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Perspectives on Emerging Monitoring Technologies: Understanding Factors that Affect Adoption

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PERSPECTIVES ON EMERGING MONITORING TECHNOLOGIES: UNDERSTANDING FACTORS THAT AFFECT ADOPTION

BY

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ABSTRACT

There are numerous technological acceptance and adoption theories that seek to explain how, why, and at what rate new technologies diffuse through systems over time. While the models can be used to explain why users adopt technologies, they do so in a general way and few, if any, studies have addressed the factors that affect monitoring technology adoption in coastal management. This study explores coastal managers' and water quality monitors' perspectives on water quality monitoring technology using various technology acceptance and adoption theories as a theoretical framework to better understand the factors that affect water quality monitoring technology adoption in coastal management.

This study utilizes qualitative and quantitative methods of data collection in a two-part approach: (1) semi-structured interviews, and (2) online surveys. In person interviews were conducted with RI coastal managers to get an in-depth understanding of the factors that affect technology adoption, attitudes and perceptions of technology innovations, and technological needs based on environmental conditions. Data from the interviews were used, along with other sources, to develop a framework of factors affecting water quality technology adoption in coastal management. The online survey investigated how the framework applies to coastal researchers within the National Estuarine Research Reserve System (NERRS). In addition, the survey investigated respondents' likelihood of adopting two innovative monitoring technologies: a low-cost, handheld nanoscale biosensor and an Imaging FlowCytobot. Factors from the existing literature on technology adoption,

such as *technological conditions* and *external conditions*, and additional factors, such as *accuracy, reliability,* and *approved method for water quality monitoring*, greatly influence the rate of technology adoption in coastal management. Findings from this study show that characteristics, needs, and preferences of coastal managers greatly affect which factors are important for technology adoption and that these factors do not necessarily align with the literature. In addition, a majority of respondents was willing to adopt the nanoscale biosensor. *Observability*, the degree to which the benefits (or limitations) of an innovation are visible to others, was statistically significantly more important to respondents who were not willing to adopt the biosensor than those who were willing to adopt it. Findings from this study provide a more detailed understanding of perceptions and attitudes towards existing and emerging monitoring technology; identify potential developments for technological innovations that can be used to better address changing environmental conditions; and provide coastal managers/water quality program directors with insight into how individuals are using technology in order to develop better water quality monitoring programs.

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1. INTRODUCTION

Coastal environments are directly and indirectly affected by natural processes and anthropogenic impacts, such as oil spills, land runoff, pipe discharges, nutrient loading, harmful algal blooms (HABs), climate change, sea level rise, and human population growth (Burroughs 2011). Changing environmental conditions are receiving increased attention from coastal managers and researchers (Betsill and Bulkeley 2007; "What is a Harmful Algal Bloom" 2016). The pace at which the coastal environment is changing requires coastal management and monitoring capabilities to evolve quickly in order to effectively quantify the change. Coastal managers and individuals responsible for water quality monitoring must adapt to deal with the rapid evolution of technology. Therefore, it is important to understand how coastal managers incorporate new technology into their water quality monitoring programs.

There are numerous general technological acceptance and adoption theories and models that seek to explain how, why, and at what rate new ideas and technologies spread or diffuse through human social systems over time (e.g., Crann et al. 2015; Rice and Pearce 2015; Rice 2009; Rogers 2003). Such theories propose numerous factors (or predictors) that influence a user's decision to adopt new technology and therefore, help explain why certain technologies have different rates of adoption (Rogers 2003). Factors that affect the adoption of technology vary depending on the needs of the user population (Renaud and van Biljon 2008). Few, if any, studies have applied these theories of technology adoption to water quality monitoring in the coastal zone.

Using technology adoption and acceptance theories as a conceptual framework, this research explores methods and technologies currently used by individuals involved in coastal water quality monitoring, trends in water quality monitoring technology, and coastal managers' perspectives on emerging monitoring technology, in order to better understand how different factors affect water quality monitoring technology adoption specific to the field of coastal management.

2. BACKGROUND

2.1 Technology Adoption and Acceptance Theories

A number of theories describe the general adoption and acceptance processes of technological innovations. An innovation can be defined as "an idea, practice, or object that is perceived as new by an individual or other unit of adopting" (Rogers 2003, p. 12). This study defines an innovation similarly to Rogers' definition but focuses on emerging, water quality monitoring technologies that are perceived as new by an individual or group associated with coastal or marine environments. *Diffusion of Innovations Theory (DIT), Unified Theory of Acceptance and Use of Technology (UTAUT),* and *Technology Acceptance Model (TAM)* explain technological, individual, and organizational factors and processes that affect adoption and acceptance of information technologies. These theories propose how and why innovations are adopted and accepted, yet there are limitations to each of them and no one theory is universally accepted (Kiwanuka 2015).

Table 1. Framework of Proposed Predictors of Successful Technology Adoption (Crann et al., 2015; Davis, 1989; Rice and Pearce, 2015; Rogers, 2003).

Predictor Category	Predictors of Technology Adoption	Technology Adoption or Acceptance Theory
Technological	Technological Conditions	UTAUT
	Relative Advantage	DIT
	Complexity	DIT
	Trialability	DIT
	Observability	DIT
	Perceived Ease of Use	TAM
Individual	Perceived Usefulness	UTAUT
	Internal Conditions	UTAUT
	Compatibility	DIT
Organizational	External Conditions	UTAUT
	Organizational Conditions	UTAUT

Everett Rogers' *Diffusion of Innovations* theory proposes five characteristics of innovations that seek to help explain why innovations have different rates of adoption: *relative advantage, compatibility, complexity, trialability, and observability* (Rogers 2003; Table 1). *Relative Advantage* refers to whether an individual perceives the innovation to be advantageous over existing and past technologies (Rogers 2003). *Compatibility* refers to the degree to which an innovation is perceived as being consistent with existing values, experiences, and needs of potential adopters (Rogers 2003). *Complexity* refers to the degree to which the innovation is perceived as difficult to use and understand (Rogers 2003). *Complexity* has been found to be negatively related to adoption in that innovations of exceeding complexity are less likely to be adopted (Crann et al. 2015). *Trialability* refers to the opportunity potential adopters have to experiment with the innovation for a limited time prior to adoption. Rogers (2003) states that an innovation that can be tested is likely to reduce the uncertainty potential users have when considering it for adoption (Rogers 2003). *Observability* is the degree to which the outcomes of the innovation are visible to others. The more obvious it is for individuals to see how the technology benefits others who are using it, the more likely they are to adopt it (Rogers 2003).

