T	06T	05T
Upper region	**10P**		0.47	-1.07	0.09	-1.47	0.14	-1.45	-3.04	-4.23	-2.28	-1.01
	50P	0.47		-0.60	0.39	-1.00	0.33	-0.97	-2.57	-3.75	-1.81	-0.54
	05P	-1.07	-0.60		-0.99	0.40	-0.93	-0.37	1.97	3.16	1.21	-0.06
	11	0.09	0.39	-0.99		-1.39	0.06	-1.36	-2.95	-4.14	-2.20	-0.93
	06P	-1.47	-1.00	0.40	-1.39		-1.33	0.03	1.56	2.75	0.81	0.46
	12	0.14	0.33	-0.93	0.06	-1.33		-1.30	-2.90	-4.09	-2.14	-0.87
	01P	-1.45	-0.97	-0.37	-1.36	0.03	-1.30		1.59	2.78	0.84	-0.43
	09T	-3.04	-2.57	1.97	-2.95	1.56	-2.90	1.59		-1.19	0.76	2.03
	07T	-4.23	-3.75	3.16	-4.14	2.75	-4.09	2.78	-1.19		1.95	3.21
	06T	-2.28	-1.81	1.21	-2.20	0.81	-2.14	0.84	0.76	1.95		1.27
	05T	-1.01	-0.54	-0.06	-0.93	0.46	-0.87	-0.43	2.03	3.21	1.27	

Appendix A12. Post-hoc pairwise comparison matrix for sites in the lower Tar-Pamlico region using combined pH data from APNEP-CMN and PCS Phosphate. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. Black pattern shaded areas denotes missing data. The map plots these sites (yellow circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 1 for site information and Table 3 for distances (kilometers) among sites.



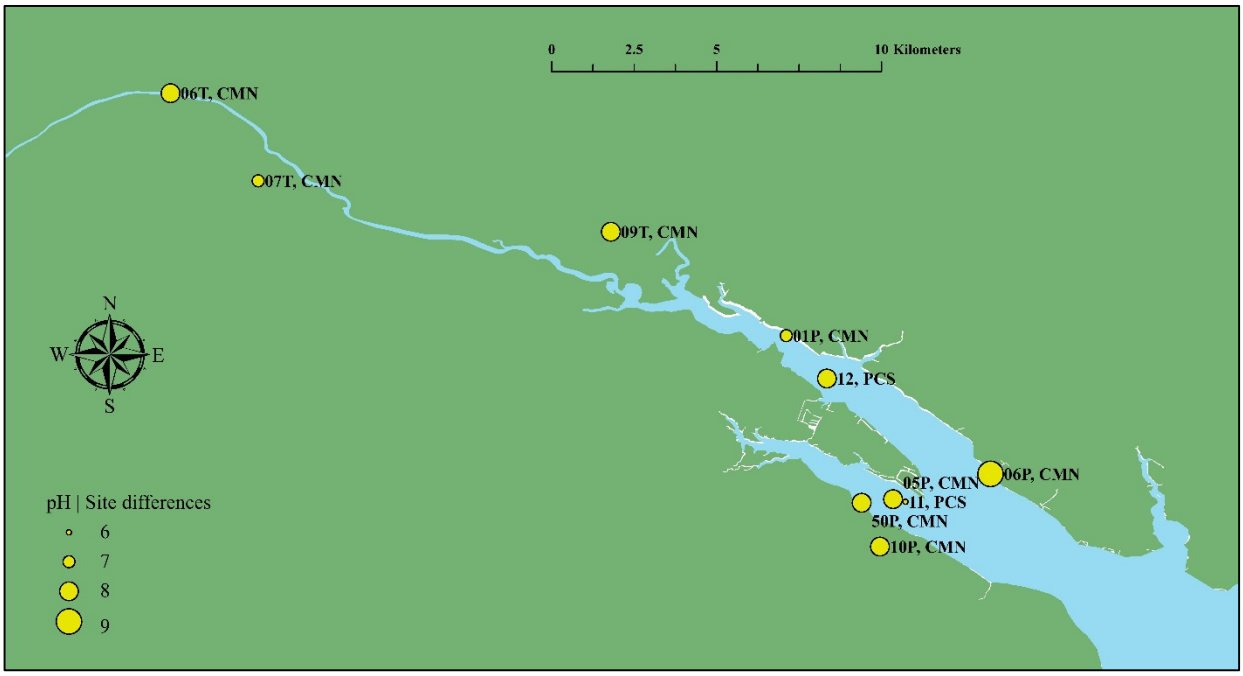
pH	Site	1	1A	17P	19P	2	3	4S	4N	4P	15P	5S	5	5N	6	57P
Lower region	1		0.24	0.59	1.01		0.09	0.00	0.58	0.49	-0.06	0.70	0.05	0.44	0.14	0.18
	1A	0.24		-0.35	-0.77		-0.14	-0.23	0.34	0.25	0.29	0.47	-0.19	0.21	-0.10	-0.05
	17P	0.59	-0.35		0.42		-0.49	-0.58	-0.01	-0.10	0.65	0.12	-0.54	-0.14	-0.45	-0.41
	19P	1.01	-0.77	0.42			-0.92	-1.01	-0.43	-0.52	1.07	-0.31	-0.96	-0.56	-0.87	-0.83
	2															
	3	0.09	-0.14	-0.49	-0.92			-0.09	0.49	0.40	0.15	0.61	-0.04	0.35	0.04	0.09
	4S	0.00	-0.23	-0.58	-1.01		-0.09		-0.58	-0.49	0.06	0.70	0.05	0.44	0.13	0.18
	4N	0.58	0.34	-0.01	-0.43		0.49	-0.58		-0.09	0.64	0.13	-0.53	-0.13	-0.44	-0.40
	4P	0.49	0.25	-0.10	-0.52		0.40	-0.49	-0.09		0.55	0.22	-0.44	-0.04	-0.35	-0.31
	15P	-0.06	0.29	0.65	1.07		0.15	0.06	0.64	0.55		0.76	0.11	0.50	0.20	0.24
	5S	0.70	0.47	0.12	-0.31		0.61	0.70	0.13	0.22	0.76		0.65	0.26	-0.57	0.52
	5	0.05	-0.19	-0.54	-0.96		-0.04	0.05	-0.53	-0.44	0.11	0.65		0.40	0.09	0.13
	5N	0.44	0.21	-0.14	-0.56		0.35	0.44	-0.13	-0.04	0.50	0.26	0.40		-0.31	0.26
	6	0.14	-0.10	-0.45	-0.87		0.04	0.13	-0.44	-0.35	0.20	-0.57	0.09	-0.31		-0.05
	57P	0.18	-0.05	-0.41	-0.83		0.09	0.18	-0.40	-0.31	0.24	0.52	0.13	0.26	-0.05	

Appendix A13. Post-hoc pairwise comparison matrix for sites in the middle Tar-Pamlico region using combined pH data from APNEP-CMN and PCS Phosphate. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (yellow circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 1 for site information and Table 3 for distances (kilometers) among sites.



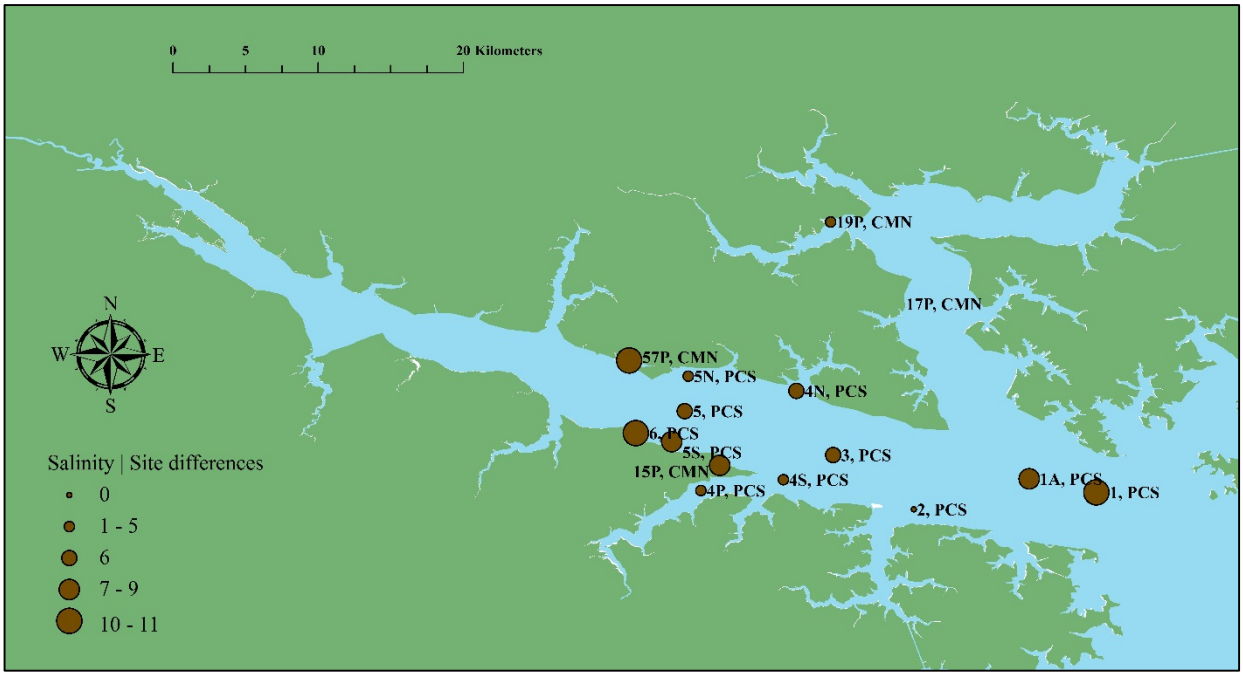
pH	Site	25N	7S	11P	13P	7N	7	8	20P	9S	65P	07P	9N	03P	10
Middle region	**25N**		-2.00	0.39	1.55	-1.80	-1.98	-2.07	1.52	-1.90	-1.98	1.54	-1.70	1.49	1.81
	7S	-2.00		-1.61	-0.45	-0.20	-0.02	-0.07	-0.49	0.10	-0.02	-0.46	0.30	-0.52	-0.20
	11P	0.39	-1.61		-1.16	-1.41	-1.59	-1.68	-1.13	-1.52	-1.59	1.16	-1.31	1.10	1.42
	13P	1.55	-0.45	-1.16		-0.25	-0.43	-0.52	0.03	-0.36	-0.43	-0.01	-0.15	-0.06	0.26
	7N	-1.80	-0.20	-1.41	-0.25		0.18	-0.27	-0.28	-0.11	0.18	-0.25	0.10	-0.31	0.01
	7	-1.98	-0.02	-1.59	-0.43	0.18		-0.09	-0.46	0.07	0.00	-0.43	0.28	-0.49	-0.17
	8	-2.07	-0.07	-1.68	-0.52	-0.27	-0.09		-0.55	0.16	-0.09	-0.53	0.37	-0.58	-0.26
	20P	1.52	-0.49	-1.13	0.03	-0.28	-0.46	-0.55		-0.39	-0.47	0.03	-0.18	-0.03	0.29
	9S	-1.90	0.10	-1.52	-0.36	-0.11	0.07	0.16	-0.39		0.08	-0.36	-0.21	-0.42	-0.10
	65P	-1.98	-0.02	-1.59	-0.43	0.18	0.00	-0.09	-0.47	0.08		-0.44	0.28	-0.50	-0.18
	07P	1.54	-0.46	1.16	-0.01	-0.25	-0.43	-0.53	0.03	-0.36	-0.44		-0.15	-0.06	-0.26
	9N	-1.70	0.30	-1.31	-0.15	0.10	0.28	0.37	-0.18	-0.21	0.28	-0.15		-0.21	0.11
	03P	1.49	-0.52	1.10	-0.06	-0.31	-0.49	-0.58	-0.03	-0.42	-0.50	-0.06	-0.21		-0.32
	10	1.81	-0.20	1.42	0.26	0.01	-0.17	-0.26	0.29	-0.10	-0.18	-0.26	0.11	-0.32	

Appendix A14. Post-hoc pairwise comparison matrix for sites in the upper Tar-Pamlico region using combined pH data from APNEP-CMN and PCS Phosphate. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (yellow circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 1 for site information and Table 3 for distances (kilometers) among sites.



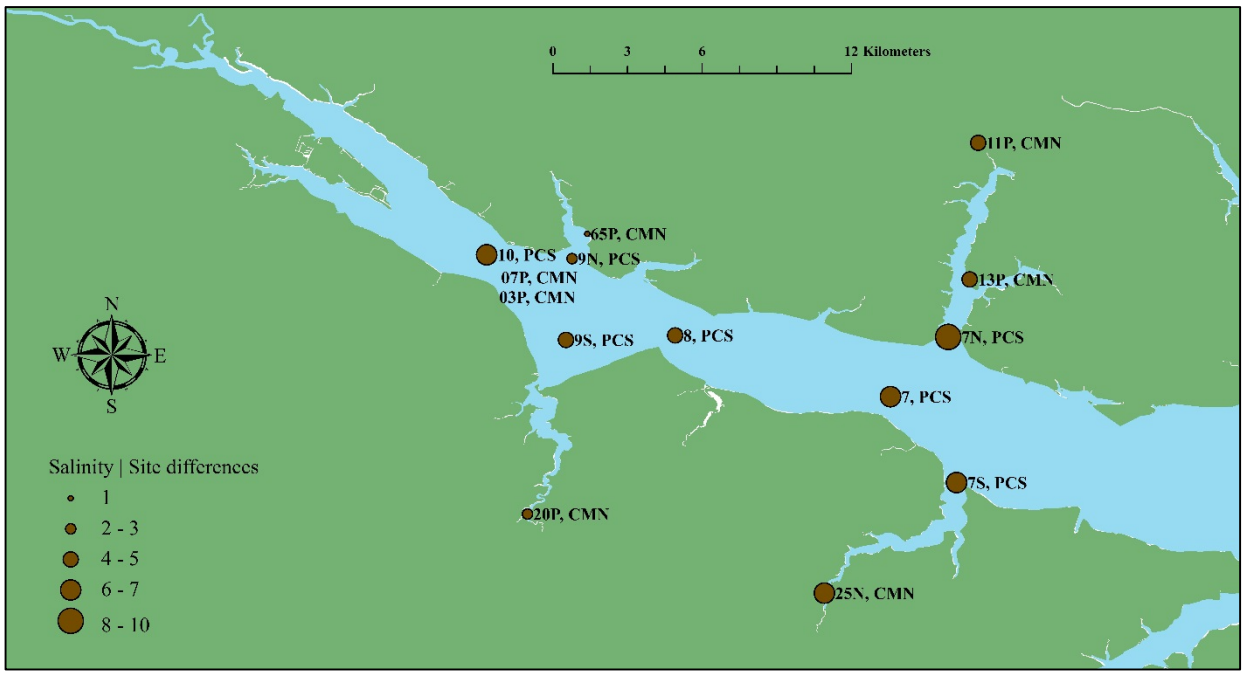
pH	Site	10P	50P	05P	11	06P	12	01P	09T	07T	06T	05T
Upper region	**10P**		-0.30	0.34	-0.06	-0.45	-0.03	-0.78	-1.11	-0.94	-0.62	-1.06
	50P	-0.30		0.04	-0.25	-0.75	-0.27	-1.09	-1.41	-1.24	-0.93	-1.36
	05P	0.34	0.04		0.28	0.79	0.31	-1.13	1.45	1.28	0.96	1.40
	11	-0.06	-0.25	0.28		-0.51	0.03	-0.84	-1.17	-1.00	-0.68	-1.12
	06P	-0.45	-0.75	0.79	-0.51		-0.48	-0.34	0.66	0.49	0.17	-0.61
	12	-0.03	-0.27	0.31	0.03	-0.48		-0.82	-1.15	-0.97	-0.66	-1.09
	01P	-0.78	-1.09	-1.13	-0.84	-0.34	-0.82		0.33	0.16	-0.16	0.28
	09T	-1.11	-1.41	1.45	-1.17	0.66	-1.15	0.33		0.17	0.49	0.05
	07T	-0.94	-1.24	1.28	-1.00	0.49	-0.97	0.16	0.17		0.32	-0.12
	06T	-0.62	-0.93	0.96	-0.68	0.17	-0.66	-0.16	0.49	0.32		-0.44
	05T	-1.06	-1.36	1.40	-1.12	-0.61	-1.09	0.28	0.05	-0.12	-0.44	

Appendix A15. Post-hoc pairwise comparison matrix for sites in the lower Tar-Pamlico region using combined salinity (parts per thousand) data from APNEP-CMN and PCS Phosphate. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. Black pattern shaded areas denotes missing data. The map plots these sites (brown circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 1 for site information and Table 3 for distances (kilometers) among sites.



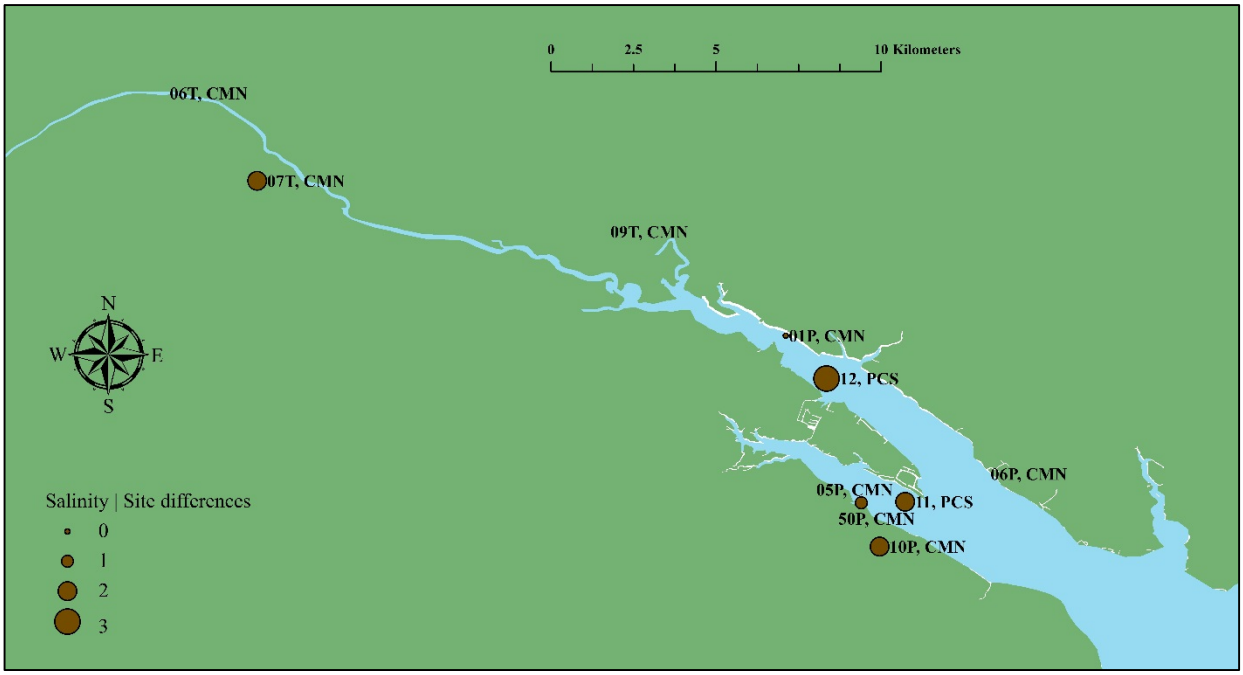
Salinity	Site	1	1A	17P	19P	2	3	4S	4N	4P	15P	5S	5	5N	6	57P
Lower region	1		1.97		2.59	1.27	3.60	3.23	2.96	3.57	0.71	4.85	4.47	4.00	5.74	7.24
	1A	1.97			-0.62	-0.70	1.63	1.26	0.99	1.60	1.26	2.88	2.50	2.03	3.77	5.27
	17P															
	19P	2.59	-0.62			-1.31	1.01	0.65	0.38	0.99	1.88	2.27	1.88	1.41	3.16	4.66
	2	1.27	-0.70		-1.31		2.33	1.96	1.69	2.30	0.56	3.58	3.20	2.73	4.47	5.97
	3	3.60	1.63		1.01	2.33		-0.37	-0.63	-0.02	2.89	1.25	0.87	0.40	2.15	3.64
	4S	3.23	1.26		0.65	1.96	-0.37		0.27	-0.34	2.53	1.62	1.24	0.77	2.51	4.01
	4N	2.96	0.99		0.38	1.69	-0.63	0.27		0.61	2.26	1.89	1.51	1.04	2.78	4.28
	4P	3.57	1.60		0.99	2.30	-0.02	-0.34	0.61		2.87	1.28	0.90	0.43	2.17	3.67
	15P	0.71	1.26		1.88	0.56	2.89	2.53	2.26	2.87		4.14	3.76	3.29	5.04	6.53
	5S	4.85	2.88		2.27	3.58	1.25	1.62	1.89	1.28	4.14		0.38	0.85	0.89	-2.39
	5	4.47	2.50		1.88	3.20	0.87	1.24	1.51	0.90	3.76	0.38		-0.47	1.27	2.77
	5N	4.00	2.03		1.41	2.73	0.40	0.77	1.04	0.43	3.29	0.85	-0.47		1.74	-3.24
	6	5.74	3.77		3.16	4.47	2.15	2.51	2.78	2.17	5.04	0.89	1.27	1.74		-1.50
	57P	7.24	5.27		4.66	5.97	3.64	4.01	4.28	3.67	6.53	-2.39	2.77	-3.24	-1.50	

Appendix A16. Post-hoc pairwise comparison matrix for sites in the middle Tar-Pamlico region using combined salinity (parts per thousand) data from APNEP-CMN and PCS Phosphate. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. Black pattern shaded areas denotes missing data. The map plots these sites (brown circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 1 for site information and Table 3 for distances (kilometers) among sites.



Salinity	Site	25N	7S	11P	13P	7N	7	8	20P	9S	65P	07P	9N	03P	10
Middle region	**25N**		-4.10	1.05	3.62	-5.93	-3.66	-1.64	2.49	-3.18	-4.06		-2.15		0.91
	7S	-4.10		-3.05	-0.47	1.84	-0.43	2.46	-1.60	0.91	-0.03		1.95		-3.19
	11P	1.05	-3.05		-2.58	-4.89	-2.62	-0.60	-1.45	-2.14	-3.02		-1.10		-0.14
	13P	3.62	-0.47	-2.58		-2.31	-0.04	1.98	1.13	0.44	-0.44		1.48		-2.72
	7N	-5.93	1.84	-4.89	-2.31		-2.27	4.29	-3.44	2.75	-1.87		3.79		-5.03
	7	-3.66	-0.43	-2.62	-0.04	-2.27		2.02	-1.17	0.48	0.40		1.52		-2.76
	8	-1.64	2.46	-0.60	1.98	4.29	2.02		0.85	-1.54	2.42		-0.50		-0.73
	20P	2.49	-1.60	-1.45	1.13	-3.44	-1.17	0.85		-0.69	-1.57		0.35		-1.59
	9S	-3.18	0.91	-2.14	0.44	2.75	0.48	-1.54	-0.69		0.88		-1.04		-2.28
	65P	-4.06	-0.03	-3.02	-0.44	-1.87	0.40	2.42	-1.57	0.88			1.92		-3.16
	07P														
	9N	-2.15	1.95	-1.10	1.48	3.79	1.52	-0.50	0.35	-1.04	1.92				-1.24
	03P														
	10	0.91	-3.19	-0.14	-2.72	-5.03	-2.76	-0.73	-1.59	-2.28	-3.16		-1.24		

Appendix A17. Post-hoc pairwise comparison matrix for sites in the upper Tar-Pamlico region using combined salinity (parts per thousand) data from APNEP-CMN and PCS Phosphate. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. Black pattern shaded areas denotes missing data. The map plots these sites (brown circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 1 for site information and Table 3 for distances (kilometers) among sites.

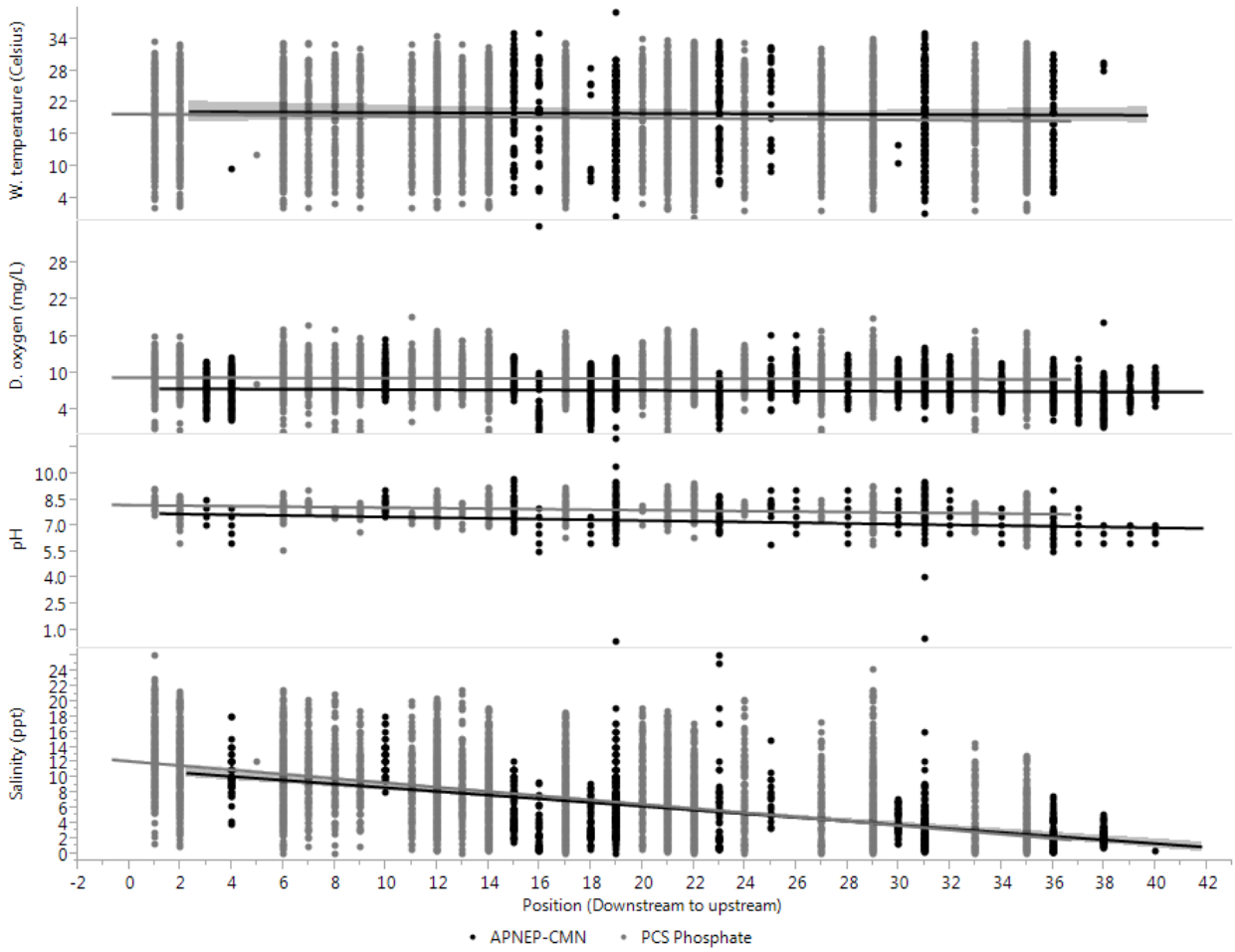


Salinity	Site	10P	50P	05P	11	06P	12	01P	09T	07T	06T	05T
Upper region	10P		0.87		0.48		2.51	-1.63		-2.04		-4.25
	50P	0.87			0.39		-1.65	-0.76		-1.17		-3.38
	05P											
	11	0.48	0.39				2.03	-1.15		-1.56		-3.77
	06P											
	12	2.51	-1.65		2.03			0.89		0.47		-1.74
	01P	-1.63	-0.76		-1.15		0.89			0.41		2.62
	09T											
	07T	-2.04	-1.17		-1.56		0.47	0.41				-2.21
	06T											
	05T	-4.25	-3.38		-3.77		-1.74	2.62		-2.21		

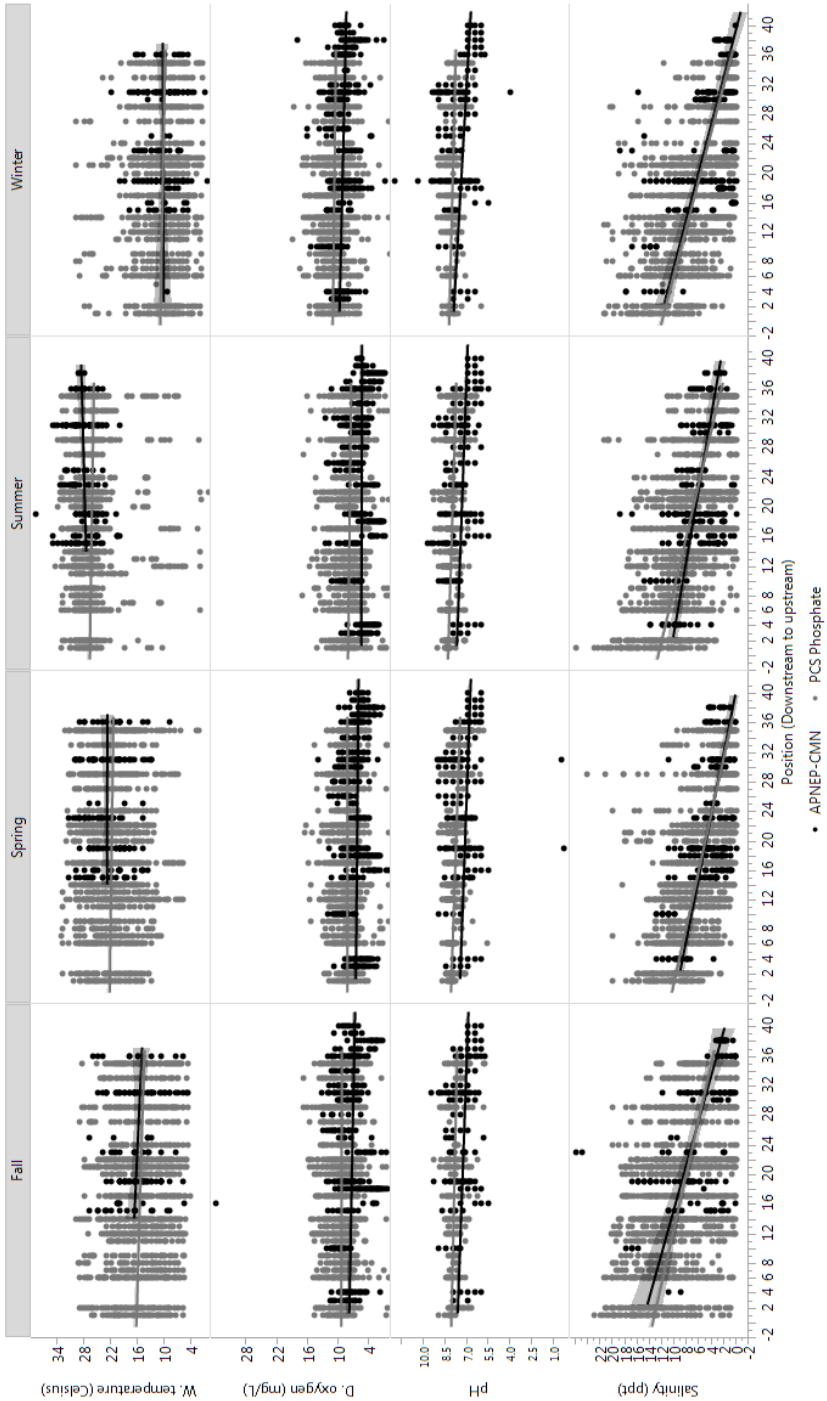
Appendix A18. Slope estimates of water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) for the Tar-Pamlico region by position (downstream to upstream) and separated by project and region. Project = APNEP-CMN, PCS Phosphate. Region = lower, middle, and upper. P-value is based on the slope of the fit line. R^2 = adjusted R-square. See Appendix A1 for sample sizes. Appendices A19 and A20 visualizes these data.

Position	Lower				Middle				Upper			
Project	**Water temperature (°C)**				**Water temperature (°C)**				**Water temperature (°C)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	4.970	1.133	0.132	0.018	9.689	0.502	< 0.01	0.028	13.054	0.199	0.408	-0.003
PCS Phosphate	20.239	-0.071	0.027	0.001	17.430	0.073	0.053	0.001	51.090	-0.942	0.007	0.009
	Dissolved oxygen (mg/L)				**Dissolved oxygen (mg/L)**				**Dissolved oxygen (mg/L)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	6.066	0.254	< 0.01	0.179	0.619	0.298	< 0.01	0.118	17.790	-0.311	< 0.01	0.162
PCS Phosphate	8.911	0.028	0.006	0.002	9.636	-0.017	0.146	0.000	9.506	-0.028	0.807	-0.001
	pH				**pH**				**pH**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	7.095	0.088	< 0.01	0.312	5.201	0.101	< 0.01	0.161	12.331	-0.153	< 0.01	0.391
PCS Phosphate	8.059	-0.001	0.744	-0.002	8.454	-0.018	< 0.01	0.023	7.904	-0.012	0.804	-0.005
	Salinity (ppt)				**Salinity (ppt)**				**Salinity (ppt)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	13.892	-0.429	< 0.01	0.253	1.576	0.208	0.022	0.010	10.062	-0.203	< 0.01	0.067
PCS Phosphate	12.530	-0.329	< 0.01	0.109	12.161	-0.277	< 0.01	0.062	37.539	-1.017	< 0.01	0.073

Appendix A19. Scatterplot with fit line for the Tar-Pamlico region plotted over site position (downstream to upstream). Water quality variables include: water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). Black = APNEP-CMN; Gray = PCS Phosphate. See Table 1 for site information and Table 3 for distances (kilometers) among sites.

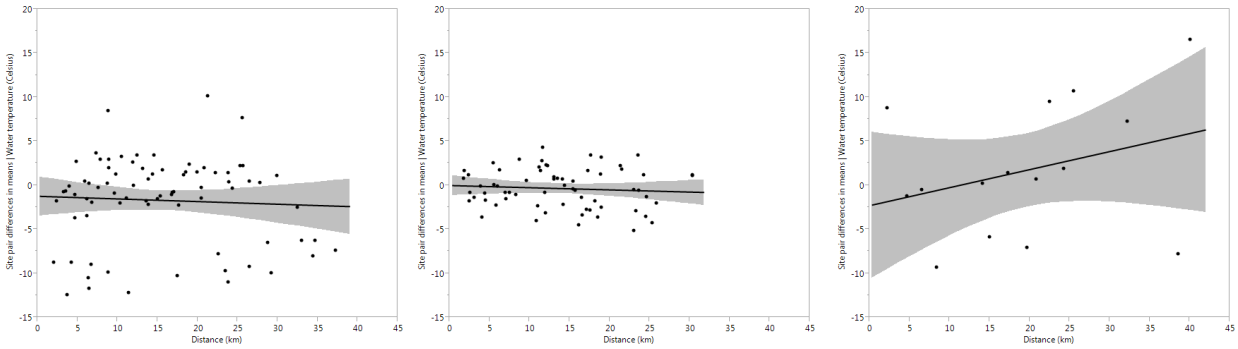


Appendix A20. Scatterplot with fit line for the Tar-Pamlico region separated by project and season plotted over site position (downstream to upstream). Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). Water quality variables include: water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). See Table 1 for site information and Table 3 for distances (kilometers) among sites.

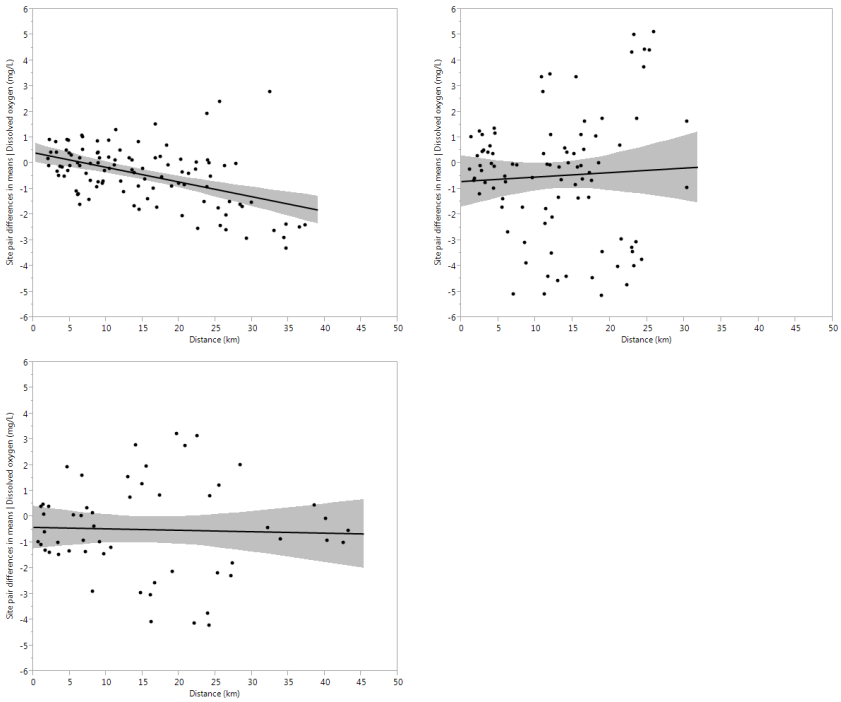


Appendix A21. Scatterplots of mean differences for all site pair combinations over distance (kilometers) and separated by region in the Tar-Pamlico region for (a) water temperature (degrees Celsius), (b) dissolved oxygen (milligrams per liter), (c) pH, and (d) salinity (parts per thousand). Left to right: lower, middle, and upper regions. See Table 3 for distances (kilometers) among sites.

(a) Water temperature

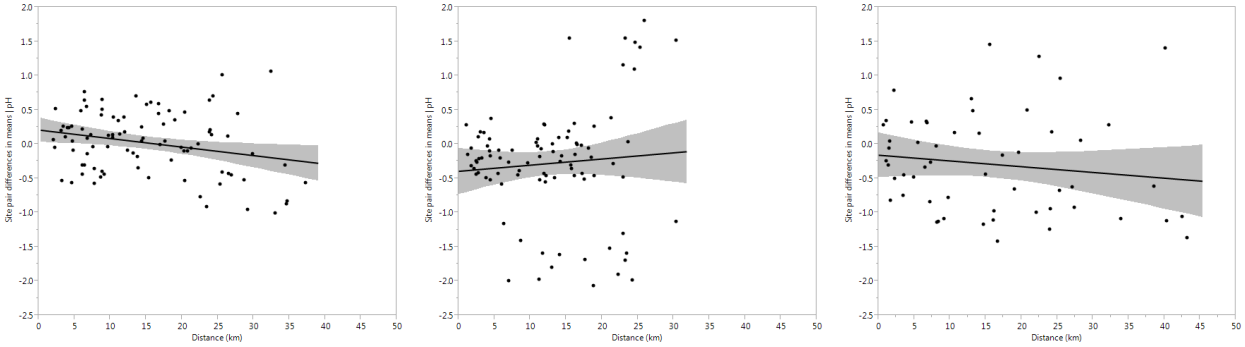


(b) Dissolved oxygen

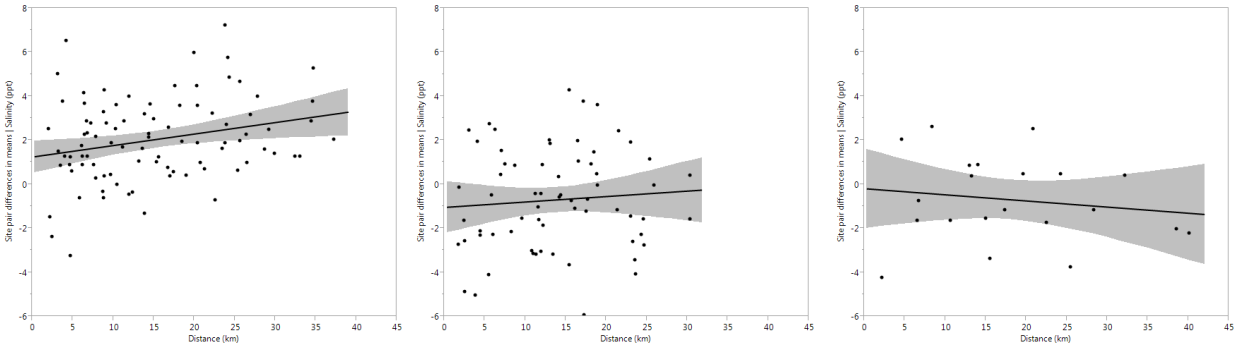


Appendix A21 (continued). Scatterplots of mean differences for all site pair combinations over distance (kilometers) and separated by region in the Tar-Pamlico region for (a) water temperature (degrees Celsius), (b) dissolved oxygen (milligrams per liter), (c) pH, and (d) salinity (parts per thousand). Left to right: lower, middle, and upper regions. See Table 3 for distances (kilometers) among sites.

(c) pH



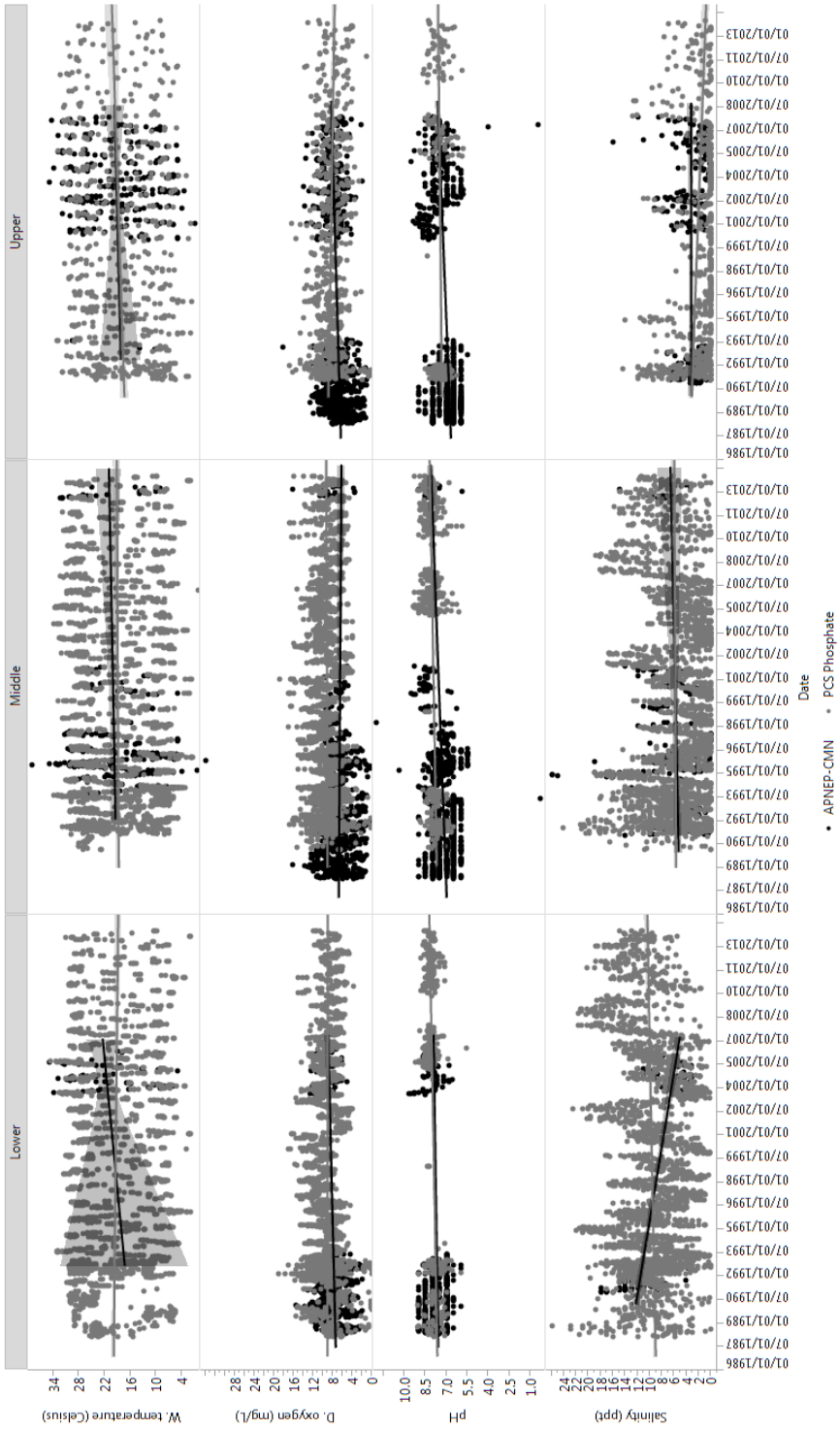
(d) Salinity



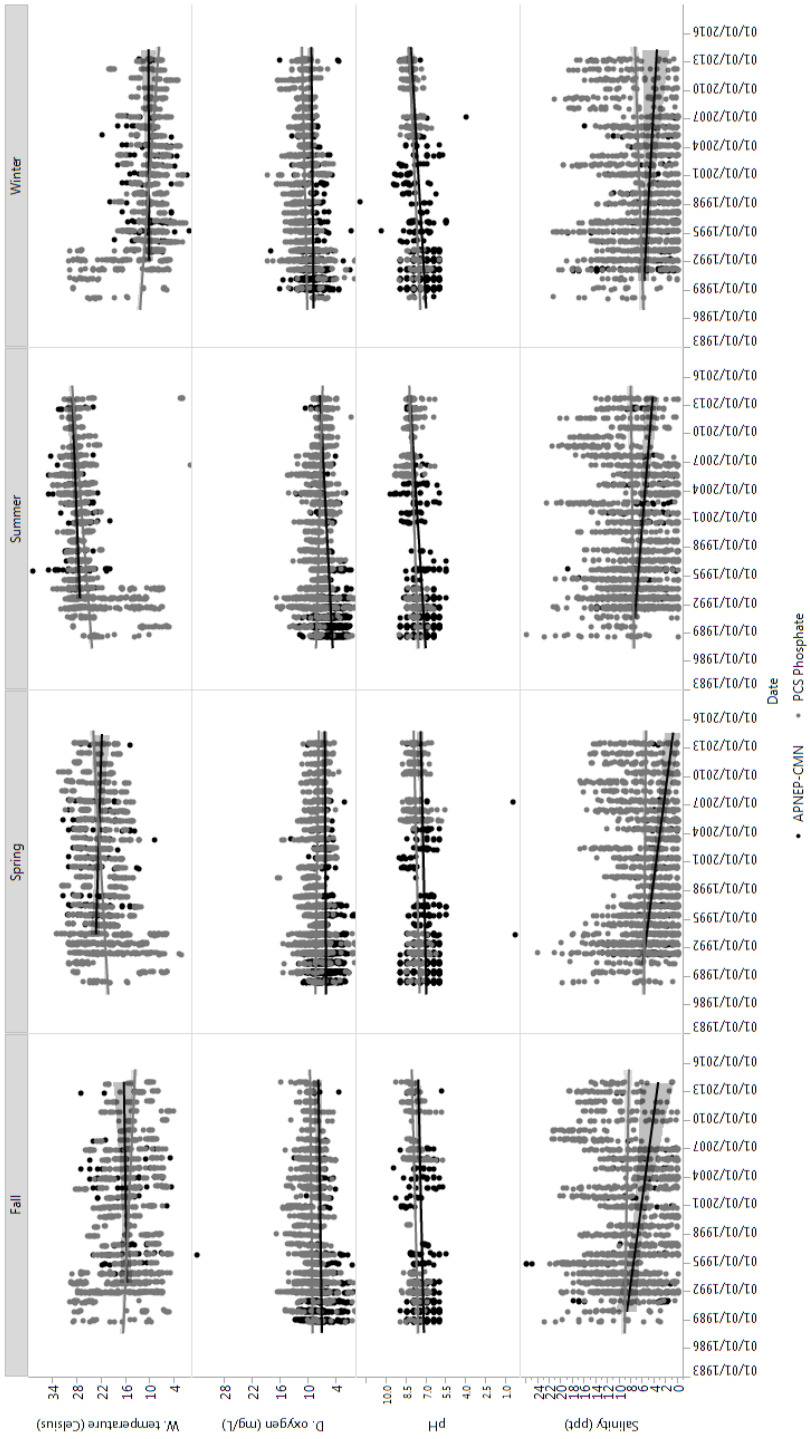
Appendix A22. Slope estimates of water temperature (degrees Celsius), dissolved oxygen (mg/L), pH, and salinity (parts per thousand) by date and separated by project, region, and season for the Tar-Pamlico region. Project = APNEP-CMN, PCS Phosphate. Region = lower, middle, and upper. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). P-value is based on the slope of the fit line. R^2 = adjusted R-square. See Appendix A1 for sample sizes. Appendices A23 and A24 visualizes these data.

Date	Fall				Spring				Summer				Winter			
Project	Water temperature (°C)				Water temperature (°C)				Water temperature (°C)				Water temperature (°C)			
	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2
APNEP-CMN																
Lower	80.153	0.000	0.771	-0.070	113.115	0.000	0.585	-0.040	46.970	0.000	0.819	-0.041	-3.697	0.000	0.648	-0.059
Middle	10.088	0.000	0.527	-0.008	33.223	0.000	0.325	0.000	24.634	0.000	0.562	-0.006	7.011	0.000	0.639	-0.007
Upper	-21.331	0.000	0.351	-0.002	16.839	0.000	0.848	-0.015	9.140	0.000	0.126	0.021	9.913	0.000	0.980	-0.016
PCS Phosphate																
Lower	27.706	0.000	< 0.01	0.018	14.485	0.000	0.001	0.012	11.757	0.000	< 0.01	0.055	32.863	0.000	< 0.01	0.075
Middle	25.439	0.000	0.002	0.014	6.263	0.000	< 0.01	0.043	10.623	0.000	< 0.01	0.044	23.045	0.000	< 0.01	0.029
Upper	15.173	0.000	0.945	-0.006	-2.604	0.000	< 0.01	0.096	-4.315	0.000	< 0.01	0.167	13.042	0.000	0.577	-0.005
	Dissolved oxygen (mg/L)				Dissolved oxygen (mg/L)				Dissolved oxygen (mg/L)				Dissolved oxygen (mg/L)			
	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2
APNEP-CMN																
Lower	5.639	0.000	0.340	-0.001	4.216	0.000	0.291	0.001	-9.235	0.000	< 0.01	0.153	4.984	0.000	0.051	0.021
Middle	9.148	0.000	0.640	-0.004	13.241	0.000	0.009	0.019	0.732	0.000	0.069	0.009	16.291	0.000	0.005	0.029
Upper	0.408	0.000	0.004	0.036	-0.040	0.000	< 0.01	0.047	-5.285	0.000	< 0.01	0.125	1.389	0.000	< 0.01	0.063
PCS Phosphate																
Lower	7.394	0.000	0.067	0.003	9.632	0.000	0.186	0.001	13.433	0.000	< 0.01	0.028	8.489	0.000	0.069	0.004
Middle	6.869	0.000	0.033	0.006	11.633	0.000	0.003	0.011	11.202	0.000	0.006	0.010	3.731	0.000	< 0.01	0.044
Upper	10.839	0.000	0.515	-0.004	15.317	0.000	< 0.01	0.065	16.475	0.000	0.002	0.049	12.288	0.000	0.433	-0.003
	pH				pH				pH				pH			
	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2
APNEP-CMN																
Lower	6.659	0.000	0.259	0.002	8.723	0.000	0.208	0.003	3.362	0.000	< 0.01	0.119	7.258	< 0.01	0.491	-0.004
Middle	5.184	0.000	0.027	0.018	5.120	0.000	0.046	0.010	3.211	0.000	< 0.01	0.093	1.376	< 0.01	< 0.01	0.103
Upper	4.317	0.000	< 0.01	0.070	3.753	0.000	< 0.01	0.064	2.274	0.000	< 0.01	0.188	1.933	< 0.01	< 0.01	0.161
PCS Phosphate																
Lower	6.264	0.000	< 0.01	0.150	5.715	0.000	< 0.01	0.196	6.107	0.000	< 0.01	0.151	5.958	< 0.01	< 0.01	0.170
Middle	6.911	0.000	0.057	0.020	6.873	0.000	0.027	0.023	5.781	0.000	< 0.01	0.105	4.315	< 0.01	< 0.01	0.344
Upper	5.943	0.000	0.062	0.051	7.711	0.000	0.663	-0.013	6.300	0.000	0.161	0.018	5.146	< 0.01	0.003	0.200
	Salinity (ppt)				Salinity (ppt)				Salinity (ppt)				Salinity (ppt)			
	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2
APNEP-CMN																
Lower	67.906	0.000	< 0.01	0.481	46.287	0.000	< 0.01	0.593	49.866	0.000	< 0.01	0.494	47.865	0.000	< 0.01	0.579
Middle	25.918	0.000	0.481	-0.008	16.115	0.000	0.006	0.049	-2.473	0.000	0.084	0.018	-10.192	0.000	0.250	0.003
Upper	-1.864	0.000	0.318	0.000	9.671	0.000	0.058	0.044	7.314	0.000	0.475	-0.008	1.229	0.000	0.705	-0.011
PCS Phosphate																
Lower	12.363	0.000	0.672	-0.001	3.122	0.000	0.005	0.009	5.167	0.000	0.014	0.006	-1.894	0.000	< 0.01	0.027
Middle	6.638	0.000	0.722	-0.001	7.457	0.000	0.142	0.002	3.324	0.000	0.166	0.001	0.168	0.000	0.084	0.004
Upper	14.037	0.000	0.018	0.027	13.911	0.000	< 0.01	0.108	6.483	0.000	0.236	0.002	9.686	0.000	0.005	0.048

Appendix A23. Seasonal scatterplot with fit line of water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) separated by region and project plotted over time for the Tar-Pamlico region. Black = APNEP-CMN; Gray = PCS Phosphate.