Based on the *Theory of Reasoned Action*, Fred Davis and Richard Bagozzi developed the *Technology Acceptance Model* (TAM), which seeks to explain how users come to accept and use a technology. TAM identifies two predictors for successful technology adoption: *perceived ease of use and perceived usefulness* of the technology (Table 1) (Crann et al. 2015). *Perceived ease of use* is the degree to which a person believes that using a particular technology would be free of effort. *Perceived usefulness* is the extent to which a person believes that the technology will enhance his/her job performance (Crann et al. 2015; Davis 1989).

The Unified Theory of Acceptance and Technology Use (UTAUT), developed by Venkatesh et al. (2003) builds upon TAM by seeking to explain user intentions and behaviors. UTAUT proposes four key constructs: performance expectancy, effort expectancy, social influence and facilitating conditions (Venkatesh et al. 2003). Facilitating conditions refer to the degree to which an individual believes the organization and technological infrastructure can support a particular innovation (Venkatesh et al. 2003). These facilitating influences include *external, internal, organizational, and technological conditions* (Table 1) (Crann et al. 2015). *External conditions* refer to the amount of support (financial and otherwise) available for the purchase of new technologies. *Internal conditions* refer to the degree to which the technology is compatible with the work style of the user. *Organizational conditions* refer to the degree to which the technology is compatible with other technologies currently in place or if a new suite of technologies is required to run the new innovation. *Technological conditions* refer to the ability of the technology to measure conditions or variables of interest (Crann et al. 2015).

Drawing from these three general adoption and acceptance theories, individual predictors of technology adoption can be grouped into a framework of three broad categories: technological, individual, and organizational (Table 1). Predictors in the **technological category** relate to the perceived and actual characteristics of the technology itself. **Individual predictors** relate to the individual user of the monitoring technology. **Organizational predictors** relate to the place where the individual is situated (e.g., coastal management agency). Some predictors fit into more than one category. This study applies this framework within the context of coastal water quality monitoring.

2.3 Water Quality Monitoring

Surface and ground water quality are influenced by anthropogenic impacts and natural processes. Surface water quality is directly related to atmospheric pollution, effluent discharges, water resource exploitation, and the use of agricultural chemicals (Glasgow et al. 2004). Typical water quality monitoring programs assess water quality by monitoring a suite of physical, chemical, and biological parameters, including: pH, dissolved oxygen, nutrients, chlorophyll *a*, fecal matter, contaminants, metals, polychlorinated biphenyls (PCBs) in fish tissue, infaunal benthic macroinvertebrate communities, amphipods, phytoplankton assemblages, and many more (Stoermer 1978; USEPA 2009).

Advancements in water quality monitoring technology are continuously emerging. Historically, water quality monitoring techniques have utilized costly, time- and labor-intensive on-site sampling and have been limited on temporal and spatial scales (Glasgow et al. 2004). In order to effectively manage and preserve water resources, accurate, intensive, and long-term data collection needs to occur. In the last several years, there has been an increased interest in the development of molecular, optical, biosensor, and analytical detectors for assessment of toxins, contaminants, and biological components in marine, estuarine, and freshwater systems (Glasgow et al. 2004). Innovative technologies such as lab on a chip technologies (e.g., spectroscopic nanoscale biosensors and environmental sample processors), visualization technologies (e.g., imaging flow cytometry), molecular probes, time series sensors, near real-time detection systems, photothermal sensors, and environment sensor networks are being developed in order to address changing environmental conditions (Dashkova et al. 2016; de Freitas et al. 2009; Glasgow et al. 2004; Heisler et al. 2008; Schaap 2012; Zheng et al. 2016). Zheng et al. (2016) is currently developing a handheld nanoscale biosensor that has the potential to measure the concentration of algae in a small water sample by detecting electromagnetic radiation at various wavelengths (Figure 1). This innovation will allow for *in situ* monitoring of algae conditions, increased sensitivity of detection, and will ultimately aid in predicting HAB events in coastal waters.

Figure 1. Nanoscale biosensor prototype (2016).

In October of 2016, Rhode Island experienced the first-ever mandatory closure of shellfish beds throughout most of Narragansett Bay due to the presence of a *Pseudo-nitzschia spp*-dominated HAB event extending throughout New England ("Emergency Shellfish Closure due to Harmful Algae Bloom in Narragansett Bay" 2016). Rhode Island has experienced two HAB events within the last five months that have caused the closure of shellfish fisheries within Narragansett Bay, lower Sakonnet River, and Rhode Island Sound ("Harmful algae forces shellfish ban in parts of New England" 2016; "Second Toxic Bloom in Some RI Waters Closes Shellfishing" 2017). Rhode Island is not alone; within the past several decades, HAB events have been observed in more locations than ever throughout the United States (Hoagland et al. 2002). Along the East Coast, there have been several HAB events in the coastal waters of Massachusetts, Florida, and Maine, which have led to bans on shellfishing as recently as May of 2017 ("Nauset Estuary Closed After Red Tide Outbreak" 2017; Neuhaus 2016; "Second Toxic Bloom in Some RI Waters Closes Shellfishing" 2017). HAB events negatively affect the economy of coastal communities through costs associated with beach cleanups, fishery closures, decreased tourism, and loss of wages. Additionally, the shellfish industry suffers from loss of revenue due to mandated temporary closures of shellfish beds and prevention of harvesting and selling goods. Van Dolah et al. (2001) reported that HABs are responsible for the loss of millions of dollars.

2.3 Water Quality and Harmful Algal Blooms

In the US, there are increasing concerns associated with water quality impacts of HABs ("Harmful Algal Blooms, Tiny Plants with a Toxic Punch" 2017). A HAB event occurs when "colonies of algae…grow out of control and produce toxic or harmful effects on people, fish, shellfish, marine mammals and birds" ("What is a Harmful Algal Bloom?" n.d.). There are two different types of HABs: (1) those that involve toxins or harmful metabolites; and (2) those that are nontoxic. Both forms of HABs result in harmful impacts to the marine and human environments from either their direct production of toxins or through changes to the ecosystem structure and dynamics due to their accumulating biomass (Anderson et al. 2002; Hoagland et al. 2002). Examples of harmful effects of HABs include human illness from toxic seafood consumption or toxin exposure, mass death of marine mammals and birds, and changes within marine ecosystems (Anderson et al. 2002). Over the last 20 years, HABs have increased in frequency, duration, geographic extent, number of toxic species, number of fisheries effects, and costs (Heisler et al. 2008).

2.4 Coastal Water Quality Management in the US and Rhode Island

Effective water quality monitoring is critical for water resource management programs (Glasgow et al. 2004). The federal Clean Water Act (CWA) (1972) requires states to restore and maintain the “chemical, physical, and biological integrity” of US waters. Section 305(b) of the CWA requires all states to assess and report on the overall quality of their water resources. The CWA is the principal method in which states, the Environmental Protection Agency (USEPA), and the public evaluate water quality. In 2009, the USEPA developed a National Coastal Condition Assessment program as a response to several reports identifying the need to improve water quality monitoring and analysis (USEPA 2009). Additionally, the Coastal Zone Management Act, section 1455(b) requires states to develop a Coastal Nonpoint Pollution Control Program in order to protect and restore coastal waters (“The

Coastal Zone Enhancement Program: The Coastal Zone Management Act of 1972" n.d.).

In Rhode Island, water quality management is a shared responsibility among all levels of government and nongovernmental organizations; however, the Department of Environmental Management (RIDEM) Office of Water Resources (OWR) has the primary authority for managing the state's water resources, which includes surface water, ground water, and wetlands ("Water Quality" 2017; "Water Quality 2035: Rhode Island Water Quality Management Plan" 2016). Pursuant to section 305(b) of the CWA, RIDEM is responsible for the Integrated Water Quality Monitoring and Assessment Reporting process ("Integrated Water Quality Monitoring and Assessment Reporting" 2015). Additional monitoring is conducted through the state's Water Monitoring Strategy ("Water Quality" 2017). Through the Water Quality Regulations, RIDEM established water quality criteria that represent parameter-specific thresholds for acceptable levels of substances in the waters of the state ("Consolidated Assessment and Listing Methodology for the Preparation of the Integrated Water Quality Monitoring and Assessment Report" 2014). Rhode Island Division of Planning is responsible for publishing a water quality management plan (WQMP), which is an element of the State Guide Plan (SGP), that supports the Statewide and coastal water nonpoint source management programs and is intended to "advance the effectiveness of public and private stewardship of the State's high quality waters for the next 20 years" ("Water Quality 2035: Rhode Island Water Quality Management Plan" 2016).

The National Estuarine Research Reserve System (NERRS) was established through the CZMA and is a network of 29 protected areas across seven coastal regions (Figure 2) that are committed to long-term research, education, and environment stewardship (“National Estuarine Research Reserve System, System-Wide Monitoring Program Plan" 2011). The NERRS represents a federal-state partnership between NOAA and the coastal states and protects over 1.3 million acres of estuaries through environmental stewardship, research, training, and education ("National Estuarine Research Reserve System, System-Wide Monitoring Program Plan" 2011; “NERRs Overview” 2017). Starting in 1995, NERRs began conducting long-term monitoring and habitat assessments. Today, this monitoring effort is part of the NERRS System-wide Monitoring Program (SWMP). The SWMP is an issue-driven monitoring assessment program that aims to collect and analyze long-term data that is relevant to management issues and to inform effective coastal zone management. The SWMP aims to “develop quantitative measurements of short-term variability and long-term changes in the meteorological, water quality, biological systems, and land-use / land -cover characteristics of estuaries and estuarine ecosystems…” ("National Estuarine Research Reserve System, System-Wide Monitoring Program Plan" 2011). Additionally, every five years, each NERR develops a management plan that is in accordance with NOAA regulations and the state’s coastal management program. The Management Plan identifies the Reserve’s management issues, research and monitoring objectives, goals, and plans ("State of Rhode Island and Providence Plantations Department of Environmental Management" 2010).

Figure 2. The 28 NERRs included in the study, broken down by region ("The NERR System" 2012).

2.5 Research Objectives

Few, if any, studies have been conducted to understand the factors that affect monitoring technology adoption in coastal management. This study investigates how and why water quality monitoring technology is adopted in coastal management and the factors that drive technology adoption and acceptance. In particular, the study:

(1) highlights technologies currently being used by coastal managers (and other individuals involved in monitoring coastal waters) in Rhode Island and in the NERRS sites;

(2) investigates how individual, organizational, and technological factors influence the adoption of water quality monitoring technology in RI;

(3) identifies the most important factors influencing adoption of water quality monitoring technology among NERRS staff; and

(4) explores the potential adoption of an emerging technology for monitoring HABs.

3. METHODS

This study utilized qualitative and quantitative research methods in order to better understand the adoption and use of water quality monitoring technology in coastal management. A two-part approach was used: (1) semi-structured interviews with 12 coastal managers and others involved in water quality monitoring in RI; and (2) online surveys of 26 research staff members at the National Estuarine Research Reserves. The interviews explored how water quality monitoring stakeholders view factors deemed important in prior studies of technology adoption (e.g., *technological conditions, perceived ease of use, external conditions, relative advantage*, etc.) and to develop a framework of factors that affect technology adoption in coastal management. The online surveys explored how the features of this framework apply to a particular coastal management context (i.e., National Estuarine Research Reserve System).

3.1 Semi-structured interviews in Rhode Island

3.1.1 Data collection

The interview protocol (Appendix A) was designed to be semi-structured, which included open-ended questions. A semi-structured design allowed for more flexibility in the sequence of questions and amount of time spent on different topics

(Robson 2011). The interview protocol was divided into three sections: (1) existing technologies & factors that affected adoption, (2) innovative, emerging technologies & factors that affect adoption, and (3) technological gaps and future needs. The interview focused on the current water quality monitoring technologies used by the respondent so they could draw upon firsthand experience, rather than on a hypothetical situation (Weiss 1994).

A combination of purposive and snowball sampling was used to identify potential interview participants (Robson 2011). Twelve interviews were conducted (07/2016-10/2016) with RI coastal managers and other individuals responsible for water quality monitoring. All interview participants were potential users of water quality monitoring technology and data collection instruments or had the authority to mandate which instruments were used for data collection. Particular effort was made to include individuals with a range of interests and experiences with water quality monitoring. Interviews were conducted in person; due to logistical constraints, two interviews were conducted over Skype. Respondents represented governmental, non-governmental, and non-profit organizations throughout Rhode Island: RI Department of Environmental Management (RIDEM), RI Department of Health (DOH), Environmental Protection Agency (EPA), New England Interstate Water Pollution Control Commission (NEIWPCC), Brown University, Narragansett Bay Commission (NBC), Watershed Watch, Save the Bay, and Cyanobacteria Monitoring Collaborative. Interviews ranged between 30 minutes and 65 minutes. Respondents were asked for names of other potential interview respondents, as part of the snowball sample approach. Snowball sampling continued until the point of data saturation, which is the point at which no new information is observed in the data. Saturation has been found to occur in qualitative studies with as few as 6 to 12 interview participants, with more respondents needed when they are not a homogenous group, data quality is poor, or the topic is broad (Guest et al. 2011).