Appendix A24. Scatterplot with fit line of water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) separated by season and project plotted over time for the Tar-Pamlico region. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). Black = APNEP-CMN. Gray = PCS Phosphate.



Appendix A25. Output from seasonal Mann-Kendall trend analysis for water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). Analysis separated by project and region for the Tar-Pamlico region. H_o = no trend; H_a = monotonic trend (upward or downward).

Project	Water temperature (°C)	
	P-value	**Trend**
APNEP-CMN	< 0.01	No trend
PCS Phosphate	0.27	Monotonic trend
	Dissolved oxygen (mg/L)	
	P-value	**Trend**
APNEP-CMN	< 0.01	No trend
PCS Phosphate	0.10	Monotonic trend
	pH	
	P-value	**Trend**
APNEP-CMN	< 0.01	No trend
PCS Phosphate	0.06	Monotonic trend
	Salinity (ppt)	
	P-value	**Trend**
APNEP-CMN	< 0.01	No trend
PCS Phosphate	< 0.01	No trend

Appendix B1. Descriptive statistics of available water quality data for the 1989-1992 block of the Albemarle region separated by site. Water quality variables include: water temperature (degrees Celsius), water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

	Upper		
Project	**Water temperature (°C)**		
	N	**Mean**	**Std. Dev.**
01C, APNEP-CMN	0		
04C, APNEP-CMN	0		
05C, APNEP-CMN	0		
06C, APNEP-CMN	0		
	Water depth (m)		
	N	**Mean**	**Std. Dev.**
01C, APNEP-CMN	62	0.93	0.25
04C, APNEP-CMN	137	1.06	0.17
05C, APNEP-CMN	166	1.04	0.19
06C, APNEP-CMN	171	2.56	0.66
	Secchi depth (m)		
	N	**Mean**	**Std. Dev.**
01C, APNEP-CMN	62	0.74	0.23
04C, APNEP-CMN	136	0.89	0.24
05C, APNEP-CMN	160	0.81	0.24
06C, APNEP-CMN	170	1.66	0.73
	Dissolved oxygen (mg/L)		
	N	**Mean**	**Std. Dev.**
01C, APNEP-CMN	57	6.94	1.03
04C, APNEP-CMN	122	7.61	1.79
05C, APNEP-CMN	144	7.75	1.66
06C, APNEP-CMN	146	8.08	1.89
	pH		
	N	**Mean**	**Std. Dev.**
01C, APNEP-CMN	60	6.38	0.43
04C, APNEP-CMN	134	6.66	0.37
05C, APNEP-CMN	163	6.56	0.41
06C, APNEP-CMN	172	6.81	0.48
	Salinity (ppt)		
	N	**Mean**	**Std. Dev.**
01C, APNEP-CMN	0		
04C, APNEP-CMN	32	3.44	1.04
05C, APNEP-CMN	20	2.83	1.07
06C, APNEP-CMN	0		

Appendix B2. Descriptive statistics of (a) water depth (meters), (b) secchi depth (meters), (c) dissolved oxygen (milligrams per liter), (d) pH, and (e) salinity (parts per thousand) for the 1989-1992 block of the upper Albemarle region separated by site. Position = numbered from downstream to upstream. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

(a) Water depth

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	20	Upper	06C	41	2.38	0.68	51	2.63	0.69	46	2.57	0.67	33	2.66	0.54
APNEP-CMN	21	Upper	04C	48	0.94	0.18	30	1.15	0.15	32	1.15	0.11	27	1.08	0.13
APNEP-CMN	22	Upper	01C	26	0.89	0.12	19	0.97	0.37	13	0.98	0.27	4	0.90	0.12
APNEP-CMN	23	Upper	05C	43	0.99	0.28	40	1.08	0.14	41	1.11	0.14	42	1.00	0.14
Sum, Mean				**158**	**1.30**		**140**	**1.46**		**132**	**1.45**		**106**	**1.41**	

(b) Secchi depth

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	20	Upper	06C	41	1.28	0.68	52	1.87	0.77	44	1.62	0.71	33	1.86	0.55
APNEP-CMN	21	Upper	04C	48	0.69	0.17	29	0.99	0.17	32	1.04	0.20	27	0.97	0.21
APNEP-CMN	22	Upper	01C	26	0.68	0.20	19	0.72	0.21	13	0.83	0.28	4	0.90	0.12
APNEP-CMN	23	Upper	05C	43	0.61	0.22	39	0.90	0.21	39	0.90	0.22	39	0.86	0.20
Sum, Mean				**158**	**0.81**		**139**	**1.12**		**128**	**1.10**		**103**	**1.15**	

(c) Dissolved oxygen

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	20	Upper	06C	34	10.14	1.35	40	7.50	0.81	42	6.30	1.08	30	9.02	1.52
APNEP-CMN	21	Upper	04C	40	9.31	0.84	22	7.03	0.97	32	5.48	0.90	28	8.07	1.22
APNEP-CMN	22	Upper	01C	24	7.55	1.06	17	6.71	0.77	12	6.13	0.72	4	6.73	0.51
APNEP-CMN	23	Upper	05C	37	9.38	1.17	33	7.41	0.97	37	5.88	0.78	37	8.31	1.16
Sum, Mean				**135**	**9.10**		**112**	**7.16**		**123**	**5.95**		**99**	**8.03**	

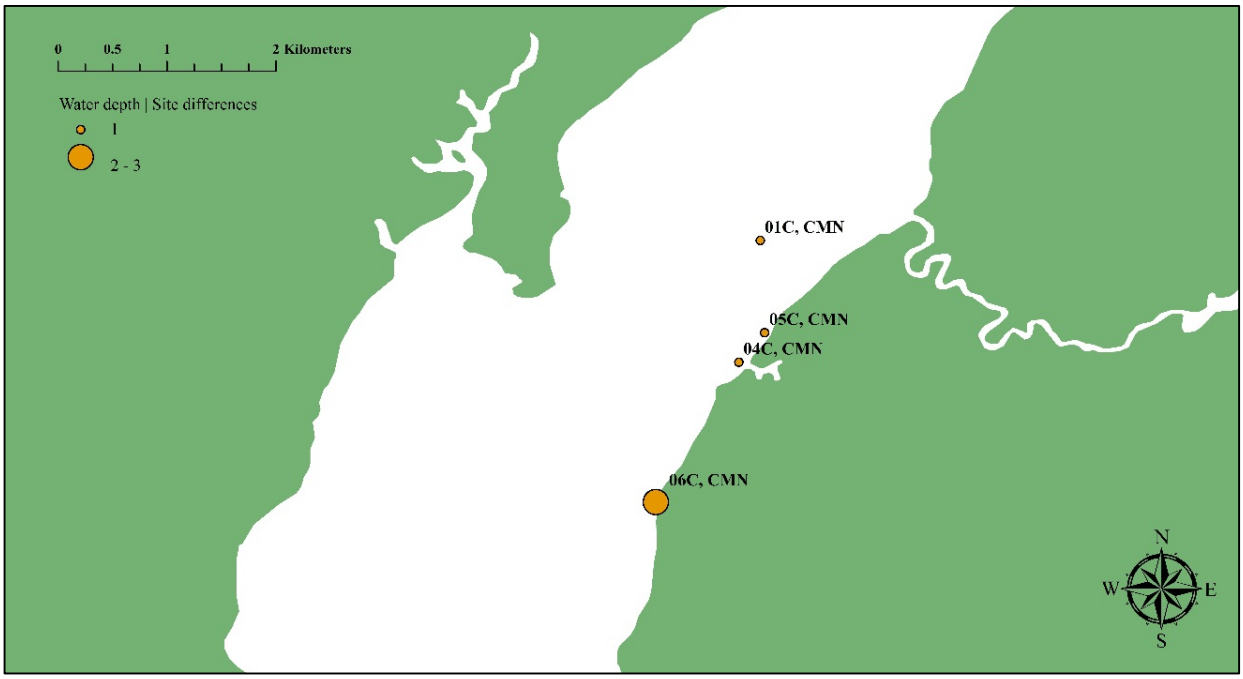
(d) pH

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	20	Upper	06C	41	6.87	0.39	52	6.75	0.44	48	6.80	0.40	31	6.82	0.74
APNEP-CMN	21	Upper	04C	47	6.71	0.39	28	6.61	0.34	31	6.60	0.30	28	6.71	0.42
APNEP-CMN	22	Upper	01C	24	6.50	0.44	19	6.29	0.42	13	6.27	0.44	4	6.38	0.25
APNEP-CMN	23	Upper	05C	42	6.70	0.48	39	6.43	0.44	41	6.45	0.33	41	6.65	0.32
Sum, Mean				**154**	**6.70**		**138**	**6.52**		**133**	**6.53**		**104**	**6.64**	

(e) Salinity

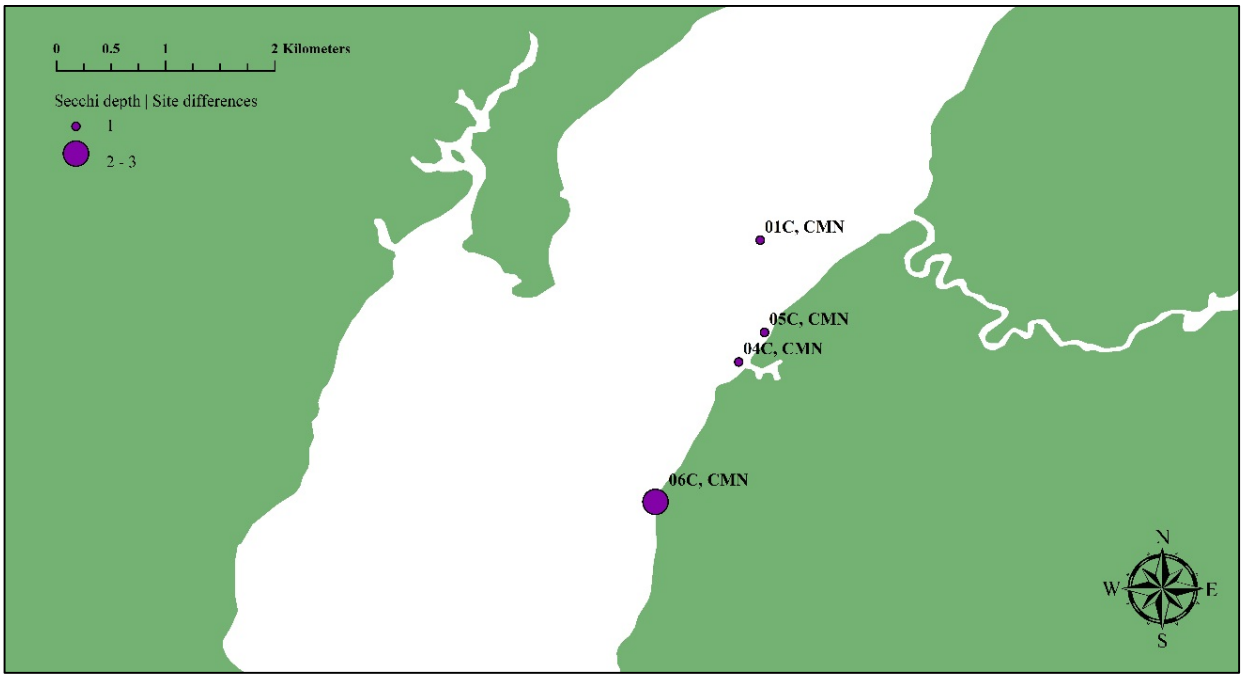
				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	20	Upper	06C	0			0			0			0		
APNEP-CMN	21	Upper	04C	10	2.46	0.70	13	3.57	0.95	9	4.36	0.38	0		
APNEP-CMN	22	Upper	01C	0			0			0			0		
APNEP-CMN	23	Upper	05C	7	1.86	0.54	10	3.18	0.87	3	3.93	0.95	0		
Sum, Mean				**17**	**2.16**		**23**	**3.37**		**12**	**4.14**		**0**		

Appendix B3. Post-hoc pairwise comparison matrix for sites in the 1989-1992 block of the upper Albemarle region using combined water depth (meters) data from APNEP-CMN sites. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (orange circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



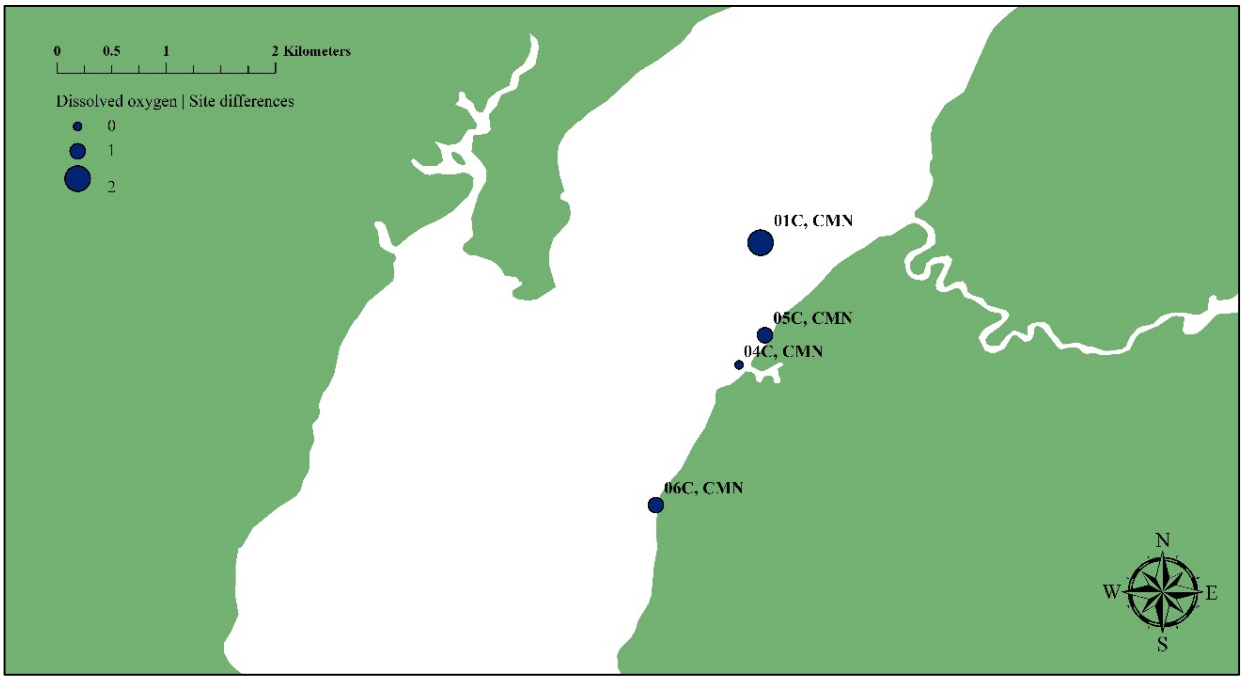
Water depth	Site	06C	04C	01C	05C
Upper region	**06C**		-1.5	-1.63	-1.51
	04C	-1.5		-0.13	0.015
	01C	-1.63	-0.13		-0.11
	05C	-1.51	0.015	-0.11	

Appendix B4. Post-hoc pairwise comparison matrix for sites in the 1989-1992 block of the upper Albemarle region using combined secchi depth (meters) data from APNEP-CMN sites. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (purple circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



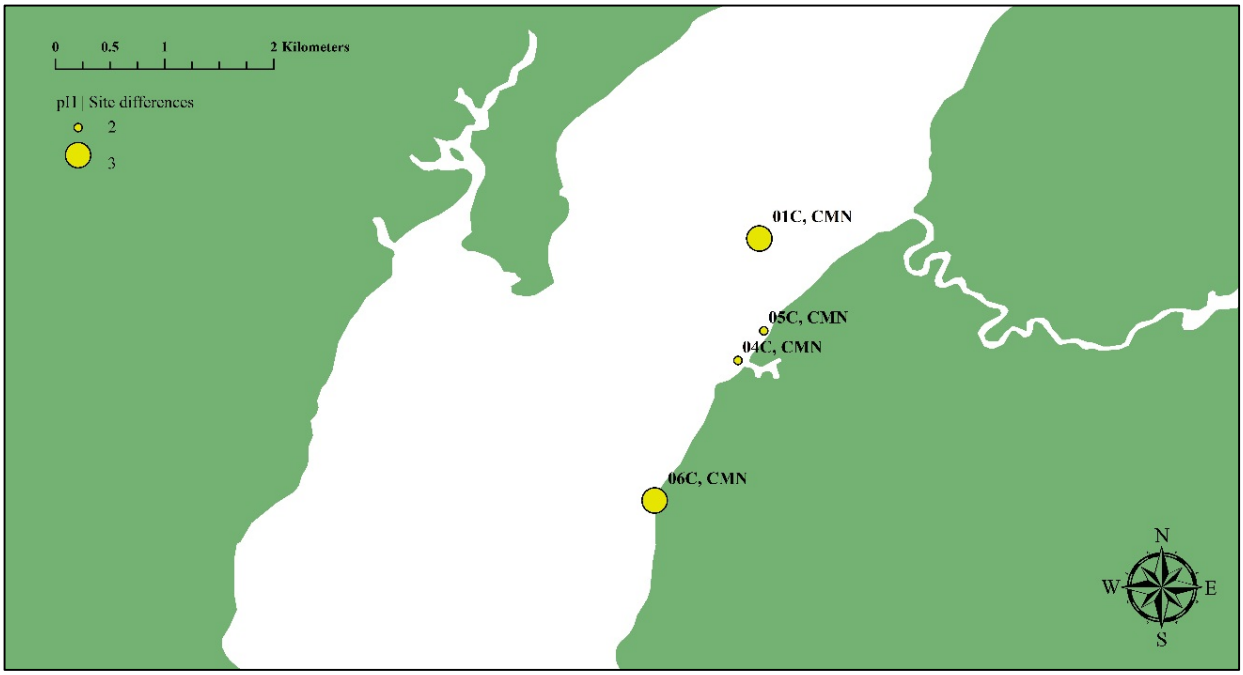
Secchi depth	Site	06C	04C	01C	05C
Upper region	**06C**		-0.77	-0.92	-0.85
	04C	-0.77		-0.15	0.078
	01C	-0.92	-0.15		-0.07
	05C	-0.85	0.078	-0.07	

Appendix B5. Post-hoc pairwise comparison matrix for sites in the 1989-1992 block of the upper Albemarle region using combined dissolved oxygen (milligrams per liter) data from APNEP-CMN sites. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (blue circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



Dissolved oxygen	Site	06C	04C	01C	05C
Upper region	**06C**		-0.47	-1.14	-0.33
	04C	-0.47		-0.66	-0.15
	01C	-1.14	-0.66		-0.81
	05C	-0.33	-0.15	-0.81	

Appendix B6. Post-hoc pairwise comparison matrix for sites in the 1989-1992 block of the upper Albemarle region using combined (a) pH and (b) salinity data from APNEP-CMN sites. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. Black pattern shaded areas denotes missing data. The map plots these sites (yellow circles) for pH, which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. All site comparisons were non-significant at the 0.05 alpha level for salinity. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



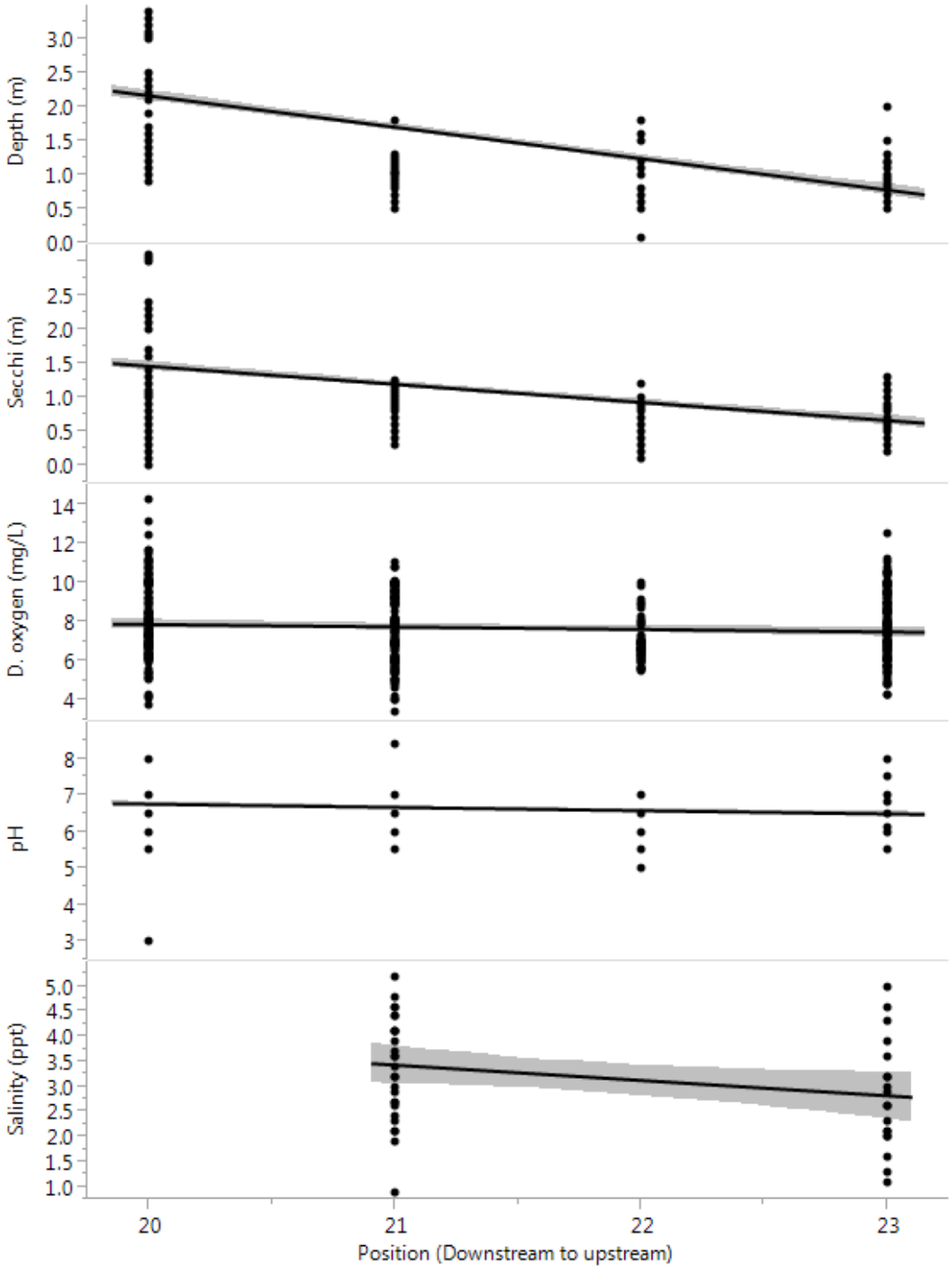
(a)

pH	Site	06C	04C	01C	05C
Upper region	06C		-0.14	-0.43	-0.24
	04C	-0.14		-0.29	0.103
	01C	-0.43	-0.29		-0.19
	05C	-0.24	0.103	-0.19	

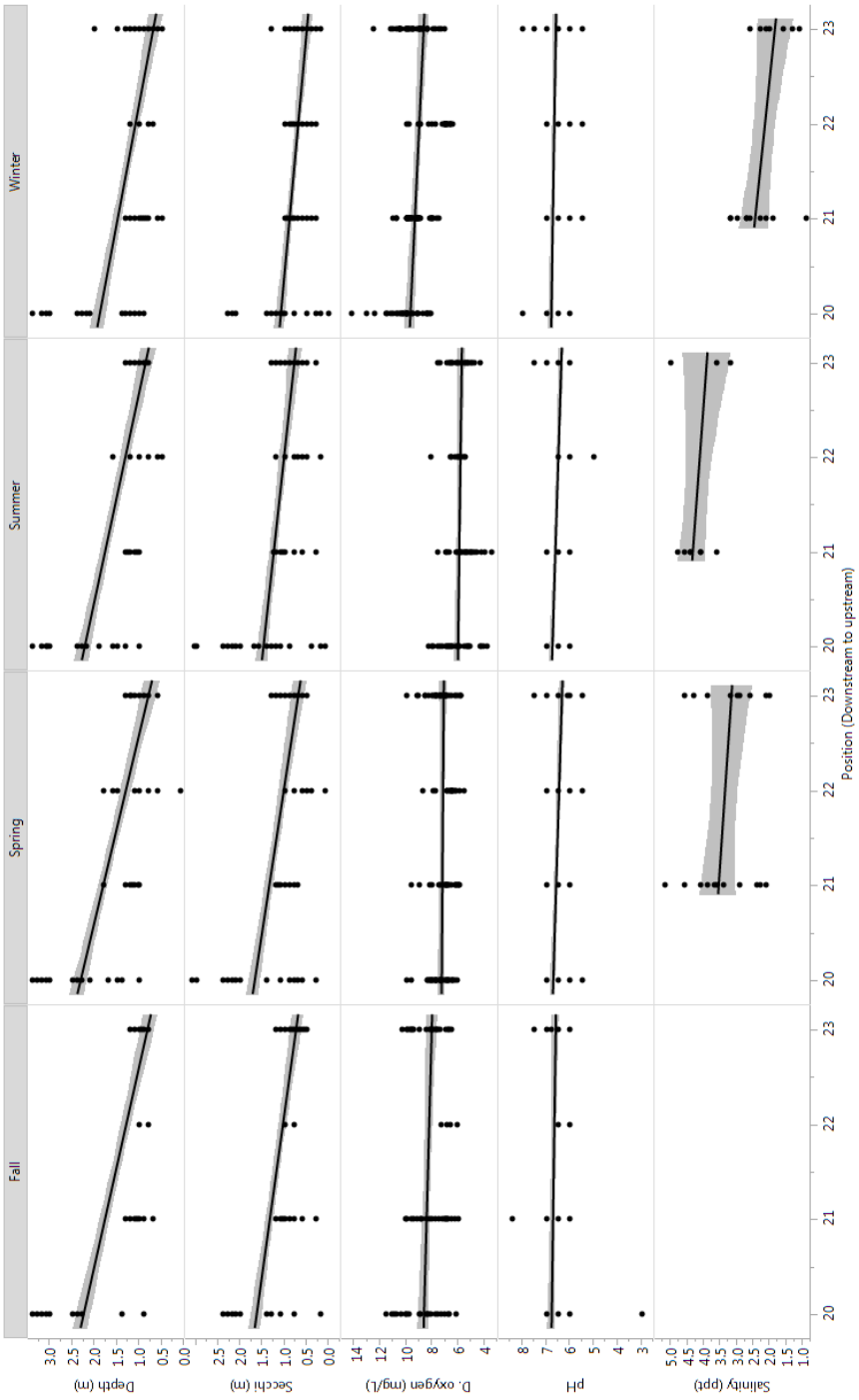
(b)

Salinity	Site	06C	04C	01C	05C
Upper region	06C				
	04C				0.614
	01C				
	05C		0.614		

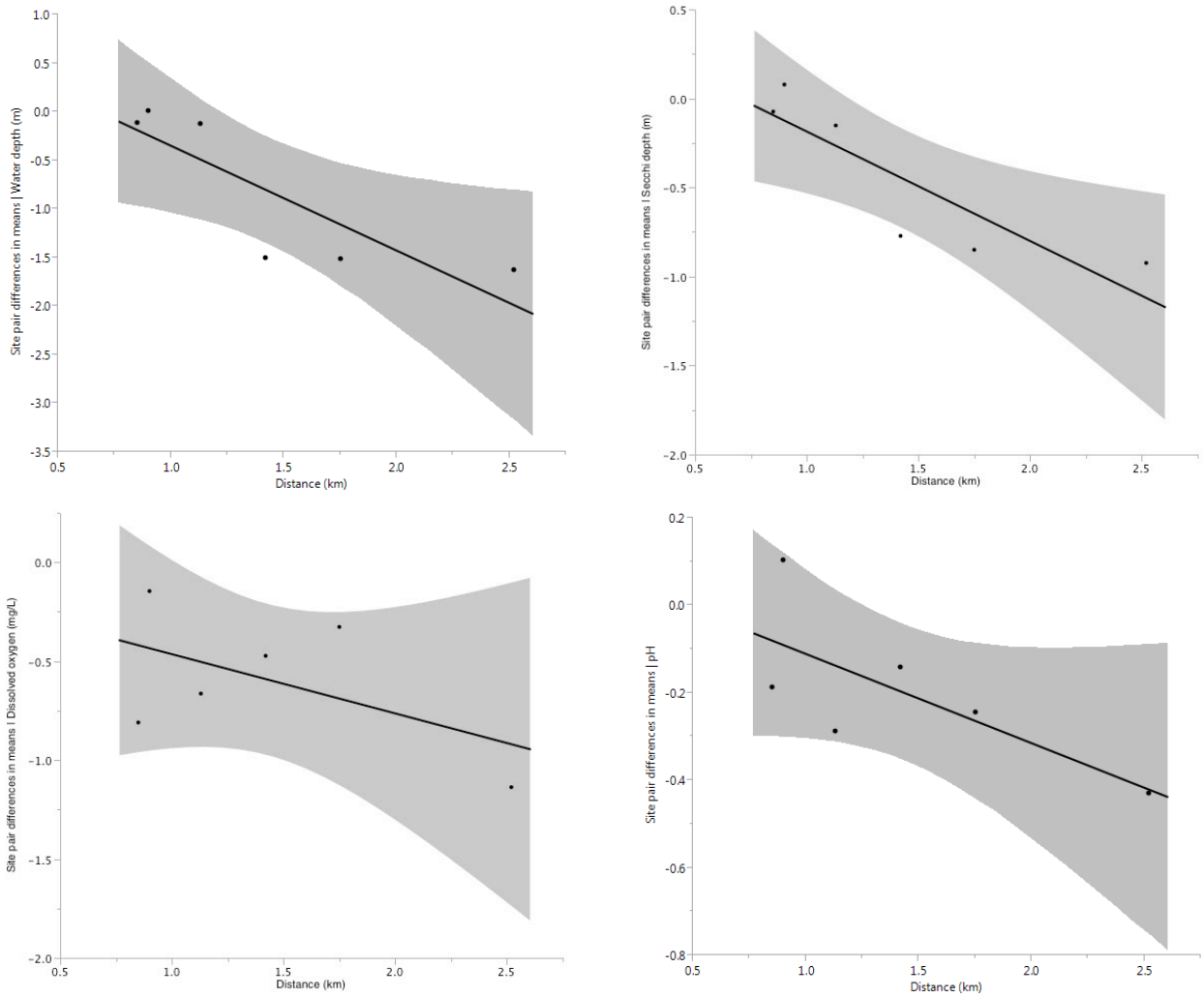
Appendix B7. Scatterplot with fit line for the 1989-1992 block of the upper Albemarle region plotted over site position (downstream to upstream). Water quality variables include: water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). See Table 2 for site information and Table 4 for distances (kilometers) among sites.



Appendix B8. Scatterplot with fit line for the 1989-1992 block of the upper Albemarle region plotted over site position (downstream to upstream) and separated by season. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). Water quality variables include: water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). See Table 2 for site information and Table 4 for distances (kilometers) among sites.



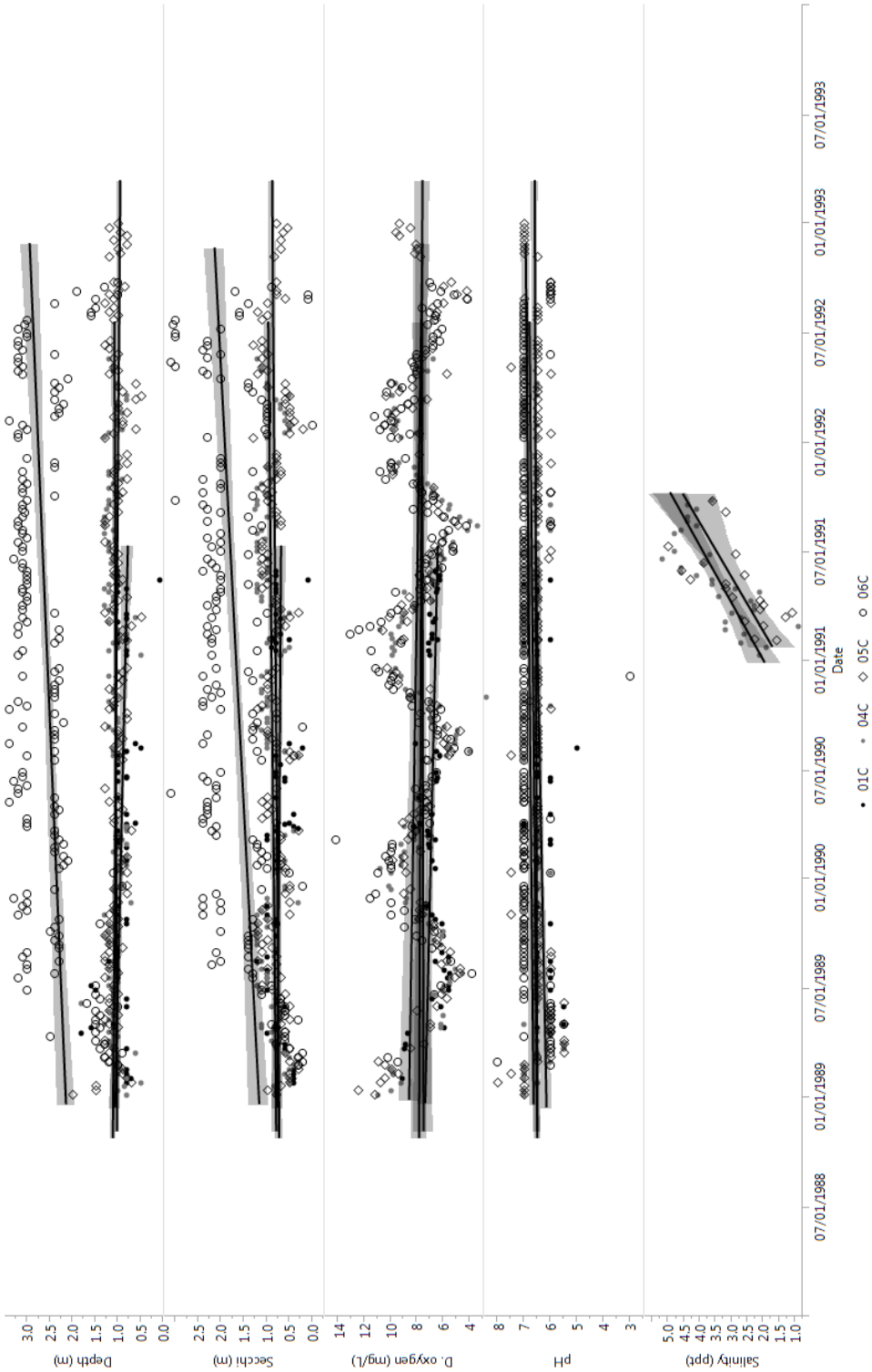
Appendix B9. Scatterplots of mean differences for all site pair combinations over distance (kilometers) in the 1989-1992 block of the upper Albemarle region. Top left to bottom right: water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), and pH. There were not enough salinity data to plot distance. See Table 4 for distances (kilometers) among sites.



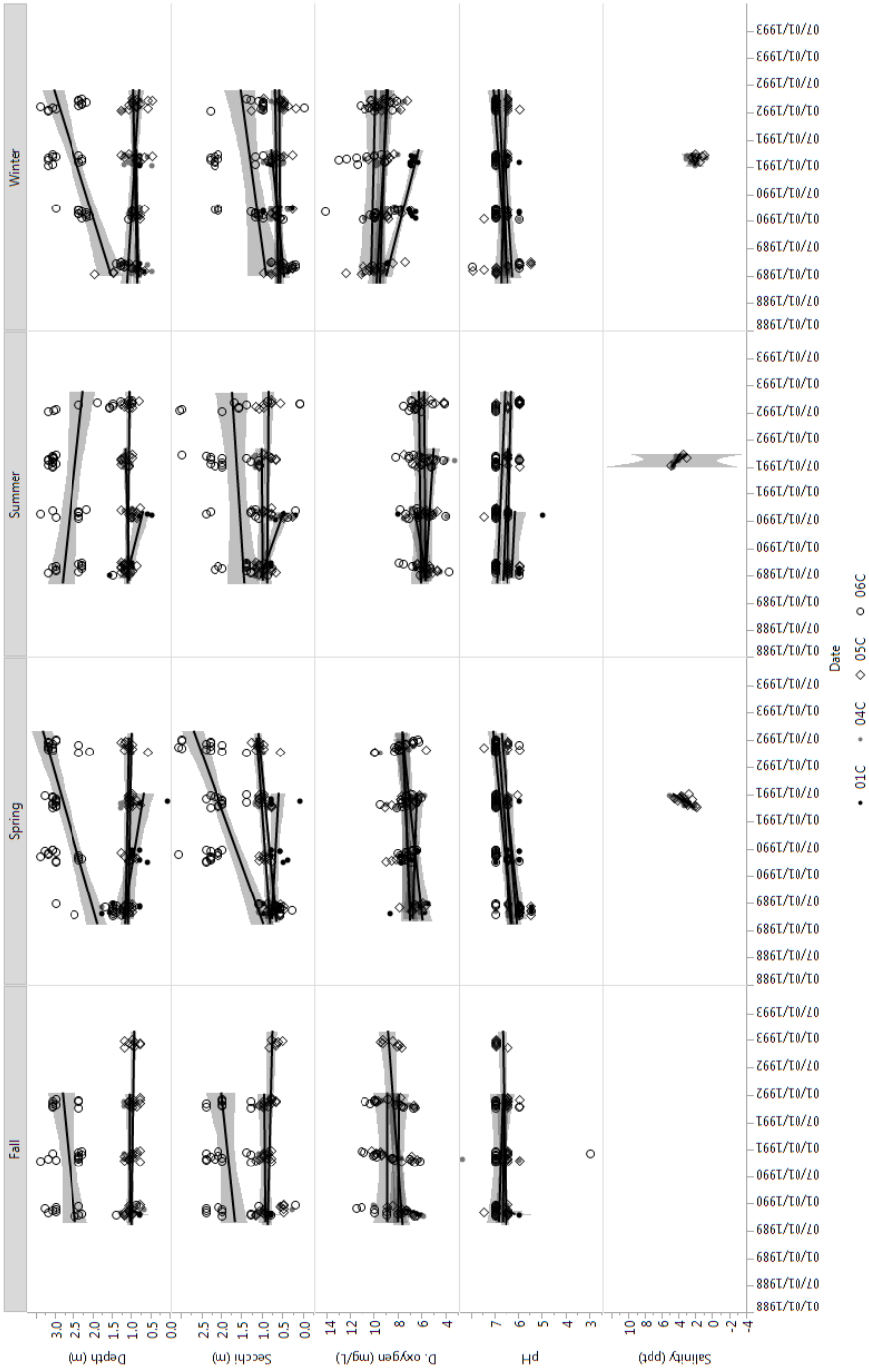
Appendix B10. Slope estimates of water depth (meters), secchi depth (m), dissolved oxygen (mg/L), pH, and salinity (parts per thousand) by date and separated by site and season for the 1989-1992 block of the upper Albemarle region. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). P-value is based on the slope of the fit line. R^2 = adjusted R-square. See Appendix B1 for sample sizes. Appendices B11 and B12 visualizes these data.

Date	Fall				Spring				Summer				Winter			
Project	**Water depth (m)**				**Water depth (m)**				**Water depth (m)**				**Water depth (m)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
01C, APNEP-CMN	-255.004	0.000	0.155	0.571	20.918	0.000	0.027	0.212	31.483	0.000	0.014	0.387	-1.289	0.000	0.433	-0.015
04C, APNEP-CMN	0.560	0.000	0.842	-0.038	3.575	0.000	0.257	0.011	-2.547	0.000	0.070	0.075	-1.700	0.000	0.185	0.017
05C, APNEP-CMN	2.525	0.000	0.362	-0.004	3.354	0.000	0.181	0.021	2.347	0.000	0.476	-0.012	8.562	0.000	0.012	0.122
06C, APNEP-CMN	-9.538	0.000	0.244	0.013	-32.479	0.000	< 0.01	0.432	15.666	0.000	0.083	0.045	-35.854	0.000	< 0.01	0.445
	Secchi depth (m)				**Secchi depth (m)**				**Secchi depth (m)**				**Secchi depth (m)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
01C, APNEP-CMN	-255.004	0.000	0.155	0.571	6.947	0.000	0.253	0.022	41.510	0.000	0.001	0.649	-11.158	0.000	0.006	0.244
04C, APNEP-CMN	-0.376	0.000	0.757	-0.036	-7.258	0.000	< 0.01	0.419	-0.152	0.000	0.765	-0.030	-1.124	0.000	0.343	-0.002
05C, APNEP-CMN	3.198	0.000	0.378	-0.005	-10.011	0.000	< 0.01	0.465	1.863	0.000	0.726	-0.024	-0.116	0.000	0.761	-0.022
06C, APNEP-CMN	-10.361	0.000	0.252	0.011	-40.285	0.000	< 0.01	0.506	-5.966	0.000	0.373	-0.004	-14.714	0.000	0.072	0.057
	Dissolved oxygen (mg/L)				**Dissolved oxygen (mg/L)**				**Dissolved oxygen (mg/L)**				**Dissolved oxygen (mg/L)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
01C, APNEP-CMN	-1285.591	0.000	0.026	0.924	20.107	0.000	0.529	-0.038	-64.818	0.000	0.058	0.246	108.027	0.000	< 0.01	0.652
04C, APNEP-CMN	11.056	0.000	0.906	-0.038	-35.992	0.000	0.014	0.231	30.073	0.000	0.154	0.035	22.625	0.000	0.249	0.009
05C, APNEP-CMN	-21.266	0.000	0.043	0.086	-7.124	0.000	0.311	0.002	2.487	0.000	0.737	-0.025	32.174	0.000	0.095	0.051
06C, APNEP-CMN	8.913	0.000	0.997	-0.036	-9.842	0.000	0.180	0.022	2.127	0.000	0.774	-0.023	19.159	0.000	0.674	-0.025
	pH				**pH**				**pH**				**pH**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
01C, APNEP-CMN	-441.457	0.000	0.317	0.200	-14.951	0.000	0.040	0.180	16.037	0.000	0.677	-0.073	-5.974	0.000	0.253	0.016
04C, APNEP-CMN	8.505	0.000	0.838	-0.037	-8.873	0.000	0.001	0.339	14.477	0.000	0.172	0.031	-3.081	0.000	0.025	0.088
05C, APNEP-CMN	3.215	0.000	0.384	-0.006	-10.096	0.000	0.001	0.240	10.845	0.000	0.267	0.007	11.635	0.000	0.354	-0.003
06C, APNEP-CMN	13.327	0.000	0.665	-0.028	-12.287	0.000	< 0.01	0.309	15.188	0.000	0.060	0.055	-7.718	0.000	0.003	0.183
	Salinity (ppt)				**Salinity (ppt)**				**Salinity (ppt)**				**Salinity (ppt)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
01C, APNEP-CMN	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
04C, APNEP-CMN	N/A	N/A	N/A	N/A	-892.146	0.000	0.001	0.616	365.348	0.000	0.013	0.556	-213.920	0.000	0.494	-0.057
05C, APNEP-CMN	N/A	N/A	N/A	N/A	-548.118	0.000	0.103	0.209	688.683	0.000	0.299	0.590	210.684	0.000	0.599	-0.129
06C, APNEP-CMN	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Appendix B11. Seasonal scatterplot with fit line of water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) plotted over time for the 1989-1992 block of the upper Albemarle region.



Appendix B12. Scatterplot with fit line of water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) separated by season and plotted over time for the 1989-1992 block of the upper Albemarle region. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March).



Appendix B13. Output from seasonal Mann-Kendall trend analysis for water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). Analysis separated by site for the 1989-1992 block of the upper Albemarle region. H_o = no trend; H_a = monotonic trend (upward or downward).

Project	Water depth (m)	
	P-value	**Trend**
01C, APNEP-CMN	0.12	No trend
04C, APNEP-CMN	0.16	No trend
05C, APNEP-CMN	0.01	Monotonic trend
06C, APNEP-CMN	< 0.01	Monotonic trend
	Secchi depth (m)	
	P-value	**Trend**
01C, APNEP-CMN	0.41	No trend
04C, APNEP-CMN	0.01	Monotonic trend
05C, APNEP-CMN	0.02	Monotonic trend
06C, APNEP-CMN	< 0.01	Monotonic trend
	Dissolved oxygen (mg/L)	
	P-value	**Trend**
01C, APNEP-CMN	0.59	No trend
04C, APNEP-CMN	0.78	No trend
05C, APNEP-CMN	0.96	No trend
06C, APNEP-CMN	0.08	No trend
	pH	
	P-value	**Trend**
01C, APNEP-CMN	0.04	Monotonic trend
04C, APNEP-CMN	0.03	Monotonic trend
05C, APNEP-CMN	0.42	No trend
06C, APNEP-CMN	< 0.01	Monotonic trend
	Salinity (ppt)	
	P-value	**Trend**
01C, APNEP-CMN	N/A	N/A
04C, APNEP-CMN	< 0.01	Monotonic trend
05C, APNEP-CMN	< 0.01	Monotonic trend
06C, APNEP-CMN	N/A	N/A

Appendix C1. Descriptive statistics of available water quality data for the 1991-1993 block of the lower and middle Albemarle regions. Water quality variables include: water temperature (degrees Celsius), water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). N = number of monitoring sessions. Std. Dev. = standard deviation.