3.1.2 Data Analysis of Interviews

All interviews were recorded and transcribed. Interview transcriptions were coded using NVivo 11 software. Thematic analysis, which is a method for identifying, analyzing, and reporting patterns within the data, was used to minimally organize and describe the data through the development of themes and subthemes and finally by relating themes to theoretical models of technology adoption (Braun and Clark 2006; Crann et al. 2015; Ryan and Bernard 2003). An initial set of codes, (called "nodes" in NVivo), based on the framework and other questions in the interview instrument, were created prior to coding interview data. Subsequent codes emerged throughout the coding process, for a total of 49 individual codes.

3.2 Structured surveys of NERRS staff

3.2.1 Data Collection

The survey next investigated how the framework of factors developed in phase 1 applies within a particular coastal management context, the system of National Estuarine Research Reserves. The survey instrument (Appendix B) used Dillman et al.'s (2014) tailored design method and included open and closed-ended questions, 7-point Likert scale questions, ranking questions, and the use of scenarios.

Likert scale questions asked respondents to rate the importance of factors when deciding to adopt technological innovations and how likely they are to adopt certain technologies. Based on the findings from the interviews with individuals involved in coastal water quality monitoring in RI, several factors were added to the original framework. Additional factors included in the survey included: *accuracy, reliability, cost, and approved method for water quality monitoring*. Respondents rated factors on the relative importance of each factor when deciding to adopt an instrument to monitor water quality at their Reserve. Additionally, the survey inquired about respondents' demographic characteristics, characteristics about their workplace, and other general information. Pilot surveys were conducted with knowledgeable coastal stakeholders to ensure clarity and directness of the questions.

Online surveys were distributed to individuals at each of the NERRs. The NERR system represents a large community of coastal managers and researchers across the United States, emphasizes research and education in its mission, and implements a system-wide water quality monitoring program. The online survey broadens the geographic scope of the study by incorporating participants from all coastal regions of the United States. Online surveys were distributed to 49 researchers of the NERR system, 28 NERRs in total at the time this study was conducted. Purposive sampling was used to identify 1 or 2 research staff members at every NERR including the Research Coordinator and System-Wide Monitoring Program staff or individuals responsible for water quality monitoring, for a total of 49 possible respondents. Survey participants were initially contacted through an e-mail, which included a link to the survey. Reminder emails were used to increase survey response rate (Dillman et al. 2014). The survey was distributed through an online survey platform (Survey Monkey) during October 2016 to January 2017, and was designed to take between 15 and 20 minutes to complete.

3.2.2 Data Analysis of surveys

The online surveys provided quantitative data related to the framework on coastal water quality monitoring technology adoption, how and why new monitoring technology is adopted in coastal management, and the importance of framework factors to NERRS staff. The average rating for each factor across all respondents was calculated. Data were statistically analyzed using descriptive statistics and predictive analyses (e.g., Mann-Whitney U test). The Mann-Whitney U test was used to compare mean factor scores between respondents who were willing to adopt the nanoscale biosensor, an emerging tool for measuring presence and abundance of HABs in coastal waters, and respondents who were not willing to adopt the nanoscale biosensor. Significance for all statistical tests was determined at the commonly accepted 5% level.

4. RESULTS

4.1 Rhode Island Interviews -- Sample Characteristics

Twelve respondents from governmental, non-governmental, and non-profit coastal management agencies and organizations throughout Rhode Island and Massachusetts completed the interview. Agencies and organizations included the RIDEM, RIDOH, EPA, New England Interstate Water Pollution Control Commission, Brown University, Narragansett Bay Commission, Watershed Watch, Save the Bay, and Cyanobacteria Monitoring Collaborative. On average, respondents held their current position for 17 years.

Interview respondents were actively involved in collecting water quality data or managing a water quality monitoring program. Typical water quality variables monitored by interview respondents include physical and chemical parameters; nutrient, metal, and pollution parameters; biological parameters; and other parameters (Appendix C). The most common water quality monitoring technology used by interview respondents was the YSI Multiparameter Sonde (various models including: 6500, 2600, 2030, 90, and 85). Twenty-three other instruments were mentioned, including fluorometers, Hydrolab Multiparameter Data Sonde, Westco Smartchem Discrete Analyzer, and more (Appendix D).

All respondents stated that Rhode Island's water quality conditions have significantly improved over the last 150 years noting that decreases in bacteria pollution, metals, total nitrogen loading, beach closures, and upgrades to wastewater treatment facilities have significantly contributed to the improvement of Providence River and Narragansett Bay's water quality. As one respondent stated:

I think there has been a lot of improvement over the last 20-30 years. The Clean Water Act definitely drove improvements, particularly in rivers. I think the [Narragansett] Bay is a lot cleaner, in terms of total pollutant loading that it's receiving, than in the past.

According to another respondent, who is actively involved in the DOH's Beach Programs, the number of beach closures is the lowest it has been in 37 years.

4.2 National Estuarine Research Reserve System Survey -- Sample Characteristics

Thirty individuals responded to the survey, however, four responses were incomplete and removed from the sample, resulting in a sample size of 26. At least one survey was completed from each of the seven NERRS regions (Figure 3). The average age of respondents was 42 years of age, ranging from 26 to 66. Fifty percent of the survey respondents identified as male (13), 38% of the respondents identified as female (10) and 11% chose not to respond (3). All respondents had some level of higher education, with ten respondents having doctorate degrees, seven respondents having graduate degrees, and nine respondents having bachelors' degrees. Job titles of respondents are outlined in Table 2. Respondents held their current positions for an average of seven years.

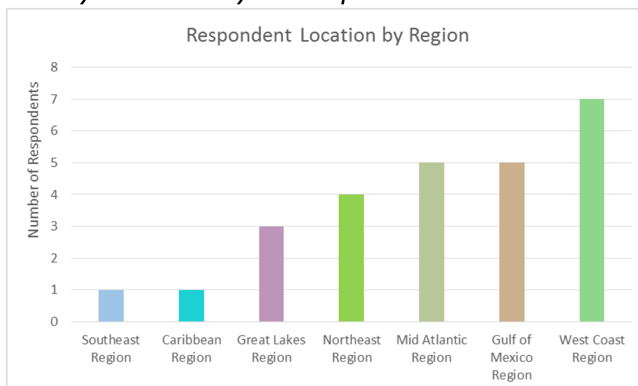

Figure 3. The number of survey respondents from each NERRS region (Southeast, Caribbean, Great Lakes, Northeast, Mid-Atlantic, Gulf of Mexico, and West Coast).

Respondents were actively involved in collecting water quality data or managing a water quality monitoring program, with the highest number of respondents working on water quality monitoring-related issues between fifty and seventy-five percent of their time (Figure 4). Appendix C lists the typical water quality variables monitored by survey respondents.

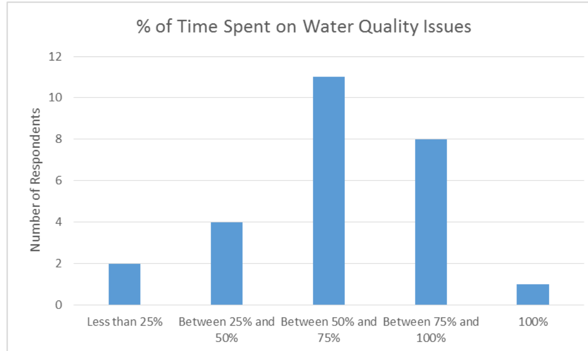

Figure 4. The amount of time survey respondents stated they spend on water quality monitoring and related issues.

The most common water quality monitoring technology used by survey respondents was the YSI Multiparameter Sonde (various models including: 6920, 6820, EXO 1 and 2). Twenty-one survey respondents cited various models of the YSI Multiparameter Sonde as the most commonly used instrument for measuring water quality parameters. The YSI measures physical and chemical parameters of the water, such as temperature, pH, dissolved oxygen, salinity, and others depending on the model used. Twenty-three other instruments were noted by survey respondents as currently being used for water quality monitoring within the NERRS (Appendix D).

Table 2. Job titles of survey respondents and the number of respondents that held each title.

Job Title	Number of Respondents
Research Coordinator	8
Technician	5
Monitoring Coordinator	4
Director of Research	2
System-Wide Monitor Program (SWMP) Manager	2
Senior Laboratory & Research Staff	1
Temporary Employee	1
Data and Lab Manager	1
Project Manager	1

Perceptions of current water quality conditions varied across the survey respondents, ranging from severely degraded to pristine, with the highest number of respondents classifying water quality at their respective reserves as average. However, due to the large area comprising some reserves (e.g., Kachemak NERR in Alaska encompasses 372,000 acres), it was difficult for respondents to make a judgement of the overall water quality status within the entire reserve. One respondent highlighted the difficulty of making a general statement regarding water quality status in the following comment:

> *[Water quality] varies quite a bit from Reserve to Reserve (we have four components separated by 300km). Where population density is high, water quality tends to be more degraded, although proximity to inlets (high flushing/low residence time) can mitigate some of the water quality issues associated with development. Overall, I think waters surrounding reserves are average. Waters within the reserves range from above average to average.*

Perceptions of trends in water quality also varied across respondents. Eleven respondents stated that the water quality conditions within their reserves have been stable for the last 15-20 years, while eight respondents stated that water quality has been declining, and seven respondents stated that water quality conditions have been improving.

In terms of the frequency with which NERRS invest in water quality monitoring technology, 12 respondents stated that their reserves *occasionally* purchase or acquire new water quality monitoring technology or equipment, while nine respondents stated that their respective reserves *frequently* purchase or acquire new monitoring technology. Five respondents stated that their respective reserves *rarely* purchase or acquire new monitoring technology. However, when asked to think back to the last time new monitoring equipment was purchased or acquired, twenty-three respondents stated that their reserves acquired new water quality monitoring technology within the last six months, while only two respondents stated that their respective reserves acquired new monitoring technology within the last two years, and only one respondent stated that his/her reserve acquired new monitoring technology within the last five years.

Respondents were asked to characterize themselves as one of Rogers' (2003) adopter categories based on a description that best fit their individual willingness to adopt new technologies (Table 3). Respondents characterized themselves as either early adopters, early majority, or late majority (Table 3). No respondents considered themselves an innovator or a laggard when adopting new technology.

Table 3. Adopter category, corresponding descriptions used in the survey instrument, and percentage of respondents who characterized themselves in each of the adopter categories Rogers 2003).

Description	Adopter Category	% of NERR Respondents
I am always thinking of ways to develop a new technology. Uncertainty and failure about a new technology do not prevent me from innovating.	Innovator	0%
I usually use a new technology before most people and I am the person to go to for advice when considering using new technologies for the first time	Early Adopter	23%
I am willing to use a new technology but I'm never the first to do so	Early Majority	69%
I am usually skeptical of new technologies and the uncertainty about new technologies must be reduced before deciding to use them	Late Majority	8%
I am usually the last to use a new technology and only do so when the technology is known to not fail	Laggard	0%

4.3 RI Interview Results

4.3.1 Framework Elements

During the interviews, respondents described how various factors within the framework influenced their decisions to adopt certain monitoring technologies. Respondents' views of the factors are grouped here by the three broad categories of the framework (Table 4): technological, organizational, and individual. The following section discusses interview respondents' views of factors within the framework of factors affecting an individual's decision to adopt monitoring technologies.

Table 4. Summary of factors affecting monitoring technology adoption in coastal management and the number of respondents who discussed each factor. Factors that emerged out of the interviews but were not found in the literature are denoted by asterisk.