	Lower			Middle		
Project	**Water temperature (°C)**			**Water temperature (°C)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	391	18.6	7.9	95	16.7	7.4
USGS	758	18.6	7.5	0		
	Water depth (m)			**Water depth (m)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	393	2.0	1.5	94	1.0	2.0
USGS	0			0		
	Secchi depth (m)			**Secchi depth (m)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	345	0.7	0.4	21	0.6	0.2
USGS	0			0		
	Dissolved oxygen (mg/L)			**Dissolved oxygen (mg/L)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	373	6.4	3.0	94	9.9	1.8
USGS	438	9.9	1.8	0		
	pH			**pH**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	389	7.2	1.0	93	7.8	0.4
USGS	0			0		
	Salinity (ppt)			**Salinity (ppt)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	198	2.9	2.6	51	1.2	2.0
USGS	725	3.0	1.5	0		

Appendix C2. Descriptive statistics of (a) water temperature (degrees Celsius), (b) dissolved oxygen (milligrams per liter), (c) pH, and (d) salinity (parts per thousand) for the 1991-1993 block of the lower and middle Albemarle regions separated by site. Position = numbered from downstream to upstream. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

(a) Water temperature

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	1	Lower	18A	35	10.43	3.36	38	20.42	5.51	37	27.23	3.19	30	13.80	5.17
APNEP-CMN	2	Lower	11CS	8	9.06	2.27	9	23.56	5.08	5	27.40	2.46	0		
USGS	5	Lower	USGS	173	8.83	2.14	235	21.14	4.27	209	26.73	1.85	141	14.32	4.36
APNEP-CMN	8	Lower	02A	40	10.25	3.39	36	21.89	4.29	39	27.35	2.60	32	13.80	4.76
APNEP-CMN	9	Lower	01A	17	9.97	3.02	19	23.55	4.10	24	28.06	2.91	22	14.07	4.37
APNEP-CMN	10	Middle	05A	23	8.61	2.55	24	19.94	4.86	26	24.54	2.46	22	12.18	5.08
Sum, Mean				**296**	**9.52**		**361**	**21.75**		**340**	**26.88**		**247**	**13.63**	

(b) Dissolved oxygen

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	1	Lower	18A	34	10.90	0.76	38	9.0	1.2	36	7.76	1.04	29	9.76	1.34
APNEP-CMN	2	Lower	11CS	8	9.41	0.52	8	7.01	0.69	5	6.02	0.76	0		
USGS	5	Lower	USGS	134	11.50	0.58	127	9.41	0.97	105	7.78	0.67	72	11.06	1.73
APNEP-CMN	8	Lower	02A	34	6.40	1.66	38	3.32	1.59	38	2.74	1.08	28	2.74	1.69
APNEP-CMN	9	Lower	01A	13	7.10	1.68	18	5.46	1.89	24	4.52	1.33	22	6.52	1.62
APNEP-CMN	10	Middle	05A	23	11.88	0.76	23	8.99	1.34	26	8.13	0.90	22	10.82	1.20
Sum, Mean				**246**	**9.53**		**252**	**7.20**		**234**	**6.16**		**173**	**8.18**	

(c) pH

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	1	Lower	18A	35	7.56	0.42	38	8.36	0.63	38	8.64	0.56	30	7.90	0.20
APNEP-CMN	2	Lower	11CS	9	7.06	0.17	9	7.22	0.36	5	7.50	0.61	0		
USGS	5	Lower	USGS	0			0			0			0		
APNEP-CMN	8	Lower	02A	9	7.06	0.17	9	7.22	0.36	5	7.50	0.61	0		
APNEP-CMN	9	Lower	01A	35	7.56	0.42	38	8.36	0.63	38	8.64	0.56	30	7.90	0.20
APNEP-CMN	10	Middle	05A	22	8.02	0.36	24	7.69	0.36	26	7.86	0.33	21	7.81	0.29
Sum, Mean				**110**	**7.45**		**118**	**7.77**		**112**	**8.03**		**81**	**7.87**	

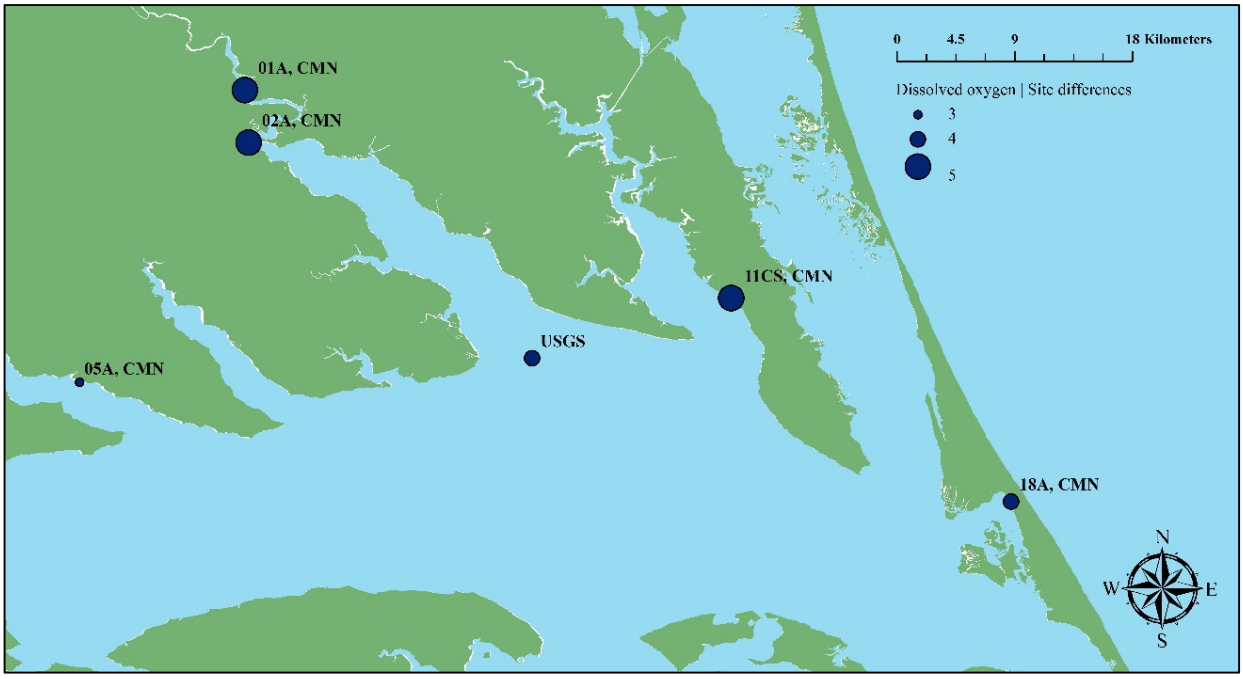
(d) Salinity

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	1	Lower	18A	22	3.83	1.02	25	4.09	1.00	22	6.00	1.25	10	7.45	1.59
APNEP-CMN	2	Lower	11CS	8	3.31	0.68	3	3.10	1.56	0			0		
USGS	5	Lower	USGS	204	3.62	1.55	180	2.49	1.19	184	2.07	0.65	157	4.02	1.46
APNEP-CMN	8	Lower	02A	14	0.00	0.00	12	0.00	0.00	14	0.00	0.00	9	0.00	0.00
APNEP-CMN	9	Lower	01A	10	3.46	1.30	14	3.01	2.16	24	2.52	2.64	11	0.00	0.00
APNEP-CMN	10	Middle	05A	11	0.00	0.00	14	0.81	2.11	21	2.30	2.12	5	0.00	0.00
Sum, Mean				**269**	**2.37**		**248**	**2.25**		**265**	**2.58**		**192**	**2.29**	

Appendix C3. Post-hoc pairwise comparison matrix for sites in the 1991-1993 block of the lower and middle Albemarle regions using combined water temperature (degrees Celsius) data from APNEP-CMN and USGS sites. Values represent mean differences among sites. All site comparisons were non-significant at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

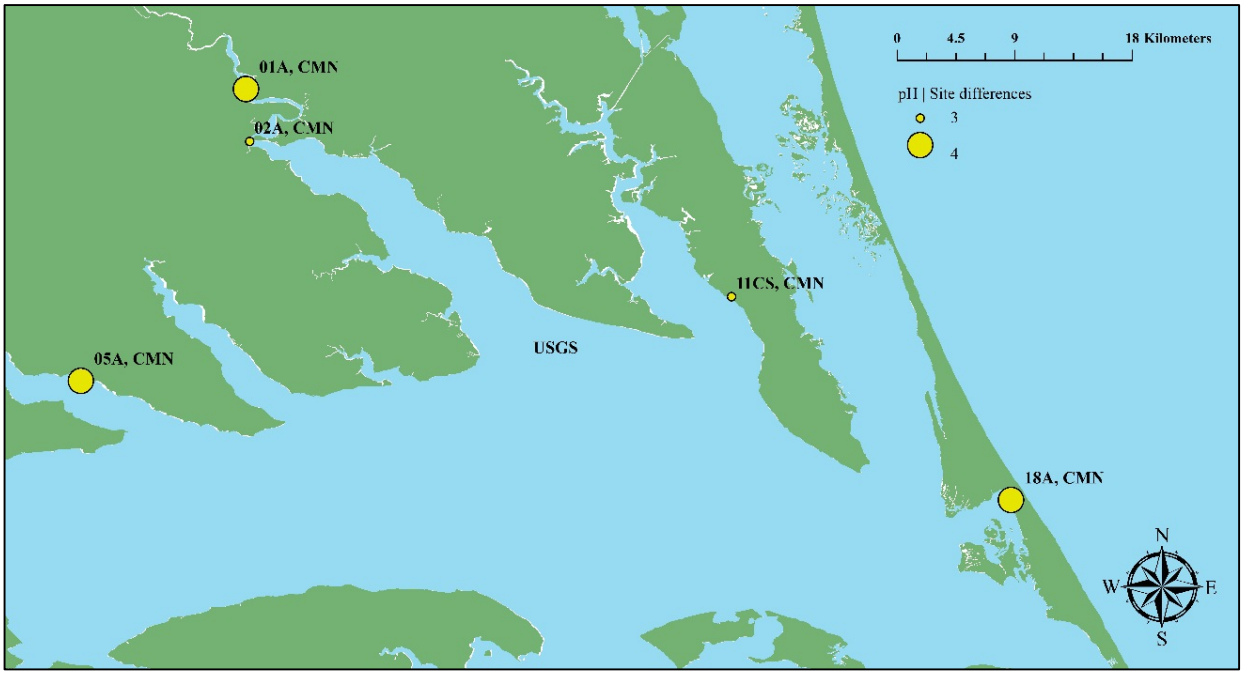
Water temperature	**Site**	**18A**	**11CS**	**USGS**	**02A**	**01A**	**05A**
Lower region	**18A**		0.86	-0.30	0.11	1.21	-1.65
Middle region	**11CS**	0.86		0.56	-0.75	0.35	-2.50
	USGS	-0.30	0.56		-0.20	0.91	-1.95
	02A	0.11	-0.75	-0.20		1.10	1.75
	01A	1.21	0.35	0.91	1.10		2.85
	05A	-1.65	-2.50	-1.95	1.75	2.85	

Appendix C4. Post-hoc pairwise comparison matrix for sites in the 1991-1993 block of the lower and middle Albemarle regions using combined dissolved oxygen (milligrams per liter) data from APNEP-CMN and USGS sites. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (blue circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



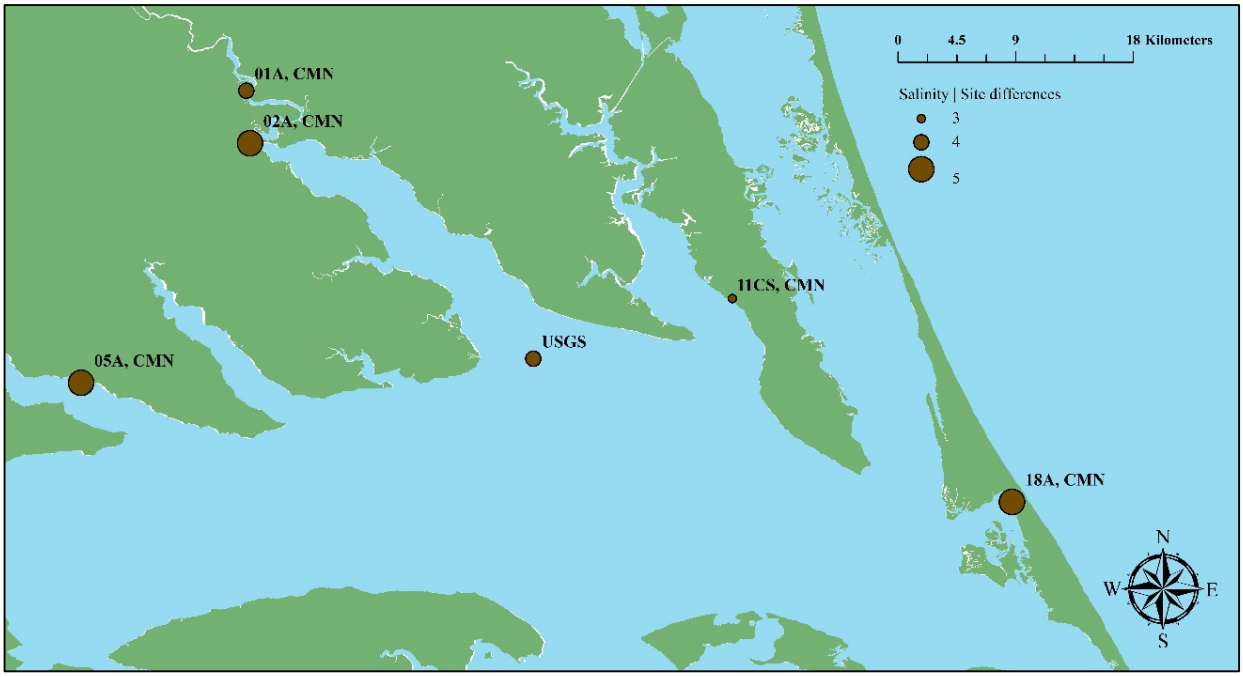
Dissolved oxygen	Site	18A	11CS	USGS	02A	01A	05A
Lower region	**18A**		-1.62	-0.63	-5.51	-3.56	0.58
Middle region	**11CS**	-1.62		-2.24	-3.89	-1.94	2.20
	USGS	-0.63	-2.24		-6.13	-4.19	-0.05
	02A	-5.51	-3.89	-6.13		1.94	-6.08
	01A	-3.56	-1.94	-4.19	1.94		-4.14
	05A	0.58	2.20	-0.05	-6.08	-4.14	

Appendix C5. Post-hoc pairwise comparison matrix for sites in the 1991-1993 block of the lower and middle Albemarle regions using combined pH data from APNEP-CMN and USGS sites. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. Black pattern shaded areas denotes missing data. The map plots these sites (yellow circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



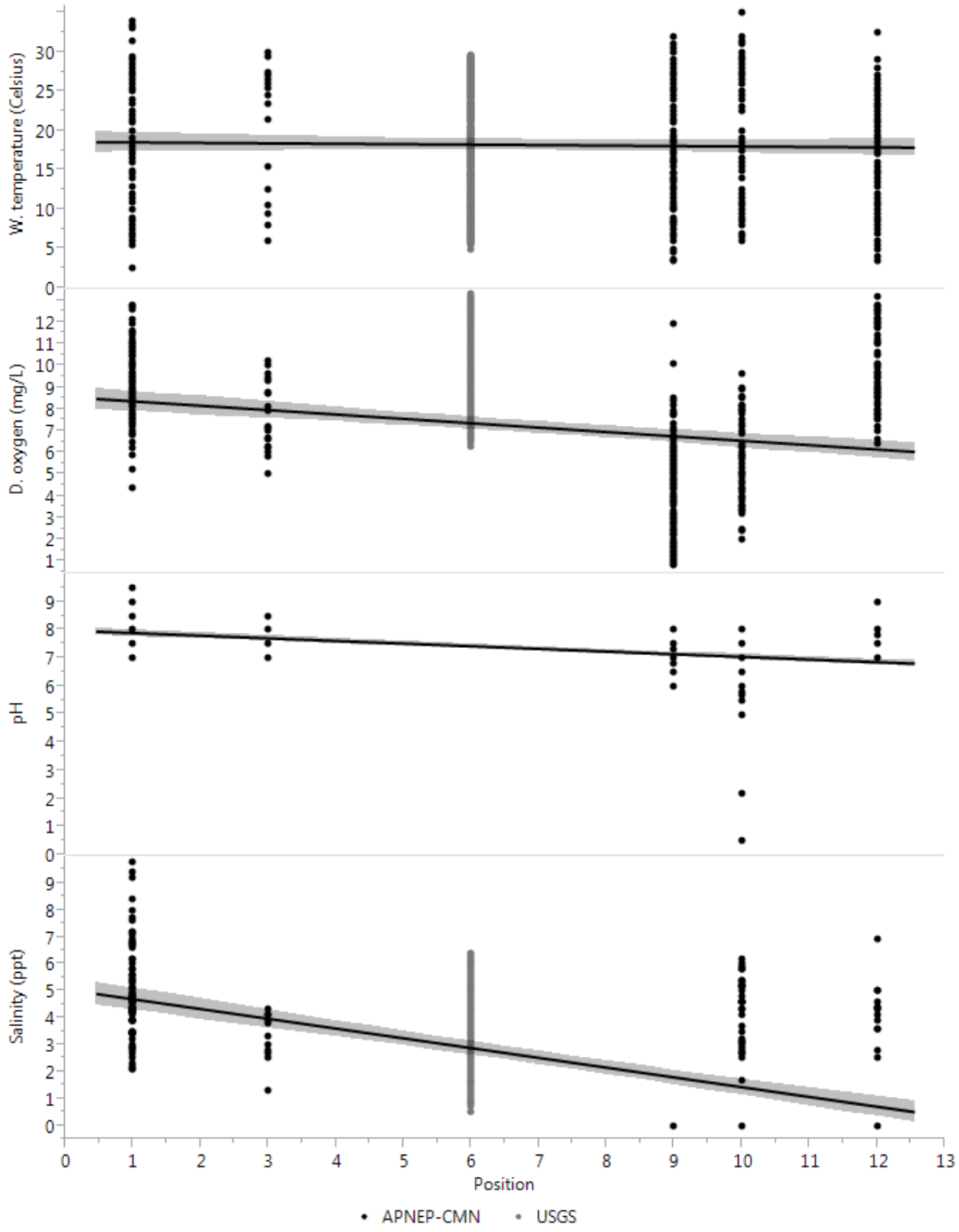
pH	Site	18A	11CS	USGS	02A	01A	05A
Lower region	**18A**		-0.92		-1.24	-2.03	-0.30
Middle region	**11CS**	-0.92			-0.31	-1.10	0.63
	USGS						
	02A	-1.24	-0.31			-0.79	-0.94
	01A	-2.03	-1.10		-0.79		-1.73
	05A	-0.30	0.63		-0.94	-1.73	

Appendix C6. Post-hoc pairwise comparison matrix for sites in the 1991-1993 block of the lower and middle Albemarle regions using combined salinity (parts per thousand) data from APNEP-CMN and USGS sites. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (brown circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

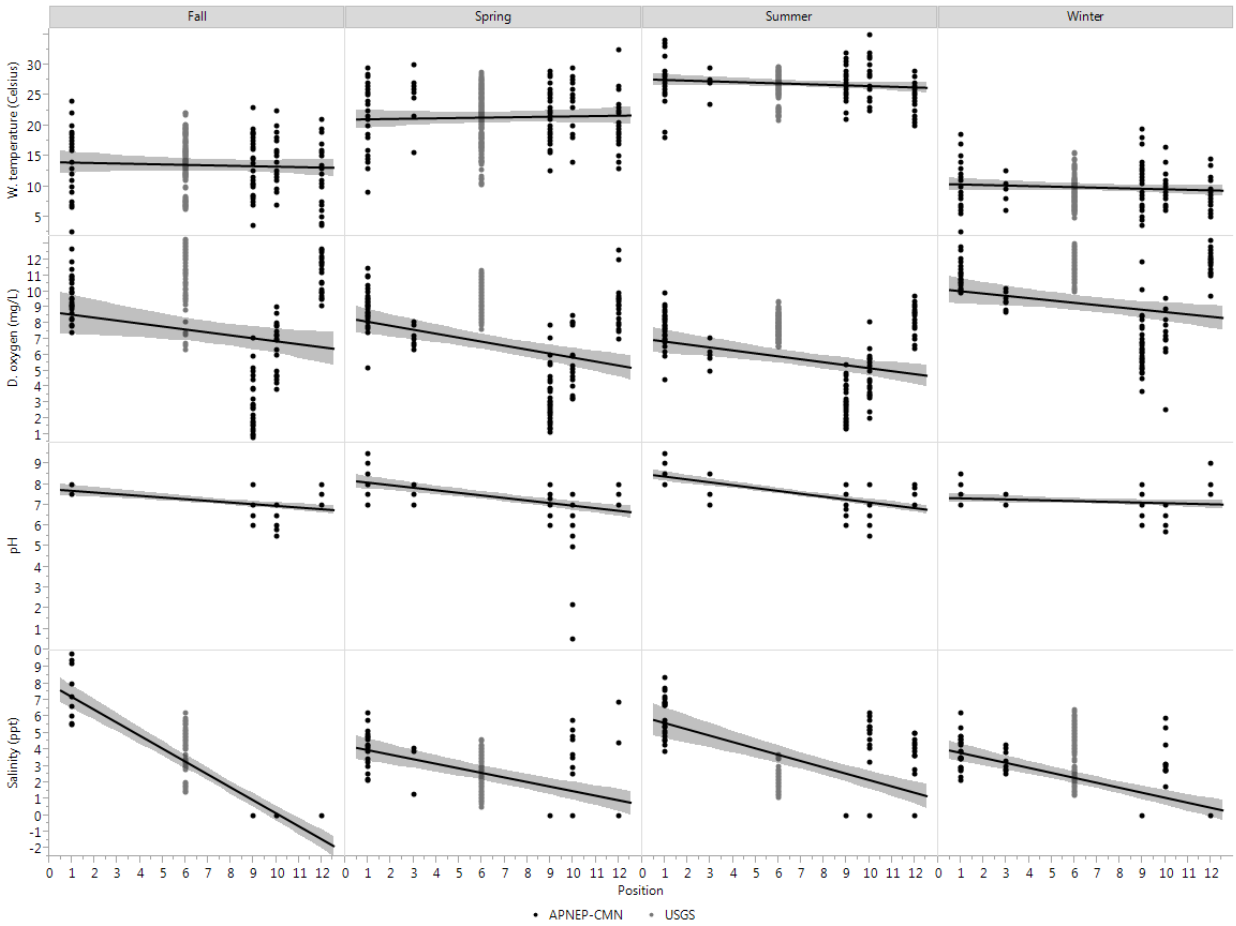


Salinity	Site	18A	11CS	USGS	02A	01A	05A
Lower region	**18A**		-1.72	1.94	-4.79	-2.65	-3.81
Middle region	**11CS**	-1.72		0.22	-3.26	-0.93	-2.09
	USGS	1.94	0.22		-3.03	-0.71	-1.87
	02A	-4.79	-3.26	-3.03		2.33	-1.17
	01A	-2.65	-0.93	-0.71	2.33		1.16
	05A	-3.81	-2.09	-1.87	-1.17	1.16	

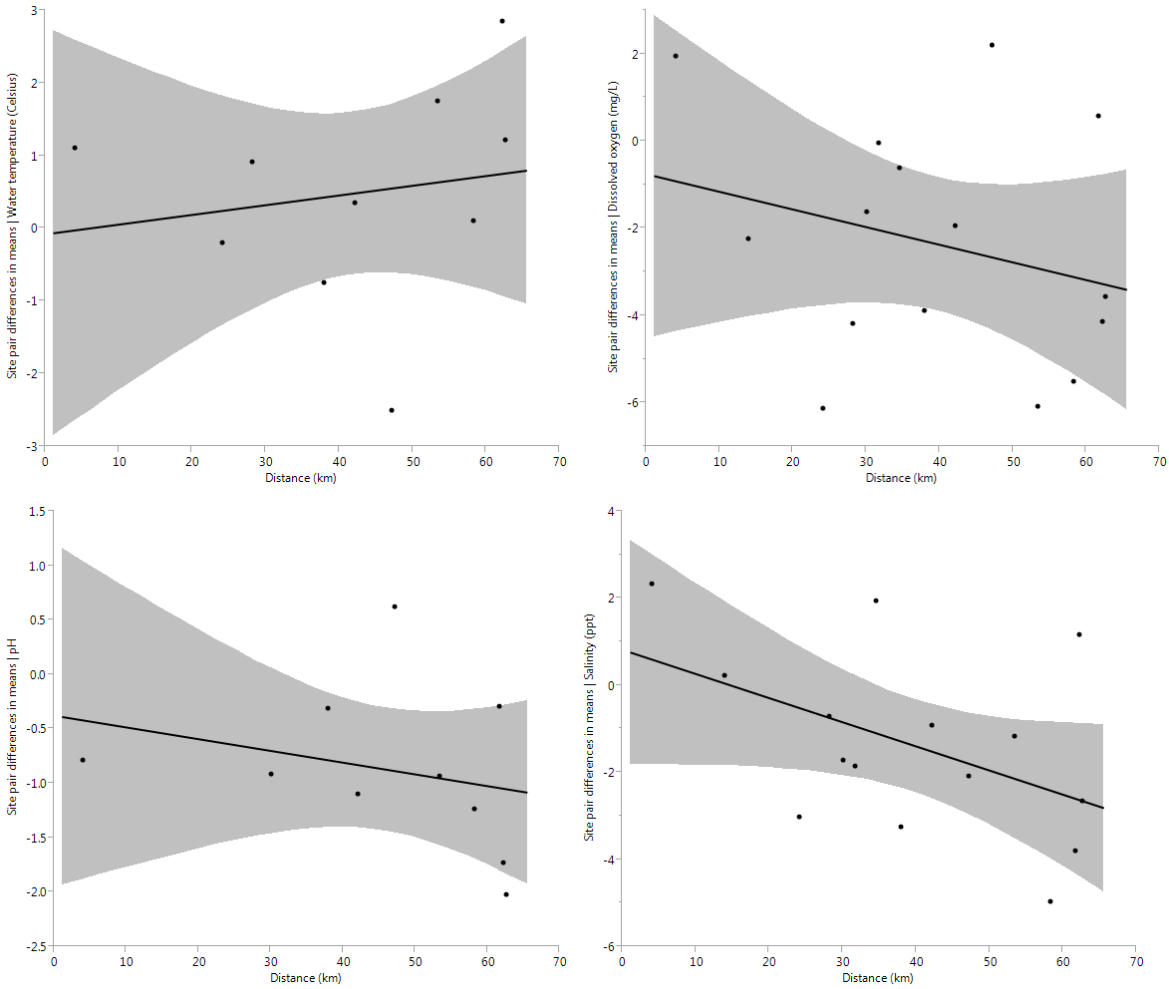
Appendix C7. Scatterplot with fit line for the 1991-1993 block of the lower and middle Albemarle regions plotted over site position (downstream to upstream). Water quality variables include: water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). Black = APNEP-CMN; Gray = USGS. See Table 6 for site information and Table 4 for distances (kilometers) among sites.



Appendix C8. Scatterplot with fit line for the 1991-1993 block of the lower and middle Albemarle regions plotted over site position (downstream to upstream) and separated by season. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). Water quality variables include: water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). Black = APNEP-CMN; Gray = USGS. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



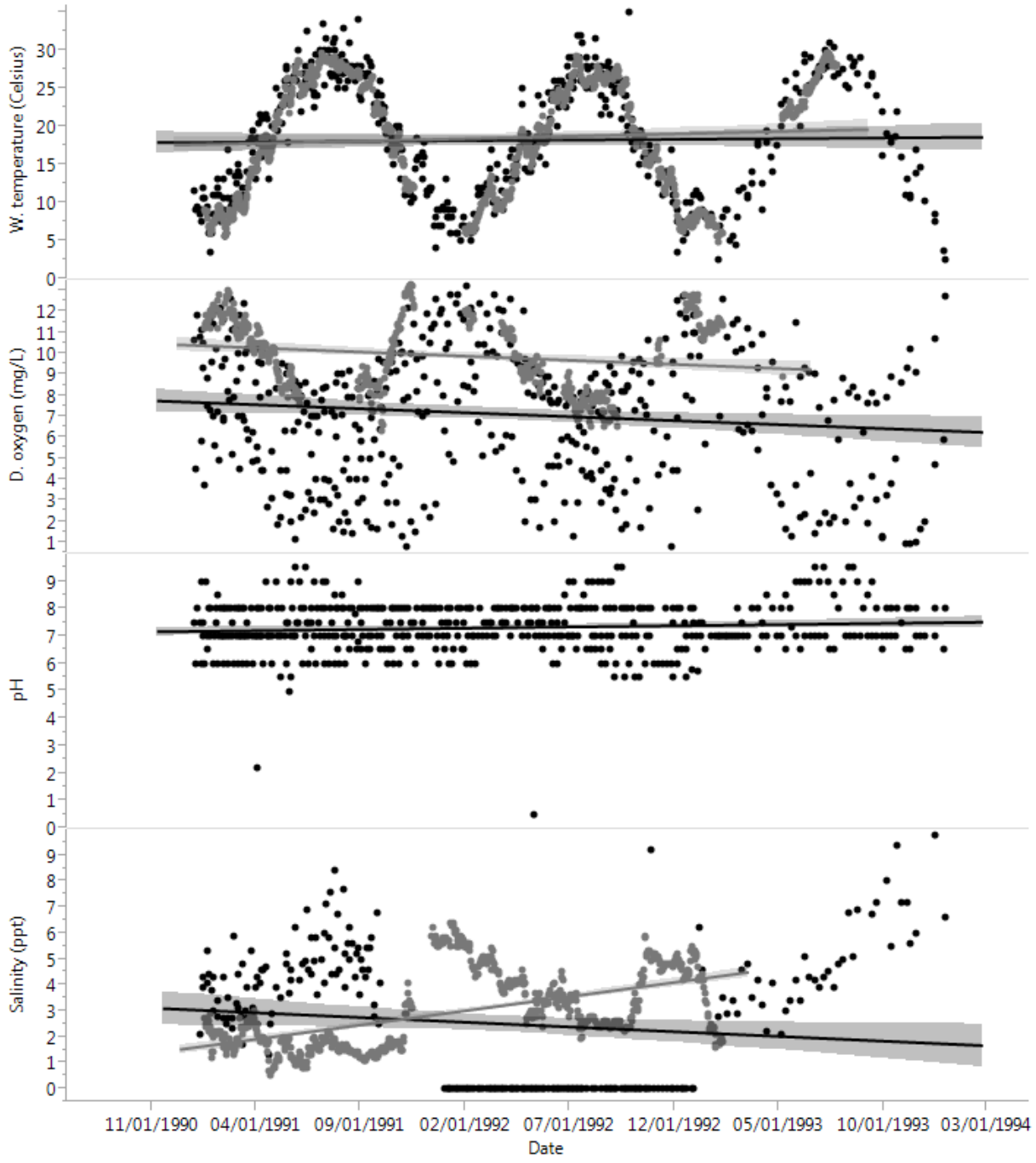
Appendix C9. Scatterplots of mean differences for all site pair combinations over distance (kilometers) in the 1991-1993 block of the lower and middle Albemarle regions. Top left to bottom left: water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). See Table 4 for distances (kilometers) among sites.



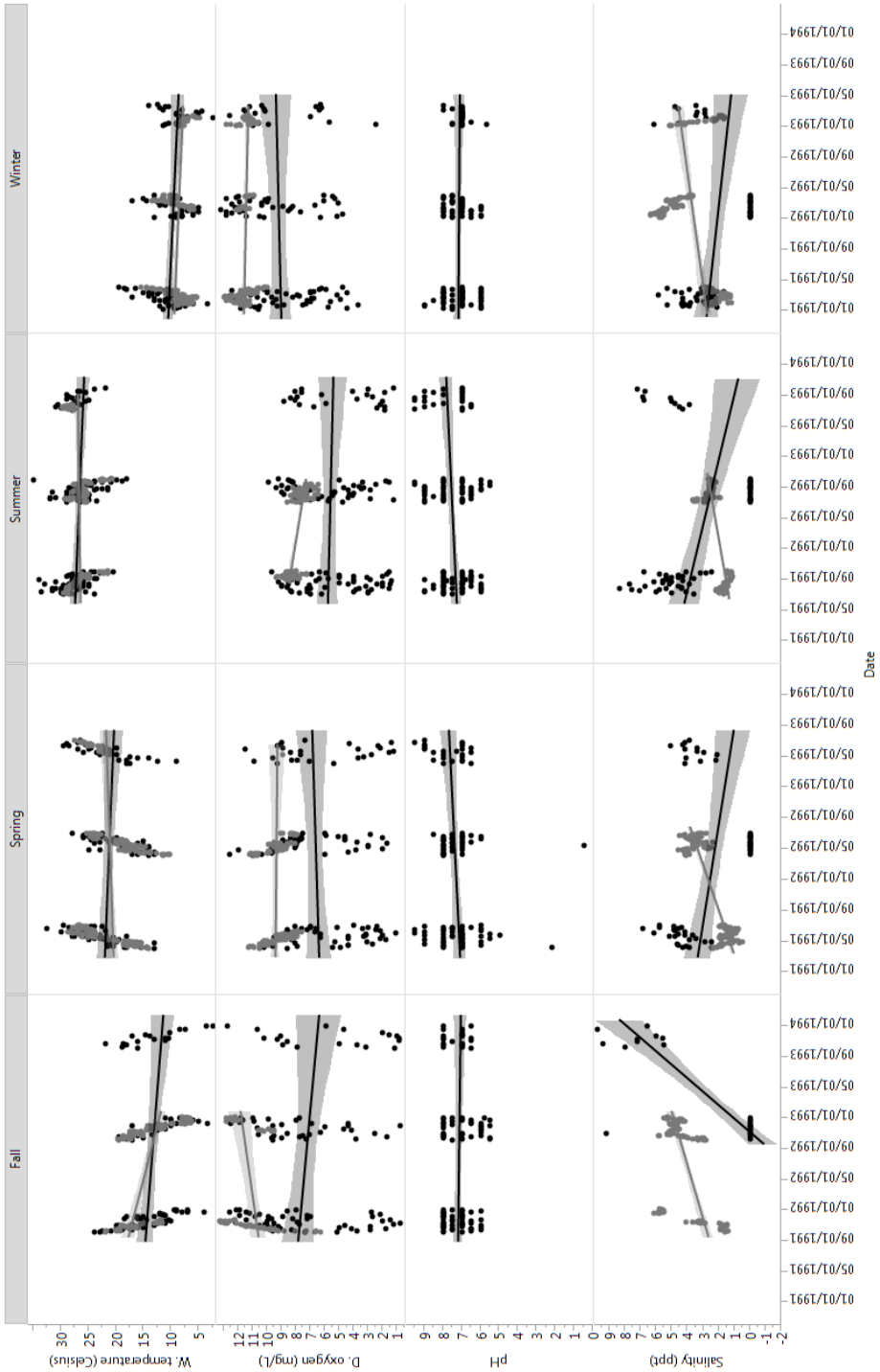
Appendix C10. Slope estimates of water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) by date and separated by site and season for the 1991-1993 block of the lower and middle Albemarle regions. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). P-value is based on the slope of the fit line. R^2 = adjusted R-square. See Appendix C1 for sample sizes. Appendices C11 and C12 visualizes these data.

Date	Fall				Spring				Summer				Winter			
Project	**Water temperature (°C)**				**Water temperature (°C)**				**Water temperature (°C)**				**Water temperature (°C)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	130.332	0.000	0.033	0.034	80.418	0.000	0.242	0.003	85.641	0.000	0.065	0.019	77.520	0.000	0.037	0.027
USGS	395.448	0.000	< 0.01	0.249	-28.168	0.000	0.114	0.006	8.551	0.000	0.291	0.001	70.191	0.000	0.001	0.056
	Dissolved oxygen (mg/L)				**Dissolved oxygen (mg/L)**				**Dissolved oxygen (mg/L)**				**Dissolved oxygen (mg/L)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	59.454	0.000	0.204	0.006	-10.465	0.000	0.565	-0.005	19.334	0.000	0.608	-0.006	-4.282	0.000	0.644	-0.007
USGS	-68.751	0.000	0.019	0.063	14.486	0.000	0.727	-0.007	99.930	0.000	<0.01	0.427	23.116	0.000	0.024	0.031
	pH				**pH**				**pH**				**pH**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	12.338	0.000	0.566	-0.006	-13.896	0.000	0.076	0.017	-12.630	0.000	0.046	0.023	10.023	0.000	0.709	-0.007
USGS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Salinity (ppt)				**Salinity (ppt)**				**Salinity (ppt)**				**Salinity (ppt)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	-607.369	0.000	<0.01	0.712	85.123	0.000	0.008	0.087	127.671	0.000	0.002	0.109	59.335	0.000	0.052	0.043
USGS	-148.581	0.000	<0.01	0.359	-177.415	0.000	<0.01	0.769	-88.257	0.000	<0.01	0.648	-68.007	0.000	<0.01	0.131

Appendix C11. Seasonal scatterplot with fit line of water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) plotted over time for the 1991-1993 block of the lower and middle Albemarle regions. Black = APNEP-CMN. Gray = USGS.



Appendix C12. Scatterplot with fit line of water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) separated by season and plotted over time for the 1991-1993 block of the lower and middle Albemarle regions. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). Black = APNEP-CMN; Gray = USGS.



Appendix C13. Output from seasonal Mann-Kendall trend analysis for water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). Analysis separated by site for the 1991-1993 block of the lower and middle Albemarle regions. H_o = no trend; H_a = monotonic trend (upward or downward).

Project	Water temperature (°C)	
	P-value	**Trend**
APNEP-CMN	0.20	No trend
USGS	0.36	No trend
	Dissolved oxygen (mg/L)	
	P-value	**Trend**
APNEP-CMN	0.01	Monotonic trend
USGS	0.08	No trend
	pH	
	P-value	**Trend**
APNEP-CMN	0.31	No trend
USGS	N/A	N/A
	Salinity (ppt)	
	P-value	**Trend**
APNEP-CMN	< 0.01	Monotonic trend
USGS	< 0.01	Monotonic trend

Appendix D1. Descriptive statistics of available water quality data for the 2002-2005 block of the upper Albemarle region. Water quality variables include: water temperature (degrees Celsius), water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

	Upper		
Site, Project	**Water temperature (°C)**		
	N	**Mean**	**Std. Dev.**
22C, APNEP-CMN	141	20.0	7.6
23C, APNEP-CMN	88	19.3	7.2
	Water depth (m)		
	N	**Mean**	**Std. Dev.**
22C, APNEP-CMN	141	1.8	0.2
23C, APNEP-CMN	89	0.5	0.3
	Secchi depth (m)		
	N	**Mean**	**Std. Dev.**
22C, APNEP-CMN	141	0.7	0.2
23C, APNEP-CMN	89	0.4	0.2
	Dissolved oxygen (mg/L)		
	N	**Mean**	**Std. Dev.**
22C, APNEP-CMN	141	3.3	3.1
23C, APNEP-CMN	87	4.9	3.0
	pH		
	N	**Mean**	**Std. Dev.**
22C, APNEP-CMN	140	6.0	0.0
23C, APNEP-CMN	88	6.0	0.1
	Salinity (ppt)		
	N	**Mean**	**Std. Dev.**
22C, APNEP-CMN	0		
23C, APNEP-CMN	0		

Appendix D2. Descriptive statistics of (a) water temperature (degrees Celsius), (b) water depth (meters), (c) secchi depth (meters), (d) dissolved oxygen (milligrams per liter), and (e) pH for the 2002-2005 block of the upper Albemarle region separated by site and season. Position = numbered from downstream to upstream. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

(a) Water temperature

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	27	Upper	22C	21	8.3	4.0	39	22.2	4.0	53	26.1	2.4	28	14.2	5.7
APNEP-CMN	28	Upper	23C	15	7.9	3.7	26	19.9	4.2	36	25.3	1.8	11	13.8	5.0
Sum, Mean				**36**	**8.1**		**65**	**21.0**		**89**	**25.7**		**39**	**14.0**	

(b) Water depth

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	27	Upper	22C	21	1.7	0.3	39	1.9	0.2	53	1.9	0.2	28	1.8	0.2
APNEP-CMN	28	Upper	23C	15	0.6	0.2	27	0.6	0.4	36	0.3	0.1	11	0.5	0.2
Sum, Mean				**36**	**1.2**		**66**	**1.2**		**89**	**1.1**		**39**	**1.2**	

(c) Secchi depth

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	27	Upper	22C	21	0.9	0.3	39	0.7	0.2	53	0.7	0.2	28	0.7	0.2
APNEP-CMN	28	Upper	23C	15	0.6	0.1	27	0.4	0.2	36	0.3	0.1	11	0.4	0.2
Sum, Mean				**36**	**0.8**		**66**	**0.6**		**89**	**0.5**		**39**	**0.5**	

(d) Dissolved oxygen

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	27	Upper	22C	21	8.7	1.9	39	2.8	1.7	53	1.3	0.9	28	3.6	3.2
APNEP-CMN	28	Upper	23C	14	9.7	1.1	26	5.5	1.9	36	2.6	1.3	11	5.1	2.8
Sum, Mean				**35**	**9.2**		**65**	**4.2**		**89**	**2.0**		**39**	**4.3**	

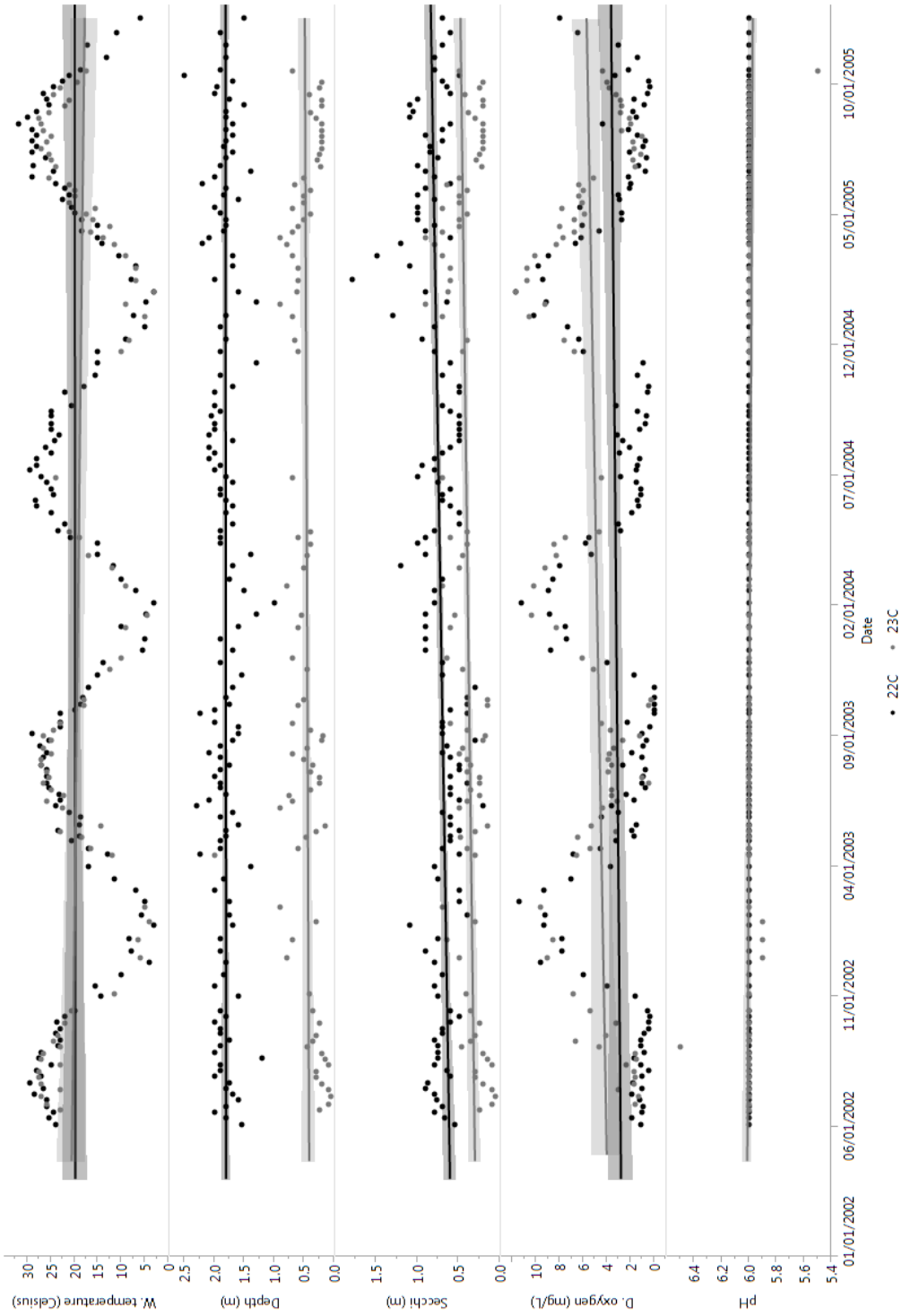
(e) pH

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	27	Upper	22C	21	6.0	0.0	38	6.0	0.0	53	6.0	0.0	28	6.0	0.0
APNEP-CMN	28	Upper	23C	15	6.0	0.0	26	6.0	0.0	36	6.0	0.1	11	5.9	0.2
Sum, Mean				**36**	**6.0**		**64**	**6.0**		**89**	**6.0**		**39**	**6.0**	

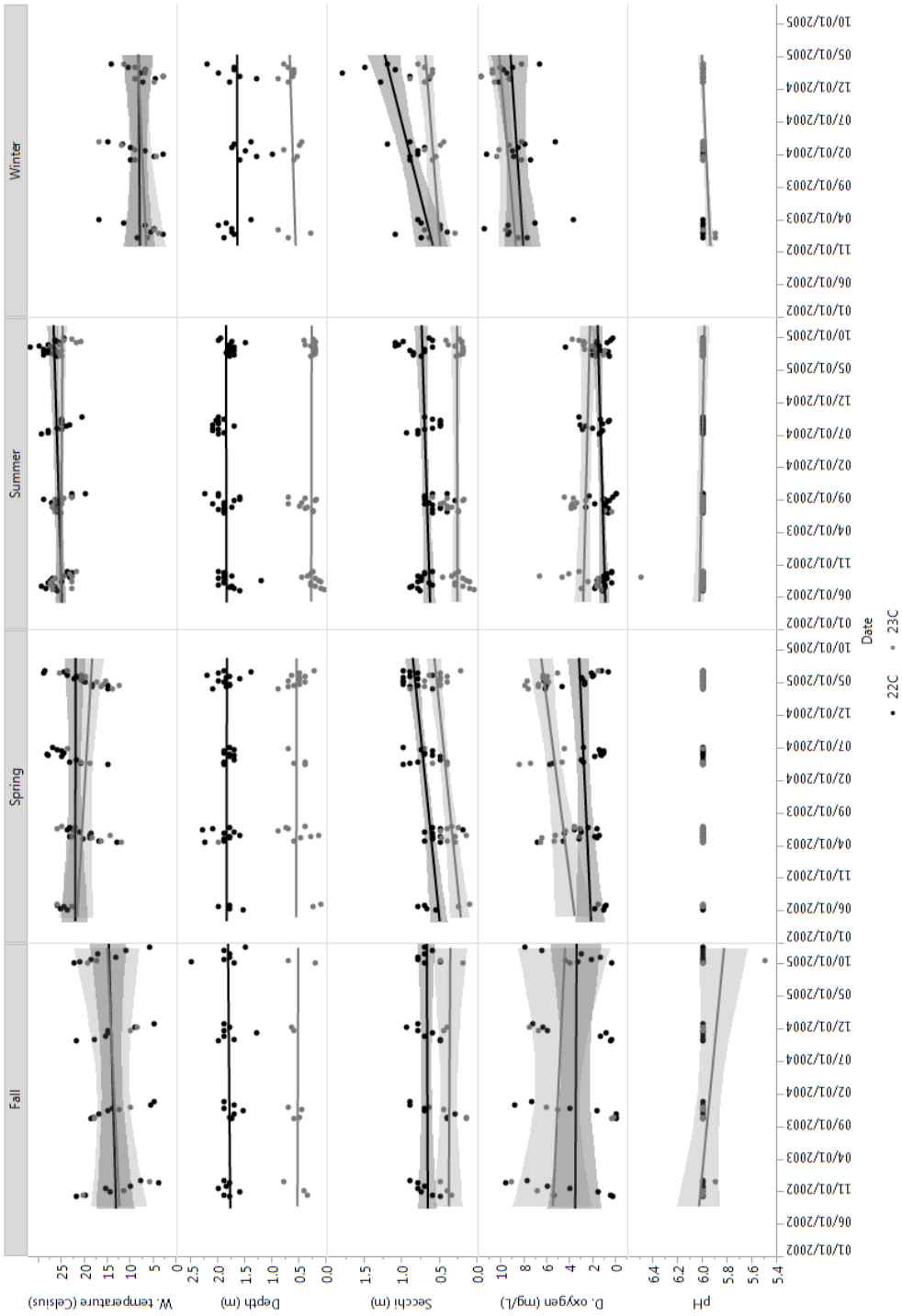
Appendix D3. Slope estimates of water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) by date and separated by site and season for the 2002-2005 block of the upper Albemarle region. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). P-value is based on the slope of the fit line. R^2 = adjusted R-square. See Appendix D1 for sample sizes. Appendices D4 and D5 visualizes these data.

Date	Fall				Spring				Summer				Winter			
Site, Project	**Water temperature (°C)**				**Water temperature (°C)**				**Water temperature (°C)**				**Water temperature (°C)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
22C, APNEP-CMN	-32.671	0.000	0.639	-0.030	24.130	0.000	0.977	-0.027	-25.523	0.000	0.075	0.042	-3.853	0.000	0.913	-0.052
23C, APNEP-CMN	-66.561	0.000	0.608	-0.077	120.289	0.000	0.220	0.023	36.546	0.000	0.640	-0.023	-69.022	0.000	0.542	-0.045
	Water depth (m)				**Water depth (m)**				**Water depth (m)**				**Water depth (m)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
22C, APNEP-CMN	0.583	0.000	0.733	-0.034	1.993	0.000	0.964	-0.027	1.553	0.000	0.889	-0.019	1.459	0.000	0.979	-0.053
23C, APNEP-CMN	0.997	0.000	0.935	-0.110	0.822	0.000	0.971	-0.040	0.500	0.000	0.914	-0.029	-3.849	0.000	0.424	-0.023
	Secchi depth (m)				**Secchi depth (m)**				**Secchi depth (m)**				**Secchi depth (m)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
22C, APNEP-CMN	0.298	0.000	0.897	-0.038	-9.954	0.000	< 0.01	0.293	-2.467	0.000	0.133	0.025	-25.480	0.000	0.002	0.390
23C, APNEP-CMN	0.999	0.000	0.902	-0.109	-10.186	0.000	0.001	0.326	0.231	0.000	0.976	-0.029	-7.542	0.000	0.081	0.156
	Dissolved oxygen (mg/L)				**Dissolved oxygen (mg/L)**				**Dissolved oxygen (mg/L)**				**Dissolved oxygen (mg/L)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
22C, APNEP-CMN	7.265	0.000	0.947	-0.038	-28.310	0.000	0.276	0.006	-17.857	0.000	0.074	0.043	-37.032	0.000	0.394	-0.012
23C, APNEP-CMN	37.584	0.000	0.710	-0.093	-83.508	0.000	0.018	0.180	19.095	0.000	0.345	-0.002	-51.000	0.000	0.138	0.105
	pH				**pH**				**pH**				**pH**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
22C, APNEP-CMN	6.000	N/A	N/A	N/A	6.000	N/A	N/A	N/A	6.000	N/A	N/A	N/A	6.000	N/A	N/A	N/A
23C, APNEP-CMN	12.049	0.000	0.176	0.104	6.000	N/A	N/A	N/A	7.151	0.000	0.302	0.003	3.136	0.000	0.007	0.395

Appendix D4. Seasonal scatterplot with fit line of water temperature (degrees Celsius), water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), and pH plotted over time for the 2002-2005 block of the upper Albemarle region. Black = 22C, APNEP-CMN. Gray = 23C, APNEP-CMN.



Appendix D5. Scatterplot with fit line of water temperature (degrees Celsius), water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), and pH separated by season and plotted over time for the 2002-2005 block of the upper Albemarle region. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). Black = 22C, APNEP-CMN; Gray = 23C, APNEP-CMN.



Appendix D6. Output from seasonal Mann-Kendall trend analysis for water temperature (degrees Celsius), water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), and pH. Analysis separated by site for the 2002-2005 block of the upper Albemarle region. H_o = no trend; H_a = monotonic trend (upward or downward).

Site, Project	Water temperature (°C)	
	P-value	**Trend**
22C, APNEP-CMN	0.86	No trend
23C, APNEP-CMN	0.45	No trend
	Water depth (m)	
	P-value	**Trend**
22C, APNEP-CMN	0.94	No trend
23C, APNEP-CMN	0.32	No trend
	Secchi depth (m)	
	P-value	**Trend**
22C, APNEP-CMN	< 0.01	Monotonic trend
23C, APNEP-CMN	0.03	Monotonic trend
	Dissolved oxygen (mg/L)	
	P-value	**Trend**
22C, APNEP-CMN	0.37	No trend
23C, APNEP-CMN	0.39	No trend
	pH	
	P-value	**Trend**
22C, APNEP-CMN	0.89	No trend
23C, APNEP-CMN	0.73	No trend

Appendix E1. Descriptive statistics of available water quality data for the 2008-2010 block of the Albemarle region. Water quality variables include: water temperature (degrees Celsius), water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). N = number of monitoring sessions. Std. Dev. = standard deviation.