Category	**Factor**	**Factor Description**	**Number of respondents that discussed the factor (Out of 12 respondents)**
Technological: perceived and actual characteristics of the technology itself	Technological Conditions	The ability of the technology to measure conditions or variables of interest	12
	Relative Advantage	Whether an individual perceives the innovation to be advantageous over existing and past technologies	10
	Complexity	The degree the innovation is perceived as difficult to use and understand	6
	Trialability	Refers to the opportunity potential adopters have to experiment with the innovation for a limited time	4
	Observability	The degree to which the outcomes of the innovation are visible to others	8
	Perceived Ease of Use	The degree to which a person believes that using a particular technology would be free of effort	8
	*Accuracy	Sensitivity of the technology in measuring environmental parameters	7
	*Reliability	The ability of the technology to record data that is not statistically different from the data	9

		recorded by a different technology	
	*Cost	Cost of associated with adopting and maintaining the instrument	8
	*Durability	The degree the technology is considered physically durable	4
Individual: related to the individual user of the monitoring technology	Perceived Usefulness	The extent to which an individual believes that the technology will enhance their job performance	6
	Internal Conditions	The degree in which the technology is compatible with the work style of the user	6
	Compatibility	Refers to the degree to which an innovation is perceived as being consistent with existing values, experiences, and needs of an individual	2
Organizational: relate to the place where the individual is situated	External Conditions	The amount of support (financial and otherwise) available for the purchase of new technologies	10
	Organizational Conditions	The degree in which the technology is compatible with other technologies and protocols currently in place or if a new suit of technologies is required to run the new innovation	8
	*External organizational Connections	The degree in which the technology is used by other coastal management agencies/organizations around the state/nation	3
	*Approved Method for Water Quality Monitoring	Refers to the importance in which the technology is am approved method (by EPA or others) for water quality monitoring	6
	*Technological Support	Quality of technological support available when problems arise	3

4.3.2 Technological factors affecting monitoring technology adoption in coastal management

Several technological factors from the literature, such as, *technological conditions*, *perceived ease of use, relative advantage,* and *observability* played a particularly important role regarding a user's decision to adopt a new technology.

During the interviews, *technological conditions* emerged as one of the most influential factors in an individual's decision to adopt new technology. *Technological conditions* are the ability of the technology to measure environmental conditions of interest (e.g., dissolved oxygen, temperature, salinity). Several respondents noted rapid response rate as an important characteristic of the technology. In fact, when asked to identify the most important factor in deciding to adopt new monitoring technology, four respondents cited the rapid response rate of sensors, three respondents cited *durability* of the technology as one of the most important factors, and two respondents cited *reliability*. The ability of the device to measure desired environmental parameters and the ability of the device to work in fresh and saltwater were also described as being the most influential factors by some respondents. A few respondents said that multiparameter sondes, such as YSI or Seabird, were useful for measuring some conditions but not others. Although these tools are designed to measure multiple parameters, such as pH, dissolved oxygen, temperature, respondents felt that they are effective at measuring only a couple of them. For instance, one respondent commented on the capability of the multiparameter sonde:

> *For temperature, [YSI] seems fine. For salinity it is okay, but I think I would like something that I had more confidence in and probably more precision. For dissolved oxygen, it's more than satisfactory but other aspects of it are lacking.*

For multiparameter sondes, or other comprehensive monitoring instruments, coastal managers only utilized certain functions or parameters. Several respondents described how the ability of the instrument to measure environmental conditions outweighed other factors, such as cost. As one respondent stated, “it [the tool] is expensive, but it is a relatively rapid thing.”

Perceived ease of use was an important factor in decisions to adopt new technology, especially for management programs that employed volunteers or students to monitor water quality conditions. Two respondents cited ease of use as the most important factor when deciding to adopt a new monitoring technology. Many of the instruments used for water quality monitoring were considered easy to use by respondents. Several participants noted that their current technology was very easy to use and required little training to operate. For instance, some respondents characterized their devices as “really easy to use, it’s a simple push button operation,” “super simple, it’s so much easier that what we were using beforehand, so a huge improvement in that way,” “[i]t’s such a simple method.” Two respondents summarized the importance of ease of use by stating, “[t]he simplicity is definitely a huge, huge benefit” and “I like that it is fairly easy to use.” Perceived ease of use of a new monitoring technology was a very important factor for organizations who employ volunteers or students to collect water quality monitoring samples in the field, as one respondent stated,

> *The fluorometer…takes more to learn, so our expectation isn’t that volunteers would really learn how to use that…it takes a little bit of finesse to use it…*

Although most respondents described ease of use as an important factor in deciding to adopt a new technology, some found that it did not matter.

Complexity is the inverse of perceived ease of use. Even though only a few of the water quality monitoring devices used by respondents were characterized as difficult to use, most respondents said they would be willing to adopt and use a complex technology. Respondents that utilized the complex technologies, such as the Segmented Flow Nutrient Autoanalyzer, Seabird Sonde, and QPCR, made statements such as, "it's not easy to use. It's definitely not easy to use" and "[n]ot super easy, but not ridiculously hard either," however, these respondents adopted the technology despite its complexity. In cases where a specific technology was difficult to use, respondents noted that only trained personnel would be allowed to use and maintain the instrument. For monitoring technology that was considered complex or difficult to use, coastal managers and researchers would be trained on how to use the instrument properly and maintain it. One respondent directly commented on this by stating, "[p]eople have a lot of expertise in it [Seabird Sonde], they have been doing it for years." Additionally, one respondent directly commented on how little individuals involved in coastal monitoring are concerned about the complexity of a device: "…there is definitely a learning curve involved with that and the calibration aspect that people tend to not think about…" This respondent's comment suggests that the relative complexity of a device is not typically prioritized during the decision making process to adopt a new technology.

Relative advantage refers to whether an individual perceives the innovation to be advantageous over existing and past technologies. All respondents believed they were adopting the technology that best met their needs as a coastal manager/researcher. Several respondents expressed that they felt they had adopted the best technology on the market. Capabilities, such as rapid response rate, reduced variability, and better design (e.g., waterproof exterior, ruggedness), made their selected instruments superior to competing instruments. Three respondents noted that relatively few companies produce water quality monitoring technology, limiting the availability of alternative technology options. Respondents commented on the limited availability of monitoring technology, with one saying "…there were 1 or 2 competitors but there weren't a lot of choices for equipment." Another noted:

> *…there weren't a lot of companies, Seabird, YSI, and Hydrolab, I'm not sure how many other companies were around at the time doing this kind of stuff in salt water areas.*

One particular monitoring technology, the YSI Multiparameter Sonde, has become one of the most widely used technologies for water quality monitoring. One respondent referred to the prevalence of YSI in coastal management by stating*, "…I think that it is so ubiquitous that I honestly don't know that other people are using other instruments."*

Observability refers to the degree to which the outcomes of the innovation are visible to others prior to adopting the technology. Knowing the technology's capabilities was important to some respondents prior to adopting the technology. For example, many respondents relied on their colleagues for recommendations on specific technology. One respondent stated,

> *…I lean on [my colleague] who is really engaged in water quality technology…and I just ask him because he has done extensive research on*

it…and I know folks over at URI [nearby university] who I talk to about this too, not recently, but I look to those folks who are experts.