	Lower			Middle			Upper		
Project	**Water temperature (°C)**			**Water temperature (°C)**			**Water temperature (°C)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	28	19.6	8.0	210	21.9	8.1	79	17.5	7.4
NCDMF	1354	19.8	8.0	2340	19.0	8.2	1464	17.5	8.9
	Water depth (m)			**Water depth (m)**			**Water depth (m)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	28	1.2	0.3	215	1.4	0.7	75	1.3	1.3
NCDMF	1359	3.2	0.2	2340	4.2	1.8	1464	4.6	1.5
	Secchi depth (m)			**Secchi depth (m)**			**Secchi depth (m)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	28	1.0	0.3	215	0.9	0.4	74	0.9	0.2
NCDMF	0			0			0		
	Dissolved oxygen (mg/L)			**Dissolved oxygen (mg/L)**			**Dissolved oxygen (mg/L)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	28	7.9	1.8	214	8.7	1.8	53	7.9	3.3
NCDMF	1359	8.1	2.0	2275	7.1	3.0	1384	6.4	3.0
	pH			**pH**			**pH**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	27	6.8	0.8	215	6.9	0.8	79	6.7	0.4
NCDMF	1093	7.2	0.8	2248	6.9	0.7	1323	6.8	0.6
	Salinity (ppt)			**Salinity (ppt)**			**Salinity (ppt)**		
	N	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	**24**	**3.0**	**1.1**	**147**	**4.6**	**2.3**	**58**	**0.2**	**0.6**
NCDMF	**1359**	**2.6**	**2.0**	**2340**	**0.6**	**0.9**	**1464**	**0.2**	**0.4**

Appendix E2. Descriptive statistics of (a) water temperature (degrees Celsius) and (b) water depth (meters) for the 2008-2010 block of the Albemarle region separated by site. Position = numbered from downstream to upstream. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

(a) Water temperature

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
NCDMF	3	Lower	9	102	8.33	3.57	182	22.97	4.28	180	26.86	2.29	99	16.73	3.22
NCDMF	4	Lower	10	65	8.90	3.67	90	23.63	4.22	166	27.48	2.04	119	17.31	3.26
APNEP-CMN	6	Lower	35A	7	9.50	3.73	10	21.80	5.30	9	26.83	1.77	2	11.50	4.24
NCDMF	7	Lower	8	48	4.61	1.90	18	26.53	0.70	112	26.91	1.77	173	12.92	5.41
APNEP-CMN	11	Middle	36A	15	10.27	3.18	35	23.51	4.92	39	28.29	2.82	24	14.56	5.70
NCDMF	12	Middle	5	83	7.15	3.81	123	24.43	3.91	183	27.53	2.03	149	12.89	5.95
NCDMF	13	Middle	6	52	8.89	3.70	155	22.93	4.08	148	27.76	1.79	156	13.26	5.55
NCDMF	14	Middle	12	34	11.44	3.56	90	20.34	3.36	0			0		
APNEP-CMN	15	Middle	32A	8	10.60	4.07	14	26.06	4.72	14	29.80	2.61	4	20.05	5.25
NCDMF	16	Middle	4	66	10.09	2.64	180	22.24	4.63	101	28.28	2.19	183	14.21	5.51
APNEP-CMN	17	Middle	25C	9	9.11	3.93	15	21.27	7.67	23	28.04	2.76	10	17.00	5.19
NCDMF	18	Middle	14	0			0			30	27.58	0.98	0		
NCDMF	19	Middle	1	101	6.51	3.21	159	23.27	3.80	120	27.21	1.93	227	12.88	4.90
APNEP-CMN	23	Upper	05C	15	8.08	3.67	16	21.13	4.15	16	26.06	1.81	19	14.37	4.32
NCDMF	25	Upper	2	71	7.30	3.91	100	23.96	4.26	153	28.11	1.73	212	13.07	5.26
NCDMF	26	Upper	11	35	9.03	3.89	48	17.49	3.08	0			0		
APNEP-CMN	27	Upper	22C	1	7.50		0			0			0		
NCDMF	29	Upper	3	91	6.24	4.29	100	23.13	4.02	109	27.47	1.81	169	11.79	5.81
APNEP-CMN	30	Upper	21C	3	11.67	2.08	9	21.22	4.58	0			0		
NCDMF	31	Upper	13	90	6.46	4.38	91	22.62	4.11	105	27.12	2.03	90	13.07	5.25
Sum, Mean				**896**	**8.51**		**1435**	**22.70**		**1508**	**27.58**		**1636**	**14.37**	

(b) Water depth

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
NCDMF	3	Lower	9	102	3.40	0.00	182	3.40	0.00	180	3.40	0.00	104	3.40	0.00
NCDMF	4	Lower	10	65	3.00	0.00	90	3.00	0.00	166	3.00	0.00	119	3.00	0.00
APNEP-CMN	6	Lower	35A	7	1.04	0.14	10	1.38	0.31	9	1.23	0.20	2	1.25	0.07
NCDMF	7	Lower	8	48	3.00	0.00	18	3.00	0.00	112	3.00	0.00	173	3.00	0.00
APNEP-CMN	11	Middle	36A	15	0.68	0.12	35	0.82	0.12	39	0.86	0.11	24	0.80	0.21
NCDMF	12	Middle	5	83	2.40	0.00	123	2.40	0.00	183	2.40	0.00	149	2.40	0.00
NCDMF	13	Middle	6	52	2.60	0.00	155	2.60	0.00	148	2.60	0.00	156	2.60	0.00
NCDMF	14	Middle	12	34	2.70	0.00	90	2.70	0.00	0			0		
APNEP-CMN	15	Middle	32A	9	1.82	0.10	14	2.06	0.09	14	2.13	0.11	5	1.94	0.14
NCDMF	16	Middle	4	66	6.70	0.00	180	6.70	0.00	101	6.70	0.00	183	6.70	0.00
APNEP-CMN	17	Middle	25C	9	1.99	0.65	15	2.11	0.22	24	2.11	0.23	12	2.18	0.14
NCDMF	18	Middle	14	0			0			30	3.00	0.00	0		
NCDMF	19	Middle	1	101	5.50	0.00	159	5.50	0.00	120	5.50	0.00	227	5.50	0.00
APNEP-CMN	23	Upper	05C	13	1.01	0.11	17	1.08	0.12	16	1.77	2.73	16	1.10	0.19
NCDMF	25	Upper	2	71	5.80	0.00	100	5.80	0.00	153	5.80	0.00	212	5.80	0.00
NCDMF	26	Upper	11	35	2.40	0.00	48	2.40	0.00	0			0		
APNEP-CMN	27	Upper	22C	1	1.90		0			0			0		
NCDMF	29	Upper	3	91	5.50	0.00	100	5.50	0.00	109	5.50	0.00	169	5.50	0.00
APNEP-CMN	30	Upper	21C	3	1.40	0.00	9	1.59	0.13	0			0		
NCDMF	31	Upper	13	90	2.40	0.00	91	2.40	0.00	105	2.40	0.00	90	2.40	0.00
Sum, Mean				**895**	**2.91**		**1436**	**3.02**		**1509**	**3.21**		**1641**	**3.17**	

Appendix E2 (continued). Descriptive statistics of (c) dissolved oxygen (milligrams per liter) and (d) pH for the 2008-2010 block of the Albemarle region separated by site. Position = numbered from downstream to upstream. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

(c) Dissolved oxygen

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
NCDMF	3	Lower	9	102	10.99	0.98	182	8.21	1.10	180	7.40	0.80	104	8.79	1.38
NCDMF	4	Lower	10	65	10.83	1.21	90	7.56	0.87	166	6.75	1.40	119	7.70	1.40
APNEP-CMN	6	Lower	35A	7	10.29	0.68	10	7.35	1.16	9	6.46	0.77	2	9.30	0.28
NCDMF	7	Lower	8	48	11.25	0.97	18	5.50	0.90	112	6.25	1.24	173	8.13	2.50
APNEP-CMN	11	Middle	36A	15	10.73	1.01	35	7.67	1.08	39	7.20	0.91	24	9.29	1.76
NCDMF	12	Middle	5	83	10.01	1.40	123	5.29	1.43	183	4.35	1.29	149	7.05	3.57
NCDMF	13	Middle	6	52	10.23	1.28	90	6.46	1.67	148	4.16	1.97	156	7.56	3.57
NCDMF	14	Middle	12	34	6.88	1.77	90	1.02	1.28	0			0		
APNEP-CMN	15	Middle	32A	9	10.06	2.08	14	8.05	1.48	14	9.34	1.51	4	9.35	0.48
NCDMF	16	Middle	4	66	10.55	1.09	180	6.75	1.34	101	5.30	1.00	183	7.59	2.29
APNEP-CMN	17	Middle	25C	9	11.48	1.67	15	9.43	1.14	24	8.21	1.63	12	9.73	1.32
NCDMF	18	Middle	14	0			0			30	7.73	0.74	0		
NCDMF	19	Middle	1	101	11.81	0.90	159	7.59	0.87	120	6.97	1.37	227	9.78	1.76
APNEP-CMN	23	Upper	05C	11	12.33	1.52	8	7.63	2.56	11	7.48	2.24	10	7.64	2.78
NCDMF	25	Upper	2	71	9.93	1.24	100	6.05	1.01	153	6.08	0.95	132	8.32	2.06
NCDMF	26	Upper	11	35	7.72	2.09	48	1.70	1.76	0			0		
APNEP-CMN	27	Upper	22C	1	7.00		0			0			0		
NCDMF	29	Upper	3	91	10.81	1.73	100	4.44	0.98	109	3.76	0.62	169	6.62	2.49
APNEP-CMN	30	Upper	21C	3	7.23	1.06	9	4.08	0.86	0			0		
NCDMF	31	Upper	13	90	10.60	1.71	91	4.09	1.11	105	2.88	0.57	90	5.83	2.31
Sum, Mean				**893**	**10.04**		**1362**	**6.05**		**1504**	**6.27**		**1554**	**8.18**	

(d) pH

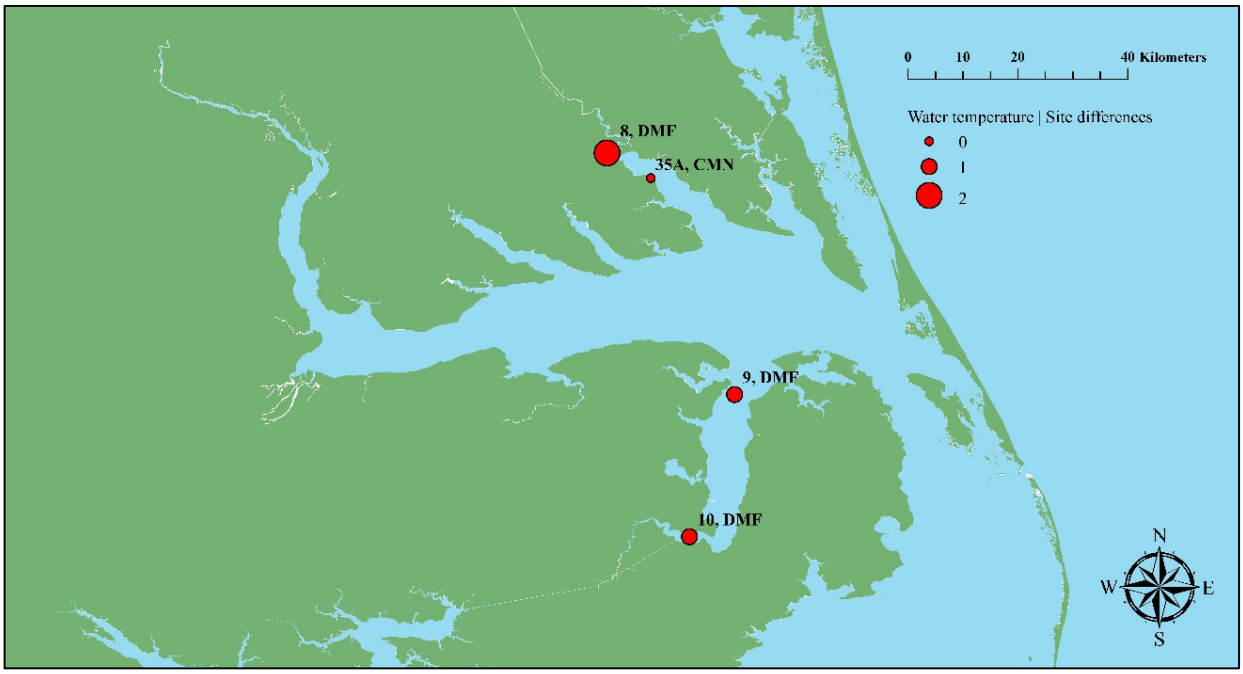
				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
NCDMF	3	Lower	9	102	7.21	0.08	182	7.38	0.20	137	7.49	0.27	77	7.33	0.27
NCDMF	4	Lower	10	65	9.40	1.53	90	6.64	0.19	123	6.54	0.47	93	7.05	0.34
APNEP-CMN	6	Lower	35A	7	7.57	0.81	10	6.80	0.72	9	6.32	0.52	1	7.00	
NCDMF	7	Lower	8	48	7.53	0.40	18	6.25	0.08	77	6.28	0.30	81	6.80	0.27
APNEP-CMN	11	Middle	36A	15	7.67	0.50	35	6.52	0.59	39	6.14	0.56	24	6.62	0.44
NCDMF	12	Middle	5	27	6.36	0.26	118	6.10	0.31	183	6.18	0.32	149	6.94	0.93
NCDMF	13	Middle	6	52	6.72	0.26	155	6.82	0.36	148	6.96	0.63	156	6.91	0.41
NCDMF	14	Middle	12	34	6.60	0.14	90	6.64	0.14	0			0		
APNEP-CMN	15	Middle	32A	9	7.06	0.58	14	7.39	0.84	14	8.46	0.77	5	7.10	0.74
NCDMF	16	Middle	4	66	7.18	0.27	180	6.97	0.29	101	7.11	0.25	152	7.08	0.43
APNEP-CMN	17	Middle	25C	9	7.02	0.07	15	7.00	0.00	24	7.00	0.00	12	7.00	0.00
NCDMF	18	Middle	14	0			0			30	7.43	0.22	0		
NCDMF	19	Middle	1	101	6.84	0.32	159	7.35	0.86	120	7.87	0.90	227	7.10	0.55
APNEP-CMN	23	Upper	05C	15	6.77	0.56	17	6.76	0.44	16	7.00	0.00	18	6.69	0.49
NCDMF	25	Upper	2	71	6.71	0.20	100	6.89	0.32	87	7.17	0.41	137	6.91	0.33
NCDMF	26	Upper	11	35	6.19	0.08	48	6.44	0.17	0			0		
APNEP-CMN	27	Upper	22C	1	6.00		0			0			0		
NCDMF	29	Upper	3	91	6.78	0.69	100	6.85	0.47	109	6.65	0.12	169	6.58	0.37
APNEP-CMN	30	Upper	21C	3	6.60	0.40	9	6.34	0.10	0			0		
NCDMF	31	Upper	13	90	6.91	0.39	91	7.41	0.92	105	7.18	1.39	90	6.72	0.34
Sum, Mean				**841**	**7.01**		**1431**	**6.81**		**1322**	**6.99**		**1391**	**6.92**	

Appendix E2 (continued). Descriptive statistics of (e) salinity (parts per thousand) for the 2008-2010 block of the Albemarle region separated by site. Position = numbered from downstream to upstream. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

(e) Salinity

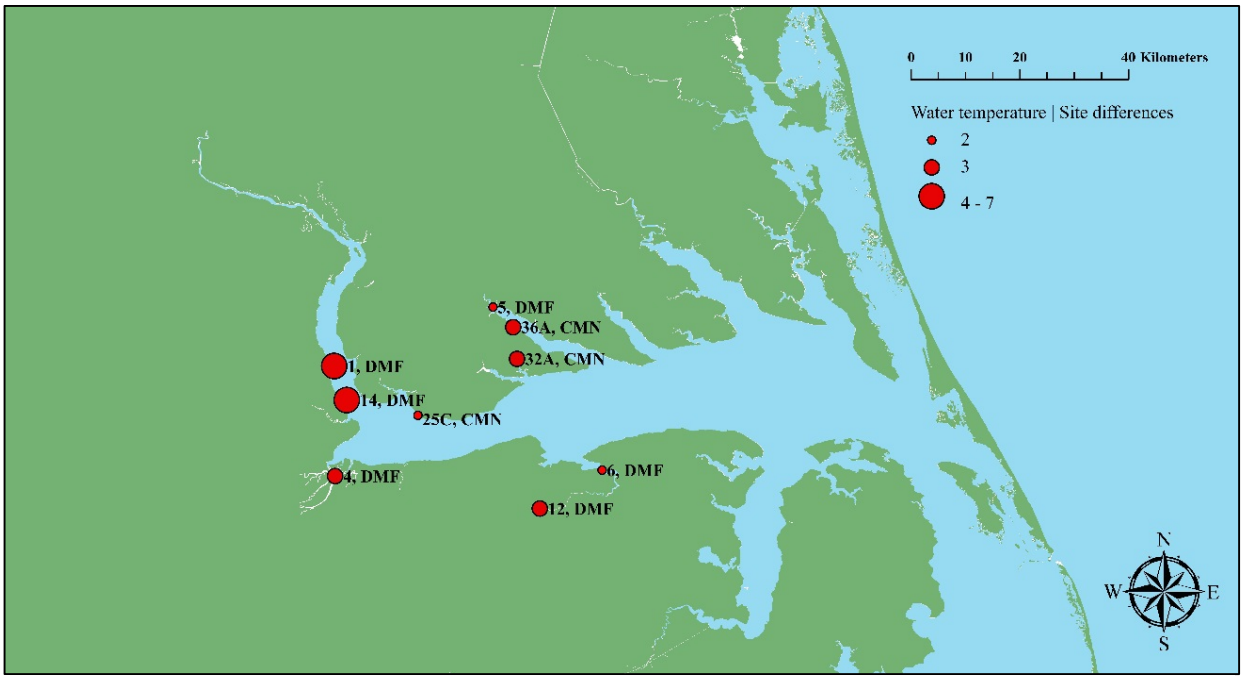
				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
NCDMF	3	Lower	9	102	1.97	0.34	182	1.28	0.19	180	2.83	1.23	104	5.08	1.13
NCDMF	4	Lower	10	65	0.98	0.38	90	1.27	0.19	166	3.97	2.85	119	4.68	2.64
APNEP-CMN	6	Lower	35A	4	3.75	0.96	9	2.22	0.44	9	2.78	0.62	2	5.50	0.71
NCDMF	7	Lower	8	48	0.78	0.54	18	2.63	0.30	112	1.78	0.84	173	2.21	0.97
APNEP-CMN	11	Middle	36A	15	7.50	2.72	35	4.96	2.13	37	4.46	1.64	24	4.78	2.42
NCDMF	12	Middle	5	83	0.20	0.16	123	0.88	1.20	183	0.96	0.83	149	0.75	0.71
NCDMF	13	Middle	6	52	0.12	0.02	155	1.23	1.29	148	1.47	0.57	156	1.26	1.05
NCDMF	14	Middle	12	34	0.17	0.02	90	0.26	0.33	0			0		
APNEP-CMN	15	Middle	32A	8	4.03	0.89	11	2.05	0.47	13	2.48	0.95	4	4.13	0.63
NCDMF	16	Middle	4	66	0.07	0.03	180	0.06	0.01	101	0.07	0.01	183	0.08	0.08
APNEP-CMN	17	Middle	25C	0			0			0			0		
NCDMF	18	Middle	14	0			0			30	1.20	0.22	0		
NCDMF	19	Middle	1	101	0.23	0.55	159	0.10	0.05	120	0.35	0.09	227	1.02	1.36
APNEP-CMN	23	Upper	05C	14	0.04	0.09	16	0.31	0.66	13	0.15	0.55	15	0.41	0.84
NCDMF	25	Upper	2	71	0.05	0.01	100	0.04	0.01	153	0.07	0.02	212	0.60	1.00
NCDMF	26	Upper	11	35	0.09	0.01	48	0.09	0.01	0			0		
APNEP-CMN	27	Upper	22C	0			0			0			0		
NCDMF	29	Upper	3	91	0.07	0.02	100	0.07	0.03	109	0.05	0.01	169	0.11	0.20
APNEP-CMN	30	Upper	21C	0			0			0			0		
NCDMF	31	Upper	13	90	0.10	0.05	91	0.07	0.01	105	0.08	0.02	90	0.08	0.03
Sum, Mean				**879**	**1.26**		**1407**	**1.09**		**1479**	**1.51**		**1627**	**2.19**	

Appendix E3. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the lower Albemarle region using combined water temperature (degrees Celsius) data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (red circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



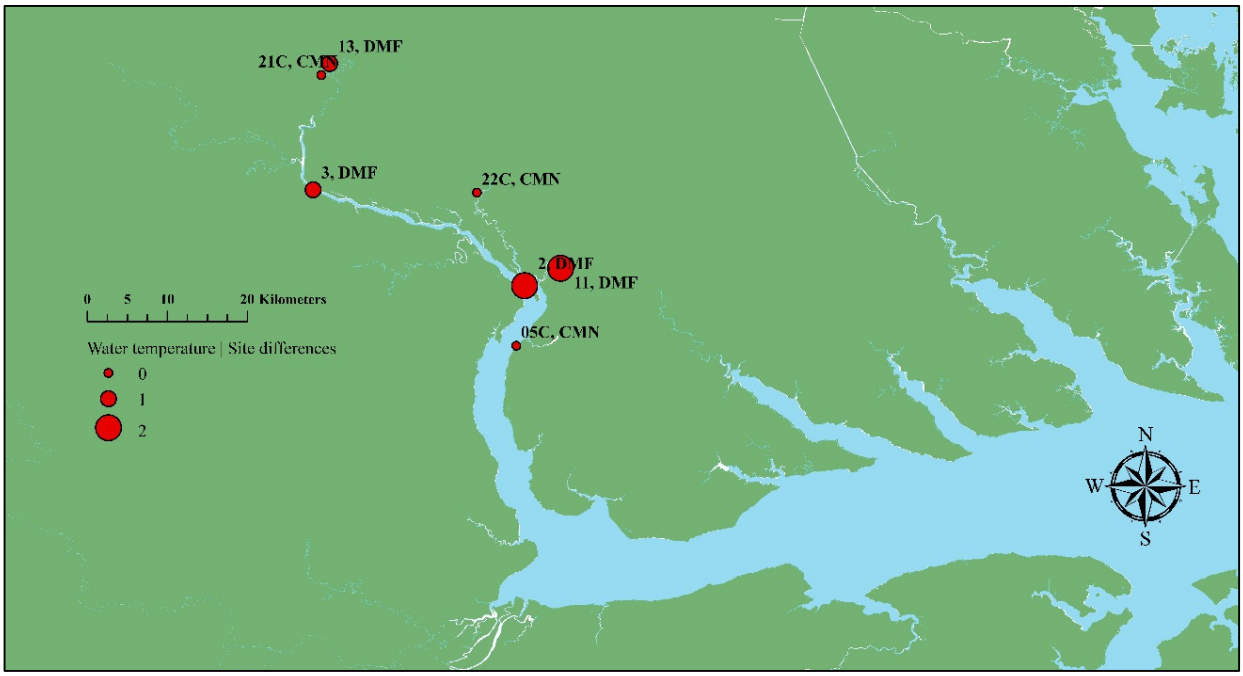
Water temperature	Site	9	10	35A	8
Lower region	**9**		0.73	-0.09	-3.52
	10	0.73		1.59	4.25
	35A	-0.09	1.59		2.66
	8	-3.52	4.25	2.66	

Appendix E4. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the middle Albemarle region using combined water temperature (degrees Celsius) data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (red circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



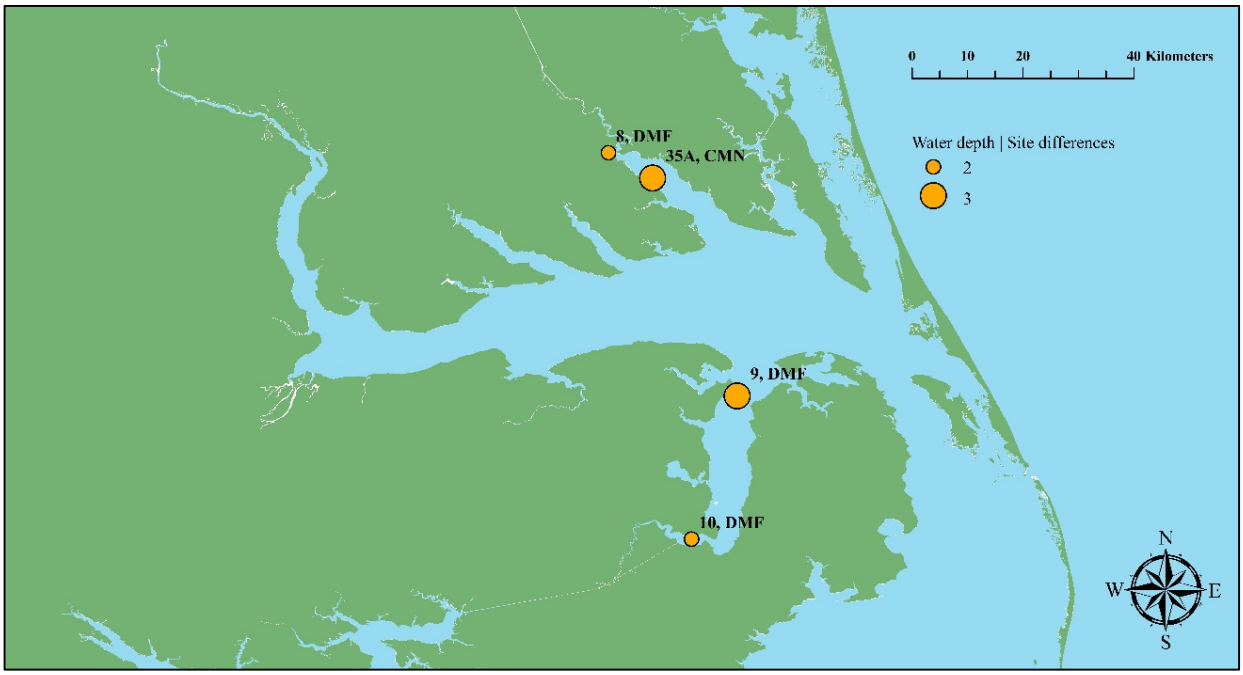
Water temperature	Site	36A	5	6	12	32A	4	25C	14	1
Middle region	**36A**		1.88	1.55	-3.61	2.17	2.40	-0.17	6.07	-4.13
	5	1.88		-0.33	-1.73	4.05	-0.52	1.71	7.95	-2.25
	6	1.55	-0.33		-2.05	3.73	-0.85	1.38	7.63	-2.58
	12	-3.61	-1.73	-2.05		-5.78	-1.21	-3.44	-9.68	-0.52
	32A	2.17	4.05	3.73	-5.78		4.57	-2.34	3.90	-6.30
	4	2.40	-0.52	-0.85	-1.21	4.57		2.23	8.47	-1.73
	25C	-0.17	1.71	1.38	-3.44	-2.34	2.23		6.24	-3.96
	14	6.07	7.95	7.63	-9.68	3.90	8.47	6.242		-10.20
	1	-4.13	-2.25	-2.58	-0.52	-6.30	-1.73	-3.96	-10.20	

Appendix E5. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the upper Albemarle region using combined water temperature (degrees Celsius) data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (red circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



Water temperature	Site	05C	2	11	22C	3	21C	13
Upper region	**05C**		-1.22	3.49	9.91	0.64	-1.42	-0.31
	2	-1.22		-4.71	11.13	1.86	-0.20	-0.91
	11	3.49	-4.71		6.42	-2.85	-4.91	-3.80
	22C	9.91	11.13	6.42		-9.28	11.33	10.22
	3	0.64	1.86	-2.85	-9.28		2.06	0.95
	21C	-1.42	-0.20	-4.91	11.33	2.06		-1.11
	13	-0.31	-0.91	-3.80	10.22	0.95	-1.11	

Appendix E6. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the lower Albemarle region using combined water depth (meters) data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (orange circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

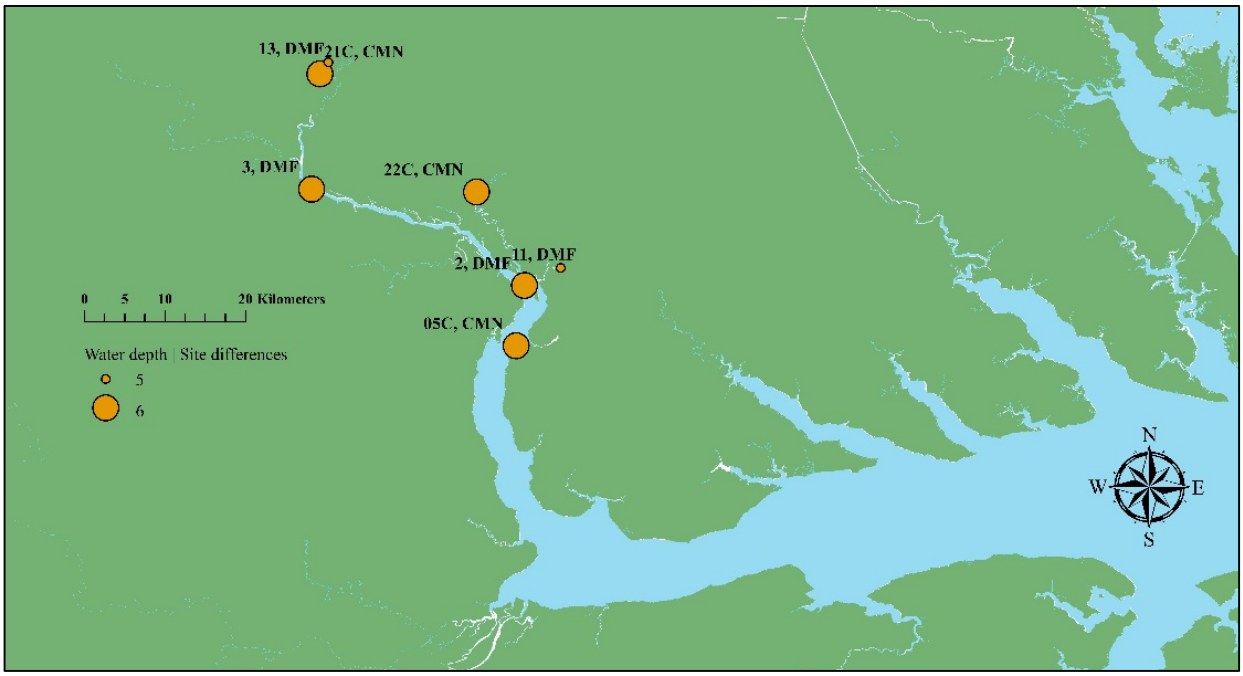


Water depth	Site	9	10	35A	8
Lower region	9		-0.40	-2.16	-0.40
	10	-0.40		1.76	0.00
	35A	-2.16	1.76		-1.76
	8	-0.40	0.00	-1.76	

Appendix E7. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the middle Albemarle region using combined water depth (meters) data from APNEP-CMN and NCDMF. Values represent mean differences among sites. All site comparisons were significant at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

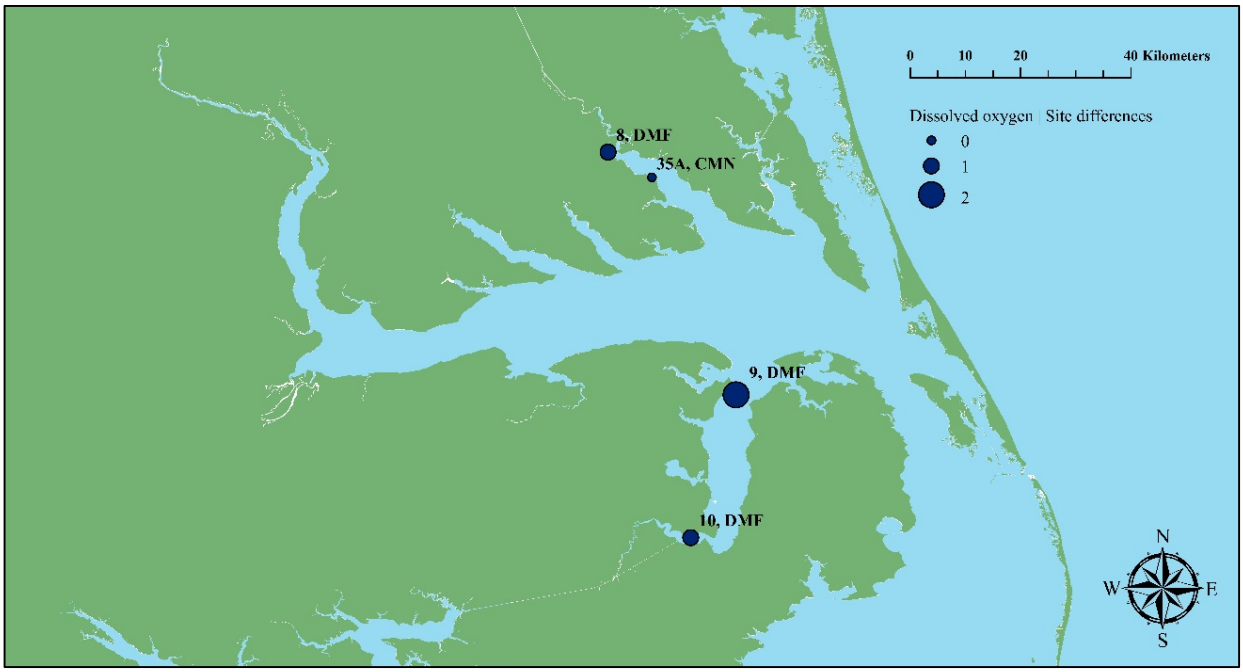
Water depth	Site	36A	5	6	12	32A	4	25C	14	1
Middle region	**36A**		-1.59	-1.79	1.89	1.21	-5.89	1.30	2.19	4.69
	5	-1.59		-0.20	0.30	-0.39	4.30	-0.30	0.60	3.10
	6	-1.79	-0.20		0.10	-0.59	4.10	-0.50	0.40	2.90
	12	1.89	0.30	0.10		0.69	-4.00	0.60	-0.30	2.80
	32A	1.21	-0.39	-0.59	0.69		-4.69	0.09	0.99	3.49
	4	-5.89	4.30	4.10	-4.00	-4.69		-4.60	-3.70	-1.20
	25C	1.30	-0.30	-0.50	0.60	0.09	-4.60		0.90	3.40
	14	2.19	0.60	0.40	-0.30	0.99	-3.70	0.895		2.50
	1	4.69	3.10	2.90	2.80	3.49	-1.20	3.395	2.50	

Appendix E8. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the upper Albemarle region using combined water depth (meters) data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (orange circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



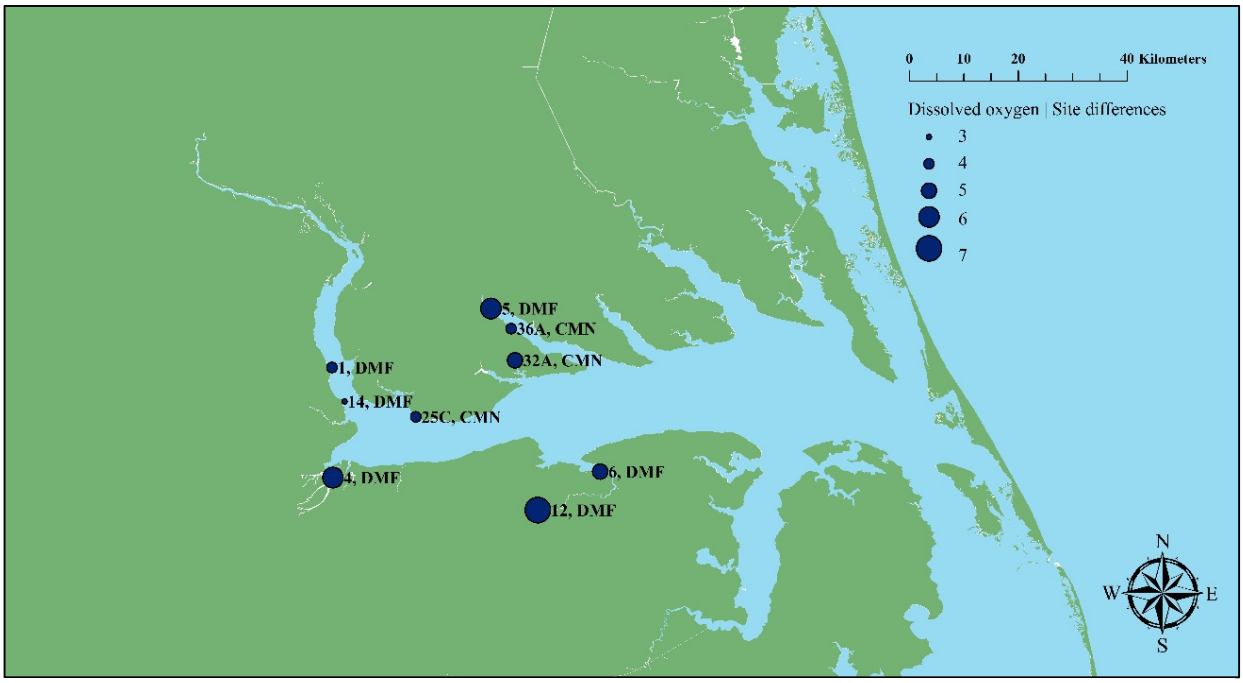
Water depth	Site	05C	2	11	22C	3	21C	13
Upper region	**05C**		-4.73	-1.33	-0.83	-4.43	-0.47	-1.33
	2	-4.73		-3.40	3.90	0.30	4.26	-3.40
	11	-1.33	-3.40		0.50	-3.10	0.86	0.00
	22C	-0.83	3.90	0.50		-3.60	-0.36	0.50
	3	-4.43	0.30	-3.10	-3.60		-3.96	-3.10
	21C	-0.47	4.26	0.86	-0.36	-3.96		0.86
	13	-1.33	-3.40	0.00	0.50	-3.10	0.86	

Appendix E9. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the lower Albemarle region using combined dissolved oxygen (milligrams per liter) data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (blue circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



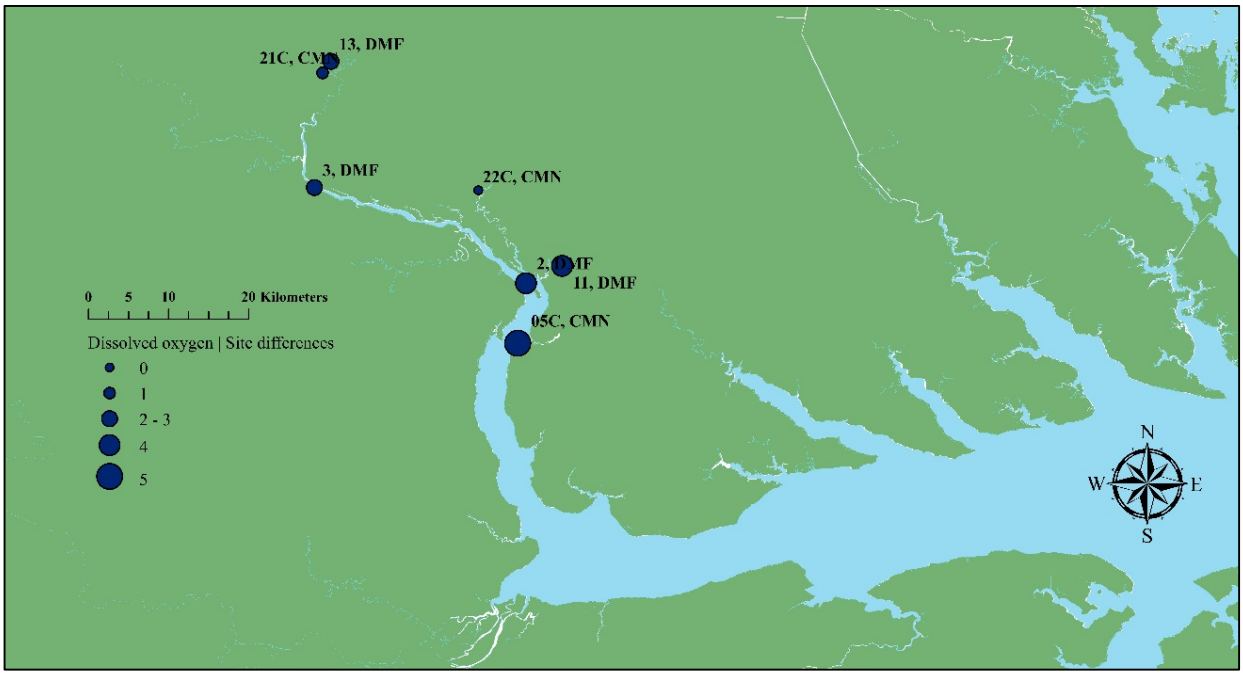
Dissolved oxygen	Site	9	10	35A	8
Lower region	9		-0.78	-0.62	-0.74
	10	-0.78		-0.16	-0.05
	35A	-0.62	-0.16		0.11
	8	-0.74	-0.05	0.11	

Appendix E10. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the middle Albemarle region using combined dissolved oxygen (milligrams per liter) data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (blue circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



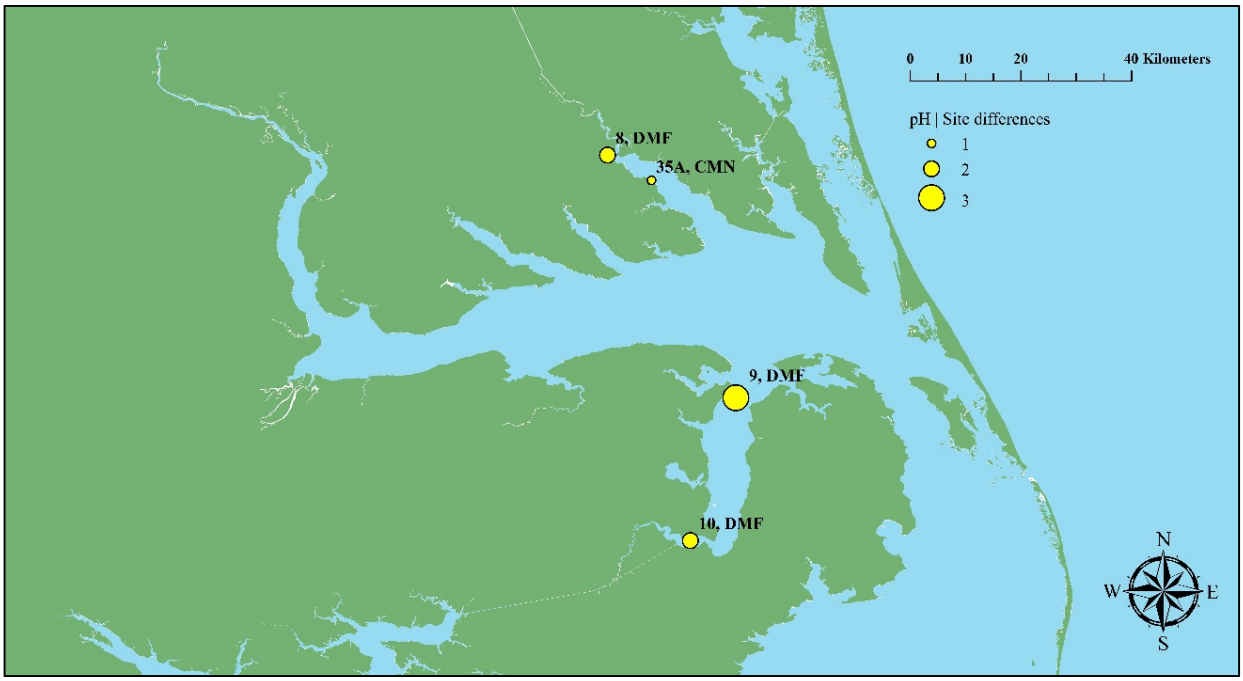
Dissolved oxygen	Site	36A	5	6	12	32A	4	25C	14	1
Middle region	**36A**		2.08	1.74	-5.63	0.80	1.02	1.05	-0.53	0.73
	5	2.08		-0.34	-3.56	2.87	1.05	3.13	1.55	2.80
	6	1.74	-0.34		-3.89	2.54	0.72	2.79	1.21	2.47
	12	-5.63	-3.56	-3.89		-6.43	-4.61	-6.69	-5.11	6.36
	32A	0.80	2.87	2.54	-6.43		1.82	0.25	-1.33	-0.07
	4	1.02	1.05	0.72	-4.61	1.82		2.08	0.50	1.75
	25C	1.05	3.13	2.79	-6.69	0.25	2.08		-1.58	-0.32
	14	-0.53	1.55	1.21	-5.11	-1.33	0.50	-1.578		1.26
	1	0.73	2.80	2.47	6.36	-0.07	1.75	-0.323	1.26	

Appendix E11. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the upper Albemarle region using combined dissolved oxygen (milligrams per liter) data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (blue circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



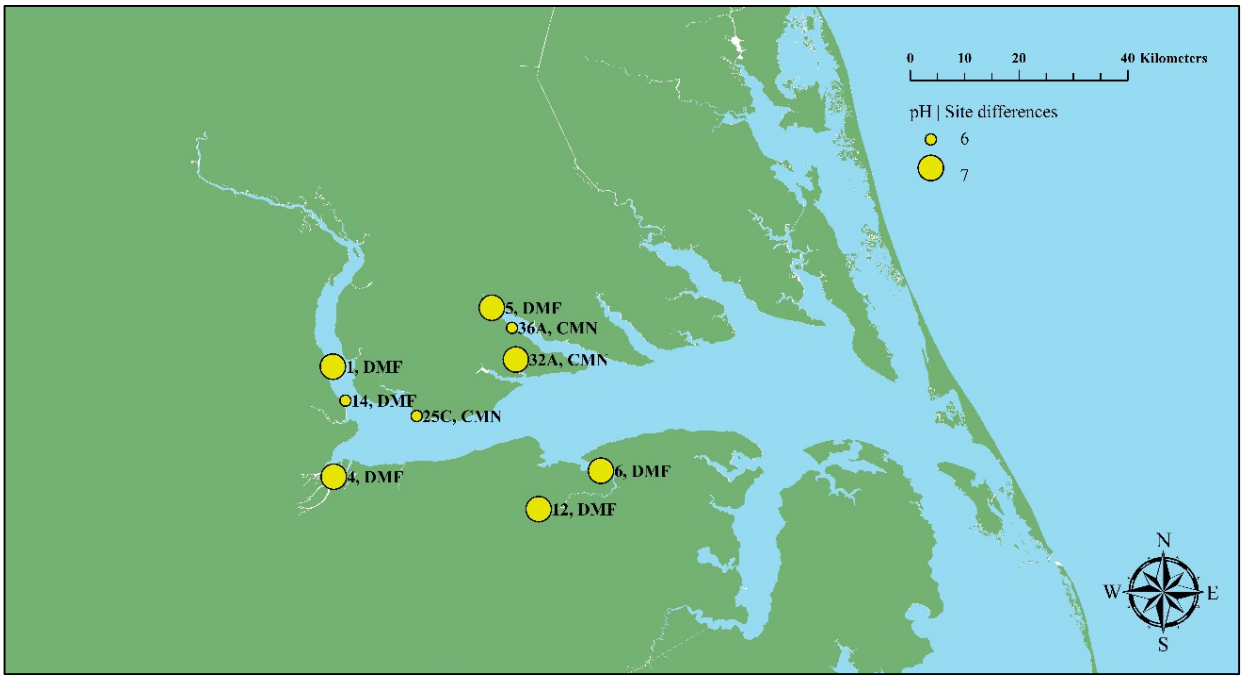
Dissolved oxygen	Site	05C	2	11	22C	3	21C	13
Upper region	**05C**		1.56	4.64	1.88	2.58	4.02	3.16
	2	1.56		-3.08	0.32	1.02	2.45	-1.60
	11	4.64	-3.08		-2.76	-2.06	-0.63	-1.49
	22C	1.88	0.32	-2.76		0.70	-2.13	-1.28
	3	2.58	1.02	-2.06	0.70		-1.44	-0.58
	21C	4.02	2.45	-0.63	-2.13	-1.44		0.86
	13	3.16	-1.60	-1.49	-1.28	-0.58	0.86	

Appendix E12. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the lower Albemarle region using combined pH data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (yellow circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



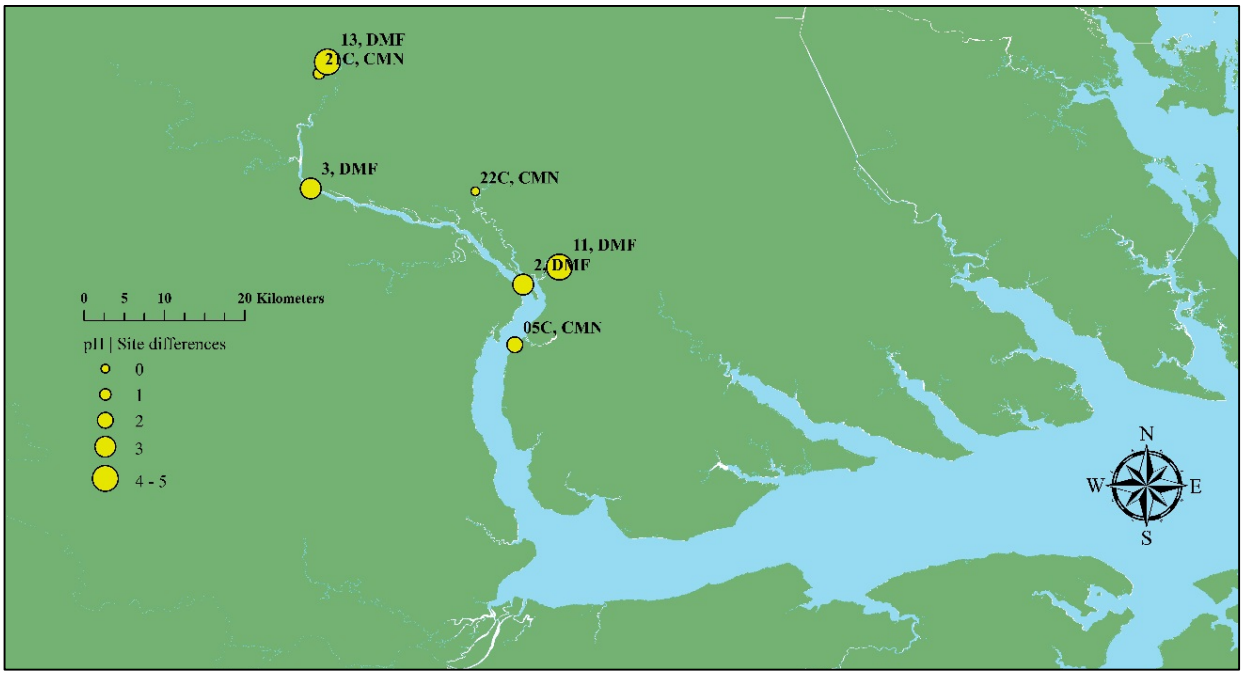
pH	Site	9	10	35A	8
Lower region	**9**		-0.18	-0.52	-0.63
	10	-0.18		0.35	0.46
	35A	-0.52	0.35		0.11
	8	-0.63	0.46	0.11	

Appendix E13. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the middle Albemarle region using combined pH data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (yellow circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level See Table 2 for site information and Table 4 for distances (kilometers) among sites.



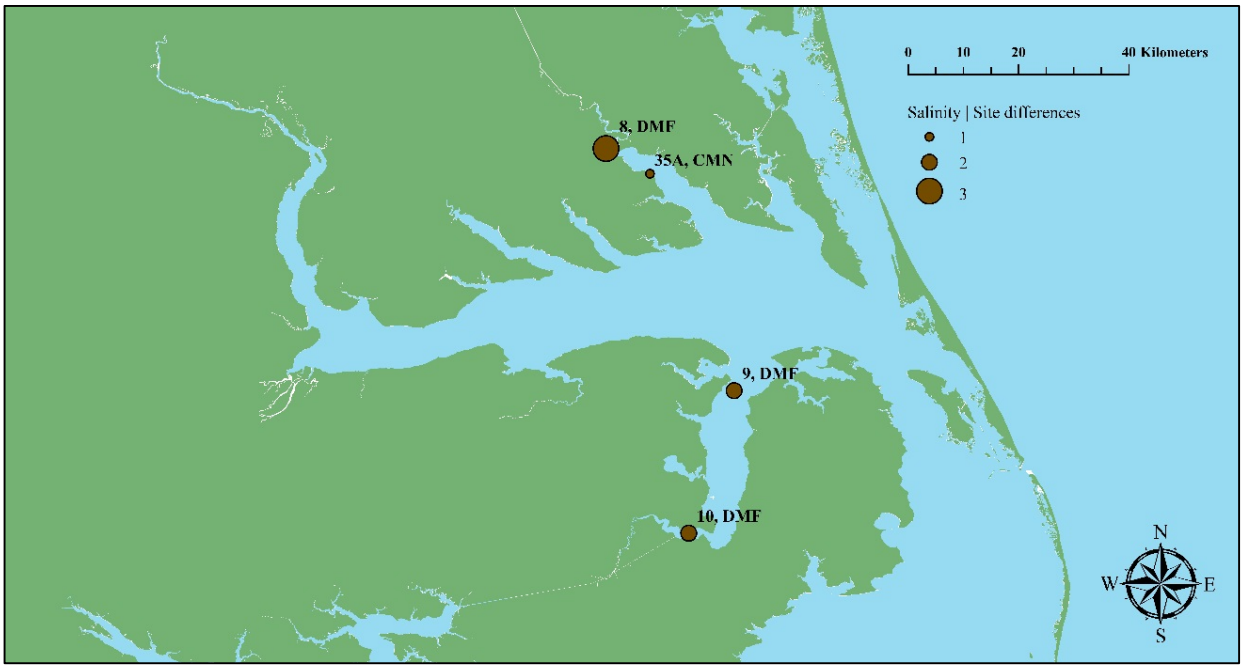
pH	Site	36A	5	6	12	32A	4	25C	14	1
Middle region	**36A**		0.15	-0.32	0.07	1.08	-0.50	0.44	0.87	0.71
	5	0.15		-0.47	0.22	1.24	0.65	0.60	1.03	0.87
	6	-0.32	-0.47		-0.25	0.76	0.18	0.12	0.56	0.40
	12	0.07	0.22	-0.25		-1.01	-0.43	-0.38	-0.81	0.65
	32A	1.08	1.24	0.76	-1.01		0.58	-0.64	-0.21	-0.37
	4	-0.50	0.65	0.18	-0.43	0.58		-0.06	0.37	0.21
	25C	0.44	0.60	0.12	-0.38	-0.64	-0.06		0.43	0.27
	14	0.87	1.03	0.56	-0.81	-0.21	0.37	0.43		0.16
	1	0.71	0.87	0.40	0.65	-0.37	0.21	0.271	-0.16	

Appendix E14. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the upper Albemarle region using combined pH data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (yellow circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



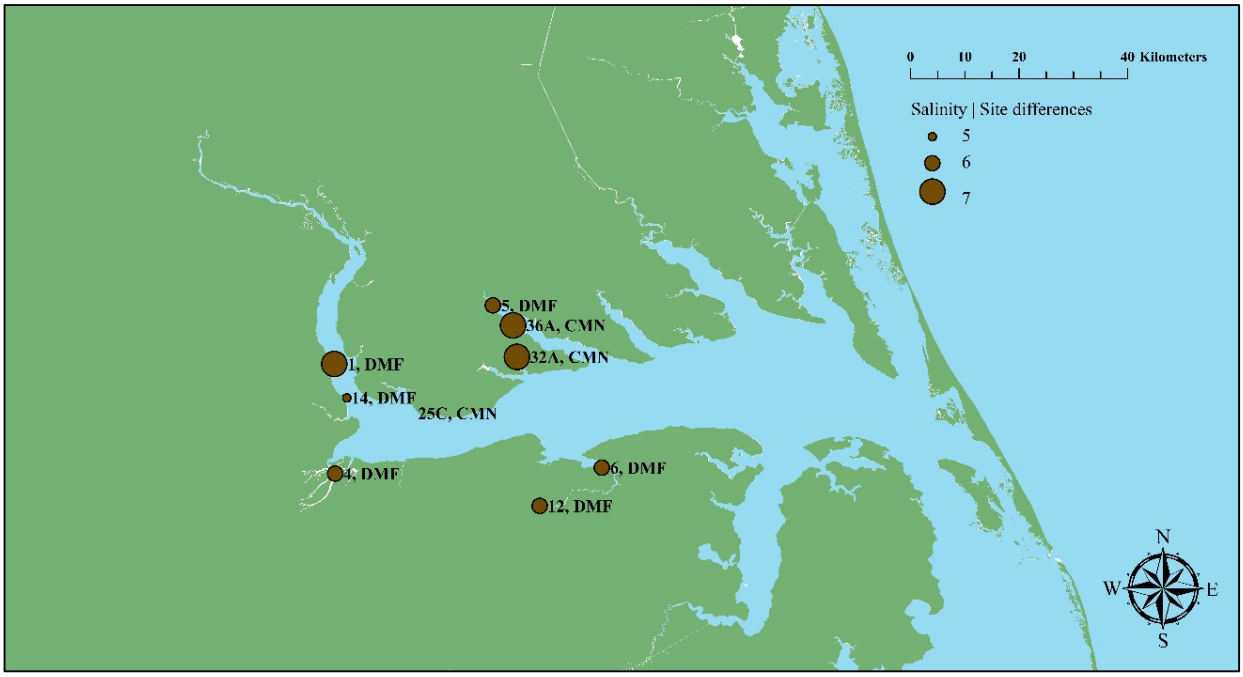
pH	Site	05C	2	11	22C	3	21C	13
Upper region	**05C**		-0.12	0.47	0.80	0.11	0.40	-0.26
	2	-0.12		-0.59	0.93	0.24	0.52	0.13
	11	0.47	-0.59		0.34	-0.36	-0.07	-0.73
	22C	0.80	0.93	0.34		-0.69	0.41	1.06
	3	0.11	0.24	-0.36	-0.69		-0.28	0.37
	21C	0.40	0.52	-0.07	0.41	-0.28		0.65
	13	-0.26	0.13	-0.73	1.06	0.37	0.65	

Appendix E15. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the lower Albemarle region using combined salinity (parts per thousand) data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. The map plots these sites (brown circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



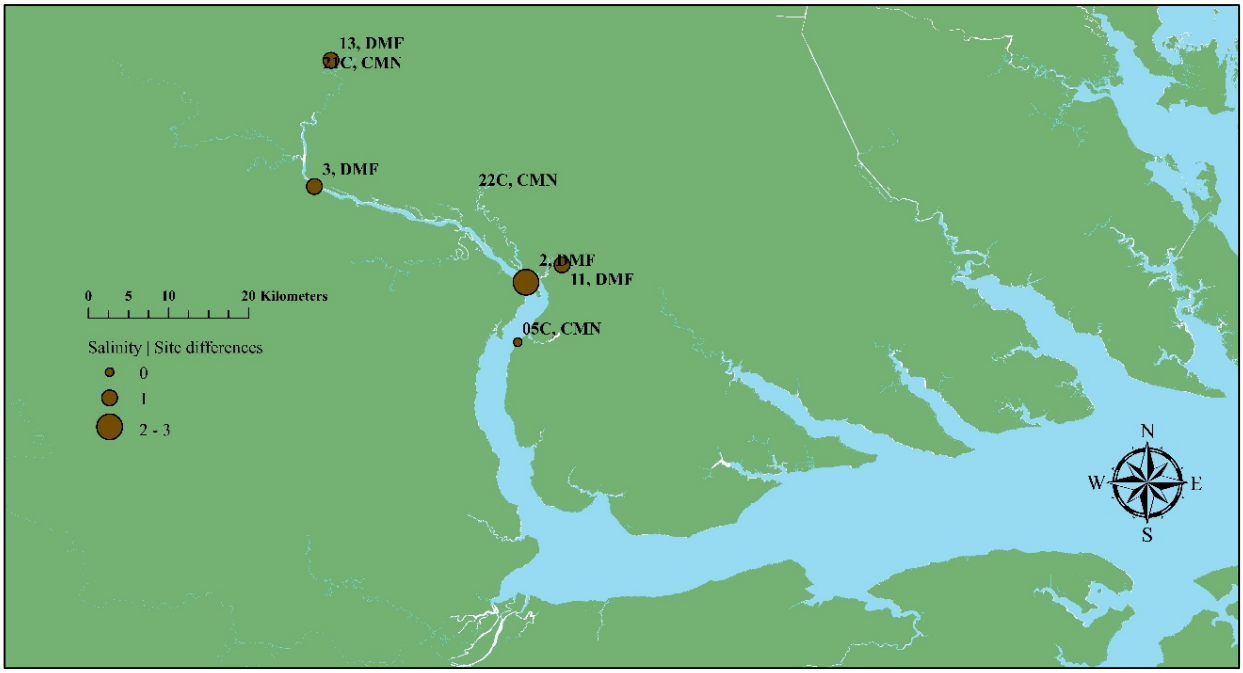
Salinity	Site	9	10	35A	8
Lower region	**9**		0.58	0.37	-0.69
	10	0.58		0.21	1.27
	35A	0.37	0.21		1.06
	8	-0.69	1.27	1.06	

Appendix E16. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the middle Albemarle region using combined salinity (parts per thousand) data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. Black pattern shaded areas denotes missing data. The map plots these sites (brown circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.



Salinity	Site	36A	5	6	12	32A	4	25C	14	1
Middle region	**36A**		4.33	3.90	-4.86	-2.22	5.02		-3.90	-4.58
	5	4.33		-0.43	-0.53	2.11	-0.69		0.44	-0.25
	6	3.90	-0.43		-0.96	1.68	-1.12		0.01	-0.68
	12	-4.86	-0.53	-0.96		-2.64	0.16		-0.97	0.29
	32A	-2.22	2.11	1.68	-2.64		2.80		-1.67	-2.35
	4	5.02	-0.69	-1.12	0.16	2.80			1.13	0.44
	25C									
	14	-3.90	0.44	0.01	-0.97	-1.67	1.13			-0.68
	1	-4.58	-0.25	-0.68	0.29	-2.35	0.44		-0.68	

Appendix E17. Post-hoc pairwise comparison matrix for sites in the 2008-2010 block of the upper Albemarle region using combined salinity (parts per thousand) data from APNEP-CMN and NCDMF. Values represent mean differences among sites. Gray shaded areas represent mean values that were significant at the 0.05 alpha level. Black pattern shaded areas denotes missing data. The map plots these sites (brown circles), which are size dependent based on the number of sites that differed significantly at the 0.05 alpha level. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

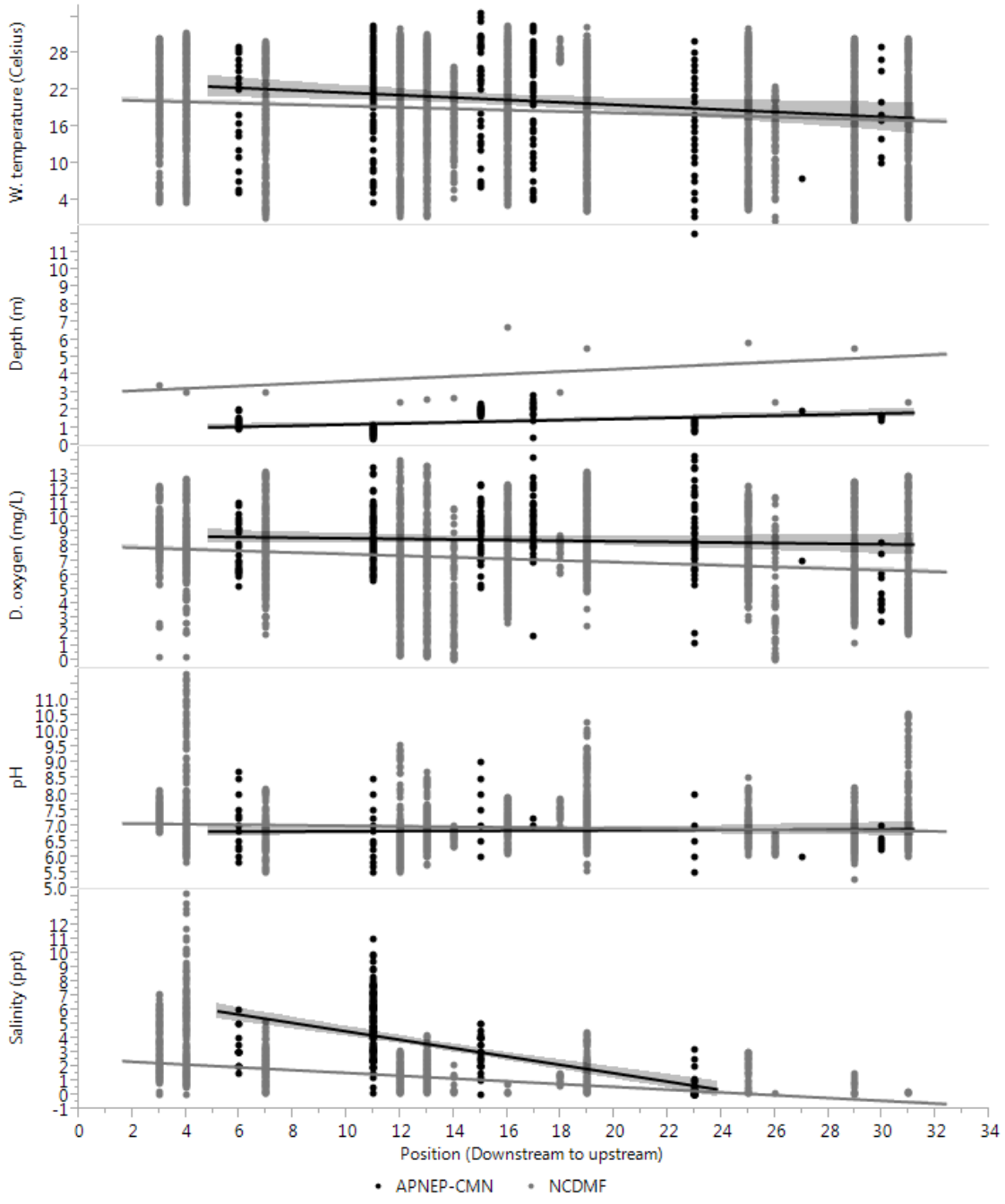


Salinity	Site	05C	2	11	22C	3	21C	13
Upper region	05C		-0.04	0.14		0.16		0.16
	2	-0.04		-0.18		-0.19		-0.19
	11	0.14	-0.18			0.01		0.01
	22C							
	3	0.16	0.19	0.01				0.00
	21C							
	13	0.16	-0.19	0.01		0.00		

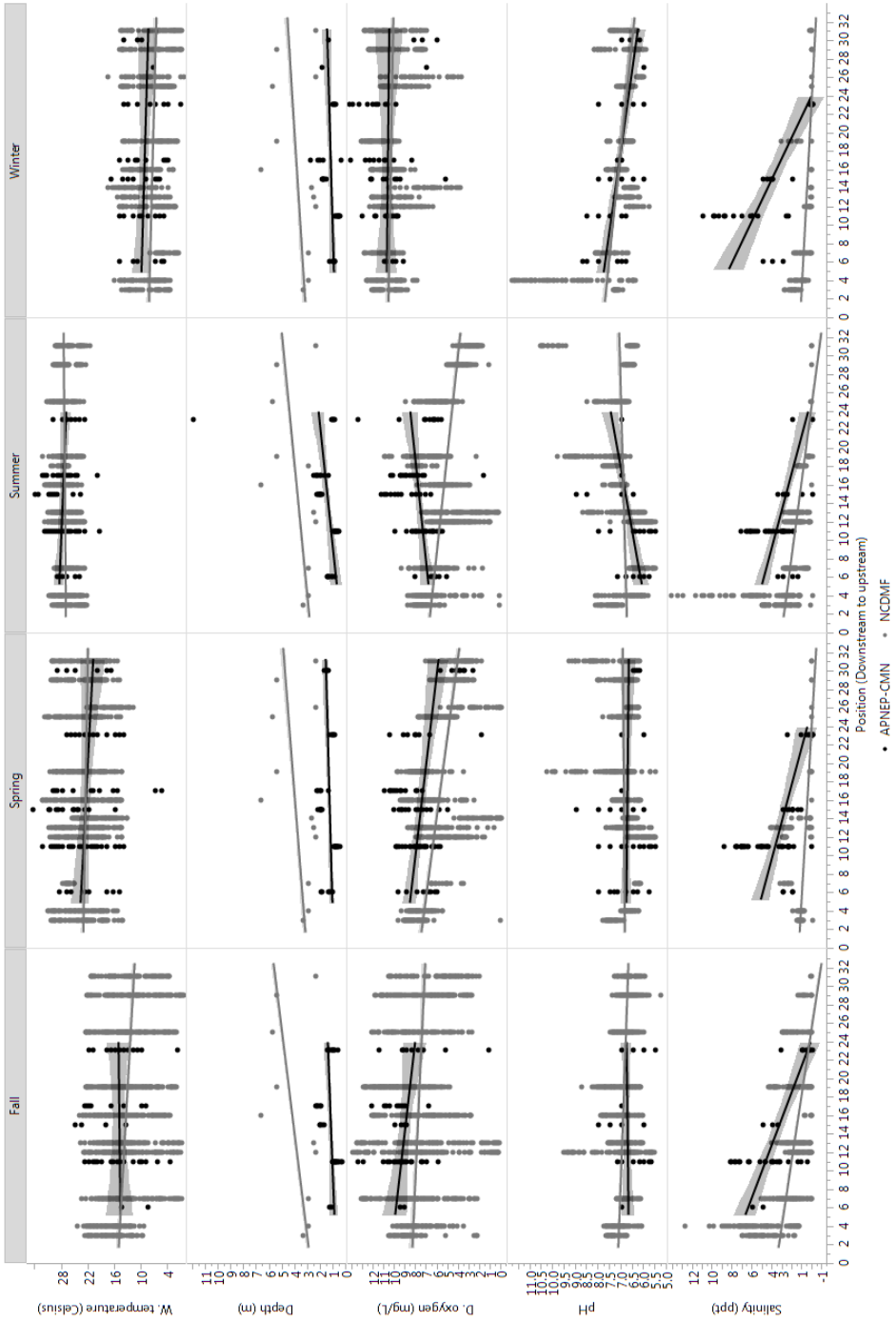
Appendix E18. Slope estimates of water temperature (degrees Celsius), water depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) by position (downstream to upstream) and separated by project and region for the 2008-2010 block of the Albemarle region. Project = APNEP-CMN, NCDMF. Region = lower, middle, and upper. P-value is based on the slope of the fit line. R^2 = adjusted R-square. See Appendix E1 for sample sizes. Appendix E19 and E20 visualizes these data.

Position	**Lower**				**Middle**				**Upper**			
Project	**Water temperature (°C)**				**Water temperature (°C)**				**Water temperature (°C)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	N/A	N/A	N/A	N/A	20.933	0.070	0.739	-0.004	14.082	0.142	0.668	-0.011
NCDMF	23.947	-0.953	< 0.01	0.036	23.294	-0.284	< 0.01	0.009	21.591	-0.145	0.123	0.001
	Water depth (m)				**Water depth (m)**				**Water depth (m)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	N/A	N/A	N/A	N/A	-1.693	0.230	< 0.01	0.864	0.215	0.045	0.433	-0.005
NCDMF	3.545	-0.087	< 0.01	0.505	-3.613	0.520	< 0.01	0.612	15.858	-0.402	< 0.01	0.431
	Dissolved oxygen (mg/L)				**Dissolved oxygen (mg/L)**				**Dissolved oxygen (mg/L)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	N/A	N/A	N/A	N/A	6.297	0.179	< 0.01	0.067	22.033	-0.572	< 0.01	0.258
NCDMF	8.801	-0.157	< 0.01	0.015	0.641	0.423	< 0.01	0.146	12.129	-0.206	< 0.01	0.028
	pH				**pH**				**pH**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	N/A	N/A	N/A	N/A	5.457	0.107	< 0.01	0.130	8.172	-0.060	0.002	0.108
NCDMF	7.834	-0.158	< 0.01	0.081	5.306	0.106	< 0.01	0.193	6.263	0.021	0.004	0.005
	Salinity (ppt)				**Salinity (ppt)**				**Salinity (ppt)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN	N/A	N/A	N/A	N/A	11.213	-0.556	< 0.01	0.168	N/A	N/A	N/A	N/A
NCDMF	3.499	-0.206	< 0.01	0.028	1.703	-0.072	< 0.01	0.047	1.078	-0.033	< 0.01	0.036

Appendix E19. Scatterplot with fit line and slope equation for the 2008-2010 block of the Albemarle region plotted over site position (downstream to upstream). Water quality variables include: water temperature (degrees Celsius), water depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). Black = APNEP-CMN; Gray = NCDMF. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

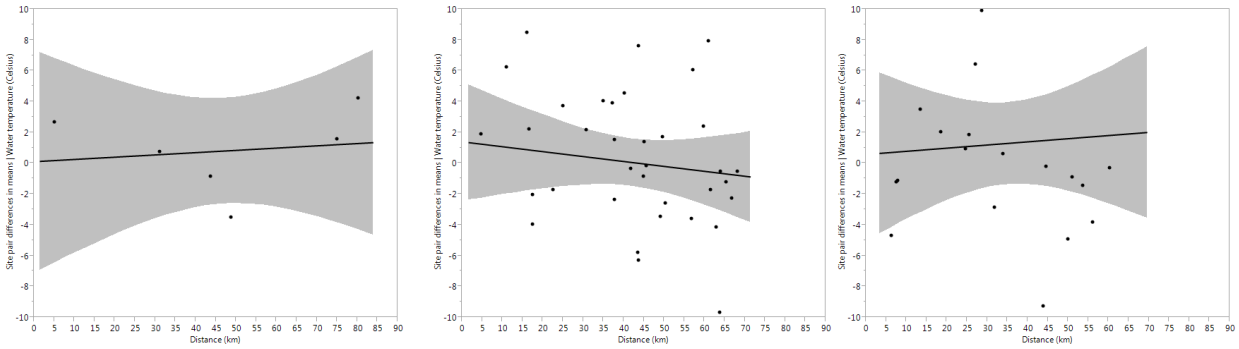


Appendix E20. Scatterplot with fit line of the 2008-2010 block of the Albemarle region plotted over site position (downstream to upstream) and separated by season. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). Water quality variables include: water temperature (degrees Celsius), water depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). Black = APNEP-CMN; Gray = NCDMF. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

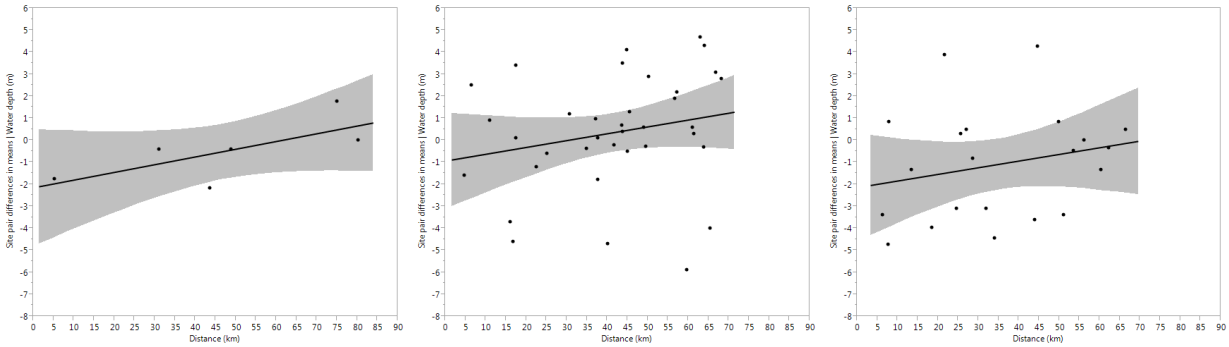


Appendix E21. Scatterplots of mean differences for all site pair combinations over distance (kilometers) and separated by region in the 2008-2010 block of the Albemarle region for (a) water temperature (degrees Celsius), (b) water depth (meters), (c) dissolved oxygen (milligrams per liter), (d) pH, and (e) salinity (parts per thousand). Left to right: lower, middle, and upper regions. See Table 4 for distances (kilometers) among sites.

(a) Water temperature

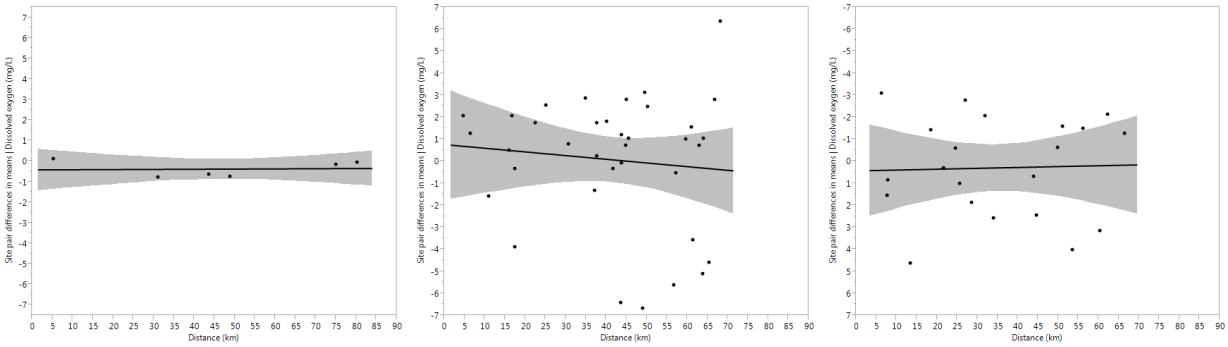


(b)Water depth

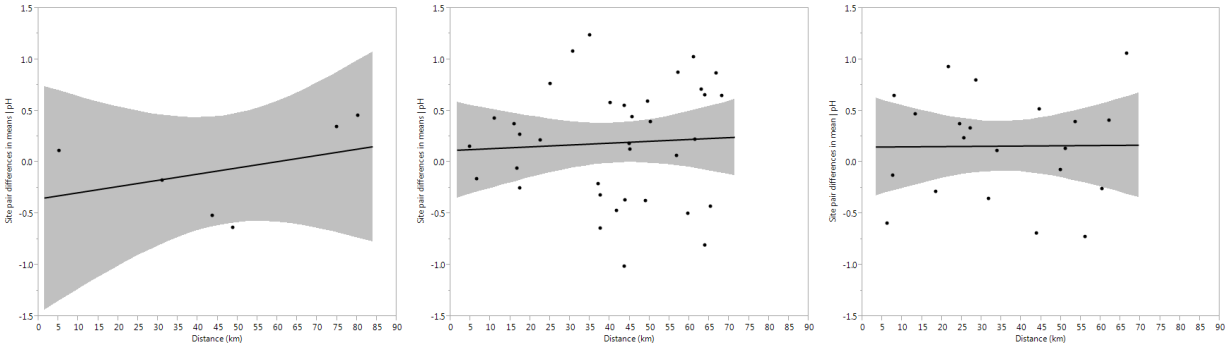


Appendix E21 (continued). Scatterplots of mean differences for all site pair combinations over distance (kilometers) and separated by region in the 2008-2010 block of the Albemarle region for (a) water temperature (degrees Celsius), (b) water depth (meters), (c) dissolved oxygen (milligrams per liter), (d) pH, and (e) salinity (parts per thousand). Left to right: lower, middle, and upper regions. See Table 4 for distances (kilometers) among sites.

(c) Dissolved oxygen

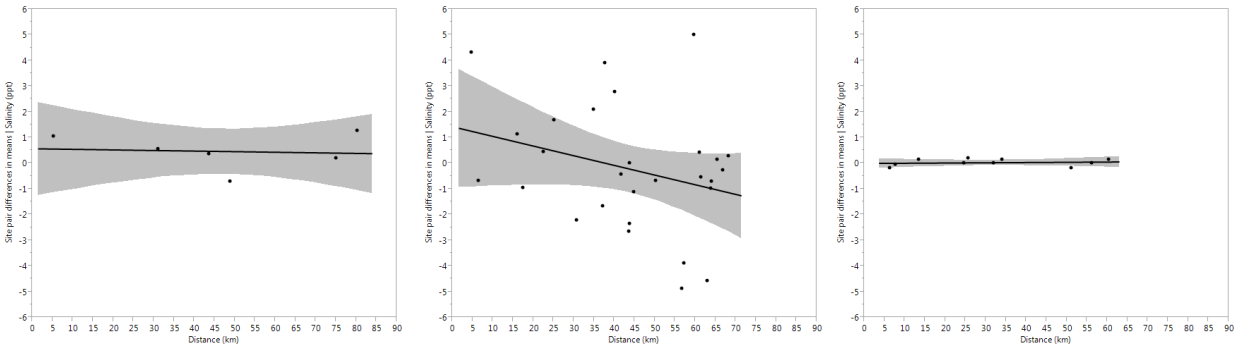


(d) pH



Appendix E21 (continued). Scatterplots of mean differences for all site pair combinations over distance (kilometers) and separated by region in the 2008-2010 block of the Albemarle region for (a) water temperature (degrees Celsius), (b) water depth (meters), (c) dissolved oxygen (milligrams per liter), (d) pH, and (e) salinity (parts per thousand). Left to right: lower, middle, and upper regions. See Table 4 for distances (kilometers) among sites.

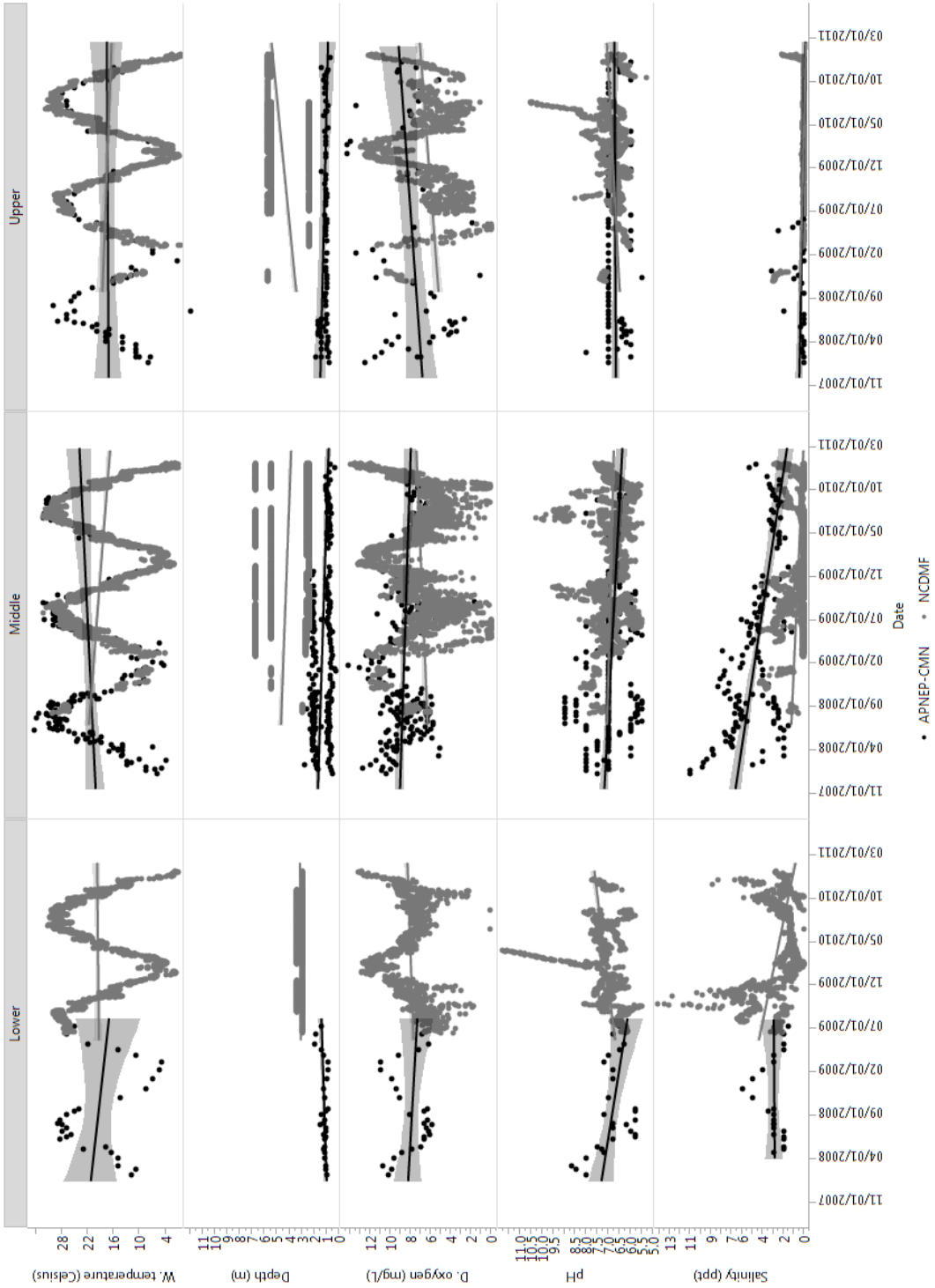
(e) Salinity



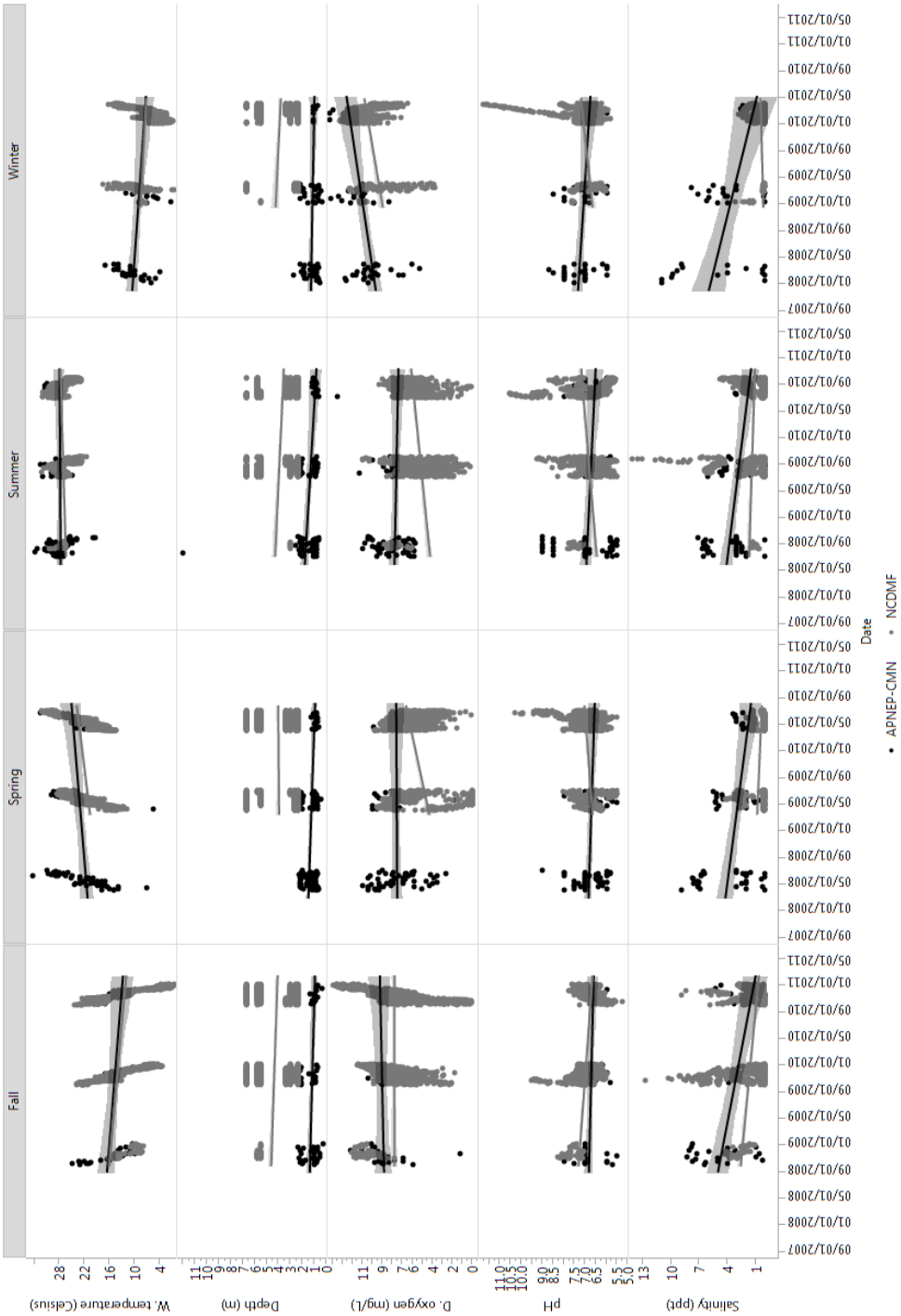
Appendix E22. Slope estimates of water temperature (degrees Celsius), water depth (meters), dissolved oxygen (mg/L), pH, and salinity (parts per thousand) by date and separated by project, region, and season for the 2008-2010 block of the Albemarle region. Project = APNEP-CMN, NCDMF. Region = lower, middle, and upper. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). P-value is based on the slope of the fit line. R^2 = adjusted R-square. See Appendix E1 for sample sizes. Appendices E23 and E24 visualizes these data.

Date	Fall				Spring				Summer				Winter			
Project	**Water temperature (°C)**				**Water temperature (°C)**				**Water temperature (°C)**				**Water temperature (°C)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN																
Lower	N/A	N/A	N/A	N/A	-77.312	0.000	0.814	-0.117	347.633	0.000	0.136	0.187	553.413	0.000	0.055	0.466
Middle	229.417	0.000	0.081	0.057	-141.096	0.000	0.095	0.029	-2.995	0.000	0.488	-0.007	13.764	0.000	0.973	-0.033
Upper	128.725	0.000	0.364	-0.007	-110.007	0.000	0.272	0.011	45.683	0.000	0.744	-0.063	204.481	0.000	0.058	0.148
NCDMF																
Lower	214.824	0.000	< 0.01	0.036	-178.766	0.000	0.080	0.007	-24.946	0.000	0.015	0.011	-5127.731	0.000	< 0.01	0.657
Middle	186.914	0.000	< 0.01	0.033	-192.082	0.000	< 0.01	0.056	-42.134	0.000	< 0.01	0.035	192.065	0.000	< 0.01	0.036
Upper	255.690	0.000	< 0.01	0.061	-471.951	0.000	< 0.01	0.176	-93.496	0.000	< 0.01	0.080	37.112	0.000	0.724	-0.003
	Water depth (m)				**Water depth (m)**				**Water depth (m)**				**Water depth (m)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN																
Lower	N/A	N/A	N/A	N/A	-57.578	0.000	0.001	0.723	-22.324	0.000	0.355	-0.002	4.192	0.000	0.811	-0.185
Middle	28.066	0.000	0.059	0.065	34.315	0.000	0.002	0.125	38.305	0.000	0.000	0.153	20.978	0.000	0.355	-0.004
Upper	-1.117	0.000	0.713	-0.061	17.222	0.000	0.023	0.164	106.588	0.000	0.237	0.034	5.693	0.000	0.580	-0.044
NCDMF																
Lower	12.703	0.000	< 0.01	0.063	-25.567	0.000	< 0.01	0.099	-10.567	0.000	< 0.01	0.102	-158.233	0.000	< 0.01	0.217
Middle	56.994	0.000	< 0.01	0.027	-1.923	0.000	0.674	-0.001	74.108	0.000	< 0.01	0.045	112.252	0.000	< 0.01	0.058
Upper	-42.166	0.000	< 0.01	0.041	-139.357	0.000	< 0.01	0.116	-84.466	0.000	< 0.01	0.070	-231.242	0.000	< 0.01	0.183
	Dissolved oxygen (mg/L)				**Dissolved oxygen (mg/L)**				**Dissolved oxygen (mg/L)**				**Dissolved oxygen (mg/L)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN																
Lower	N/A	N/A	N/A	N/A	116.919	0.000	0.209	0.088	141.790	0.000	0.153	0.164	15.004	0.000	0.940	-0.198
Middle	-27.224	0.000	0.268	0.007	49.040	0.000	0.081	0.033	56.179	0.000	0.044	0.040	-38.700	0.000	0.297	0.004
Upper	-54.956	0.000	0.588	-0.082	-116.021	0.000	0.116	0.100	-69.900	0.000	0.378	-0.014	-228.192	0.000	0.002	0.489
NCDMF																
Lower	-1.489	0.000	0.652	-0.002	-163.961	0.000	< 0.01	0.088	-97.052	0.000	< 0.01	0.146	1044.228	0.000	< 0.01	0.323
Middle	40.202	0.000	0.098	0.002	-129.286	0.000	< 0.01	0.064	47.891	0.000	0.003	0.013	-93.555	0.000	< 0.01	0.049
Upper	30.211	0.000	0.327	0.000	-233.942	0.000	< 0.01	0.260	-165.802	0.000	< 0.01	0.227	-225.001	0.000	< 0.01	0.127
	pH				**pH**				**pH**				**pH**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN																
Lower	N/A	N/A	N/A	N/A	64.622	0.000	0.295	0.028	-6.711	0.000	0.851	-0.137	153.737	0.000	0.004	0.810
Middle	12.002	0.000	0.591	-0.018	28.997	0.000	0.055	0.043	40.596	0.000	0.034	0.046	20.923	0.000	0.408	-0.009
Upper	21.361	0.000	0.319	0.003	-7.393	0.000	0.193	0.031	N/A	N/A	N/A	N/A	12.979	0.000	0.705	-0.050
NCDMF																
Lower	-7.686	0.000	0.019	0.018	-103.263	0.000	< 0.01	0.284	-60.371	0.000	< 0.01	0.209	-619.161	0.000	< 0.01	0.075
Middle	48.124	0.000	< 0.01	0.151	2.664	0.000	0.408	0.000	8.152	0.000	0.852	-0.002	46.547	0.000	< 0.01	0.209
Upper	43.256	0.000	< 0.01	0.259	-61.818	0.000	< 0.01	0.162	-133.724	0.000	< 0.01	0.323	-60.799	0.000	< 0.01	0.151
	Salinity (ppt)				**Salinity (ppt)**				**Salinity (ppt)**				**Salinity (ppt)**			
	Intercept	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**	**Intercept**	**Slope**	**P**	**R^2**
APNEP-CMN																
Lower	N/A	N/A	N/A	N/A	38.262	0.000	0.314	0.021	139.638	0.000	0.055	0.348	1014.943	0.000	0.035	0.897
Middle	183.961	0.000	0.000	0.410	162.811	0.000	0.000	0.289	112.410	0.000	0.000	0.219	255.683	0.000	0.004	0.294
Upper	58.915	0.000	0.026	0.274	9.450	0.000	0.689	-0.059	32.686	0.000	0.120	0.133	5.187	0.000	0.102	0.141
NCDMF																
Lower	253.102	0.000	< 0.01	0.297	142.742	0.000	< 0.01	0.640	254.065	0.000	< 0.01	0.300	-144.035	0.000	0.066	0.011
Middle	83.681	0.000	< 0.01	0.205	78.243	0.000	< 0.01	0.154	26.418	0.000	< 0.01	0.032	28.290	0.000	< 0.01	0.127
Upper	58.279	0.000	< 0.01	0.204	2.149	0.000	< 0.01	0.099	0.076	0.000	0.957	-0.003	3.635	0.000	< 0.01	0.068

Appendix E23. Seasonal scatterplot with fit line of water temperature (degrees Celsius), water depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) separated by region and plotted over time for the 2008-2010 block of the Albemarle region. Region = lower, middle, and upper. Black = APNEP-CMN. Gray = NCDMF.



Appendix E24. Scatterplot with fit line of water temperature (degrees Celsius), water depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) separated by season and plotted over time for the 2008-2010 block of the Albemarle region. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). Black = APNEP-CMN; Gray = NCDMF.



Appendix E25. Output from seasonal Mann-Kendall trend analysis for water temperature (degrees Celsius), water depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). Analysis separated by project and region for the 2008-2010 block of the Albemarle region. H_o = no trend; H_a = monotonic trend (upward or downward).

Project	Water temperature (°C)	
	P-value	**Trend**
APNEP-CMN	0.13	No trend
NCDMF	0.26	No trend
	Water depth (m)	
	P-value	**Trend**
APNEP-CMN	< 0.01	Monotonic trend
NCDMF	< 0.01	Monotonic trend
	Dissolved oxygen (mg/L)	
	P-value	**Trend**
APNEP-CMN	0.16	No trend
NCDMF	< 0.01	Monotonic trend
	pH	
	P-value	**Trend**
APNEP-CMN	< 0.01	Monotonic trend
NCDMF	0.04	No trend
	Salinity (ppt)	
	P-value	**Trend**
APNEP-CMN	< 0.01	Monotonic trend
NCDMF	0.13	No trend

Appendix F1. Descriptive statistics of available water quality data for the 2011-2012 block of the upper Albemarle region. Water quality variables include: water temperature (degrees Celsius), water depth (meters), secchi depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

	Upper		
Site, Project	**Water temperature (°C)**		
	N	**Mean**	**Std. Dev.**
05C, APNEP-CMN	44	15.9	7.9
CB, ECU	10	17.3	8.3
	Water depth (m)		
	N	**Mean**	**Std. Dev.**
05C, APNEP-CMN	42	1.2	0.8
CB, ECU	0		
	Secchi depth (m)		
	N	**Mean**	**Std. Dev.**
05C, APNEP-CMN	42	1.2	0.8
CB, ECU	0		
	Dissolved oxygen (mg/L)		
	N	**Mean**	**Std. Dev.**
05C, APNEP-CMN	27	9.8	3.4
CB, ECU	10	11.4	8.8
	pH		
	N	**Mean**	**Std. Dev.**
05C, APNEP-CMN	45	6.9	0.2
CB, ECU	10	8.5	0.3
	Salinity (ppt)		
	N	**Mean**	**Std. Dev.**
05C, APNEP-CMN	36	0.2	0.6
CB, ECU	9	1.0	0.2

Appendix F2. Descriptive statistics of (a) water temperature (degrees Celsius), (b) dissolved oxygen (milligrams per liter), (c) pH, and (d) salinity (parts per thousand) for the 2011-2012 block of the upper Albemarle region separated by site and season. Position = numbered from downstream to upstream. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). N = number of monitoring sessions. Std. Dev. = standard deviation. See Table 2 for site information and Table 4 for distances (kilometers) among sites.

(a) Water temperature

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	23	Upper	05C	12	8.1	4.1	10	18.3	5.6	10	25.1	2.6	12	13.9	6.5
ECU	24	Upper	CB	3	10.5	3.9	2	23.1	7.1	2	28.3	3.7	3	12.9	2.8
Sum, Mean				**15**	**9.3**		**12**	**20.7**		**12**	**26.7**		**15**	**13.4**	

(b) Dissolved oxygen

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	23	Upper	05C	8	9.9	2.3	7	9.4	2.4	6	9.6	3.8	6	10.5	5.5
ECU	24	Upper	CB	3	10.1	1.1	2	7.5	0.1	2	20.9	21.3	3	8.9	0.7
Sum, Mean				**11**	**10.0**		**9**	**8.4**		**8**	**15.2**		**9**	**9.7**	

(c) pH

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	23	Upper	05C	11	7.0	0.0	11	7.0	0.2	11	7.0	0.4	12	6.9	0.3
ECU	24	Upper	CB	3	8.4	0.3	2	8.5	0.2	2	8.6	0.0	3	8.6	0.4
Sum, Mean				**0**	**7.7**		**0**	**7.7**		**0**	**7.8**		**0**	**7.7**	

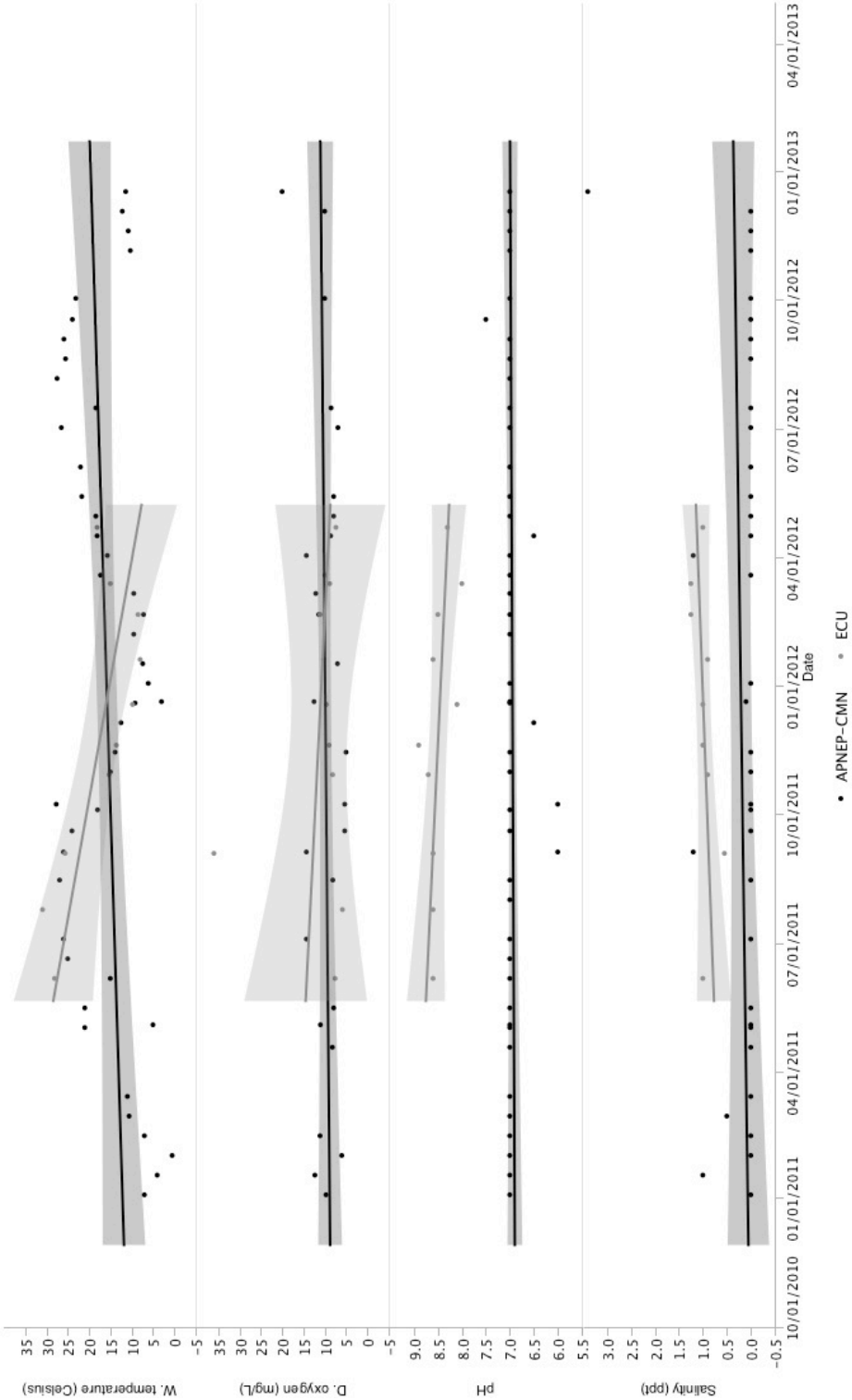
(d) Salinity

				Winter			Spring			Summer			Fall		
Project	**Position**	**Region**	**Site**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**
APNEP-CMN	23	Upper	05C	8	0.2	0.4	9	0.1	0.4	9	0.1	0.4	10	0.4	1.1
ECU	24	Upper	CB	3	1.1	0.2	2	1.0	0.0	1	0.6		3	1.0	0.1
Sum, Mean				**0**	**0.7**		**0**	**0.6**		**0**	**0.3**		**0**	**0.7**	

Appendix F3. Slope estimates of water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) by date and separated by site and season for the 2011-2012 block of the upper Albemarle region. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). P-value is based on the slope of the fit line. R^2 = adjusted R-square. See Appendix F1 for sample sizes. Appendices F4 and F5 visualizes these data.

Date	Fall				Spring				Summer				Winter			
Site, Project	Water temperature (°C)				Water temperature (°C)				Water temperature (°C)				Water temperature (°C)			
	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2
05C, APNEP-CMN	253.923	0.000	0.580	-0.065	-254.918	0.000	0.526	-0.066	142.287	0.000	0.554	-0.074	-360.430	0.000	0.148	0.117
CB, ECU	4398.592	0.000	0.080	0.969	1250.499	0.000	N/A	N/A	5236.560	0.000	N/A	N/A	-4783.495	0.000	0.360	0.425
	Dissolved oxygen (mg/L)				Dissolved oxygen (mg/L)				Dissolved oxygen (mg/L)				Dissolved oxygen (mg/L)			
	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2
05C, APNEP-CMN	-692.259	0.000	0.153	0.296	-36.009	0.000	0.847	-0.190	409.554	0.000	0.370	0.004	-36.962	0.000	0.798	-0.153
CB, ECU	-1149.250	0.000	0.096	0.955	29.563	0.000	N/A	N/A	-29617.310	0.000	N/A	N/A	914.749	0.000	0.632	-0.404
	pH				pH				pH				pH			
	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2
05C, APNEP-CMN	-18.272	0.000	0.209	0.068	17.113	0.000	0.344	0.000	-23.145	0.000	0.204	0.081	7.000	0.000	N/A	N/A
CB, ECU	519.137	0.000	0.429	0.221	45.272	0.000	N/A	N/A	8.600	0.000	N/A	N/A	424.382	0.000	0.302	0.583
	Salinity (ppt)				Salinity (ppt)				Salinity (ppt)				Salinity (ppt)			
	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2	Intercept	Slope	P	R^2
05C, APNEP-CMN	-79.646	0.000	0.279	0.037	-20.889	0.000	0.503	-0.067	29.572	0.000	0.345	0.003	28.016	0.000	0.425	-0.040
CB, ECU	-73.014	0.000	0.392	0.333	1.000	0.000	N/A	N/A	N/A	N/A	N/A	N/A	-267.580	0.000	0.266	0.672

Appendix F4. Seasonal scatterplot with fit line of water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) plotted over time for the 2011-2012 block of the upper Albemarle region. Black = 05C, APNEP-CMN. Gray = CB, ECU.



Appendix F5. Scatterplot with fit line of water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand) separated by season and plotted over time for the 2011-2012 block of the upper Albemarle region. Season = fall (October–December), spring (April–June), summer (July–September), and winter (January–March). Black = 05C, APNEP-CMN; Gray = CB, ECU.

Appendix F6. Output from seasonal Mann-Kendall trend analysis for water temperature (degrees Celsius), water depth (meters), dissolved oxygen (milligrams per liter), pH, and salinity (parts per thousand). Analysis separated by site for the 2011-2012 block of the upper Albemarle region. H_o = no trend; H_a = monotonic trend (upward or downward).