Other respondents noted that they learned about how a technology works through conversations with others, advice from mentors, knowledge of another program pioneering a technology, online reviews of the technology, and through conferences. However, nine respondents stated that they were not familiar with the technology prior to adoption but adopted the instrument regardless and therefore, insinuated that being familiar with the technology was not an important factor when deciding to adopt a new technology. One respondent noted that her monitoring program utilizes a YSI Multiparameter Sonde because it had been used in previous years and she did not want to disrupt the method of data collection/analysis.

Trialability, the opportunity to try out a new technology prior to adoption, was not a major influence on an individual's decision to adopt new technology. Many respondents said they did not try out new technologies before buying or using them. Five respondents directly recalled not having any opportunity to trial the technology before adopting it. However, two respondents recalled having the opportunity to trial the technology. One of which had the opportunity to trial the technology through a colleague and the other saw the technology being demonstrated at a scientific conference. In one unique case, a respondent was awarded a grant to trial a new method of bacterial monitoring prior to purchasing the new technology and implementing new protocols. The respondent said this helped her understand the limitations of the technology and determine if it was an appropriate method for monitoring. *Trialability* was considered useful by respondents, but was not a necessity for adopting a new coastal monitoring technology.

Respondents cited a number of technological factors related to technology adoption that have not been discussed in detail in the technology adoption literature: *reliability, accuracy*, *durability,* and *cost. Reliability, accuracy*, and *durability* all refer to the ability of the technology to measure environmental conditions. Nine respondents emphasized the importance of the *reliability* of the instrument in capturing quality data. *Reliability* refers to the ability of the technology to record data that is not statistically different from the data recorded by a different technology. Several respondents noted that their program could not afford to make mistakes or collect inaccurate data during the transition to a new monitoring instrument. Three respondents reported running new technology in tandem with old technology in order to ensure the data is comparable. One respondent highlighted her hesitancy to give up using an instrument known to be reliable:

> *I think we would be reluctant to change what we do as something that's reliable to something that is brand new, unless it had some level of proven track record to it.*

Accuracy was a recurring theme throughout the interviews. *Accuracy* refers to the sensitivity of the technology in measuring environmental parameters. Often times, water quality monitoring data are used for more than basic research; instead, they are used to inform policy decisions. Several respondents emphasized the importance of precise, sound data that could be used in coastal planning and management. One respondent specifically stated:

> *[w]hat's important to us is that we develop sound science, and that management decisions by the state [DEM] or EPA are based on sound science. In order to have sound science, you need accurate data.*

Additionally, one respondent reported that accuracy and precision of the technology was one of the most influential factors when deciding to adopt a new monitoring technology.

Respondents indicated that *durability* of the monitoring instrument is an important factor in decisions to adopt new technology for coastal monitoring. *Durability* refers to the degree that the physical technology is considered durable and/or able to withstand difficult environmental conditions. One respondent mentioned the value of automated maintenance features, such as self-cleaning wipers on a YSI Multiparameter Sonde and self-cleaning brushes on probes, to ensure the device continues to function in a dynamic environment. One respondent stated that the durability, or ruggedness, of the instrument was one of the most important reasons for adopting a specific monitoring instrument.

Almost all respondents found that *cost* associated with monitoring equipment was a major influence on their decisions to adopt new monitoring technology. In fact, four respondents cited cost of the technology as the most important factor when deciding to adopt a new monitoring technology. *Cost* refers to the cost associated with adopting and maintaining the instrument. *Cost* is related to external condition, in that the agency/organization must have sufficient resources to cover the cost of the technology in order for the technology to be adopted. Most respondents, including those from state and volunteer-based organizations, stated that external conditions, such as the resources available for acquisition of new monitoring technologies, were extremely limited, and therefore, the cost of the technology itself was an important factor influencing their decision to adopt a new technology. Respondents also highlighted that the costs associated with data collection, analysis, and maintenance, not just the initial costs of the tool, influence their decisions to choose certain technologies.

4.3.3 Individual factors affecting monitoring technology adoption in coastal management

Perceived usefulness, the degree to which the technology enhanced an individual's job performance and ability to collect high-quality data, was the most influential factor in the individual category regarding a respondent's decision to adopt a certain technology. Perceived usefulness greatly influenced respondents' decisions to adopt new monitoring technology. Several respondents believed that the technology they used allowed them to perform their job better by increasing efficiency of data collection. Two respondents noted that an increase in response time and reduced instrument calibration time for instruments such as YSI Multiparameter Sonde and Seabird Profiling CTD have led to an increase in productivity. One respondent described how one particular tool, the EPA bacteria kit, provides tangible evidence of sewage discharge into the waterbody and allows the individual responsible for monitoring to determine the source of pollution and identify whether it is human or animal waste. The respondent expressed the value of this technological innovation:

> *It's nice to be able to have an idea or have some evidence when I go to a municipality and say 'look you are having a discharge here and its discharging sewage into the water, here's the evidence that I have.' Right? And it gives me some evidence. And they can use that kit going upstream to try and identify where the source is.*

Prior to the development of the EPA bacteria kit, tracking the source of pollution was very difficult. This technology allows for increased detection of pollution in highly urbanized watersheds and is particularly useful to towns and municipalities. Another technology, Quantitative PRC (QPCR), was cited by two respondents as having the ability to reduce lag time, which increases efficiency in the workplace and reduces the time a beach is closed due to elevated levels of bacteria and prevents unnecessary beach closures. Respondents spoke about adopting different technologies that all benefited the user in some way. Respondents were more likely to adopt a new technology if they felt it was advantageous for their job.

Internal conditions, which refers to the degree to which the technology is compatible with the work style of the user, was not relatively important to interview respondents when deciding to adopt a new technology. Only two respondents stated that using a device that matches their work style, such as their current methods for collecting monitoring data, is important to them. One respondent noted the importance of using a device that is capable of collecting real-time data in order to develop sound science and management decisions, *"[w]e can go on our computer and look at water quality conditions at those sites, at any time. So, real time data is always very important."* During a trial period for a new method of measuring bacterial concentrations in the water column, the respondent noted that the method already does not match their work style,

> *[it] has also got a lot of drawbacks, one being that the sample would need to come into the laboratory earlier in the day than we typically do…in order to get a result back four hours later to affect the management action the same day.*

This respondent noted that her organization has not decided whether or not that specific technology will be implemented permanently. Users were generally likely to adopt a new technology even if it was not compatible with their work style.