Site, Project	Water temperature (°C)	
	P-value	**Trend**
05C, APNEP-CMN	0.06	No trend
CB, ECU	0.03	Monotonic trend
	Dissolved oxygen (mg/L)	
	P-value	**Trend**
05C, APNEP-CMN	0.52	No trend
CB, ECU	0.28	No trend
	pH	
	P-value	**Trend**
05C, APNEP-CMN	0.52	No trend
CB, ECU	0.07	Monotonic trend
	Salinity (ppt)	
	P-value	**Trend**
05C, APNEP-CMN	0.52	No trend
CB, ECU	0.05	Monotonic trend

CHAPTER 3

What do you know about water quality: Using consensus analysis to understand cultural beliefs of water quality among citizen science volunteers and other cultural groups

ABSTRACT

Scientists often argue that the public should be more aware of our physical environment. One way to resolve this argument is citizen science, which has been linked to promoting scientific literacy among its volunteers and participants of education campaigns. Often times, citizen science is questioned for the reliability of volunteer data, which may increase the potential for these projects to be eliminated if the costs outweigh the benefits. A better understanding of the relationship between citizen science and scientific literacy can help identify areas of weakness for improved volunteer training and education campaigns. These improvements may also strengthen the reliability of volunteer data. The impetus of this study was to investigate cultural beliefs of water quality among five cultural groups: (1) volunteers of citizen science that focus on water quality monitoring, (2) water quality professionals, (3) water quality educators, (4) commercial and recreational fishers, and (5) individuals with no experience in water quality. An online survey containing 55 statements on various water quality topics was distributed to representatives from multiple federal/state government and non-profit programs for broadcast to listserv subscribers' colleagues, and social media. Cultural consensus analysis was used to analyze 285 completed surveys to determine level of agreement (consensus) and cultural competencies within, and across, the cultural groups. Results suggested there was consensus within, and across, the cultural groups. Based on these results, it remains unclear whether citizen science is promoting scientific literacy. However, water quality educators and volunteers of citizen science had the strongest consensus within their groups; water quality professionals had the least consensus. Mean cultural competencies were also greater among volunteers and educators. The mean cultural competencies were not significantly different among the groups; the only exception was among educators and individuals with no experience in water quality. Results suggested that volunteers are receiving

their information on water quality primarily from educators, which are often involved in fostering citizen science projects. Discrepancies among the other cultural groups may have been associated with differences in education and professional backgrounds in water quality. There was 92 percent accordance (or unanimous agreement) among the cultural groups and survey statements. Eight percent discordance was observed for the following survey water quality topics: (1) time of day fluctuations, (2) water quality appearance, (3) pH, and (4) storm events. Coordinators of citizen science projects and educators are encouraged to include these topics for discussion during volunteer training sessions, follow-up site visits, and education campaigns. Influencing factors of the survey's design and distribution were also discussed.

INTRODUCTION

Citizen science is attributed to promoting scientific literacy through projects that enable volunteers to actively collect scientific data towards real scientific investigations (Bonney et al. 2009). Education also plays a major role in citizen science. The establishment of education campaigns help assist with volunteer recruitment in addition to providing an educational service to various interest groups.

Scientists often argue that the public should be more involved about environmental issues that impact our physical environment (Mooney 2010). Citizen science is one answer to this argument. With increasing technology and ideas, formal education practices may not be as strong as they once were (Hacker and Harris 1992). Projects that allow citizens to take on a more active role in the scientific process is most likely to improve scientific literacy (Evans et al. 2005). In addition, citizen science offers scientists opportunities to receive data in regions that are not routinely monitored, thus eliminating additional costs. Importantly, citizen science helps foster a community that is more scientific literate, which can have cascading effects when volunteers take on an ambassador role (Trumbull et al. 2000; Brewer 2002).

However, citizen science is sometimes questioned by scientists, decision makers, and managers about the reliability of volunteer data. Unfortunately, this can lead to volunteer data not being used for its intended purpose, thus creating a disservice to the volunteers and the scientific community. If citizen science project costs outweigh the benefits, then the probability that the project will be eliminated due to budgetary setbacks or general disinterest will be greater. While not all citizen science projects create uncertainty among certain groups, there still lies a need to better understand the full benefits of citizen science, such as scientific literacy. Surveys and open-

ended interviews can be used to gauge important information about community demographics and cultural beliefs of particular environmental issues.

Case study concerning citizen science and scientific literacy

Evans et al. (2005) investigated volunteer outcomes from a citizen science ecological research project titled, *Neighborhood Nestwatch*. The project began in 2000, and within its inaugural year, gathered 175 households to collect data about birds in the Washington, D.C. area. The two major goals of this project were to collect data that could help scientists better understand the ecology and population dynamics of eight bird species. The other goal was to teach volunteers living in urban/suburban areas about bird biology. During the second year of the project, staff issued volunteers a survey that included questions about demographics, level of education, level of experience/expertise, prior participation in similar projects, and their overall motivation to join the project. Open-ended interviews were also conducted with willing volunteers who represented different levels of age and education. Results showed that volunteers were primarily motivated to join the project because they wanted to be part of a real scientific investigation. The second motivating factor was to learn more about birds. Analysis was divided into two separate outcomes, (1) scientific literacy, and (2) sense of place. When asked about scientific literacy, 90 percent of the volunteers reported they learned more about bird biology and behavior. During the interviews, volunteers that identified as experienced birders reported learning something new about birds. For sense of place, 83 percent reported increased awareness when it comes to backyards serving as habitat for plants and animals. This led to some of the volunteers changing their behaviors such as planting more vegetation in their yard to offer additional habitat.

Face to face interactions among volunteers and scientists were discussed during the interviews. These direct interactions were important in helping volunteers improve their

knowledge of birds, data collection techniques, as well as interpretation of their observations. Additionally, discussions were instigated which allowed the volunteers to witness how scientists make decisions based on inquiries or presentation of data. Another perspective is the camaraderie that developed throughout this symbiotic relationship between volunteer and scientist. This relationship had the potential to break down the wall of intimidation that can exist between an experienced scientist and novice (Hogan 2002).

Introduction to study and water quality monitoring

The impetus for my study closely followed the design and scope of Evans et al. (2005) but instead sought to better understand cultural beliefs, or knowledge, of water quality among citizen science volunteers that conduct water quality monitoring. The United States Geological Survey (2013) defines water quality monitoring as the repetitive measurement, or observation, of a water body over time. Water quality is collected repetitively to detect changes and trends in water conditions that occur due to natural events and/or pollution. In order to detect trends and natural dynamics, water quality monitoring is a long-term effort (Meals et al. 2012). Volunteers of citizen science that conduct water quality monitoring assist scientists by collecting data in regions that are not regularly monitored such as smaller tributaries or along shorelines. This helps fill in the gaps to achieve a more complete data record of water quality in any given region.

Volunteers of citizen science and water quality

Prior to collecting water quality data, volunteers receive training from the coordinator or educator of the citizen science project. This training provides volunteers with a basic understanding of water quality. A "basic" understanding can be described as knowing the different water quality variables; being able to interpret the measurements of these variables; and a general sense of how these variables interact with one another, including biological activity.

The following sections will introduce cultural consensus theory, which was the theoretical framework used for this study. The intent was to use cultural consensus analysis to estimate cultural beliefs of citizen science volunteers that conduct water quality monitoring and how their beliefs concerning water quality may be similar or different when compared to other cultural groups with recognized cultural beliefs (e.g., water quality professionals).

What is culture and why is it relevant?

Weller (2007) defines culture as a set of learned and shared beliefs, and these cultural beliefs are the normative beliefs of a group. Culture is shaped from normative theory, or norms, which explain why individuals behave a certain way. The behaviors of these individuals shape their attitudes, thus potentially creating a culture. The strength of these norms also plays a role in influencing attitudes among these individuals and groups (Vaske and Whittaker 2004). Individuals with established norms will display stronger behaviors and public influence, whereas those with emerging norms may display weaker, less influential attitudes. For example, volunteers of the Albemarle-Pamlico National Estuary Partnership's Citizens' Monitoring Network (APNEP-CMN) may represent a cultural group. Their knowledge of water quality may separate them from other individuals who are not familiar with water quality.

Cultural consensus theory

Cultural consensus theory (CCT) is often used to estimate cultural beliefs down to the level at which individuals display those beliefs. If you were to ask individuals a set of questions (e.g., survey) about a similar topic, CCT could be used to examine the answers of each individual and aggregate them into groups who share similar cultural beliefs. In order to use CCT, there are three assumptions that must be met. First, each individual must answer questions independently with no consultation from other individuals and the one administering the questions. Second, the questions

must be on one topic and the difficulty range should be constant. The individual administering the questions should be mindful of jargon in their questions to avoid confusion, which can potentially skew results. Third, there must be one single set of answers to the questions; otherwise, aggregating the individuals into groups would prove difficult (Weller 2007). By not adopting these assumptions, the potential for response biases are greater.

Cultural consensus analysis is a technique based from cultural consensus theory and it can be broken down into two models. First to be developed was the formal model (Romney et al. 1986), which is a model of how questions are asked and answered. The formal model has individuals answer open-ended and multiple-choice questions. The responses for the open-ended questions can range from one word to a paragraph. The multiple-choice questions can be written so the responses would either read as true/false or yes/no. The assumption to the formal model is that there is no response bias in the individuals' answers to the questions. In other words, how might the individual respond if he/she does not know the answer? The formal model also corrects for guessing. The informal model (Romney et al. 1987) is a series of analytical procedures to determine the culturally correct answers and how the individuals assemble into different groups. This model can handle responses that are ordinal or scaled. Like the name suggests, it is not as restricted as the formal model. The formal model was used for this study.

Studies using cultural consensus theory

Boster and Johnson (1989) were interested to see how novice and expert fishers classified or grouped fishes and whether their decisions were based on form (morphological characteristics) or function (use and behavioral characteristics). Novices consisted of undergraduates in an anthropology course that had the least experience in saltwater fish identification or had no interest in fishing. The expert group consisted of recreational fishers from areas in the southeastern United

States. Results revealed that novices grouped fishes based on their form while experts were between form and function. When the groups were asked to explain, 98 percent of the novices said they based their groupings based on morphological features such as fin placement and body shape. The remaining two percent of the novices grouped the fishes based on their form and function. The experts (from North Carolina) were divided, with 30 percent saying they grouped the fishes based on their form and family membership. The majority of explanations grouped fishes on how edible they were, the level of sport in catching them, or habitat.

Boster and Johnson (1989) suggested that experts would be more consistent with their responses as opposed to novices. This is supported by the assumption that experts would have more knowledge of fishes as opposed to novices. The cultural consensus formal model (Romney et al. 1986) was applied to determine if knowledge resulted in a consensus. When both experts and novices were tested on how they grouped the fishes, there was a consensus among the two groups. When informants were tested against other informants from their group, there were strong correlations among novices. Correlations among the experts were not as strong. The novices tended to agree with how they grouped the fishes whereas the experts may agree less. This solidifies the conclusion that novices grouped the fishes on form alone while experts used both form and function. The reasoning is that experts carry more knowledge of the functional attributes of fishes, which can also vary from fisher to fisher. Novices have limited knowledge and most likely only able to group the fishes on form alone, which suggests why novices are highly correlated to one another.

Johnson and Griffith (2010) used the cultural consensus model (Romney et al. 1987) to look at cultural conceptions among three groups: (1) commercial fishers, (2) recreational fishers, and (3) managers. The purpose of this research was to better understand cultural variations in how

these groups dealt with problems concerning conceptions of coastal resource problems and how it should be managed. In-depth interviews were first conducted with central individuals from each group. During these interviews, individuals provided details concerning environmental issues and resource declines in North Carolina. These interviews helped the researchers come up with 59 statements (in an agree/disagree format) that centered on the causes of these environmental and resource problems. Managers that were considered "highly knowledgeable" were interviewed in person and respondents from the three groups received the questionnaire containing the 59 statements through mail. Results showed a cultural separation among commercial and recreational fishers. It was also evident that recreational fishers agreed with each other. There were also a few commercial and recreational fishers that agreed with each other. Managers appeared to be between the commercial and recreational fishers. Johnson and Griffith (2010) had hypothesized that managers would be seen as mediators between the commercial and recreational fishers.

In their final results, Johnson and Griffith (2010) concluded that commercial fishers placed blame on natural events/cycles, pollution, and tourism for problems associated with the environment and resource limitation. There was not a strong consensus among the commercial fishers group, which was a result of gear conflicts. Recreational fishers responded opposite, citing that commercial fishers were to blame although they did recognize natural events/cycles and pollution. Both commercial and recreational fishers agreed that the other group received special treatment, which hints at hostility among the two groups. Both fisher groups also agreed that compromise was something that would be limited. These results allowed Johnson and Griffith (2010) to further examine the relationships among these groups. For example, which statement(s) from the questionnaire showed the most agreement or disagreement? This would help resource managers identify areas of critical need, user groups, and strategies for conflict resolution.

Identification of cultural groups

For my study, cultural consensus analysis was used to estimate cultural beliefs of citizen science volunteers that conduct water quality monitoring and how their beliefs concerning water quality may be similar or different when compared to other cultural groups. For example, would citizen science volunteers share similar cultural beliefs to water quality professionals or educators? These cultural groups include: [1] volunteers of citizen science that focus on water quality monitoring, [2] water quality educators, [3] water quality professionals, [4] fishers (both commercial and recreational), and [5] individuals that have no experience with water quality (i.e., the general public). These groups are defined below:

1. Citizen science volunteer: An individual that has volunteered for a water quality monitoring project that required initial training and has been involved in measuring water quality variables on a routine basis. Volunteers do not have to be currently active with a citizen science project to identify with this group.
2. Water quality educator: An individual that leads formal and informal education campaigns/workshops that include water quality issues and/or water quality monitoring.
3. Water quality professional: An individual with formal educational training in water quality issues and/or water quality monitoring that receives monetary compensation.
4. Fisher: An individual that either classifies themselves as either a commercial or recreational fisher.
5. No experience with water quality: Individuals that have no experience in water quality and do not identify with any of the above groups.

It can be argued that volunteers who have a basic understanding of water quality are most likely to collect more reliable data, which could strengthen the project. If not, what can project coordinators of citizen science and educators do to improve cultural beliefs, or knowledge, of water quality?

RESEARCH QUESTIONS AND HYPOTHESES

Research Questions

1. What are the cultural beliefs concerning water quality for citizen science volunteers that conduct water quality monitoring and how might their beliefs be similar, or different, to other cultural groups such as water quality professionals, water quality educators, fishers (commercial and recreational), and individuals with no experience in water quality?
2. Is there consensus among the individuals of each cultural group? Does this change when cultural groups are combined?
3. Are cultural competencies among the different cultural groups significant?
4. Was there evidence that citizen science promotes scientific literacy among volunteers?

Hypotheses

1. Each cultural group will display consensus. When all cultural groups are combined into one group, there will be no consensus.
2. Volunteers of citizen science that focus on water quality monitoring will display a stronger consensus when compared to the cultural group that has no experience with water quality.
3. There will be significant differences among the mean cultural competencies of the cultural groups.

METHODS

Survey Design

The first assumption of cultural consensus theory is that statements included in the survey must center on one topic (Weller 2007). The survey designed for this study focused on water quality. Specifically, the survey included the following topics: (1) submerged aquatic vegetation; (2) water quality appearance; (3) storm events; (4) time of day fluctuations; (5) biological activity; (6) dissolved oxygen; (7) salinity; (8) water temperature; (9) pH; (10) precipitation; (11) macroinvertebrates, (12) and landscape types. These topics were selected to present a broad view of water quality issues that include monitoring variables (e.g., dissolved oxygen, pH, salinity) and ecological health. Topics were written for this study as statements that required the survey respondent to either agree or disagree. There were two statements that provided illustrated answer choices for topics that centered on submerged aquatic vegetation and biological activity. Statements were also generated from personal conversations with volunteers from the Albemarle-Pamlico National Estuary Partnership's Citizens' Monitoring Network (APNEP-CMN). Between 2006 and 2011, I served as project coordinator for APNEP-CMN and was directly involved in training volunteers for water quality monitoring. Water quality topics that were discussed to volunteers during these initial training sessions and follow-up visits were also included as water quality statements in the survey. Statements that involved specific protocols for water quality monitoring (e.g., methodology for measuring dissolved oxygen) were not included. Careful attention was made to avoid negative connotation or scientific jargon when writing the statements to avoid potential biases. For instance, dissolved oxygen was written in the survey as the *amount of air in the water* and submerged aquatic vegetation was written as *underwater plants*.

Demographic questions were also included in the design of the survey. These included basic information such as gender, age, and residence. For residence, respondents were asked if they lived near a water body, estimated distance from water body, and the number of annual visits to the water body. Respondents were also asked if they had any preceding knowledge of water quality through citizen science projects, education, or professional endeavors. If so, they were asked to describe their knowledge for clarity.

Prior to the survey being finalized, it went through eight drafts that were reviewed and edited by researchers who are fluent in survey design, water quality professionals, and individuals with no experience in water quality. A total of 79 statements/questions were included on the final survey. There were 55 statements on the previously listed water quality topics, which were randomly mixed. The other 22 questions were on respondent demographics, prior experience in citizen science, and previous knowledge of water quality. Two additional questions were asked at the beginning and end of the survey regarding participation agreement and whether the respondent was familiar with the objectives of this study prior to taking the survey, respectively. The final survey draft is presented in Appendix 1.

Survey distribution

Before collecting survey data, this study was reviewed and approved by the University and Medical Center Review Board at East Carolina University, number UMCIRB 13-002655 (Appendix 2). The survey was built using Qualtrics®, a software package that specializes in online surveys. Distribution of the survey was 100 percent online. A link to the survey was provided to potential respondents through email and social media platforms. Solicitation for survey distribution were sent to representatives of the following groups: (1) North Carolina Environmental Educators Listserv, (2) Rachel Carson Reserve (3) Pamlico-Tar River Foundation,

(4) North Carolina Sea Grant, (3) Albemarle-Pamlico National Estuary Partnership [APNEP], (4) APNEP Citizens' Monitoring Network, (5) North Carolina Division of Water Quality, and (6) North Carolina Division of Marine Fisheries. Representatives from each group forwarded the survey link to their colleagues, listserv subscribers, or used their social media pages to broadcast the survey link (Appendix 3).

The second assumption of cultural consensus theory is that individuals were to complete the survey independently with no consultation (Weller 2007). As surveys were distributed, no information concerning the reasoning behind the survey was provided until after the survey was completed. Respondents had to either agree or disagree with completing the survey independently without consultation before launching the survey (Appendix 4). Upon completion and submission of the survey, respondents were provided contact information for questions or information.

To run cultural consensus analysis, a minimum of 30 respondents were required for each cultural group (Weller 2007). Qualtrics® managed all logistics as respondents completed the survey. Weekly checks were made to see if the minimum number of respondents for each cultural group were met. If not, representatives from the groups listed above were contacted again to see if they could resend the survey link as a "second call" or "third call" message, or repost the survey link on their social media pages (Appendix 3).

Data Analysis

Once the survey closed, data were exported from Qualtrics® to Microsoft Excel before being imported in UCINET 6, a software package that is used for the analysis of social network data (Borgatti et al. 2002). Each column in Excel represented a statement from the survey. For statements that were multiple-choice, each answer choice was entered as a separate column. The

rows in Excel represented survey respondents. General information regarding the survey (e.g., gender, age, state, education, etc.) were also included in the Excel spreadsheet.

For the responses to the agree/disagree statements, a binary coding system was used. If the respondent agreed with a statement, then it was entered as "1" in the Excel spreadsheet. If the respondent disagreed with the statement, then it was entered as a "0." This also applied to the multiple-choice statements.

Once survey data were entered into Excel, it was imported into UCINET 6 (Borgatti et al. 2002) for running cultural consensus analysis. Only the binary data were imported into UCINET; otherwise, it would have disrupted analysis. First, cultural consensus analysis was performed for binary data within each cultural group. Second, analysis was performed for binary information for all combined cultural groups. Running a consensus analysis in UCINET was a quick process with a few initial adjustments that were based on how these binary data were entered (i.e., true value is set to "1" to accommodate the data's binary coding structure). Consensus analysis is based on factor analysis, so it generated results based on the first two factor loadings. The output displayed a respondent-by-respondent matrix, a list of cultural competence scores, eigenvalue ratio, and the culturally correct answer key. It also provided a general statement if these data fit the consensus model. This general statement was based on three criteria: (1) there were no negative competencies, (2) the first to second eigenvalue ratio was greater than 3, and (3) the mean competence scores were greater than 0.05. If the output statement and values followed these criteria, then results indicated consensus within, and across, the cultural groups based on the statements from the survey. When the eigenvalue ratios among the cultural groups were compared, the group with the highest ratio displayed a stronger consensus and cultural competency (or cultural knowledge).

To determine if the competence scores for each cultural group were significantly different from one another, a one-way analysis of variance (ANOVA) was conducted using SYSTAT®, Version 12. A returned P-value significance value less than 0.05 would cause the null hypothesis to be rejected and to accept the null hypothesis, which concluded that at least one of the cultural groups is significantly different from the others. A Tukey post-hoc test was applied to further investigate differences in competence scores among each cultural group. The Levene test for variance homogeneity or heterogeneity was also conducted to validate the ANOVA results. If the P-value significance level for the Levene test was less than 0.05, then variances among the cultural groups were significantly different (heterogeneity) and conducting a parametric test such as ANOVA would be inappropriate.

Running consensus analysis for each of the five cultural groups separately determined if there was consensus within each group, but it does not tell us how these groups might overlap. UCINET 6 (Borgatti et al. 2002) was also used to produce a metric multidimensional scaling plot among the cultural groups, which plotted each respondent based on the first two factor loadings. Closer Euclidean distances among the respondents indicated agreement with one another in addition to whether respondents from the cultural groups agreed with each other.

Output from the consensus analysis also generated a culturally correct answer key for each cultural group. These answer keys listed the statements where there was unanimous accordance (agreement) or discordance (disagreement) among the cultural groups. Information from these answer keys provided further insight for identifying water quality topics that needed improvement.

RESULTS

The survey opened on August 24, 2014 and closed on February 28, 2015. There were a total of 351 surveys with an 81 percent completion rate, making 285 surveys available for analysis. The minimum of 30 respondents per cultural group was acquired to run cultural consensus analysis (Weller 2007). There were 43 respondents who identified as volunteers of citizen science that conduct water quality monitoring; 87 water quality educators; 50 water quality professionals; 49 fishers (both commercial and recreational); and 56 respondents who did not have any experience with water quality (Figure 1).

Combined respondent demographics

Survey respondents for all cultural groups combined were mostly female (61 percent) with an age range between 22 and 79 with an average of 46 years (± 15 standard deviation, n = 285). Respondents mostly resided in suburban areas (41 percent) followed by rural (30 percent) and urban areas (25 percent) (Figure 2); nearly all respondents (99 percent) resided near a water body. Specifically, distance of residence from the nearest water body ranged from 0 to 128.7 kilometers (km) with a mean of 3.64 km (± 9.53 standard deviation, n = 281). One respondent listed 128.7 kilometers. If this data point was removed, the modified range would be 0 to 48.3 km with a mean of 3.19 km (± 5.91 standard deviation, n = 280). The number of annual visits to a water body ranged from 1 to 365 days with an average of 128 days (± 132, n = 277). For education, 89 percent of all respondents either held a Bachelor's or graduate degree (n = 285). Table 1 lists this demographic information for each cultural group and combined groups. JMP®, Version 12 Pro was used to generate this information.

Volunteers of citizen science

When all respondents were asked if they had previous knowledge of water quality prior to joining a citizen science project that focused on water quality monitoring, 27 percent (or 76 respondents) answered "yes"; nine percent answered "no" and 64 percent provided no answer (n = 285) (Table 1). However, there were only 43 respondents that identified as volunteers of citizen science. Of these 43 respondents, 51 percent identified having previous citizen science background. It can be interpreted that the 42 percent that replied having no previous background in citizen science were first-time volunteers or had no previous knowledge of water quality; seven percent did not answer. The names of these projects varied and were not restricted to eastern North Carolina. Nine respondents listed themselves as volunteers of the Albemarle-Pamlico National Estuary Partnership's Citizens' Monitoring Network (APNEP-CMN). Other projects stemmed from the Pamlico-Tar River Foundation, Maryland Stream Monitoring, and the North Carolina Coastal Federation. The goals of these projects were mixed but commonly focused on collecting and improving water quality data, monitoring macroinvertebrate habitat, water quality monitoring to benefit migrating birds, education, and bacteria testing. Concern about the ecological health of local water bodies was the primary reason volunteers joined these projects (39 percent) followed by contributing water quality data to a long-term scientific database (18 percent). Few said they were encouraged to volunteer by other water quality monitoring volunteers (six percent) or to learn more about water quality (five percent) (Figure 3). The number of years' respondents were involved with citizen science projects spanned from 4 months to 27 years with an average of 5.4 years (± 5.6 standard deviation, n = 96).

Education or professional backgrounds in water quality

Respondents were asked if they had any previous knowledge with water quality prior to completing the survey. Over half the respondents (62 percent) mentioned having previous education background in water quality while 38 percent did not. When asked to describe their education background, their responses were diverse. Some of these included having a basic knowledge of general biology to receiving graduate degrees in either biology, ecology, or marine biology.

Over half of all respondents (57 percent) said their profession included water quality. When asked to describe their profession, the recurring responses were commercial fishers; oceanographers; marine biologists; educators in the public school system and higher education; field technicians; and water quality monitors for federal/state government programs.

Cultural consensus analysis and cultural competencies

Cultural consensus analysis was performed for each cultural group separately. To determine if respondents within each cultural group were in consensus with the statements in the survey, there should be (1) no negative competencies, (2) first to second eigenvalue ratio should be greater than 3, and (3) a mean competence score above 0.05 (Weller 2007). Results showed that respondents within each cultural group were in consensus with each other regarding the survey statements. In order from highest to lowest levels of consensus, water quality educators had the highest first to second eigenvalue ratio (ratio = 19.71, n = 87); 19.65 (n = 43) for volunteers of citizen science that focus on water quality monitoring; 16.85 (n = 49) for commercial and recreational fishers; 16.62 (n = 56) for individuals with no experience in water quality; and 14.82 (n = 50) for water quality professionals. When data for all cultural groups were combined, there

was consensus among the survey statements with a 19.47 eigenvalue ratio (n = 285). These data are summarized in Table 2.

The one-way analysis of variance (ANOVA) resulted in a significant difference among the mean cultural competencies of the cultural groups (P-value = 0.02). Results from the Levene test established that variance among the competency values was homogeneous (P-value = 0.354), thus validating use of the parametric ANOVA.

The post-hoc Tukey test revealed all possible combinations between two cultural groups were not significantly different (Tukey P-value > 0.05). The only exception was among water quality educators and individuals with no experience in water quality (Tukey P-value = 0.009) (Table 3). Figure 4 visualizes these data.

Metric multidimensional scaling

The overall appearance of the metric multidimensional scaling plot (Figure 5) looked similar to a "shotgun blast" where there is no clear separation among the cultural groups. A closer look at the spread of the distance points do reveal levels of agreement, or consensus. Distance points for water quality professionals were widespread, thus illustrating lack of consensus among the responses to the survey statements. Volunteers of citizen science and water quality educators had less distance among the data points, thus indicating a stronger consensus.

Accordance and discordance of survey statements among cultural groups

There was 92 percent accordance among the cultural groups for statements on the following water quality topics: (1) submerged aquatic vegetation, (2) biological activity, (3) dissolved oxygen, (4) salinity, (5) water temperature, (6) precipitation, (7) macroinvertebrates, and (8) landscape types (Table 4).

There were four water quality topics that exhibited discordance: (1) time of day fluctuations, (2) water quality appearance, (3) pH, and (4) storm events (Table 5). First, water quality professionals were the only ones that agreed the amount of oxygen in the water (i.e., dissolved oxygen) is higher during the afternoon. In addition, water quality professionals and individuals with no water quality experience were the only two groups that disagreed that the amount of oxygen in the water is higher during the early morning hours. Second, volunteers of citizen science, water quality educators, and water quality professionals were the only groups that disagreed that clear water is indicative of good water quality. Third, all cultural groups with the exception of commercial and recreational fishers disagreed that acidity increases (lower pH) as water temperature rises. Fourth, water quality professionals, commercial and recreational fishers, and individuals with no experience in water quality agreed that foul odors following a hurricane event is associated with little to no oxygen in the water.

DISCUSSION

Cultural consensus analysis

Based on the sample population and results from this study, it remains unclear to whether citizen science is promoting scientific literacy. Results from the cultural consensus analysis suggested that all cultural groups shared similar cultural beliefs of water quality. The post-hoc Tukey test also revealed no significant differences (Tukey P-value > 0.05) among the mean cultural competencies of the cultural groups; the only significant difference was among water quality educators and individuals with no experience in water quality (Tukey P-value < 0.05). However, water quality educators and volunteers of citizen science displayed the greatest mean cultural competencies and consensus with the survey statements. Typically, water quality educators are

often involved with directing citizen science projects. This might explain why these two groups were in close agreement.

Commercial and recreational fishers were in close agreement with individuals that had no experience in water quality. Similarities in education background of water quality might have contributed to these two groups being in agreement. Only 35 percent of fishers reported having an educational background in water quality; 25 percent for individuals with no experience in water quality. Fishers mostly described their knowledge of water quality coming from environmental or limnology courses that were part of their education degree requirements, occasional water quality monitoring, and knowledge of state water quality regulations. Individuals with no experience in water quality reported gaining knowledge through their place of employment or internships at environmentally-themed institutions. Other respondents reported having a general interest in environmental issues such as point source polluters that are known to influence water quality.

Water quality professionals displayed the weakest consensus among all cultural groups. On a few occasions, I received follow-up emails regarding the content to some of the survey statements. Most commented difficulty in either agreeing or disagreeing with statements based on the dynamic nature of water quality. In response, cultural consensus theory required that each survey statement focus on one thought, or idea (Weller 2007). The tendency for professionals to have wavering perspectives of thought might have caused responses to be varied, thus triggering a weaker consensus. This result was also observed in the Boster and Johnson (1989) study. There was consensus among experts and novices when it came to how they grouped fishes. However, there was a weaker consensus among the experts as a result of having a greater wealth of knowledge about fishes as opposed to novices.

Overall, there was consensus across all cultural groups, which suggested similar cultural beliefs of water quality based on the survey statements. My first hypothesis predicted consensus within each cultural group but no consensus across the groups. Results from the cultural consensus analysis support the first part of this hypothesis (consensus within groups) but not the second part (consensus across the groups).

My second hypothesis predicted that volunteers of citizen science would display a stronger consensus when compared to individuals with no experience in water quality. Results are in support of this hypothesis – although there was consensus among the two cultural groups, the volunteers displayed a stronger consensus (higher first to second eigenvalue ratio). The only argument is the similarity of the mean cultural competencies among the two groups (Tukey P-value = 0.142).

The third hypothesis extends on this argument, which stated that the mean cultural competencies would be significantly different among the cultural groups. Based on the post-hoc Tukey test, water quality educators and individuals with no experience in water quality was the only pair where there were significant differences (Tukey P-value = 0.01) among mean cultural competencies. This evidence does not support the third hypothesis as there were no significant differences among mean cultural competencies (Tukey P-value > 0.05) of the remaining cultural group pairs.

Volunteer accordance and discordance

Respondents across the cultural groups were in accordance for 92 percent of the survey statements, leaving only eight percent discordance. Interestingly, volunteers of citizen science and water quality educators had the exact discordance pattern (i.e., agreed to disagree). This could be coincidental, or supportive of the possibility that volunteers are receiving their water quality

information from educators during training, follow-up visits, or education campaigns. Discordance was also observed among water quality educators and professionals regarding the survey statements on time of day fluctuations with the amount of oxygen in the water (i.e., dissolved oxygen) and foul odors associated with little to no oxygen following a hurricane event. Both groups were in accordance for water quality appearance and pH.

Coordinators, or staff, of citizen science projects should focus volunteer training and education efforts on the following topics: (1) time of day fluctuations, (2) water quality appearance, (3) pH, and (4) storm events. Volunteers should understand that water quality variables are expected to fluctuate throughout the day. Without this understanding, volunteers may assume it is okay to measure water quality at different times of day, which may disrupt determining water quality trends over time. The appearance of water in regards to its quality is perhaps a common misconception. Commercial and recreational fishers plus individuals with no experience in water quality both agreed that clear water is indicative of good water quality. This oversight can be potentially hazardous to these individuals, especially in waters with harmful bacteria or other undetected pollutants. Volunteers should also be mindful to how water quality variables are interconnected for the best understanding and interpretation of their collected data. While volunteers were in accordance with most statements that revolved around water quality, the relationship between pH and water temperature could be strengthened by instruction from the project coordinator or staff. This also applies to water quality changes and biological activity following a hurricane event.

Influencing factors, survey design and distribution

Results from the cultural consensus analysis might have turned out differently if statements focused on more controversial water quality issues. There might have been lack of consensus

among the different cultural groups. Previous studies using cultural consensus theory that focused on more controversial issues includes the previously mentioned study by Johnson and Griffith (2010), which investigated how commercial and recreational fishers perceive management of coastal resources. Another study by Kaneshiro-Pineiro (2013) examined public perceptions of jellyfish in North Carolina and how they are managed.

With the survey being distributed 100 percent online, it might have instigated problems that could have skewed the results. First, there was no way to fully determine if respondents completed the survey independently. The only confirmation was if the respondent agreed to follow this instruction before launching the survey. Second, survey respondents were solicited by contacting representatives from various government and non-profit groups to broadcast the survey link to their listserv subscribers or social media pages. By doing this, it might have only targeted individuals who had pre-existing background or interest in environmental issues such as water quality, which was suggested from the the demographic results (Table 1). In addition, respondents that reside in coastal areas might be more environmentally aware of issues such as water quality due to local media coverage; or for maintaining the natural aesthetic of the coast, which might carry impact on property values and tourism.

Although less efficient, survey distribution using face-to-face methods versus online might have changed the results by removing some of these potential response biases. Face-to-face methods might have also tightened the geographic range of the survey respondents. An extended geographic range could present various perspectives on water quality based on physical surroundings. For instance, an inland community versus coastal.

Conclusions and recommendations

Results of the cultural consensus analysis suggested that cultural beliefs of water quality are similar across the cultural groups. Mean cultural competencies and consensus were greater for volunteers of citizen science and water quality educators but there were no significant differences among the cultural groups; the only exception was among water quality educators and individuals with no experience in water quality. Responses for the survey statements revealed a 92 percent accordance among the groups, which suggested similar cultural beliefs for nearly all water quality topics featured in the survey. Discordance was only observed in four topic areas: (1) time of day fluctuations, (2) water quality appearance, (3) pH, and (4) storm events. To improve in these areas, coordinators of citizen science projects and educators should include them for discussion during training sessions, follow-up site visits, and education campaigns. By sustaining and fostering knowledge of water quality, the likelihood of volunteers to produce reliable data for these projects is also strengthened.

This information can also be extended to water quality educators. Active learning strategies should be implemented in the design of education campaigns (see chapter 4). Citizen science is one strategy that promotes a more active approach by getting the public involved with the scientific process. Partnerships among educators and scientists to establish and support these projects will help expand scientific literacy among the public.

Results from this study can be valuable towards environmental-themed government and non-profit programs. A better understanding towards the cultural beliefs concerning water quality across different cultural groups may help reprioritize work plans that could assist in better fulfilling the missions of these programs. Additional investigations that include cultural consensus theory can foster a better understanding of cultural beliefs among populations for certain environmental

issues such as water quality, submerged aquatic vegetation, invasive species, or climate change. This understanding can lead to better development and implementation of citizen science projects throughout the nation to improve scientific literacy even further.

Based on the results from this study, a question that remains is why there was consensus among all five cultural groups. This might have been a result of the sample population in relation to education background. Demographic results revealed that 62 percent of all survey respondents had previous education background in water quality prior to taking the survey. This high percentage might have strengthened consensus among the cultural groups. Further investigation should include separating respondents who either had, or did not have, previous education background in water quality and conducting another cultural consensus analysis.

For future investigations that include a new sample population, survey distribution using face-to-face methods might remove potential response biases, which was discussed earlier in this section. Eliminating response biases by refining survey distribution methods may provide better representation of respondents from each cultural group, particularly fishers and individuals with no experience in water quality.

Statements included in the survey could also be modified to include more controversial aspects of water quality such as point-source polluters, fish kills, and resource management. By introducing these controversies into the survey statements, cultural consensus analysis could provide a better estimate of cultural beliefs among the different cultural groups concerning water quality.

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Figure 1. Pie chart depicting the number of surveys completed for each cultural group. Boxes include counts and percentages for each pie slice.

Figure 2. Pie chart depicting the residency type of the survey respondents. Boxes include counts and percentages for each pie slice.

Figure 3. Pie chart depicting the reasons why survey respondents became involved in citizen science projects. Boxes include counts and percentages for each pie slice.

Figure 4. Boxplot of cultural competencies for each cultural group. Horizontal line within the box represents the median cultural competence score. The upper part of the box extends to the third quartile and the lower part extends to the fifth quartile. The vertical lines that extend the upper and lower parts of the box represent maximum and minimum values, respectively. The circles indicate outliers. Letters represent significance of mean cultural competence scores among the cultural groups determined by the Tukey post-hoc test. A = no significance (P-value > 0.05); B = significance (P-value < 0.05). Educators = water quality educators; Fishers = commercial and recreational fishers; No experience = individuals with no experience in water quality; Professionals = water quality professionals; Volunteer = volunteers of citizen science involved in water quality monitoring.

Figure 5. Metric dimensional scaling plot of the survey statements for each cultural group that were derived from the results of the cultural consensus analysis. Squares = water quality educator; Triangles = commercial and recreational fisher; X = individuals with no experience in water

quality; Diamonds = water quality professional; Circles = volunteers of citizen science that focus on water quality monitoring.

Table 1.

	Cultural group					
Number of respondents	**Combined** n = 285	**Volunteer** n = 43	**Educator** n = 87	**Professional** n = 50	**Fisher** n = 49	**No experience** n = 56
Gender (%)						
Male	39	49	17	64	63	23
Female	61	51	83	36	37	77
Age						
Mean	46	53	43	42	47	48
Range	22-79	23-78	24-73	24-79	22-68	22-78
Reside near waterbody (%)						
Yes	99	98	99	100	98	98
No	1	2	1	0	2	2
Distance from nearest waterbody (kilometers)						
Sample (n)	281	42	86	49	49	55
Mean	2.26	0.81	2.58	1.34	3.77	2.32
Standard deviation	5.92	1.6	4.09	2.25	12.11	3.77
Range	0-80	0-10	0-20	0-10	0-80	0-15
Number of annual visits to waterbody						
Sample (n)	277	42	85	50	47	53
Mean	128	139	109	136	171	101
Standard deviation	133	142	126	120	146	128
Range	1-365	1-365	1-365	1-365	3-365	2-365
Popular activities while visiting waterbody	Swimming Boating Fishing Sunbathing Kayaking Walking Watching Working Hiking Relaxing	Fishing Walking Swimming Boating Sunbathing Canoeing Testing Sampling	Swimming Sunbathing Boating Walking Fishing Kayaking Teaching Hiking Running Education	Swimming Fishing Boating Working Kayaking Sunbathing Walking Surfing Beach Research	Fishing Boating Swimming Kayaking Walking Sunbathing Hunting Scuba Diving	Swimming Walking Sunbathing Boating Looking/Scenery Kayaking Fishing
Education (%)						
Some high school	0	0	0	0	2	0
High school	4	5	2	0	12	2
Associate's (2-year degree)	7	2	2	6	10	14
Bachelor's (4-year degree)	40	49	33	38	49	39
Graduate	49	44	62	56	27	45
Previous knowledge of water quality prior to joining a citizen science project that monitored water quality (%)						
Yes	27	51	36	36	10	0
No	9	42	6	4	2	0
No answer	64	7	58	60	88	0
Previous education background in water quality (%)						
Yes	62	51	92	86	35	25
No	38	49	8	14	65	75
Profession involves water quality (%)						
Yes	57	30	93	90	35	11
No	43	70	7	10	65	89

Table 2.

Results	Cultural group					
Consensus Analysis	**Combined** n = 285	**Volunteer** n = 43	**Educator** n = 87	**Professional** n = 50	**Fisher** n = 49	**No experience** n = 56
Mean	0.39	0.4	0.4	0.39	0.39	0.37
Standard deviation	0.05	0.05	0.05	0.04	0.05	0.06
Minimum	0.17	0.26	0.17	0.29	0.24	0.17
Maximum	0.47	0.47	0.47	0.46	0.47	0.47
Eigenvalue ratio (first to second)	19.47	19.65	19.71	14.82	16.85	16.62
Consensus (Yes/No)	Yes	Yes	Yes	Yes	Yes	Yes

Table 3.

Cultural group comparison		P-value	Significant
Educators	No experience	0.009	Yes
No experience	Volunteers	0.142	No
No experience	Professionals	0.288	No
Fishers	No experience	0.398	No
Educators	Professionals	0.720	No
Educators	Professionals	0.836	No
Fishers	Volunteers	0.976	No
Educators	Volunteers	0.985	No
Professionals	Volunteers	0.993	No
Fishers	Professionals	1.000	No

Table 4.

Number	Statement	V	E	P	F	NE
1	The presence of underwater plants suggest poor water quality conditions.	0	0	0	0	0
2	Vegetation helps filter out pollutants from storm water before entering the water body.	1	1	1	1	1
4	Agricultural areas are considered low risk for water with high nutrient levels (e.g., nitrogen, phosphorus).	0	0	0	0	0
5	As water becomes more acidic, the number of aquatic organisms will increase.	0	0	0	0	0
6	The presence of green algae on top of the water is an indicator of poor water quality.	1	1	1	1	1
7	A high amount of suspended solids (e.g., sediments, dirt, debris) in the water will reduce photosynthesis.	1	1	1	1	1
8	Salt water is denser than fresh water.	1	1	1	1	1
10	Warmer water is less dense than colder water.	1	1	1	1	1
11	A high amount of suspended solids in the water poses multiple hazards to fish.	1	1	1	1	1
12	During the course of the day, water temperature will change.	1	1	1	1	1
13	Select the picture that best illustrates good water quality: No vegetation.	0	0	0	0	0
14	Select the picture that best illustrates good water quality: Green algae.	0	0	0	0	0
15	Select the picture that best illustrates good water quality: Low vegetation.	0	0	0	0	0
16	Select the picture that best illustrates good water quality: Medium vegetation.	1	1	1	1	1
17	Select the picture that best illustrates good water quality: High vegetation.	0	0	0	0	0
18	Wetlands are known to add pollutants to the water.	0	0	0	0	0
19	Underwater plants help decrease the acidity of the water.	1	1	1	1	1
20	Water will become clearer following large amounts of precipitation.	0	0	0	0	0
21	The decomposition process of organic materials in the water requires oxygen.	1	1	1	1	1
22	Rainfall will decrease the amount of salts in the water.	1	1	1	1	1
23	The presence of underwater plants will have an effect on human health if exposed.	0	0	0	0	0
24	Water quality conditions will remain the same following a hurricane event.	0	0	0	0	0
25	Decomposing green algae will increase the amount of oxygen in the water.	0	0	0	0	0
27	Areas with different topography (e.g., flat, hilly) will have similar water quality conditions.	0	0	0	0	0
28	Water run-off from paved areas (e.g., parking lots) will increase following high amounts of precipitation	1	1	1	1	1
29	Too many nutrients (e.g., nitrogen, phosphorus) in the water can create pollution problems.	1	1	1	1	1
30	Salt water is more common in inland waters as opposed to coastal waters.	0	0	0	0	0
31	Circle the picture that best illustrates good water quality: Some organisms.	0	0	0	0	0
32	Circle the picture that best illustrates good water quality: Low number of organisms.	0	0	0	0	0
33	Circle the picture that best illustrates good water quality: Medium number of organisms.	0	0	0	0	0
34	Circle the picture that best illustrates good water quality: High number of organisms.	1	1	1	1	1
35	Hurricane winds will push salt water from the coast to fresher water upstream.	1	1	1	1	1
36	Vegetation along the water provides habitat areas for juvenile fish.	1	1	1	1	1
37	Storm surge (rising water) from hurricane events will decrease the chances of pollutants entering the water.	0	0	0	0	0
38	You can look at the water and get and idea of how much oxygen is in it.	0	0	0	0	0
39	As oxygen levels in the water decrease, the pH has a tendency to be more acidic.	1	1	1	1	1
40	Water quality remains the same throughout the 24-hour day.	0	0	0	0	0
41	Industrial areas can be considered high risk for water pollution.	1	1	1	1	1
42	Nutrient levels are limited in fresh water environments.	0	0	0	0	0
43	Oxygen levels are lowered when underwater plants undergo photosynthesis.	0	0	0	0	0
44	Underwater plants filter out pollutants from the water.	1	1	1	1	1
45	Salt water will decrease the amount of oxygen in the water.	0	0	0	0	0
46	The amount of oxygen in the water is important for aquatic organisms.	1	1	1	1	1
47	Water temperature is influenced by the presence of vegetation along the water.	1	1	1	1	1
48	Aquatic insects may be an indicator of water quality conditions.	1	1	1	1	1
50	Evaporation will decrease the amount of salts in the water.	0	0	0	0	0
51	Colder water holds less oxygen in contrast to warmer water.	0	0	0	0	0
52	All aquatic organisms can live in fresh and salt water environments.	0	0	0	0	0
53	Underwater plants increase the amount of oxygen in the water.	1	1	1	1	1
55	An overabundance of nutrients will eventually increase the amount of oxygen in the water.	0	0	0	0	0
56	High oxygen levels in the water contribute to fish kills.	0	0	0	0	0
57	The presence of vegetation along the water can lead to sediment erosion, which makes the water cloudy.	0	0	0	0	0
58	Decomposing aquatic organisms in the water will cause the amount of oxygen in the water to increase.	0	0	0	0	0
59	Stagnant (non-flowing) and flowing water usually have similar oxygen levels.	0	0	0	0	0
60	Aquatic organisms (e.g., fish, shellfish, amphibians) consume the oxygen in the water.	1	1	1	1	1
61	The presence of litter can lead to poor water quality.	1	1	1	1	1
62	Water quality conditions impacted by a hurricane event will eventually recover.	1	1	1	1	1

Table 5.

Number	Statement	V	E	P	F	NE
3	The amount of oxygen in the water is higher during the afternoon.	0	0	1	0	0
9	The amount of oxygen in the water is higher during the early morning hours.	1	1	0	1	0
26	Clear water indicates good water quality.	0	0	0	1	1
49	As water temperature rises, it becomes more acidic.	0	0	0	1	0
54	A foul odor following a hurricane event is associated with little to no oxygen in the water.	0	0	1	1	1

Figure 1.

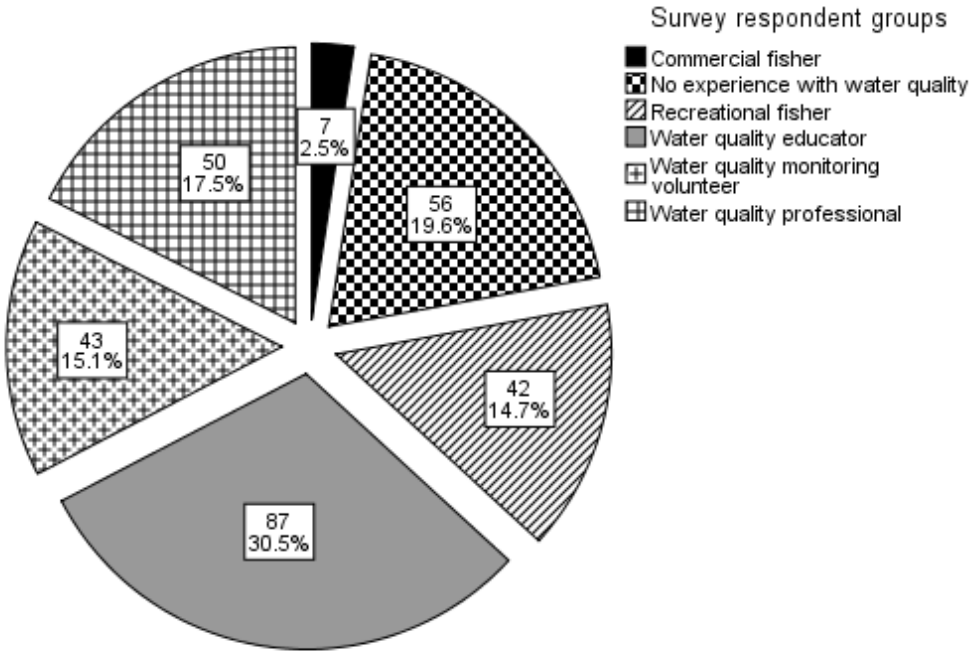

Survey respondent groups
Commercial fisher
No experience with water quality
Recreational fisher
Water quality educator
Water quality monitoring volunteer
Water quality professional
7
2.5%
56
19.6%
42
14.7%
87
30.5%
43
15.1%
50
17.5%

Figure 2.

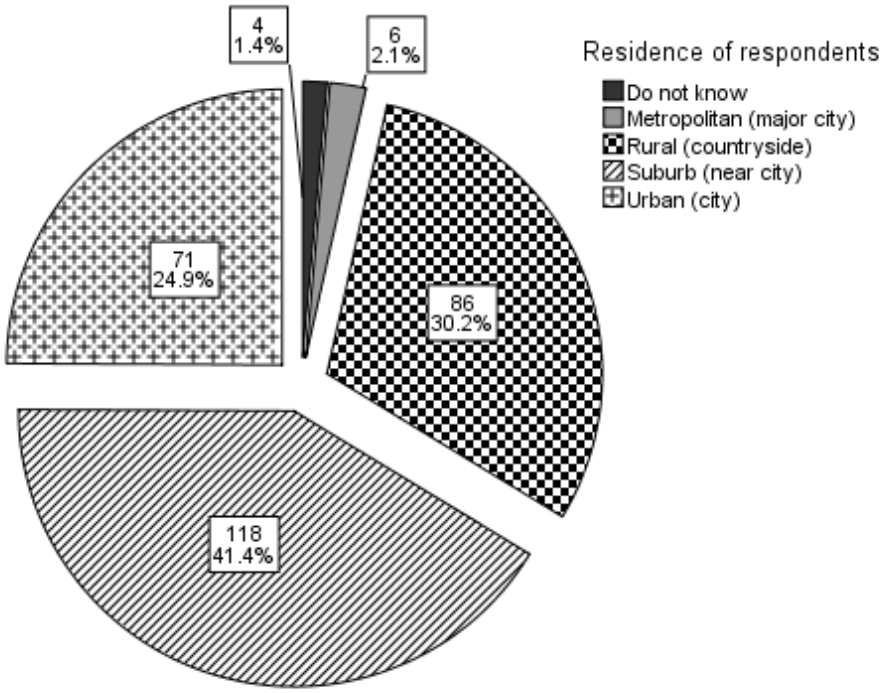

4
1.4%
6
2.1%
71
24.9%
86
30.2%
118
41.4%
Residence of respondents
Do not know
Metropolitan (major city)
Rural (countryside)
Suburb (near city)
Urban (city)

Figure 3.

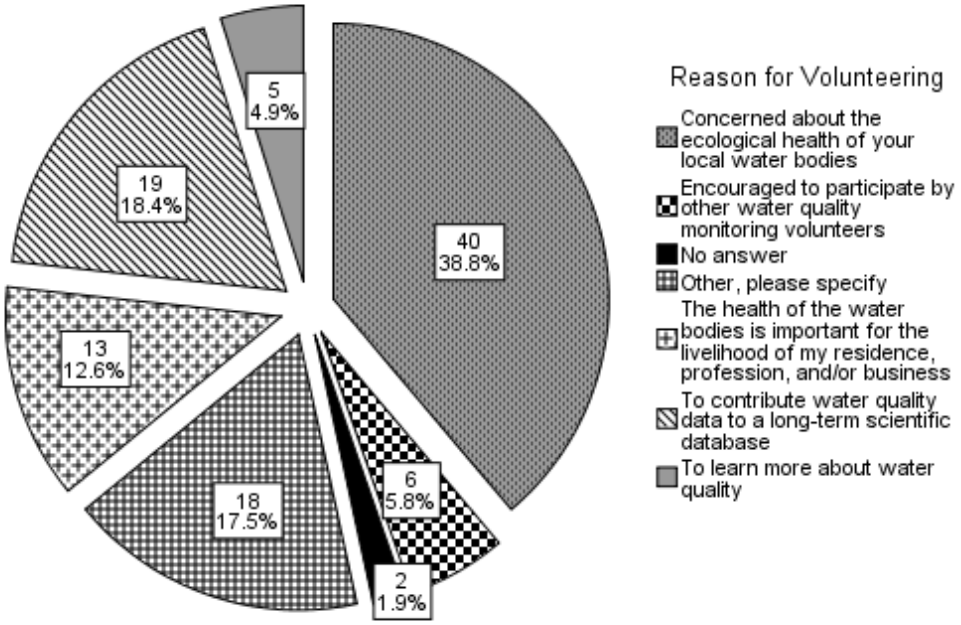

Reason for Volunteering
Concerned about the ecological health of your local water bodies
Encouraged to participate by other water quality monitoring volunteers
No answer
Other, please specify
The health of the water bodies is important for the livelihood of my residence, profession, and/or business
To contribute water quality data to a long-term scientific database
To learn more about water quality
40 38.8%
6 5.8%
2 1.9%
18 17.5%
13 12.6%
19 18.4%
5 4.9%

Figure 4.

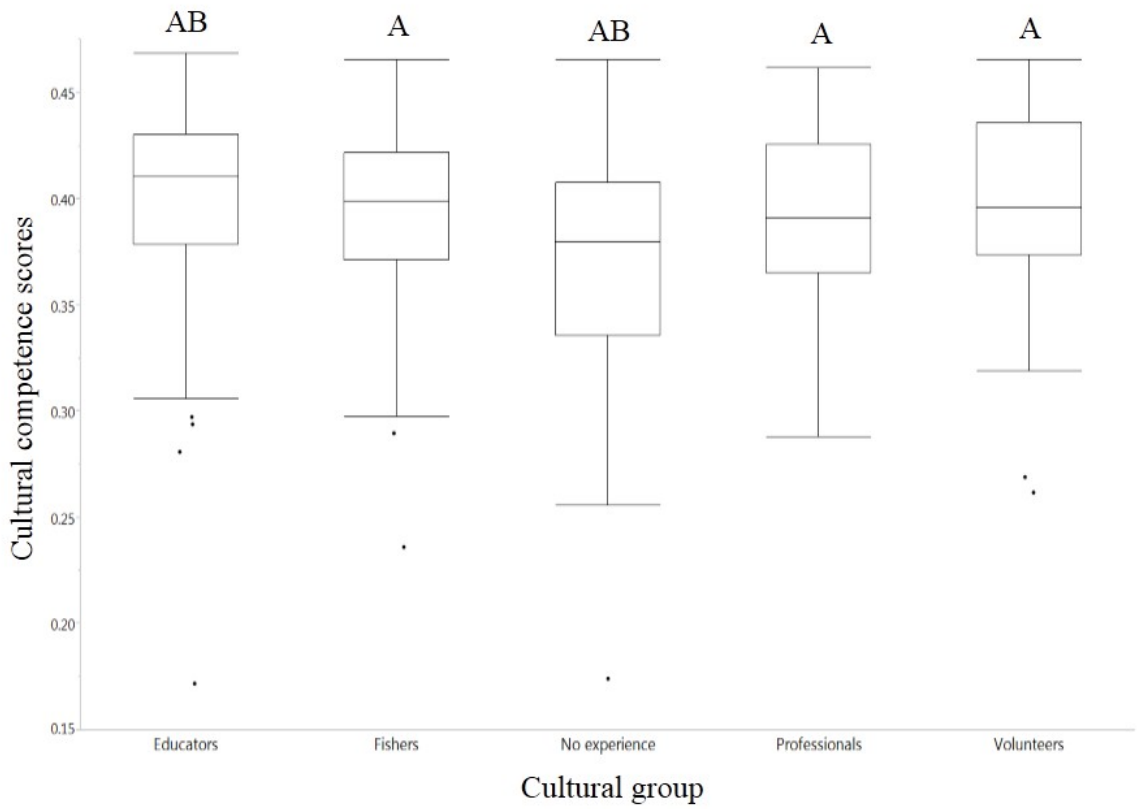
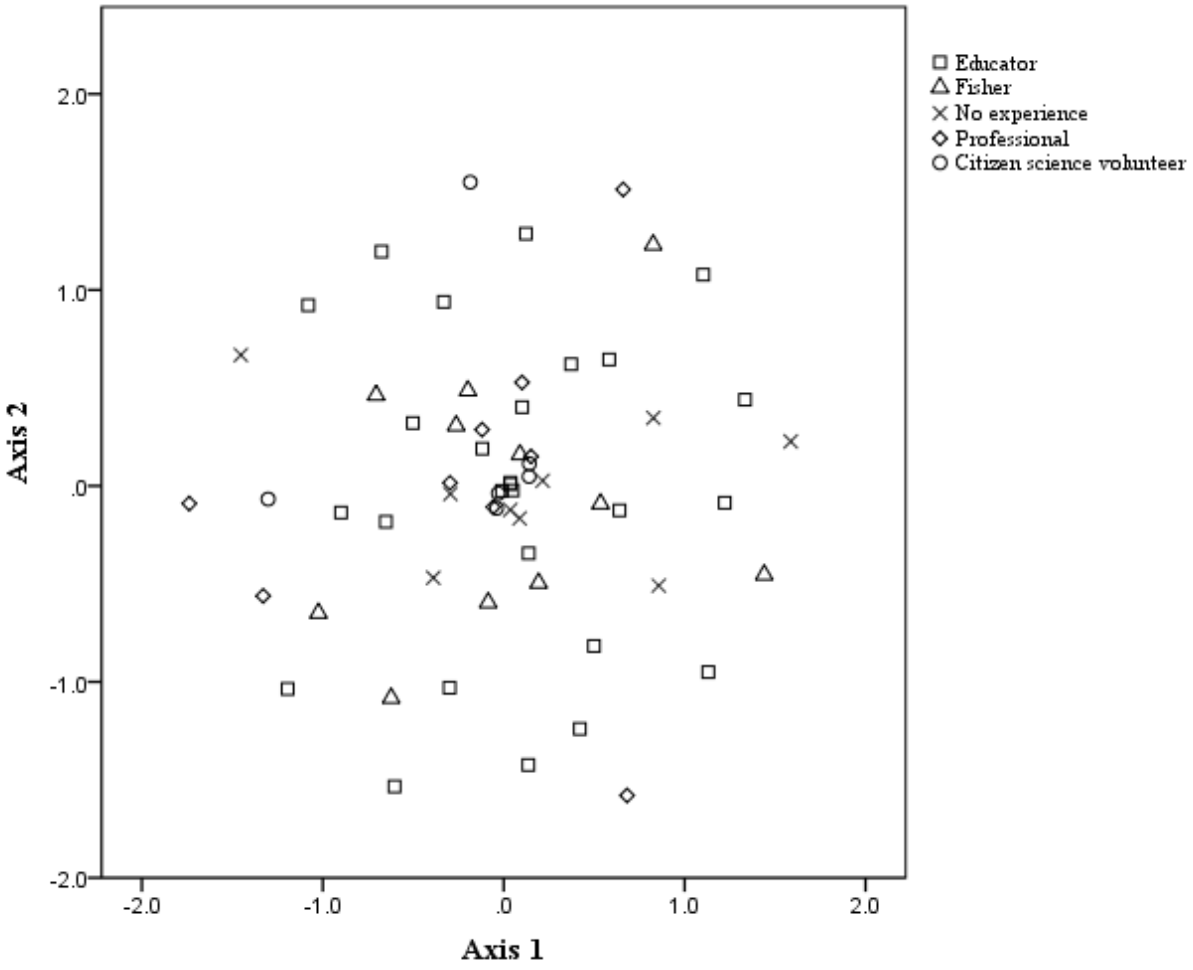

AB
A
AB
A
A
0.45
0.40
0.35
0.30
0.25
0.20
0.15
Cultural competence scores
Educators
Fishers
No experience
Professionals
Volunteers
Cultural group

Figure 5.


Educator
Fisher
No experience
Professional
Citizen science volunteer
2.0
1.0
.0
-1.0
-2.0
Axis 2
-2.0
-1.0
.0
1.0
2.0
Axis 1

Appendix 1. Water quality survey exported from Qualtrics®. The formatting presented is different from how the survey appeared online.

WATER QUALITY SURVEY

Thank you for taking the time to participate in this research study, "What do you know about water quality." This information will assist us in understanding what people know about water quality for the improvement of related citizen science projects and education campaigns. Water quality describes the condition of the water with respect to its suitability for a certain purpose such as drinking or recreation. This includes both chemical, biological, and physical characteristics of the water.

Your participation in this research study is voluntary and you may stop at any time. There is no penalty for not taking part in this study. Your responses will remain anonymous so please do not include your name anywhere on the survey.
Please answer all questions on your own without consulting any outside resources. If you do not know the answer to a question, please provide your best guess. This survey should take 15-20 minutes to complete.

This survey has been reviewed and approved by the East Carolina University Institutional Review Board, Study ID: UMCIRB 13-002655. If you have questions about your rights as a research participant, you may contact the Office for Human Research Integrity at 252-744-2914.

For questions related to the survey, please contact Chad Smith at 252-328-1747, or smithmich@ecu.edu.

Please select whether you agree or disagree to participate in this study.

- o Agree
- o Disagree

1. What gender do you identify with?
    - Male
    - Female

2. What is your age?

3. What is the zip code of your residence?

4. Where is your residence located?
    - Rural (countryside)
    - Suburb (near city)
    - Urban (city)
    - Metropolitan (major city)
    - Do not know

5. Do you reside near a body of water? Near = 20 miles or less; body of water = pond, lake, stream, creek, river, sound, sea, ocean.
    - Yes
    - No

6. Approximately how many miles is the nearest body of water from your residence?

7. Approximately how many times do you visit any body of water each year?

8. What is your primary activity when visiting a body of water (e.g., swimming, fishing, boating, sunbathing, etc.)?

9. Have you been involved in a volunteer water quality monitoring project(s) that involved water quality monitoring?
    - Yes
    - No

If you answered YES to the question 9, please answer questions 10-14. If you answered NO to question 9, you can skip to question 15.

10. What was the name of the project(s)?

11. Briefly describe the major goal of the project(s).

12. How many years were you involved with the project?

13. Did you have previous knowledge of water quality prior to joining the project(s)?
    - Yes
    - No

14. Select the reason that BEST led you to join the volunteer water quality monitoring project.
    - To learn more about water quality
    - Concerned about the ecological health of your local water bodies
    - To contribute water quality data to a long-term scientific database
    - The health of the water bodies is important for the livelihood of my residence, profession, and/or business
    - Encouraged to participate by other water quality monitoring volunteers
    - It was an option for required community service
    - Other, please specify: ____

15. Select the highest level of education you have completed.
    - Some high school. Enter highest grade completed: ____
    - High school
    - Associate's (2-year degree)
    - Bachelor's (4-year degree)
    - Graduate

16. Do you have an educational background in the environmental sciences?
    - Yes
    - No

If you answered NO to question 16, you can skip question 17 and move to question 18.

17. What broad knowledge do you have about water quality?

18. Does your work profession include water quality issues, water quality education, and/or water quality monitoring?
    - Yes
    - No

If you answered NO to question 18, you can skip question 19 and move to question 20.

19. Briefly describe your expertise with water quality.

20. Select the group that you BEST identify with.
    - Water quality monitoring volunteer
    - Water quality professional
    - Water quality educator
    - Commercial fisher
    - Recreational fisher
    - No experience with water quality

21. List any words that first come to mind when you think of GOOD water quality. Separate words with a comma.

22. List any words that first come to mind when you think of BAD water quality. Separate words with a comma.

The remaining portion of the survey is a series of water quality statements. Please answer all statements on your own without consulting any outside resources. Do not look up any answers to the survey questions. If you do not know the answer to a question, please provide your best guess.

1. The presence of underwater plants suggest poor water quality conditions.
    - Agree
    - Disagree

2. Vegetation helps filter out pollutants from storm water before entering the water body.
    - Agree
    - Disagree

3. The amount of oxygen in the water is higher during the afternoon.
    - Agree
    - Disagree

4. Agricultural areas are considered low risk for water with high nutrient (e.g., nitrogen, phosphorus) levels.
    - Agree
    - Disagree

5. As water becomes more acidic, the number of aquatic organisms will increase.
    - Agree
    - Disagree

6. The presence of green algae on top of the water is an indicator of poor water quality.
    - Agree
    - Disagree

7. A high amount of suspended solids (e.g., sediments, dirt, debris) in the water will reduce photosynthesis.
   - Agree
   - Disagree

8. Salt water is denser than fresh water.
   - Agree
   - Disagree

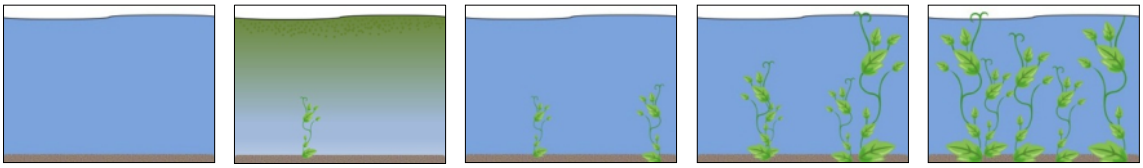
9. The amount of oxygen in the water is higher during the early morning hours.
   - Agree
   - Disagree

10. Warmer water is less dense than colder water.
   - Agree
   - Disagree

11. A high amount of suspended solids in the water poses multiple hazards to fish.
   - Agree
   - Disagree

12. During the course of the day, water temperature will change.
   - Agree
   - Disagree

13. Select the picture that best illustrates good water quality.



A (no vegetation) | B (green algae) | C (low vegetation) | D (medium vegetation) | E (high vegetation)

14. Wetlands are known to add pollutants to the water.
   - Agree
   - Disagree

15. Underwater plants help decrease the acidity of the water.
   - Agree
   - Disagree

16. Water will become clearer following large amounts of precipitation.
    - Agree
    - Disagree

17. The decomposition process of organic materials in the water requires oxygen.
    - Agree
    - Disagree

18. Rainfall will decrease the amount of salts in the water.
    - Agree
    - Disagree

19. The presence of underwater plants will have an effect on human health if exposed.
    - Agree
    - Disagree

20. Water quality conditions will remain the same following a hurricane event.
    - Agree
    - Disagree

21. Decomposing green algae will increase the amount of oxygen in the water.
    - Agree
    - Disagree

22. Clear water indicates good water quality.
    - Agree
    - Disagree

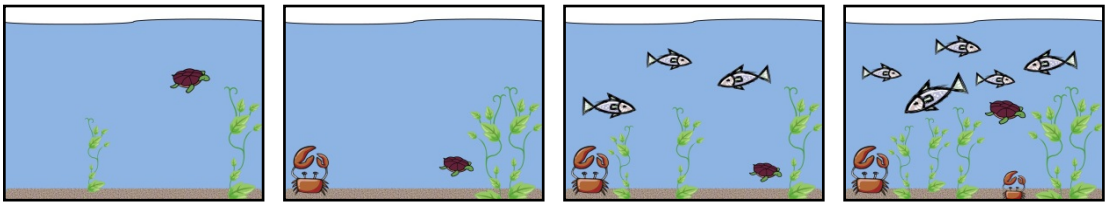
23. Areas with different topography (e.g., flat, hilly) will have similar water quality conditions.
    - Agree
    - Disagree

24. Water run-off from paved areas (e.g., parking lots) will increase following high amounts of precipitation.
    - Agree
    - Disagree

25. Too many nutrients (e.g., nitrogen, phosphorus) in the water can create pollution problems.
    - Agree
    - Disagree

26. Salt water is more common in inland waters as opposed to coastal waters.
    - Agree
    - Disagree

27. Select the picture that best illustrates good water quality.



A (some organisms) B (low # of organisms) C (medium # of organisms) D (high # of organisms)

28. Hurricane winds will push salt water from the coast to fresher water upstream.
    - Agree
    - Disagree

29. Vegetation along the water provides habitat areas for juvenile fish.
    - Agree
    - Disagree

30. Storm surge (rising water) from hurricane events will decrease the chances of pollutants entering the water.
    - Agree
    - Disagree

31. You can look at the water and get and idea of how much oxygen is in it.
    - Agree
    - Disagree

32. As oxygen levels in the water decrease, the pH has a tendency to be more acidic.
    - Agree
    - Disagree

33. Water quality remains the same throughout the 24-hour day.
    - Agree
    - Disagree

34. Industrial areas can be considered high risk for water pollution.
    - Agree
    - Disagree

35. Nutrient levels are limited in fresh water environments.
    - Agree
    - Disagree

36. Oxygen levels are lowered when underwater plants undergo photosynthesis.
    - Agree
    - Disagree

37. Underwater plants filter out pollutants from the water.
    - Agree
    - Disagree

38. Salt water will decrease the amount of oxygen in the water.
    - Agree
    - Disagree

39. The amount of oxygen in the water is important for aquatic organisms.
    - Agree
    - Disagree

40. Water temperature is influenced by the presence of vegetation along the water.
    - Agree
    - Disagree

41. Aquatic insects may be an indicator of water quality conditions.
    - Agree
    - Disagree

42. As water temperature rises, it becomes more acidic.
    - Agree
    - Disagree

43. Evaporation will decrease the amount of salts in the water.
    - Agree
    - Disagree

44. Colder water holds less oxygen in contrast to warmer water.
    - Agree
    - Disagree

45. All aquatic organisms can live in fresh and salt water environments.
    - Agree
    - Disagree

46. Underwater plants increase the amount of oxygen in the water.
    - Agree
    - Disagree

47. A foul odor following a hurricane event is associated with little to no oxygen in the water.
    - Agree
    - Disagree

48. An overabundance of nutrients will eventually increase the amount of oxygen in the water.
    - Agree
    - Disagree

49. High oxygen levels in the water contribute to fish kills.
    - Agree
    - Disagree

50. The presence of vegetation along the water can lead to sediment erosion, which makes the water cloudy.
    - Agree
    - Disagree

51. Decomposing aquatic organisms in the water will cause the amount of oxygen in the water to increase.
    - Agree
    - Disagree

52. Stagnant (non-flowing) and flowing water usually have similar oxygen levels.
    - Agree
    - Disagree

53. Aquatic organisms (e.g., fish, shellfish, amphibians) consume the oxygen in the water.
    - Agree
    - Disagree

54. The presence of litter can lead to poor water quality.
    - Agree
    - Disagree

55. Water quality conditions impacted by a hurricane event will eventually recover.

- o Agree
- o Disagree

Were you familiar with this research study prior to completing this survey?

- o Yes
- o No

Appendix 2. Notification of exempt certification by the University and Medical Center Institutional Review Board Office of East Carolina University.

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
4N-70 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** · **www.ecu.edu/irb**

Notification of Exempt Certification

From: Social/Behavioral IRB
To: Chad Smith
CC:
Tracy Van Holt
Date: 3/3/2014
Re: UMCIRB 13-002655
Cultural Consensus Analysis

I am pleased to inform you that your research submission has been certified as exempt on 3/3/2014. This study is eligible for Exempt Certification under category #2 .

It is your responsibility to ensure that this research is conducted in the manner reported in your application and/or protocol, as well as being consistent with the ethical principles of the Belmont Report and your profession.

This research study does not require any additional interaction with the UMCIRB unless there are proposed changes to this study. Any change, prior to implementing that change, must be submitted to the UMCIRB for review and approval. The UMCIRB will determine if the change impacts the eligibility of the research for exempt status. If more substantive review is required, you will be notified within five business days.

The UMCIRB office will hold your exemption application for a period of five years from the date of this letter. If you wish to continue this protocol beyond this period, you will need to submit an Exemption Certification request at least 30 days before the end of the five year period.

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

Appendix 3. Survey participation agreement that was used in correspondence for survey distribution.

EMAIL

You are being invited to participate in research titled "What do you know about water quality." This study will assist us in understanding what people know about water quality for the improvement of related citizen science projects and education campaigns. We are surveying individuals that reside near or along the North Carolina and Virginia coasts. The survey will take less than 20 minutes to complete and will remain anonymous. The study is being conducted by Chad Smith, a PhD candidate in the Coastal Resources Management Program at East Carolina University in the Institute of Coastal Science and Policy.

Please contact Chad Smith at 252-328-1747 or smithmich@ecu.edu for any research related questions or survey technical assistance.

MESSAGE FOR FORWARDERS

Citizen science is an emerging tool that bridges the public to the scientific community. With advancements in technology, it is easier for citizen volunteers to provide real time data about various issues such as water quality, bird watching, weather patterns, etc. Questions do remain about how to improve data collection and how well these projects promote scientific literacy. These concerns are vital towards the evolution of citizen science and better integration within the scientific community.

Appendix 4. Survey respondents had to agree with the following opening agreement before commencing the survey.

QUALTRICS® OPENING AGREEMENT

Thank you for taking the time to participate in this research study, "What do you know about water quality." This information will assist us in understanding what people know about water quality for the improvement of related citizen science projects and education campaigns. Water quality describes the condition of the water with respect to its suitability for a certain purpose such as drinking or recreation. This includes both chemical, biological, and physical characteristics of the water.

Your participation in this research study is voluntary and you may stop at any time. There is no penalty for not taking part in this study. Your responses will remain anonymous so please do not include your name anywhere on the survey.

Please answer all questions on your own without consulting any outside resources. If you do not know the answer to a question, please provide your best guess. This survey should take 15-20 minutes to complete.

This survey has been reviewed and approved by the East Carolina University Institutional Review Board, Study ID: UMCIRB 13-002655. If you have questions about your rights as a research participant, you may contact the Office for Human Research Integrity at 252-744-2914.

For questions related to the survey, please contact: Chad Smith at 252-328-1747 or smithmich@ecu.edu.

Please select whether you agree or disagree to participate in this study.

- o Agree
- o Disagree

CHAPTER 4

Design of the education campaign: Creating a motivated, environmentally concerned public through improved scientific literacy

ABSTRACT

The previous chapters of this dissertation focused on two main areas, (1) the integrity of volunteer data and (2) the knowledge of water quality among different cultural groups. Improved volunteer training and education campaigns were mentioned as recommendations to strengthen these areas. The aspiration of this chapter was to introduce different social theories, education tools, and communication models from the primary literature and apply them towards the enhancement of education campaigns. Scientists, water quality educators, and project coordinators of citizen science were the target groups for this research. "Educating the public" is a common phrase heard among scientists when it comes to creating a motivated, environmentally concerned public. Scientists often take on the role as educator to administer environmental education through education campaigns such as classroom events or workshops. A successful campaign is dependent on the careful framework of planning, implementation, and evaluation. The succeeding ideas were introduced from the primary literature and discussed how they can be applied towards education campaigns. Cognitive and social development theories, including knowledge of various learning types, are important in finding target audiences. Bloom's Taxonomy is a tool that assists educators in developing learning objectives by categorizing different levels of thinking. The Elaboration Likelihood Model of Persuasion uses two communication routes, central and peripheral, which are contingent to the cognitive abilities and motivation of the audience. The success of an education campaign is not immediate, thus requiring different modes of evaluation. Challenges such as campaign longevity, changing population demographics, technology, and the "doom and gloom" mentality of audiences to ensure campaign success were also discussed.

INTRODUCTION

"Education is the most powerful weapon which you can use to change the world."

- Nelson Mandela, 2003

About this chapter

In addition to data collection, citizen science typically includes an education component, which includes the design and implementation of education campaigns that help recruit volunteers as well as educate the public. The previous chapters of this dissertation focused on two main areas, (1) the integrity of volunteer data and (2) the knowledge of water quality among different cultural groups. Recommendations from these two chapters included improved volunteer training and education campaigns. The purpose of this chapter was to introduce different social theories, education tools, and communication models from the primary literature towards the enhancement of education campaigns. Information mined from the literature should assist scientists, water quality educators, and project coordinators of citizen science. Conclusions and recommendations based on the literature will aid in promoting environmental stewardship, scientific literacy, recruitment of citizen science volunteers, and integrity of volunteer data.

Educating the public

As a scientist, *educating the public* is a phrase heard quite often. Perhaps at public hearings, committee meetings, conferences, or everyday conversation with colleagues. Scientists will usually agree this is necessary in order to create a more sustainable environment in the face of current issues such as climate change, sea level rise, overfishing, and increasing human population. However, *educating the public* is often attached to some criticism among scientists and even the public itself (Mooney 2010).

Scientists argue that the public should be able to think scientifically about an issue so they can make informed decisions about it. The big question here is whether scientists can motivate the public to become more scientifically literate and environmentally conscious. Mooney (2010) reported the findings of a 2009 study that surveyed both the public and scientists about their views on the scientific community. Results revealed that the public was overall positive about the scientific community while scientists were negative towards the public by describing them as uninformed and the media as imprudent. While not all scientists think of the public and media this way, there may be some logical reasoning behind the surveyed results. Scientists cannot guarantee that the public will agree with their findings or reasoning. There is also the possibility that the public does not understand what the scientists are saying as a result of improper communication. Each public member has his/her own ideologies or political standpoints, which create dissenting opinions about the presented science.

The nature of media can be harmful to both the public and scientists, not to mention the environmental issue at hand. The media may present a one-sided view, or not accurately report the given facts for the sake of television ratings or number of views. A recent example was in 2012 when North Carolina lawmakers rejected sea level rise predictions along the North Carolina coasts. A panel of scientists on the Coastal Resources Commission reported that the North Carolina coastline could see a rise of 39 inches by the year 2100 based on multiple studies. A coastal economic group called NC-20 dubbed the result as *pseudoscience* by arguing that North Carolina only saw an eight-inch increase in sea level rise over the past 100 years and the prediction does not match historic trends. NC-20 also argued that scientists' sea level rise predictions would escalate insurance costs plus hurt the economy by not being able to develop on coastal property. After some debate, North Carolina House Bill 819 was passed and a moratorium was enacted so

as not to report findings on sea level rise until scientists can provide more accurate predictions rather than basing it on models. This decision to ban sea level rise in North Carolina also gained media coverage. Specifically, *The Colbert Report*, where comedian-host Stephen Colbert jokingly mocked North Carolina about its decision. This media example provided a glimpse of poor communication among scientists and the public.

While not all environmental issues are as controversial as sea level rise, scientists should continue their efforts to educate the public in a way that gets them more motivated about the environment through improved scientific literacy. The question that remains is, what can scientists do to accomplish this when they take on the role as educator?

This chapter introduces the importance of environmental education and discusses different strategies for developing education campaigns that are applicable towards any environmental topic such as water-related issues. Throughout the chapter, words such as *educator* and *audience* will be used frequently. Here, educators indicate scientists, water quality educators, and project coordinators of citizen science. The audience refers to students, learners, volunteers of citizen science, or workshop participants. In addition, some of the references cited throughout this chapter are decades-old but are considered landmark studies that remain applicable to education sciences.

BACKGROUND

What is environmental education?

Environmental education was on the rise in the 1960s and 1970s with increasing public awareness on problems associated with climate, water, air, and excessive energy demands. This philosophy and approach became labeled as environmental education. The North American Association for Environmental Education (NAAEE) (1983) defined environmental education as

"the process that promotes the analysis and understanding of environmental issues and questions as the basis for effective education, problem solving, policy-making, and management. The purpose of environmental education is to foster the education of skilled individuals and their ability to understand environmental problems and possessing the expertise to devise effective solutions to them. In the broader context, the purpose of environmental education is to assist in the development of a citizenry conscious of the scope and complexity of current and emerging environmental problems and supportive of solutions and policies which are ecologically sound" (Jacobson 1999). The ideas of environmental education expanded to numerous venues to include formal institutions (e.g., schools, universities), informal outlets (e.g., museums, nature centers), media outlets, and both professional and business groups.

There are three known branches of education: formal, non-formal, and informal. Formal education takes place in formal institutions and requires the audience to learn and display certain competencies through assessments (Meredith et al. 2000). Non-formal education involves structured activities but takes place in informal venues. Informal education is any unstructured activity that takes place outside formal institutions where individuals learn on their own terms, whether it is through exhibits, media, or everyday life experiences (NAAEE 1983).

The National Environmental Education Advisory Council (2005) stated that the goal of environmental education is to improve scientific and environmental literacy among the public. Environmentally literate citizens are those who display logical stewardship, possess positive values/attitudes, and knowledge of the natural environment. They are also more likely to go the extra step from taking *awareness* to *action* (Henderson 1984) by participating in environmentally themed projects or become environmental ambassadors to their family, friends, and community (Jacobson 1999). The importance of this goal will become increasingly important as time moves

forward. The public will have to make decisions that affect the environment, thus making it important to know and understand current and forthcoming environmental issues, risk assessment, and how decisions will affect the environment on local and global scales. The first step towards this goal is to start thinking about education campaigns that pertain to environmental education. There are several ways to describe an education campaign. It may be a single event, or a series of events that center on a particular focus area and audience. The goals of these campaigns may also be different such as creating awareness while others may encourage active participation in citizen science.

While planning the education campaign, it is recommended that educators have insight into cognitive and social development theories for a better understanding of the learning abilities of the audience (Jacobson 1999). Learning types and environment are also imperative. Bloom's Taxonomy is an advantageous tool since it gets the educator thinking about the learning objectives and expected goals. Another tool is the Elaboration Likelihood Model of Persuasion (ELM), a communication model that has the potential to change or create new attitudes towards a given topic. ELM is recommended if the educator aspires to change negative attitudes and behaviors towards a given issue such as climate change and associated sea level rise.

The remaining sections of this chapter discusses these recommendations under the framework of three main phases of successful campaigns: planning, implementation, and evaluation (Jacobson 1999).

PLANNING THE EDUCATION CAMPAIGN

The first step in designing an education campaign is to come up with a focus area followed by listing goals and developing learning objectives from those goals. For example, one goal of this

chapter was to motivate the public to become environmentally concerned through improved scientific literacy. One of the learning objectives that can be extracted from this goal is to discuss how cognitive and social development theories are important for finding the right audience. Developing goals and learning objectives are discussed later in this chapter.

Educators involved in PreK-12 classrooms will most likely follow curriculum guidelines and education standards for a particular grade level. Educators outside the formal classroom may choose a focus area that best aligns with the mission statement of their hosting program. A pilot research study is a good way to select focus areas and develop specific learning objectives. For example, the educator might survey a population or visit a classroom to ask questions of the students. Results of these efforts can help the educator isolate critical areas during the education campaign that needs the most attention. For example, how does the population of a coastal community feel about submerged aquatic vegetation (SAV)? Is there agreement or disagreement that SAV negatively impacts water quality health, recreation, or aesthetics? How the population responds to these questions will help the educator determine whether or not a campaign on SAV is needed, and if so, the critical focus of the campaign. The following sections addresses the learning capabilities of the audience.

Introduction to cognitive and social development theories

Cognitive and social development theories suggest that as individuals' age, the level of knowledge or intelligence goes up meaning that different ages will react differently to educational campaigns (Jacobson 1999). For example, a child will not benefit from a campaign that is geared to adults. Children may require more hands-on activities to understand the goal, while adults can achieve the same goal with other delivery methods such as a discussion or presentation.

Robert Selman (1980) identified five stages of social development that can be useful when designing a campaign for a particular audience. The five social development stages are: (1) infancy, (2) two through six years, (3) seven through eleven years, (4) adolescence, and (5) adult. During the infancy stage, there are no social skills. Between the ages of two and six, individuals are more self-centered but begin to realize the existence of different perspectives. During the ages of seven through eleven, individuals become influenced by their peer groups and become aware of different ideas and points of view on given topics. It is not until the adolescent and adult stages that individuals develop broad social perspectives (Muuss 1982; Knudson et al. 1995).

These different stages of social development can be applied to an *awareness to action* learning hierarchy model (Henderson 1984), which can assist educators in matching education campaign types to the appropriate age level. The bottom level of the hierarchy to the top level is as follows: (1) little awareness, (2) awareness, (3) appreciation, (4) understanding, (5) concern, and (6) action (Figure 1).

For example, a campaign for children ages 2-6 should follow the first level of the hierarchy, which is *little awareness*. The reasoning behind this assumption is that children in this age range do not have much perspective on other issues. They focus more on themselves and would not benefit from a campaign where the goal is more action-oriented. Children aged between seven and eleven years can move up to the third level, which is *awareness* since their perspectives are beginning to broaden. Campaigns for adolescents and adults can reach the top level of the learning hierarchy, which is *action*. It is during these stages of social development that they can make decisions and take action on their beliefs. However, the first three levels of the hierarchy should be included in all campaigns since the awareness and appreciation levels remain important (Figure 1). Also, the educator should not assume the audience is knowledgeable of everything discussed

during the campaign. To ensure success, the educator should take the time to make sure all terminology and concepts are discussed followed by the opportunity to ask questions to clear up any lingering misconceptions.

Learning types

The next step in knowing the audience is to think about how they learn as an individual. Jacobson (1999) suggests there are four types of learners: (1) action-oriented, (2) routine-oriented, (3) research-oriented, and (4) people-oriented. Each learning type is described below.

Action-oriented learners prefer more hands-on activities that are spontaneous, exploratory, and challenging. For example, action-oriented learners may be bored with a lecture-based education campaign on water quality but may excel at a campaign that involves activities such as on-site water quality testing. This learning type is perhaps most seen in adults and most children. Additionally, this learning type may be appropriate for advanced learners that require little introductory information during the campaign (Jacobson 1999).

Routine learners enjoy structure such as lectures and instruction-based activities. This learning type thrives on classroom structure thus making it prevalent in children though some adults may also be routine learners. This learning type may also be common for beginners. For example, if adults are learning how to collect water quality data, they may prefer an opening lecture on the importance of water quality followed by step-by-step instructions when using test kits to collect data for the first time (Jacobson 1999).

Research-oriented learners prefer to focus on one particular concept and benefit from the idea of discovery. The audience may prefer to go through the education campaign themselves as opposed to the educator. For example, the audience would take the campaign topic and conduct

their own research with the educator simply being facilitators. This learning type is common in adults and some children and is best suited for a group that has a curious nature (Jacobson 1999). People-oriented learners enjoy working with other individuals and discussing how the education campaign topic may relate to their own lives. For example, if the audience is made up of volunteers who collect water quality data, they may be more interested in having a group discussion among each other to talk about their shared experiences and opinions on data collection. This learning type is common in adults (Jacobson 1999).

It is vital that educators provide education campaigns that are suitable for all learner types. Otherwise, the effectiveness of the campaign may decrease. If the educator is unsure which learner type dominates the audience, then a solution would be to design an education campaign that blends activities that satisfy each learner type. For example, if the goal of a campaign is to train volunteers in collecting water quality data, it would be good to start with either a presentation (routine learners) on the importance of water quality followed by on-site water quality testing (action-oriented learners). During this part of the campaign, the educator can be available to provide step-by-step instructions for those who may need guidance (routine learners) in using the water quality test kits. After the water quality data have been collected, individuals can work in groups (people-oriented learners) to discuss the findings and make a decision (research-oriented learners) on the results of the water quality testing.

The National Research Council (1997; 2003) and the National Science Foundation (1996) have encouraged educators to adopt active learning techniques in any educational setting. Active learning gets the audience participating in activities that involve mental and physical stimulation as they gather information, process it, and apply it to various problems (Collins and O'Brien 2003). The contrast would be passive learning, which is more lecture-based and involves little to no

involvement from the audience. Huba and Freed (2000) stated that educators who rely on traditional lectures are perhaps the only ones that are learning since they are seeking new information, organizing it, and presenting it in a creative and meaningful way. Instead, why not shift this process to the audience? Some examples of active learning techniques include: (1) inquiry-based learning, (2) discovery learning, (3) technology-enhanced learning, and (4) group work (Michael and Modell 2003).

Each of the four learning types described previously by Jacobson (1999) incorporate these techniques. In the situation where the educator wants to preserve a more lecture-based education campaign, Bonwell and Eison (1991) suggests providing questions every ten to twenty minutes during the lecture, which coincides with the average listener's attention span. Another alternative is to bookend the lecture with discussion questions before and after (Smith et al. 2005). Educators will also benefit since it involves less preparation time by shifting the work to the audience rather than the educator lecturing the entire time (Allen and Tanner 2005); this also helps educators who may be timid (Felder 1997). The only stipulation is that the questions being asked should be thought provoking rather than trivial, which only elicits a *yes* or *no* response. As the questions become more complex, the greater the audience will grow intellectually; it also helps stimulate and sustain a healthy discussion (Felder 1997; Freedman 1994).

While active learning techniques are encouraged, there may be some trepidation from the audience, who may be more accustomed to passive learning techniques (Felder 1997; Goodwin et al. 1991). This may be a result of audience members who attended a university where large-enrollment classes and traditional lectures were commonplace (Edgerton 2001). The audience may feel disconnected from the educator and get an overall sense of disorganization (Felder 1997). The response to this potential problem is to incorporate learning-cycle models in the campaign design

(Allard and Barman 1994; Ebert-May et al. 1997). A classic example of this is the 5E's instruction model (Bybee et al. 2006), which is comprised of the following five steps: (1) engagement, (2) exploration, (3) explanation, (4) elaboration, and (5) evaluation. To briefly describe this model, educators should first *engage* their audience by presenting them with questions and ideas on a given concept. This allows the audience to talk about what they already know and how it may connect to new ideas. From there, the audience should be able to *explore* these newly connected ideas through hands-on activities or further research. Through a mutual exchange between the educator and the audience, the concept is further *explained* to help build a stronger foundation. At this point, the audience should be able to *elaborate* their newfound knowledge of the concept through application to different situations. Finally, the audience should be able to *evaluate* by assessing what they learned and be able to provide this evidence to the educator.

The foundation of these model types is that each step builds on one another as the audience progresses through the cycle. This learning framework still uses active learning techniques but also requires interaction between the educator and the audience along the way (Allen and Tanner 2005). For example, the explanation and evaluation phases requires more input from the educator while the other three phases are more dependent on the audience through active learning techniques.

Learning environment

The learning environment of the education campaign should be taken seriously during the planning phase. Each individual may have their own type of environment they find conducive to learning, whether it is in a classroom, crowded café, or a quiet room. The audience is more likely to focus if there are no distractions (Hart 1991). For example, conducting a campaign along a

greenway may be distracting for a younger audience, who may be easily swayed by passing greenway users.

Another concern is the safety of the environment (Hart 1991). If the campaign takes place in a wooded area where the terrain path is not conducive for easy passage, the audience may shift focus to their own safety rather than listening to the educator. However, this does not mean that the audience prefers to be in the classroom for the entire campaign; devote some time get them outdoors (Hart 1991). The important thing is for the educator to make sure that the learning environment, whether indoor or outdoor, are suitable by asking the audience if they are comfortable, or taking notice of body language that may indicate uneasiness.

Learning objectives and Bloom's Taxonomy

After determining the target audience and best learning environment, developing campaign goals and corresponding learning objectives should come next when planning an education campaign. The learning objectives are the building blocks that will help the educator reach the desired campaign goals. Objectives also provide means for assessing campaign performance. For example, a formal educator would create assessments based off the objectives. If the audience is aware of these objectives upfront, then they recognize what is expected of them. The educator can then gauge the effectiveness of the campaign from the assessment scores. However, if the assessments do not align with the learning objectives, then the audience will most likely perform poorly thus making the campaign unsuccessful.

Bloom's Taxonomy is a tool commonly used by educators for categorizing types of thinking into six different levels (Bloom et al. 1956). These six levels are: (1) knowledge, (2) comprehension, (3) application, (4) analysis, (5) synthesis, and (6) evaluation. These levels are arranged from low to high cognitive thinking skills (Figure 2). In the field of biology, Bloom's

Taxonomy has been used in the design of rubrics for evaluating student work (Bissell and Lemons 2006), the development of assessment questions (Allen and Tanner 2002), and course design (Allen and Tanner 2007). Zoller (1993) and Crowe et al. (2008) classified *knowledge* and *comprehension* as low cognitive skill; *application* serves as the transitional level from low to high cognitive skill. Crowe et al. (2008) argued that higher cognitive skill levels are not hierarchical, referring to the fact that the audience does not need to have *analytical* or *synthesis* skills prior to displaying *evaluation* skills. However, the audience would need to be comfortable with the first three levels of Bloom's Taxonomy. This is similar to the structure of Henderson's (1984) *awareness to action* model discussed previously (Figure 1).

Anderson et al. (2001) revised Bloom's Taxonomy to translate their criteria to their active verb counterparts, which are: (1) remember, (2) understand, (3) apply, (4) analyze, (5) create, and (6) evaluate (Figure 2). The learning objectives should include verbs that align with the chosen thinking level of Bloom's Taxonomy (Bloom et al. 1956; Anderson et al. 2001). For instance, a learning objective that uses the *application/apply* level would read: *The learner should be able to predict why dissolved oxygen measurements change throughout the day.* The action verb in this objective is *predict*. This tells the audience they are expected to apply their knowledge of dissolved oxygen to why it changes throughout the day. Again, this suggests that the first three levels of Bloom's Taxonomy are hierarchical where the audience needs to demonstrate general knowledge and comprehension in order to answer an application-based question successfully (Crowe et al. 2008).

Education campaigns for children

Jacobson (1999) stated that attitudes concerning the environment are shaped during childhood. This is a result of their natural curiosities about the living environment, thus making

them an important audience. Educators have reported that children in the PreK-12 classroom are more attentive to environmental education over other subject areas (Coyle 2005). Children are most likely to be either action-oriented or routine-oriented learners based on their natural curiosity and exposure to a structured classroom setting, respectively. Education campaigns should include hands-on activities that stimulate the senses as well as opportunities to ask questions. Children are less likely to respond well to an education campaign that is strictly lecture-based. The learning environment should be clear of distractions and safety threats. Children also respond well when called upon by name and when the educator stands close to them. This technique also works well for other age groups (Jacobson 1999).

There are a variety of environmental resources that are available for educators that target a young audience. One example is the Project WET Foundation (1984), which focuses on action-oriented education for enabling young learners to better understand the multiple properties of water. The Foundation has published numerous curriculum and activity guides that contain teaching modules covering an array of water-related issues. The layout for these publications vary but the Project WET Curriculum and Activity Guide, which was originally published in 1995, offers a layout that is user-friendly. Each module within this guide indexes appropriate age/grade levels, activity duration, setting (i.e., classroom, outdoors), vocabulary, and learned skills. The modules also provide learning objectives, materials, background information, procedures, and assessments.

These guides are available for purchase or download from the Project WET website (www.projectwet.org). One of the modules from this guide is titled, *Sum of the Parts*. The purpose of this module was to get the audience thinking about where pollution comes from and how it contributes to water quality degradation and how that can affect aquatic life. The audience was

asked to develop property along a river. This can range from a farm to a major shopping development. Upon completion, the audience talked about their development, from upstream to downstream, and how it might contribute to river pollution. Each audience member also discussed the cumulative effects from the upstream developments. To end the module, the educator and the audience discussed alternative strategies to reduce pollution. This module accommodated all four learning types that were discussed earlier in the chapter. Referring back to Henderson's (1984) *awareness to action* model (Figure 1), this module fits within the middle to upper level hierarchies of awareness (e.g., understanding how land development contributes to pollution) to action (e.g., developing strategies to reduce pollution).

Education campaigns for adults

An adult audience is most likely to reach the highest-level hierarchy in Henderson's (1984) *awareness to action* model (Figure 1). Education campaigns for adults should offer a variety of techniques that will accommodate all learner types. For example, routine learners may benefit from a lecture-based campaign whereas action-oriented learners may not. A group discussion with limited guidance from the educator will appeal to people-oriented learners specifically but may also reach other learner types. Shortcomings for a group discussion are digressions from the topic and talkative individuals who have a tendency to dominate the discussion.

Adults may not respond well to activities that are considered childish. Referring back to the previous example that describes the *Sum of the Parts* module, adults may not respond well to this technique unless the educator modifies the procedure or uses it as an ice-breaker activity. An alternative would be to list and discuss potential pollution hazards from each land development and how it contributes to water quality degradation. This may also include an on-site visit to a local waterway impacted by a point-source polluter to conduct water quality testing followed by a

discussion of results. This is supported by a study conducted in North Carolina, where results revealed that adults prefer techniques that involve: (1) doing, (2) seeing, and (3) discussing (Richardson 1994).

Education campaigns for mixed audiences

Education campaigns for a mixed audience are a challenge, as it requires careful planning. A mixed audience is common with non-formal and informal education since it may include family participation. It is important that the educator does not plan the entire campaign to the lowest cognitive level in the audience. Instead, all cognitive levels and learner types should be included in campaign planning. Some activities are considered appropriate for all age levels (Jacobson 1999). For example, an engaging question-answer session will appeal to the natural curiosity that is present in all ages. Another option is to have two versions of a given activity, one that appeals to the adults and the other for children. However, some adults do benefit from children-based activities in an informal setting (Knudson et al. 1995). For example, some campaigns may include activities or games that appeal more to the children in the audience. However, adults may choose to participate even though it might not be as appealing to them. Regardless of their decision to participate, chances are the adults will still learn something valuable from the activity (Jacobson 1999).

Get involved with citizen science

As discussed in the previous chapters, citizen science is a tool that unites the public to science with the goal of enhancing scientific literacy (Bonney et al. 2009). Many government and non-profit groups have implemented citizen science projects into their annual work plans and budgets. As of 2010, the United States Environmental Protection Agency identified over 900 citizen science projects in the United States (Loperfido et al. 2010). These projects typically

involve volunteer citizens that collect and submit scientific data on a routine basis. These data stem in multiple directions, depending on the scope or mission of the project, which may be water quality, species presence/absence, bird watching, or detecting submerged aquatic vegetation. Prior to collecting data, the volunteer citizen undergoes a training session led by the project coordinator. Data collected through the project is entered into a database that is often available to the public and goes towards research efforts within the scientific community. These projects usually include an educational component with the intent of recruiting volunteers and promoting scientific literacy.

Educators should consider citizen science in their efforts to foster an environmentally concerned public. Arguably, there is no better way to motivate the public than actively involving them in the scientific process. First, the educator should see what citizen science projects already exist in their region. Second, talk with scientists in the region about research priorities and data needs. Third, get involved – whether it is promoting an existing project or developing a new one. The Cornell Lab of Ornithology (CLO) is a world leader in the study, appreciation, and conservation of birds. CLO is also known for supporting citizen science through multiple projects that include over 200,000 volunteers. The CLO website (www.birds.cornell.edu) is a good hub to learn more about citizen efforts through their active blog, webinars, and supporting literature on project development. In CLO's Proceedings of the Citizen Science Toolkit Conference, McEver et al. (2007) listed major steps for the development of new citizen science projects:

1. Find an audience and develop scientific questions.
2. Hire or find a project team.
3. Develop data collection protocols and standardized data sheet.
4. Locate a supplier for monitoring provisions.
5. Recruit volunteers.

6. Train volunteers for data collection and interpretation.
7. Develop protocols for submitting and editing volunteer data for potential error.
8. Analyze data.
9. Publish results through a website or report. Make data available to scientists.
10. Apply results towards the research objectives of the project.
11. Measure effects through follow-up events.

For educators already involved with a citizen science project, an additional way to expand scientific literacy is to develop a teaching module using project data and make it publicly available to educators in the PreK-12 classroom or through an education publisher such as the Project WET Foundation. For instance, this module could include exploration and evaluation of project data using the 5E's instructional model (Bybee et al. 2006), which was discussed earlier in this chapter. Visiting the classroom or attending an educator's workshop are good ways to test the module and also provides a venue to promote the citizen science project for volunteer recruitment.

IMPLEMENTING THE EDUCATION CAMPAIGN

The next phase is implementation. Broadly speaking this is when the campaign is presented to an actual, or mock audience. This gives the educator a chance to see how the audience responds to the campaign. Some of the items to consider during implementation are: (1) the eagerness of the audience willing to participate, (2) the adequacy and information levels of the provided resources, and (3) the comfort level of the learning environment. In addition, the educator may have to contemplate persuasive communication methods to change the attitudes of individuals within the audience, which are discussed in the next section.

Elaboration Likelihood Model of Persuasion (ELM)

The general purpose of education campaigns is to create a motivated, environmentally concerned public through improved scientific literacy. In some cases, the educator may have an additional layer to peel away, which are negative or neutral attitudes about an environmental issue. Going back to the earlier example of climate change and associated sea level rise, does the public have a negative attitude about this issue? If so, what are the reasons behind it? The answer could be socioeconomic factors, political agendas, lack of knowledge on the issue, or exaggerated media. Regardless, the goal of the campaign would be to shift any negative or neutral attitudes to more positive ones. To achieve this shift, the educator must adopt a persuasive communication approach during the campaign's implementation.

Over time, researchers have developed diverse theories that pertain to changes in attitude and relationships between knowledge, attitudes, and behavior (Petty et al. 1992). One of the earlier theories for influencing attitude change involved a series of steps (Strong 1925; McGuire 1985). The first step is *exposure*, which presents new information to the individual. Second, the individual must *attend* the information. In other words, the individual must absorb the information that is presented to them verbally, or in the form of a brochure or sign. The third step is *reception*, which involves the individual transferring particular pieces of the information into long-term memory. The fourth step is how the individual *interprets* the information; this will help determine if a change in attitude will take place. Received information may prompt positive, negative, or neutral thoughts within the individual. It is more likely that a change in attitude will occur if the individual responds to the information in a positive way or opposite if the response is negative (Greenwald 1968; Petty and Cacioppo 1981). The fifth step is *integration*, which involve individuals taking their personalized interpretation of the information and forming their own attitudes and placing it into

memory (Anderson 1981). The sixth and last step is *action*, which involves individuals taking on their newly formed attitudes (Petty and Cacioppo 1984a). One of the limitations of this six-step process is that some individuals may not complete all six steps when presented with information (McGuire 1981).

Referring back to the six-step process, Petty and Cacioppo view the *interpretation* stage as the most important because this stage is when an individual will either accept or reject the information presented to them (Petty et al. 1992). Using the concept of *interpretation*, Petty and Cacioppo developed the Elaboration Likelihood Model of Persuasion (ELM). Within the model, there are two persuasion routes, central and peripheral, which can be linked to new and changing attitudes (Petty and Cacioppo 1981; 1986a). Figure 3 diagrams the order of communication for both the central and peripheral routes of ELM.

The central route requires more cognitive activity. The individual draws on prior knowledge and experience to evaluate the merits of the argument at hand. For this route to be successful, the individual must have the motivation and the ability to process the information given to them. The central route is responsible for changes in attitude that are easily comprehensible and impervious to change until their attitudes are contested by divergent information (Petty and Cacioppo 1986a) (Figure 3).

The peripheral route typically encompasses pleasantries to persuade an individual in accepting an argument. This route is best suited when the individual's motivation is low and/or the cognitive ability for processing the information is low. The peripheral route is perhaps the best route if the purpose is an immediate change in attitude. A good example of the peripheral route is using a well-liked celebrity to narrate a public service announcement on an environmental issue. The individual who watches or listens to the public service announcement may not have prior

knowledge or experience with the issue, but knows he/she likes the celebrity and is willing to endorse or accept the celebrity's argument on the issue. Therefore, the individual is being influenced by simple cues of persuasion to change his/her attitude. The limitation of the peripheral route is that it is short-term since the cognitive foundation is low. Using the example of a celebrity-endorsed public service announcement, the individual may later dislike the celebrity. Therefore, the attitude is most likely to shift in the opposite direction (Petty et al. 1992) (Figure 3).

Both central and peripheral routes are valuable, but it is important to know which route is best fitted for a given argument or audience. Combining both routes is also an option, starting with the peripheral route and ending with the central route (Petty and Cacioppo 1986a). Additionally, individuals are more likely to process information if it carries personal significance. Burnkrant and Unnava (1989) found that changing pronouns in an argument statement from third person to second person will increase personal involvement thus making the argument more persuasive. Petty et al. (1976) noted that distractions that occur during delivery of the argument would have an effect on the audiences' ability to attend the information. This goes back to the importance of the learning environment. Smith and Shaffer (1991) mentioned that the speed of argument delivery also has an effect on the thinking process. Talking too fast may inhibit the individual from hearing and processing the argument clearly.

There are three distinctions of elaboration likelihood. When elaboration likelihood is low, personal understanding and relevance will be low and the ability or effort to process the argument will be low. The argument may be too complex or the individual may not be able to focus due to distractions from the learning environment. For moderate elaboration likelihood, the individual will be unsure or how relevant the argument may be to them. The individual may also question the credibility of the information source. As a result, the individual will be unsure whether or not the

argument is worth processing. When elaboration likelihood is high, individuals will have prior knowledge of the argument that may stem from personal relevance; therefore, the message will be easier for them to understand and evaluate (Petty et al. 1992).

Petty and Cacioppo (1984b) added that source factors could have an effect on persuasion. For low elaboration likelihood, expertise and attractiveness of the educator are positive cues for persuading individuals to accept an argument regardless of its validity. For moderate elaboration likelihood, expertise and attractiveness determined how much individual thought went into the argument. For high elaboration likelihood, cues such as expertise and attractiveness do not have much effect on the individual since attention is on the arguments alone and did not depend on external cues of persuasion. Moore et al. (1986) conducted a case study comparing the speed of argument delivery against the three distinct levels of elaboration likelihood. They used a radio advertisement placed at three different speed levels (very rapid, normal, moderately rapid) to test their case. The credibility of the speaker and the quality of the arguments were mixed. When the advertisement was delivered at a very fast pace (low elaboration likelihood), listeners found listening to the argument difficult. Listeners approved of the speaker's credibility but the quality of the argument had no effect since it was presented at such a fast pace. When the advertisement was delivered at a normal pace (high elaboration likelihood), listeners were able to process it easier, thus changing their perspective on the quality of the argument. When the advertisement was delivered at a moderately rapid pace (moderate elaboration likelihood), most listeners were able to process the argument, but not without challenge. These results suggest that faster than normal advertisements lower the chances of the listeners to elaborate on the argument of the message. Therefore, the listeners may switch focus over to peripheral cues. In this case, the likeability of the radio advertiser's voice.

It is important to consider what happens after an attitude change has occurred. Ajzen and Fishbein's (1980) Theory of Reasoned Action describes the process in how attitudes guide behavior. This theory suggests that people will think about the consequences of their actions before they participate, or not participate in a given behavior. Ajzen (1988) followed up on this theory by listing three factors that described how attitudes can have a greater impact on behavior. They are: (1) the attitudes can have a greater impact on behavior if the attitudes in question are consistent with fundamental beliefs, (2) attitudes are based on high amounts of argument-relevant information and/or personal experience, and (3) attitudes are formed as a result of considerable argument-relevant thinking.

Application of Elaboration Likelihood Model of Persuasion (ELM)

ELM can be a helpful tool when deciding which method is best for changing an individual's attitude, thus predicting behaviors. For example, what would be the best persuasion route to take if the learning goal of an education campaign is to inform a small coastal community that submerged aquatic vegetation (SAV) is an indicator of good water quality and serves as a food source for aquatic life and refuge for juvenile fishes?

If the educator takes the central route, is the audience motivated to process the information? In this case, yes, because prior knowledge suggests that the audience believes that SAV is considered a nuisance that dirties their beaches and clogs their boat engines so it carries personal relevance. At this point, will the audience have the ability to process the information that the educator provides on SAV? This relates back to the learning environment and whether or not the learner is distracted, or if they can comprehend the information. If so, what is the nature of the cognitive processing? If the learner's attitude is favorable toward the educator's viewpoints and changes his/her cognitive structure, then a positive attitude change will result. If the learner finds

the information unfavorable followed by cognitive structure change, then a negative attitude will result. These attitudes will be resistant to change. For example, a positive attitude will result in conservation-minded behavior of SAV habitats or methods to prevent excessive SAV growth such as limiting fertilizer use in yards. A negative attitude will most likely result in methods to eradicate SAV in their areas through illegal routes such as destruction of habitat or application of herbicides to kill off the SAV, which will do more harm to aquatic life and surrounding habitats.

What happens if there is no motivation or ability to process the information that is provided by the educator? What if the learner has neutral thoughts as opposed to favorable or unfavorable, and undergoes no cognitive structure change? In this case, the peripheral route would be the best option. Is there a peripheral cue present? A peripheral cue can be a public service announcement voiced by a well-liked celebrity or even a SAV mascot. If these cues are present, then a peripheral attitude change will occur. If not, then the learner will retain or regain the initial attitude that SAV is bad. A change in attitude through the peripheral route is temporary, susceptible to change, and non-predictive of behavior. To overcome this possibility, the educator can shift back to the central route to make the attitude adjustment more permanent (Figure 3).

For education campaigns designed to train volunteers for environmental data monitoring, the central route may be better suited. Since the eventual goal of the campaign is to produce volunteers to routinely collect environmental data, high cognitive skills and motivations are required. Using the example of a citizen science water quality monitoring project, the audience for this type of campaign should be comprised of individuals who have prior knowledge, concerns, and motivation on water quality issues and monitoring. However, individual motivations may differ. Some individuals may be concerned about water quality health of their waterfront properties while some may be more interested in the effects of point-source pollution. During the campaign,

the audience receives information regarding the protocol for water quality monitoring, learns the meanings of water quality measurements, and understands the differences between pollution-induced or natural causes of water quality fluctuations. The audience should be attentive throughout the campaign and interested in the information that is being passed down to them. In the end, knowledge will be continuously reinforced as they monitor and collect data at their locations on a weekly to bi-weekly basis. Furthermore, volunteers of citizen science that focus on water quality monitoring should also be encouraged to be environmental ambassadors and pass the knowledge they have gained to their family, friends, and community.

While the central route may be better suited for volunteers involved in monitoring projects, the peripheral route can be advantageous to boost volunteer recruitment. In this case, the educator may use peripheral cues at information booths at an environmental trade-show, outdoor center event, or a teacher's workshop. The educator's time and audience will be limited due to the pass-through nature of these events. Answering a basic question or spinning a wheel for a prize (peripheral cue) is a good method for bringing individuals to the booth. The goal of the peripheral route is to have an immediate change in the individual's attitude. Reaching this goal will enable the educator to provide enough information in a short amount of time to persuade that individual to participate in the monitoring project or sign up for volunteer training. Another form of recruitment is through monitor networking, a process that is dependent on the individual volunteer and not the educator. Still, the attitude of the volunteer has been partially shaped by the educator, which shows the importance of providing quality education campaigns and volunteer training sessions.

ELM criticism

Perloff (2008) stated that any persuasion model that stimulates research would generate criticism. This is supported from the idea that theories, in general, are critiqued and that new ideas arise from this conflict. One argument is that the Elaboration Likelihood Model of Persuasion (ELM) has the power to explain all possible outcomes, thus making it difficult or impossible to prove the model wrong (Stiff and Boster 1987). Several ELM supporters, including model creators R.E. Petty and J.T. Cacioppo, argued that critics are not recognizing the model's strengths. They stated that individuals would be more likely to elaborate on messages when listener motivation and cognitive ability are high and that peripheral cues were needed when listener motivation and cognitive ability are low (Petty et al. 1987; Petty et al. 1993). By understanding the framework of how persuasion factors work, predicting behaviors from attitude shifts can become clear (Haugtvedt and Wegener 1994; Petty and Wegener 1998). ELM supporters recognized that the intertwining of persuasion and human behavior is not an easy task to apprehend. Furthermore, it is not likely that predictions can be made for every variable during persuasive communication. However, ELM does provide a useful framework for developing a better understanding of persuasion when presented in multiple settings (Perloff 1988).

Supporters and critics both agreed that ELM offers a solid theory on cognitive processing, which helped educators think about the subtleties of persuasive messages that were not as clearly defined before its inception. They also agreed that, despite ELM's strong foundation, it does carry imperfections. For example, Perloff (2008) stated that ELM does not factor in human emotion when it comes to persuasion. Another imperfection is that ELM does not identify the type of message that should be used when communicating with highly involved individuals. For example, the goal of the educator is to produce positive thoughts to the audience, but what type of message

can generate these positive thoughts? Johnson et al. (2005) stated that ELM does not support this question. To argue that statement, ELM has two sides. One side is ELM itself while the other is how the educator uses it. An education campaign that is tailored to accommodate all learning types and age groups has the likelihood to yield campaign success (i.e., positive attitude shift) compared to campaigns that are not well planned.

EVALUATION AND CHALLENGES OF THE EDUCATION CAMPAIGN

The last phase is evaluation, which should involve multiple modes of evaluation from the perspectives of colleagues, educators, and most importantly, the audience (Jacobson 1999). It is important to remember that the success of an education campaign is not immediate. There is some degree of trial and error in the planning and implementation phases. Suggestions for evaluation include administering a pre- and post-survey or assessment following the campaign. Feedback or assessment scores can identify misconceptions as well as strengths and weaknesses towards the delivery of the campaign. Feedback from other educators are also valuable for the same reasons just mentioned. In addition, educators can provide pedagogical recommendations based on past experiences and formal training.

One thing to remember is that educators have different education backgrounds and experience. Educators that have little to no experience with planning and implementing campaigns should consider partnering with an experienced educator and look for other helpful resources. Most government programs include offices that are devoted to education. For example, the North Carolina Department of Environment and Natural Resources includes the Office of Environmental Education (NCOEE), which was established to encourage, promote, and support environmental education in the region. Organizing educator workshops, conferences, webinars, environmental

educator certifications, and education campaigns are just several items that the NCOEE has accomplished since its inception in 1993. In addition, the NCOEE hosts a database that catalogs numerous resource types such as citizen science projects, outdoor classroom supplies, speakers, curriculum guides, and grant opportunities. The information and opportunities provided by the NCOEE is a wonderful way to assist educators with all three phases of campaign design.

Challenges

A big challenge for education campaigns is financial sustainability. Government programs that do not prioritize education in their work plan may cut or decrease funding to basic operation levels, thus making education opportunities limited to non-existent. This may be a result of budgetary cutbacks or social/political pressures. Although this is unforeseen, the pre-emptive solution is for educators to establish partnerships with other programs or businesses to share the budget or possibly receive education supplies as donations. Grant opportunities should be investigated and answered to maximize potential funds. In the unanticipated event that the budget suffers cutbacks, the progression or success of the campaign will not be hindered as a result of financial alternatives. This is particularly important for campaigns with longevity.

Changing population demographics is something else to consider. Hudson (2001) stated that an increase in minority populations, societal demands of family life, and an aging population are changing the structural nature of environmental education. An increasing minority population creates cultural diversity, thus presents different cultural norms and values. For instance, minority populations may not be well-exposed to environmental issues, which may be the result of language barriers and/or geographic location. This goes back to campaign planning. A campaign will not be successful if it is not sustainable for the population being targeted. To combat this issue, there are

scholarships, grant opportunities, and curriculums that are designed to encourage minority populations to become more involved with environmental education and research.

Educators are also challenged with the societal demands of family life. Families often tackle a congested schedule and educators may have to compete with other family-oriented events such as sports, performing arts, and vacations. Successful strategies to entice families are to plan campaigns that are engaging, amusing, and most importantly, involves the whole family.

Populations are also aging out of active participation with environmental-based activities and projects. If campaigns were mostly comprised of older individuals, then a solution would be to focus on campaign planning that encourages participation of younger audiences. Otherwise, there is a risk that the campaign may become stagnant over time. Hudson (2001) suggested that pairing both young and older audiences through mentorships within the campaign might be a good way to bridge the generations for advocating environmental concerns.

Social media is a convenience that has become a staple in the everyday lives of most societies. Over the past decade, social media and networking have evolved into marketing platforms as well as the fast transfer of knowledge. As of March 2013, Facebook reported 1.11 billion registered users on their site. The World Bank reported that the human population was little over seven billion in 2013, which calculates to 15.6 percent of the human population that are registered Facebook users. While this percentage may seem low, it is important to think about the other 84.4 percent that do not use Facebook. There is no argument that Facebook and other related sites are good platforms to promote education campaigns at little to no monetary cost. Posting event dates, photos, and related news articles along with visible contact information are good strategies to find and engage audiences. However, educators should be careful while managing their social media accounts. For example, educators should avoid letting their social media page

become stagnant. Not only does it reduce visibility, it will also suggest to viewers that the campaign is no longer active. The other issue is relying too heavily on social media to handle campaign logistics. Educators should also promote their campaigns in offline settings such as environmentally themed events and workshops so it will not exclude the individuals who are apathetic towards social media.

Educators should often ask themselves if they are relying too much on technology in their campaigns. While learning about the environment through documentary films, video games, and computer-based graphics can be fun and informative, it is important that audiences connect with the environment directly by getting outdoors and getting their hands dirty. Rivkin (1995) stated that the audiences, particularly children, have to experience nature directly in order to gain better appreciation. Rivkin (1995) also mentioned that direct contact with nature is said to stimulate physical, cognitive, and emotional responses that current technology cannot surpass.

The outlook of *doom and gloom* is often concurrent with major environmental issues such as climate change, sea level rise, greenhouse gas emissions, and water conservation (Hudson 2001). Learning about these topics involves both sides of the coin, which includes what the human population has done to the environment and efforts to remedy it. The problem to avoid is creating a hopeless mentality within the individual when it comes to environmental conservation. Hudson (2001) suggested that educators talk to their audiences about success stories from environmental pioneers to the average citizen who have made a difference. Using the example of water conservation, what would happen if everyone turned the water off when they brushed their teeth? One individual may think doing this will not make a difference. However, if that individual was thinking collectively, over a million gallons of water could be conserved from this simple task; it is all about perspective. Hudson (2001) uses the world-renowned Jane Goodall as a leading

example about her direct witnesses of environmental harm throughout her career as a primatologist, ethologist, and animal welfare activist. Rather than be consumed by these negative experiences, Dr. Goodall instead travels the world giving motivational talks to spread a message of hope that has inspired audiences to make a difference for the good of the human spirit, and the environment. It is a step in the right direction.

"Every individual matters. Every individual has a role to play.
Every individual makes a difference."
- Jane Goodall, 1999

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LIST OF FIGURES

Figure 1.


Infancy
Little awareness
2-6 years
7-11 years
Awareness
Appreciation
Understanding
Concern
Adolescents
Adults
Action

Figure 2.

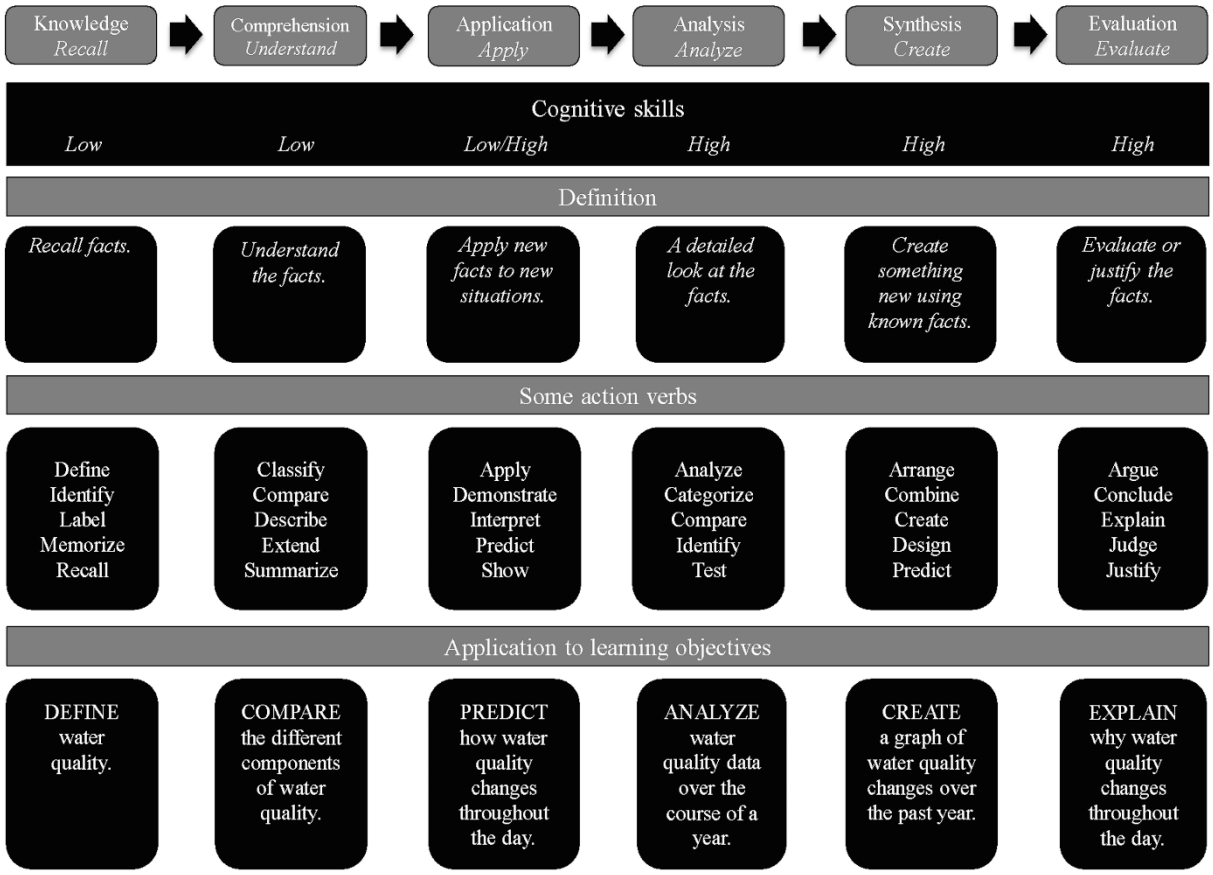
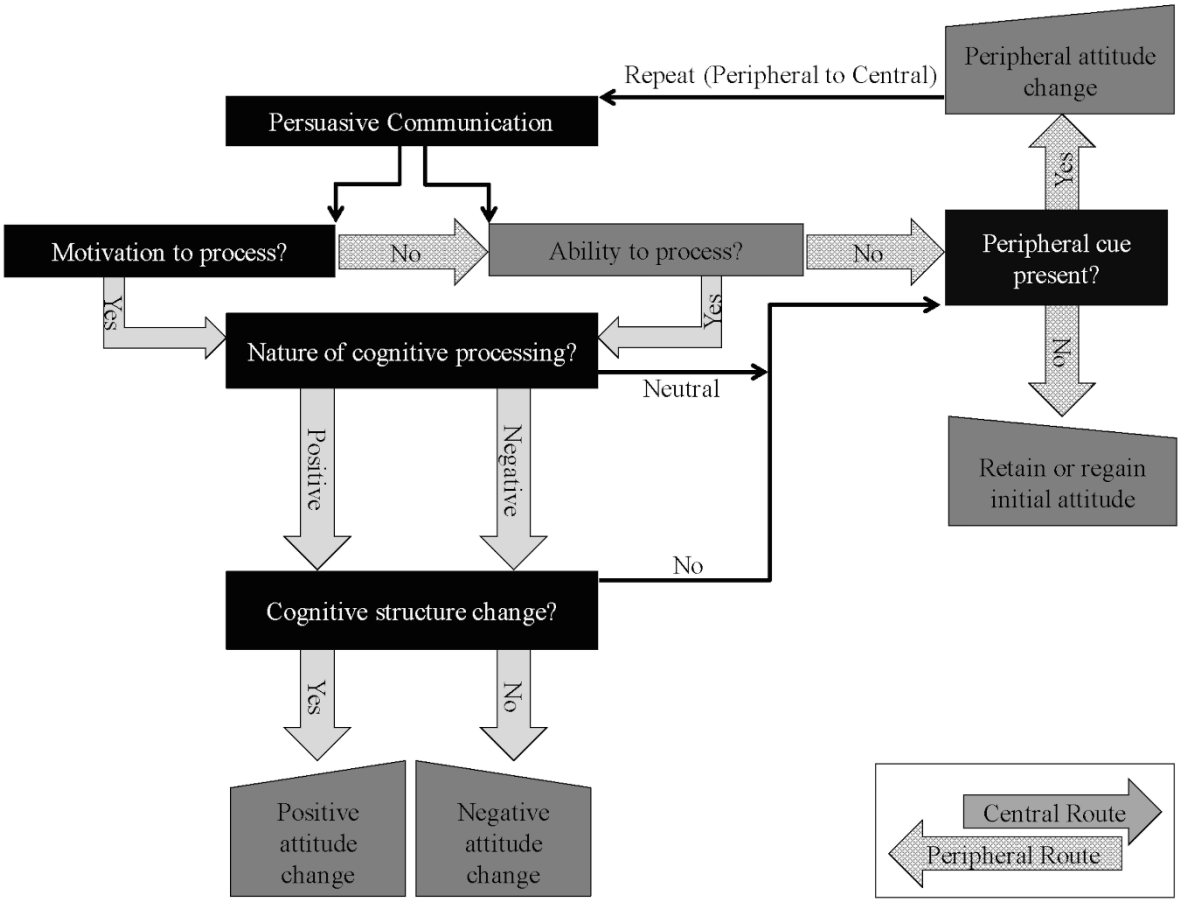

Knowledge
Recall
Comprehension
Understand
Application
Apply
Analysis
Analyze
Synthesis
Create
Evaluation
Evaluate
Cognitive skills
Low
Low
Low/High
High
High
High
Definition
Recall facts.
Understand the facts.
Apply new facts to new situations.
A detailed look at the facts.
Create something new using known facts.
Evaluate or justify the facts.
Some action verbs
Define Identify Label Memorize Recall
Classify Compare Describe Extend Summarize
Apply Demonstrate Interpret Predict Show
Analyze Categorize Compare Identify Test
Arrange Combine Create Design Predict
Argue Conclude Explain Judge Justify
Application to learning objectives
DEFINE water quality.
COMPARE the different components of water quality.
PREDICT how water quality changes throughout the day.
ANALYZE water quality data over the course of a year.
CREATE a graph of water quality changes over the past year.
EXPLAIN why water quality changes throughout the day.

Figure 3.


Repeat (Peripheral to Central)
Peripheral attitude change
Persuasive Communication
Yes
Motivation to process?
No
Ability to process?
No
Peripheral cue present?
Yes
Yes
Nature of cognitive processing?
Neutral
No
Retain or regain initial attitude
Positive
Negative
No
Cognitive structure change?
Yes
No
Positive attitude change
Negative attitude change
Central Route
Peripheral Route

CHAPTER 5

Conclusions of dissertation

Citizen science provides opportunities to build and foster mutualistic relationships among scientists and the public. Contributions to long-term data sets and promoting scientific literacy throughout the community are just a couple benefits of citizen science. To answer the question of my dissertation title, *Citizen Science: Is it worth your time*, my response is yes. Citizen science should continue to thrive throughout the globe. With increasing human population and the demands placed on our natural resources, there needs to be a push to get the public more in-tune to our environment, whether it is through citizen science projects or education campaigns.

Results from my dissertation have addressed some of the concerns associated with citizen science such as data integrity and scientific literacy. Both concerns are interconnected and will influence the other, thus signifying their importance. For instance, improved scientific literacy among citizen science volunteers may positively impact the reliability of volunteer data. In addition, improved scientific literacy among the community can help develop a more environmentally-aware public.

The following sections summarizes the results discussed in the previous chapters. Conclusions and recommendations based from these results are also provided to assist in the improvement of citizen science and education campaigns.

CONCLUSIONS AND RECOMMENDATIONS

Chapter two

This study investigated data integrity of a long-term water quality data set produced by volunteers of the Albemarle-Pamlico National Estuary Partnership's Citizens' Monitoring Network (APNEP-CMN), a water quality monitoring project initiated in 1988. Using various statistical methods, these volunteer data were compared to multiple government water quality

projects managed by professionals in the Tar-Pamlico and Albemarle regions of eastern North Carolina. In some cases, volunteer data were compared to other volunteer data within APNEP-CMN. Two hypotheses were investigated: (1) water quality data among monitoring sites within the same region will produce similar results (P-value > 0.05) although significant differences (P-value < 0.05) were expected for dissolved oxygen and salinity due to more involved measuring protocols; and (2) APNEP-CMN volunteers with monitoring sites in close proximity to one another will produce similar water quality data (P-value > 0.05). Various statistical methods such as the one-way ANOVA, Kruskal-Wallis (KW), and Mann-Whitney U tests (MW) were used to investigate differences among volunteer and government data.

Results suggested significant differences (KW, MW P-value < 0.05) in water quality data for most variables (water temperature, water depth, secchi depth, dissolved oxygen, pH, and salinity) among monitoring sites within a similar region (lower, middle, or upper) and the same season (fall, spring, summer, or winter) in the Tar-Pamlico and Albemarle regions (Tables 1 and 2a-b). These results were not in support of my first hypothesis although significant differences (KW P-value < 0.05) were detected for dissolved oxygen and salinity. The only exception was the 1991-1993 block of the Albemarle region, which supported the first hypothesis (Table 1). Only two block comparisons in the Albemarle region investigated my second hypothesis – results were not in support of this hypothesis.

With the natural variability of water quality through time and space, differences were expected. This was perhaps the biggest limitation with this study. Observed discrepancies could have been the result of differing monitoring equipment, geographic location, local precipitation, and volunteer training protocols.

To better understand monitoring equipment, unpublished water quality data was acquired to investigate whether different monitoring equipment influenced differences in water quality when measured side-by-side at one location. Results detected no significant differences (Independent t-test, P-value = 0.07, df = 7) among the means for dissolved oxygen when collected by the YSI Model 85 Water Quality Meter and the dissolved oxygen titration/chemical kit manufactured by the LaMotte Company. For pH, results detected significant differences (ANOVA, P-value < 0.01, df = 11) among the means for pH when measured using three types of monitoring equipment: (1) pH colorimetric test kit manufactured by the LaMotte Company, (2) pH Pen Model EX60, and (3) Hydrion pH paper. While government data used for this study included different types of equipment, results from this investigation (Rulifson 2015) may suggest that different monitoring equipment can produce water quality measurements that are not precise. The question to which method is accurate is up for debate and warrants further scientific investigation.

Additional investigations to explore the integrity of volunteer data are recommended to strengthen the results from this study. For example, how might geographic differences among volunteer and government sites impact differences in water quality? The experimental design of these future investigations might benefit from a more controlled environment. For example, comparing water quality data from volunteers and professionals that were measured side-by-side at specific locations or providing volunteers with lab-prepared water samples with known nutrient concentrations to see how their measurements compare to the known samples (Loperfido et al. 2010). A recent study conducted in freshwater streams of Nova Scotia revealed that volunteer data were similar to government, or professional, data for the following variables when measured side-by-side: water temperature, pH, conductivity, and discharge. Similarities of these data were based

on whether volunteer data were within accuracy requirements of mechanical and government criteria. The only significant difference was with dissolved oxygen. Recommendations from this study included the modification of volunteer training protocols and calibration techniques (Shelton 2013).

Listed below are recommendations that can assist the project coordinator or staff in improving data integrity for citizen science projects that focus on water quality monitoring.

1. For new citizen science projects, a quality assurance/quality control plan should be first developed and followed for the duration of the project. This plan is required for all projects that are listed and supported by the United States Environmental Protection Agency (USEPA).
2. A copy of the quality assurance/quality control plans should be made available to volunteers and participants of the project. This will enable them to have a clear understanding to what they are doing, why it is important, and how collected data will be managed.
3. For established citizen science projects without a quality assurance/quality control plan, the USEPA provides a document on their website that contains the necessary components for building a plan (USEPA 2013).
4. All volunteers of citizen science projects should be properly trained before collecting data. Training should include discussion to what water quality variables are being measured and how to interpret them for a clearer understanding.
5. The coordinator, or trainer, should not assume that volunteers already know how to measure and interpret data despite them having previous experience with water quality.

6. The duration or frequency of training should also be considered based on the difficulty of water quality variables being measured.
7. Project coordinators, or training staff, should make follow-up site visits to reevaluate protocols being used. Volunteers may need to be advised whether or not their established monitoring system is negatively impacting their data measurements.
8. Project coordinators should investigate whether monitoring equipment is responsible for discrepancies in water quality data. Equipment that offers fewer steps in protocol may present less human error. However, volunteers should be trained in calibration protocols.
9. Project coordinators should maintain transparency within the project so volunteers feel connected to the scientific community.
10. Newsletters, volunteer spotlights, data reports, and social media are methods that can be used to establish or improve transparency within the citizen science project. This will also assist in volunteer recruitment.
11. Project coordinators should make concerted efforts to sustain the project by making sure volunteer data are made available to all that would benefit from it.
12. Inform volunteers when their contributed data are being used for scientific investigations. This was a common question asked by volunteers of the Albemarle-Pamlico National Estuary Partnership's Citizens' Monitoring Network.
13. Additional investigations to explore the integrity of volunteer data are recommended to strengthen the results from this study. The experimental design of these future investigations might benefit from a more controlled environment.

Chapter three

Cultural consensus theory was used to estimate cultural beliefs, or knowledge, of water quality among different cultural groups. Water quality knowledge is defined as the general characteristics and behaviors of water quality parameters and how it affects aquatic life and the surrounding environment; mechanics on how each water quality variable is measured were not included. Data were collected through an online survey that included statements on various water quality topics. Respondents of the survey identified with one of the following cultural groups: (1) citizen science volunteers that focus on water quality monitoring, (2) water quality educators, (3) water quality professionals, (4) fishers [commercial and recreational], and (5) individuals with no experience in water quality. In addition, questions that related to demographics, previous experiences, and expertise in water quality were included in the survey.

Cultural consensus analysis and one-way ANOVAs were used to investigate three hypotheses: (1) each cultural group will display consensus. When all cultural groups are combined into one group, there will be no consensus; (2) volunteers of citizen science that focus on water quality monitoring will display a stronger consensus when compared to the cultural group that has no experience with water quality; and (3) there will be significant differences among the mean cultural competencies of the cultural groups. Cultural consensus analysis provided cultural competencies and whether there was consensus within, and across, the cultural groups (Weller 2007). The one-way ANOVA was used to determine if there were significant differences among the mean cultural competencies among the cultural groups. By using multiple cultural groups with different cultural beliefs of water quality, results determined if citizen science played a role in improving scientific literacy.

Cultural beliefs of water quality were similar among the different cultural groups, although it remains unclear whether citizen science is promoting scientific literacy. Of the five cultural groups, volunteers of citizen science that focus on water quality monitoring and water quality educators received the highest mean cultural competence scores and showed the strongest consensus; water quality professionals displayed the weakest consensus (Table 3). Overall, there was consensus within and across the five cultural groups. No significant differences were found among the mean cultural competencies of the cultural groups; the only exception was among educators and individuals with no experience in water quality (Table 4). The similarities among the educator and volunteer groups were perhaps due to educators being more directly involved with citizen science projects. Inconsistencies among the other groups may have been associated with differences in education and professional backgrounds in water quality.

There was 92 percent accordance with the survey statements on water quality among the cultural groups. Eight percent discordance was observed for the following survey topics: (1) time of day fluctuations, (2) water quality appearance, (3) pH, and (4) storm events. Project coordinators and educators are encouraged to include these topics for discussion during volunteer training, volunteer meetings, and education campaigns. Improved knowledge of water quality in these areas may also have a positive impact on the reliability of volunteer data.

The question that remains is why there was consensus among all five cultural groups. This might have been a result of the sample population in relation to education background. Demographic results revealed that 62 percent of all survey respondents had previous education background in water quality prior to taking the survey. This high percentage might have strengthened consensus among the cultural groups. Further investigation should include separating

respondents who either had, or did not have, previous education background in water quality and conducting another cultural consensus analysis.

For future investigations that include a new sample population, survey distribution using face-to-face methods might remove potential response biases. Eliminating response biases by refining survey distribution methods may provide better representation of respondents from each cultural group, particularly fishers and individuals with no experience in water quality.

Statements included in the survey could also be modified to include more controversial aspects of water quality such as point-source polluters, fish kills, and resource management. By introducing these controversies into the survey statements, cultural consensus analysis could provide a better estimate of cultural beliefs among the different cultural groups concerning water quality

Based on the results from this study, the following conclusions and recommendations should assist citizen science project coordinators or educators:

1. Results from these survey data were not able to clearly determine if citizen science is promoting scientific literacy. However, volunteers of citizen science and water quality educators displayed a stronger consensus and greater mean cultural competencies when compared to the other cultural groups.
2. Active learning strategies such as citizen science allows the public to become more involved with the scientific process. Results from this study suggested similar cultural beliefs of water quality among individuals with no experience in water quality (i.e., general public) and water quality educators. Partnerships among educators and scientists to establish and support citizen science will help improve scientific literacy among the public.

3. Results from this study can be valuable towards environmental-themed government and non-profit programs. A better understanding towards the cultural beliefs concerning water quality across different cultural groups may help reprioritize work plans that could assist in better fulfilling the missions of these programs. *See Appendix 1 in chapter three for the water quality survey.*
4. Additional investigations that include cultural consensus theory can foster a better understanding of cultural beliefs among populations for certain environmental issues such as water quality, submerged aquatic vegetation, invasive species, or climate change. This understanding can lead to the better development and implementation of citizen science projects throughout the nation to improve scientific literacy even further.
5. Survey distribution using face-to-face methods may reduce response biases such as education and professional backgrounds.
6. Statements included in the survey could also be modified to include more controversial aspects to water quality. By introducing these controversies into the survey statements, cultural consensus analysis could provide a better estimate of cultural beliefs among the different cultural groups concerning water quality.

Chapter four

Education campaigns are essential for promoting scientific literacy through raised awareness and action. Successful campaigns are built under the careful framework of three major phases: planning, implementation, and evaluation (Jacobson 1999). Listed below is a recap of key points discussed throughout the chapter:

1. The phrase, *educating the public* is often heard among scientists. This is important for fostering a public that is environmentally conscious through improved scientific literacy. Scientists often take on the roles as educator to accomplish this.
2. Environmental education is defined as the process that promotes the analysis and understanding of environmental issues and questions as the basis for effective education, problem solving, policy-making, and management (NAAEE 1983). Educators have reported that children in the PreK-12 classroom are more attentive to environmental education over other subject areas (Coyle 2005).
3. There are three known branches of education: formal, non-formal, and informal. Formal education takes place in formal institutions that requires the audience to learn and display certain competencies through assessments (Meredith et al. 2000). Non-formal education involves structured activities but takes place in informal outlets. Informal education is any unstructured activity that takes place outside formal institutions where the individual learns on his/her own terms whether it is through exhibits, media, or everyday life experiences (NAAEE 1983).
4. Establish the focus of the education campaign by conducting pilot research to identify environmental misconceptions and educational needs of a population.
5. Cognitive and social development theories suggested that as individuals' age, the level of knowledge or intelligence goes up. This advocates that different ages will react to different education campaigns (Jacobson 1999).
6. The goals and learning objectives of the campaign should be based on how target audiences' fit within the *awareness to action* model (Henderson 1984). Younger ages will fall within the first three levels of the model. Adolescents and adults will reach the highest

level, which is action. However, all education campaigns should include the first three levels of the hierarchy, as awareness is important for all ages (Figure 1).

7. Learning types will vary across audiences. Action-oriented learners prefer more hands-on activities. Routine learners enjoy structure such as lectures and instruction-based activities. Research-oriented learners prefer to focus on one particular concept and benefit from discovery. People-oriented learners enjoy working with other individuals and participating in discussions (Jacobson 1999).
8. The National Research Council (1997; 2003) and the National Science Foundation (1996) have encouraged educators to adopt active learning techniques. Active learning involves the audience participating in activities that involves mental and physical stimulation as they gather information, process it, and apply it to various problems (Collins and O'Brien 2003). In contrast, passive learning is more lecture-based and involves little to no involvement from the audience.
9. The learning environment is important to the success of the education campaign. Audiences will be more attentive if they are not distracted and feel safe in their environmental surroundings (Jacobson 1999). Getting audiences outside the classroom is a good way to make them feel more connected with the environment (Hart 1991).
10. Bloom's Taxonomy is an education tool used by educators for categorizing types of thinking into six different levels: (1) knowledge, (2) comprehension, (3) application, (4) analysis, (5) synthesis, and (6) evaluation. These levels are arranged from low to high cognitive thinking skills. Bloom's Taxonomy is recommended for developing appropriate learning objectives based off the goals of the education campaign (Bloom et al. 1956) (Figure 2).

11. The Elaboration Likelihood Model of Persuasion (ELM) is an important tool for changing an individual's attitude through two routes of persuasion. The central route is better suited for education campaigns when the audience's motivation and ability to process the information are high. The peripheral route is better for campaigns where the audience's motivation and ability to process the information are low. The peripheral route is also better suited for campaigns that are short in length such as recruitment events when individuals are passing through (Petty and Cacioppo 1981) (Figure 3).
12. The two routes of ELM can be combined, starting with the peripheral route and ending with the central route. This will move from a temporary attitude change to a more permanent attitude change that is resistant to change (Petty and Cacioppo 1986).
13. Education campaigns will be comprised of different age groups. Children will benefit from hands-on activities whereas adults prefer methods of seeing, doing, and discussing (Richardson 1994). Campaigns for a mixed audience should satisfy all cognitive levels in the audience. Activities should also appeal to all ages, or offer two versions of an activity; one for the adults and the other for children (Jacobson 1999). Adults also benefit from observing and participating in children-oriented activities (Knudson et al. 1995).
14. There are a variety of resources that include curriculum guides, activities, assessments, etc. available for educators who need assistance in developing education campaigns. These include foundations such as Project WET and government offices that center on environmental education.
15. Educators should consider incorporating citizen science in their efforts to foster an environmentally concerned public. Citizen science is a tool that unites the public to science

with the goal of enhancing scientific literacy (Bonney et al. 2009). Volunteers of citizen science often collect environmental data that are beneficial to the scientific community.

16. The success of an education campaign is not immediate. There is some degree of trial and error in the planning and implementation of campaigns. All campaigns should be evaluated to identify the strengths and weaknesses towards the delivery of the campaign.
17. The longevity of the campaign may present a challenge to educators. During the planning phase, educators may need to develop strategies that can sustain the campaign in the event of unforeseen obstructions such as budgetary cutbacks.
18. Changes in population demographics and technology are happening. Educators should modify their campaigns over time in order to adapt to these changes (Hudson 2001). Despite the conveniences of technology, it is important to get audiences outdoors to experience nature firsthand. This will stimulate a more physical, cognitive, and emotional response from the audience (Rivkin 1995).
19. Audiences may develop a *doom and gloom* mentality when learning about certain environmental issues. While educators should not shy away from discussing the cause and effects of environmental harm, they must give audiences a sense of hope that each one of them can make a difference (Hudson 2001).

Future directions

Data acquired from this dissertation will be further explored to improve methodologies that should benefit the citizen science, scientific, and education communities.

For chapter two, individual water quality variables and specific geographic locations will be selected for further investigation. The development of a report card system using a scoring

rubric to investigate water quality health from both volunteer and government data independently will be explored.

Results from chapter three will further investigate the cultural beliefs of water quality survey respondents who either had, or did not have, previous education background in water quality. For future investigations that include a new sample population, survey distribution using face-to-face methods to remove potential response biases will be considered. Eliminating response biases by refining survey distribution methods may provide better representation of respondents from each cultural group. Adjusting the water quality survey (Chapter 3, Appendix 1) to include more controversial aspects of water quality such as point-source polluters, fish kills, and resource management will also be considered. By introducing these controversies into the survey statements, cultural consensus analysis could provide a better estimate of cultural beliefs among the different cultural groups concerning water quality.

For chapter four, face-to-face interviews or survey questionnaires may be used to better understand what education tools and communication models are being used by project coordinators of citizen science and/or water quality educators. This information will help explore different methods that have been successful, or not successful, for their respective citizen science projects and education campaigns.

Closing statements

The potential for citizen science to change how the public perceives our natural environment continues to grow. With increasing human population and the continued strain on our natural resources, it is imperative that educators and scientists discuss strategies as to how citizen science and education campaigns might benefit their community.

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Figure 2. A diagram of Bloom's Taxonomy detailing the six original levels of thinking (Bloom et al. 1956) and revised levels from Henderson (2001). Each level is further described by cognitive skill level, definition, action verbs, and examples of learning objectives (Zoller 1993; Crowe et al. 2008).

Figure 3. A flow chart explaining the two routes of persuasion based on the Elaboration Likelihood Model of Persuasion (modified from Petty and Cacioppo 1986b).

Table 1.

Comparison	Factor	Region/Block	Water quality variable					
			Water temperature	Water depth	Secchi depth	Dissolved oxygen	pH	Salinity
V-G	Project	**Tar-Pamlico**						
		Lower	0.010	N/A	N/A	< 0.01	< 0.01	0.747
		Middle	0.038	N/A	N/A	< 0.01	< 0.01	0.336
		Upper	0.137	N/A	N/A	< 0.01	< 0.01	< 0.01
		Albemarle						
V-V	Site	1989-1992 block	N/A	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
V-G	Project	1991-1993 block	0.551	N/A	N/A	< 0.01	N/A	< 0.01
V-V	Site	2002-2005 block	0.353	< 0.01	< 0.01	< 0.01	0.088	N/A
V-G	Project	2008-2010 block						
		Lower	0.795	< 0.01	N/A	0.358	0.016	0.003
		Middle	< 0.01	< 0.01	N/A	< 0.01	0.664	< 0.01
		Upper	0.674	< 0.01	N/A	< 0.01	0.738	< 0.01
V-G	Project	2011-2012 block	0.616	N/A	N/A	0.758	< 0.01	< 0.01

Table 2.

(a) APNEP-CMN

Project	Factor	Region/Block	Water quality variable					
			Water temperature	Water depth	Secchi depth	Dissolved oxygen	pH	Salinity
		Tar-Pamlico						
APNEP-CMN	Season	*Lower*	< 0.01	N/A	N/A	< 0.01	< 0.01	< 0.01
		Middle	< 0.01	N/A	N/A	< 0.01	< 0.01	< 0.01
		Upper	< 0.01	N/A	N/A	0.074	< 0.01	< 0.01
		Albemarle						
APNEP-CMN	Season	1989-1992 block	N/A	N/A	N/A	N/A	N/A	N/A
		1991-1993 block	< 0.01	N/A	N/A	< 0.01	0.012	< 0.01
		2002-2005 block	< 0.01	0.003	0.014	< 0.01	1.000	N/A
		2008-2010 block						
		Lower	< 0.01	0.037	N/A	< 0.01	0.033	0.004
		Middle	< 0.01	0.141	N/A	< 0.01	< 0.01	0.008
		Upper	< 0.01	0.213	N/A	< 0.01	0.022	0.224
		2011-2012 block	< 0.01	N/A	N/A	0.952	0.580	0.885

(b) Government and APNEP-CMN

Project	Factor	Region/Block	Water quality variable					
			Water temperature	Water depth	Secchi depth	Dissolved oxygen	pH	Salinity
		Tar-Pamlico						
PCS Phosphate	Season	*Lower*	< 0.01	N/A	N/A	< 0.01	< 0.01	< 0.01
		Middle	< 0.01	N/A	N/A	< 0.01	< 0.01	< 0.01
		Upper	< 0.01	N/A	N/A	< 0.01	0.349	< 0.01
		Albemarle						
APNEP-CMN	Season	1989-1992 block	N/A	N/A	N/A	N/A	N/A	N/A
USGS		1991-1993 block	< 0.01	N/A	N/A	< 0.01	N/A	< 0.01
APNEP-CMN		2002-2005 block	< 0.01	< 0.01	< 0.01	< 0.01	0.019	N/A
NCDMF		2008-2010 block						
		Lower	< 0.01	< 0.01	N/A	< 0.01	< 0.01	< 0.01
		Middle	< 0.01	< 0.01	N/A	< 0.01	< 0.01	< 0.01
		Upper	< 0.01	< 0.01	N/A	< 0.01	< 0.01	< 0.01
ECU		2011-2012 block	0.069	N/A	N/A	0.381	0.549	0.314

Table 3.

Results	Cultural group					
Consensus Analysis	**Combined** n = 285	**Volunteer** n = 43	**Educator** n = 87	**Professional** n = 50	**Fisher** n = 49	**No experience** n = 56
Mean	0.39	0.4	0.4	0.39	0.39	0.37
Standard deviation	0.05	0.05	0.05	0.04	0.05	0.06
Minimum	0.17	0.26	0.17	0.29	0.24	0.17
Maximum	0.47	0.47	0.47	0.46	0.47	0.47
Eigenvalue ratio (first to second)	19.47	19.65	19.71	14.82	16.85	16.62
Consensus (Yes/No)	Yes	Yes	Yes	Yes	Yes	Yes

Table 4.

Cultural group comparison		P-value	Significant
Educators	No experience	0.009	Yes
No experience	Volunteers	0.142	No
No experience	Professionals	0.288	No
Fishers	No experience	0.398	No
Educators	Professionals	0.720	No
Educators	Professionals	0.836	No
Fishers	Volunteers	0.976	No
Educators	Volunteers	0.985	No
Professionals	Volunteers	0.993	No
Fishers	Professionals	1.000	No

Figure 1.


7-11 years
Adults
Infancy
Little awareness
Awareness
Appreciation
Understanding
Concern
Action
2-6 years
Adolescents

Figure 2.

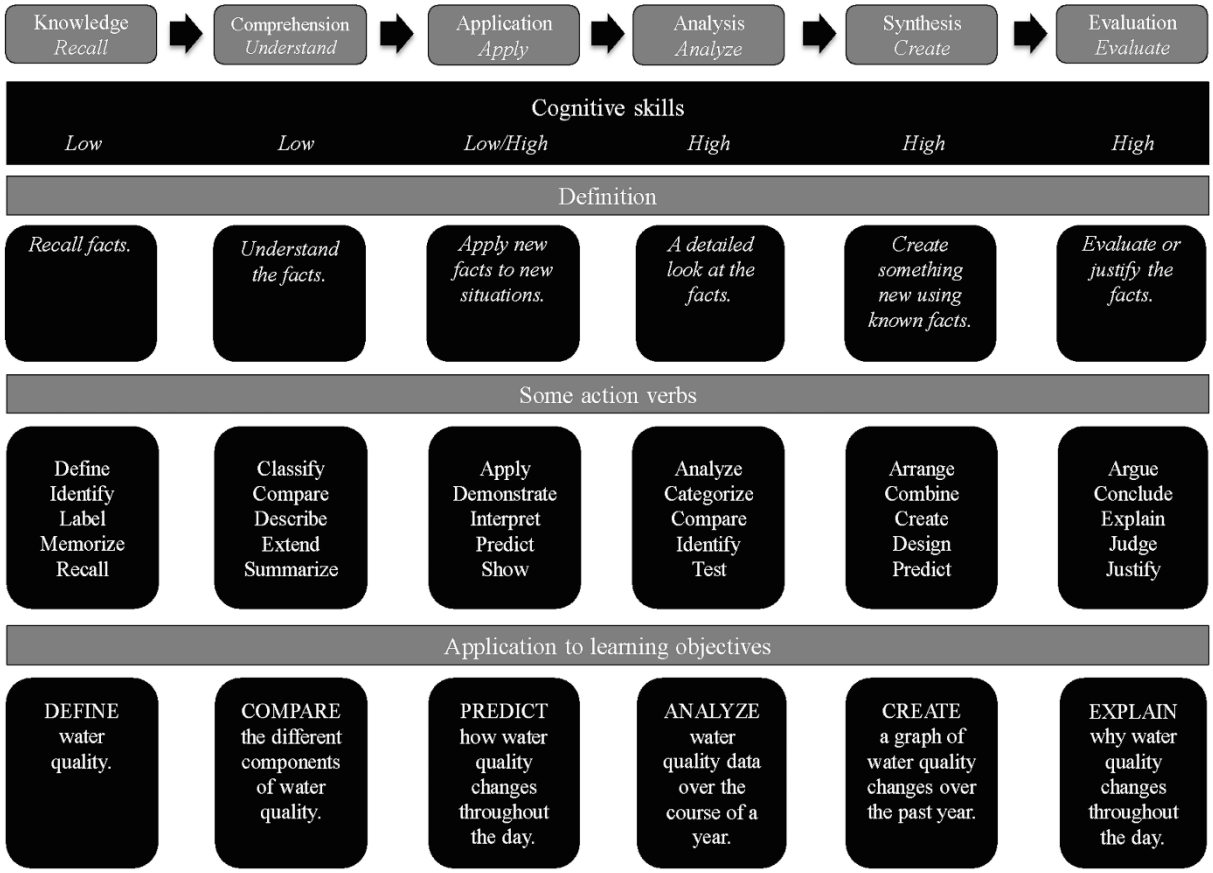
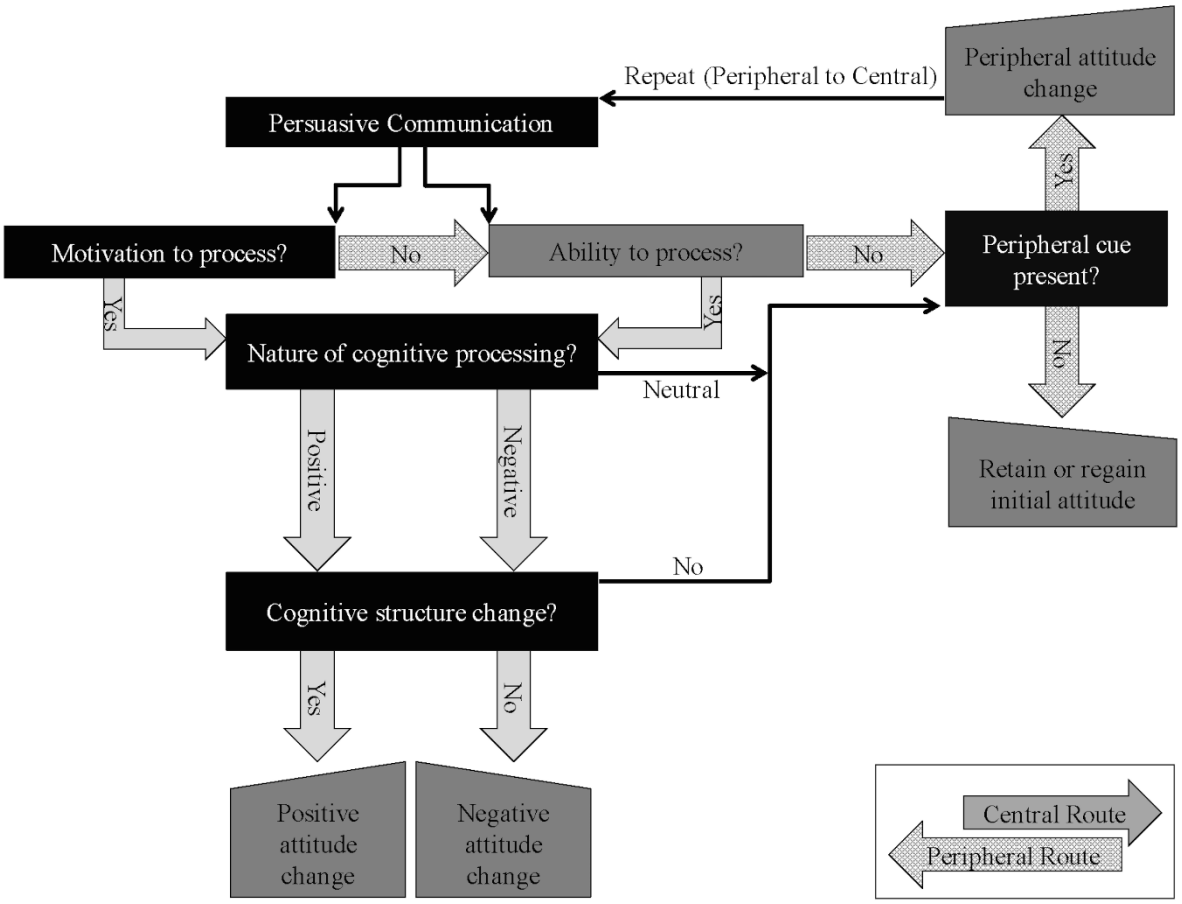

Knowledge
Recall
Comprehension
Understand
Application
Apply
Analysis
Analyze
Synthesis
Create
Evaluation
Evaluate
Cognitive skills
Low
Low
Low/High
High
High
High
Definition
Recall facts.
Understand the facts.
Apply new facts to new situations.
A detailed look at the facts.
Create something new using known facts.
Evaluate or justify the facts.
Some action verbs
Define Identify Label Memorize Recall
Classify Compare Describe Extend Summarize
Apply Demonstrate Interpret Predict Show
Analyze Categorize Compare Identify Test
Arrange Combine Create Design Predict
Argue Conclude Explain Judge Justify
Application to learning objectives
DEFINE water quality.
COMPARE the different components of water quality.
PREDICT how water quality changes throughout the day.
ANALYZE water quality data over the course of a year.
CREATE a graph of water quality changes over the past year.
EXPLAIN why water quality changes throughout the day.

Figure 3.


Repeat (Peripheral to Central)
Peripheral attitude change
Persuasive Communication
Yes
Motivation to process?
No
Ability to process?
No
Peripheral cue present?
Yes
Yes
Nature of cognitive processing?
No
Neutral
Positive
Negative
Retain or regain initial attitude
No
Cognitive structure change?
Yes
No
Positive attitude change
Negative attitude change
Central Route
Peripheral Route