Compatibility, which refers to how the technology works with an individual's values and past experiences, had limited effect on a respondent's decision to adopt new monitoring technology. While all respondents valued accurate data, only one respondent explicitly stated the importance of using a technology that is capable of gathering accurate data because the respondent's organization values developing and using sound science for management decisions.

4.3.4 Organizational factors affecting monitoring technology adoption in coastal management

External conditions, which include the resources available for new monitoring equipment/technology, were the most important factor in the organizational category and played a significant role in an individual's decision to adopt new monitoring technology. When determining whether enough funds are available to acquire a new technology, the cost of the technology needs to be considered, along with the cost of maintenance of the device, as one respondent stated, *"[w]e do not have any excess funds for equipment, so we run stuff pretty long…."* RI coastal managers and researchers tend to prolong the life of their technology in order to continue monitoring, due to limited resource availability for upgrades. Resources were largely characterized as limited to none in RI coastal management. When asked how they would characterize the amount of resources available for new monitoring equipment, nearly all respondents stated that their organizations have little to no funding for new equipment/technology, as one respondent stated, *"I would say zero [funding] except for EPA's funding."* One respondent noted that water quality monitoring has not been a priority for the state of RI and that state budgets have been cut back. With little to no funds available through respondents' organizations, coastal managers were required to search elsewhere for funding. Respondents typically acquired resources to purchase new technologies primarily through grants and federal funding, from sources such as the EPA or NOAA. RI coastal managers are unlikely to purchase new technology when resources for new technology are limited; instead, they make do with older existing technology.

Organizational conditions refer to whether the technology is compatible with other technologies and protocols currently in place. The degree to which *organizational conditions* influenced coastal managers' decisions to adopt a new monitoring technology depended on three factors: (1) how the technology fits the user's values and needs; i.e., work style, (2) the physical characteristics of the technology, i.e. a handheld device or a complete laboratory setup, and (3) the degree to which the new technology is compatible with existing technologies. Many instruments currently being used for water quality monitoring have the capability to work with other technologies via Bluetooth. For instance, YSI and Seabird sondes are able to send data directly to a computer or the data can be uploaded directly to a website. Respondents who valued real-time data collection for monitoring water quality parameters, such as temperature, dissolved oxygen, salinity, pH, chlorophyll, turbidity, and nitrate, found it particularly important that the monitoring technology they adopted worked well with the network system used by their organization. Additionally, one respondent noted that when an individual adopts a technology, he/she tend to acquire additional components and supporting materials related to that technology over the years. For instance, YSI meters have capacity to swap out sensors, so that the user is able to measure different environmental parameters using the same tool. Respondents highlighted that when deciding to adopt a new technology, it is difficult to transition to a completely new suite of devices and leave all of the older technology behind. They found it easier to stick with one brand of monitoring technology over time, in order to maximize the benefits of the technology and simultaneously minimize cost inputs. Several respondents agreed with this view, as one respondent stated,

> *[w]e don't have the capacity to replace the whole system and we don't want to mix up the protocols, so we are pretty much stuck on YSI for the time being…*

In the cases where a technology was a standalone device, the decision to adopt the technology was not affected by an organization's investment in other equipment.

Respondents cited a couple of organizational factors related to technology adoption that have not been discussed in detail in the technology adoption literature: *external organizational connections, technological support*, and *approved method for* *water quality monitoring*. Another factor that affects technology adoption in coastal management is *external organizational connections*, which refers to the degree in which the technology is used by other coastal management agencies/organizations around the state/nation. RI water quality monitoring is not conducted by a single organization; rather it is a collective effort of several organizations throughout the state. The ability of coastal management organizations to compare data collected across a variety of organizations is important to RI coastal managers and water quality monitors. Respondents highlighted the importance of collecting data that could be aggregated with data from other organizations. One respondent directly voiced the importance of this by stating,

> *[w]e try to all use comparable equipment, so that the data set from the entire network can be used together with the least amount of manipulation possible.*

Another respondent commented on the importance of creating consistency across projects, within and outside of their organizations. One other respondent noted that he adopted a specific water quality monitoring technology because,

> *[i]t is also a standard piece of equipment used by the Narragansett Bay National Estuarine Research Reserve, so they have equipment specifications that they're using…we just stuck to those.*

Three respondents indicated that the availability of *technological support* is an important factor when deciding to adopt new technology. Two respondents cited technological support as the most important factor when deciding to adopt a new monitoring technology, with one respondent stating that customer service was one of the most important reasons for adopting a specific technology. Water quality monitoring instruments are typically expensive, and in some cases, complex, so respondents found it beneficial to have responsive technological support for unanticipated issues, as one respondent stated:

> *If we had an issue they [instrument support team] would say to just drive down here tomorrow and we will take a look at it, which you can't get from any of these technical companies. So, that was the kind of service you had…that was a big deal, to have that support very close by where the next day you can resolve an issue.*

Several respondents discussed the need for technology to be an *approved method for water quality monitoring*, which refers to whether the technology is an approved method by the regulating and/or funding agency for water quality monitoring. Organizations in which the water quality data is intended to support legal defenses or to support management decisions consider whether the new technology is an approved method for water quality monitoring. One respondent emphasized the importance of using only approved methods for water quality monitoring stating,

> *[t]he method is approved by the EPA, which is who we have to validate all of our data through--with a quality assurance project plan--so the data can be used by EPA and others. Most of our funding comes from that source, so that's very important to us.*

According to one source, *"there's a list and we can only use things on the list. If it is outside of the list, it has to be vetted to be included."*

4.4 NERRS Survey Results

4.4.1 Factor Ratings

In the surveys of the NERRS water quality monitoring staff, respondents reported all factors included in the survey to be between slightly important (=3 on 7-point Likert scale) and moderately important (=5 on a 7-point Likert scale) (Figure 5). No factors had an average rating of very important or extremely important. The technological category included the factor with the highest mean rating, *accuracy* (=5), and the factor with lowest mean rating, *trialability* (=3.35) (Figure 5). Of the top five factors with the highest average ratings for NERRS staff, three factors, including *accuracy, reliability*, and *cost*, were not included in the original framework derived from the literature on technology adoption.

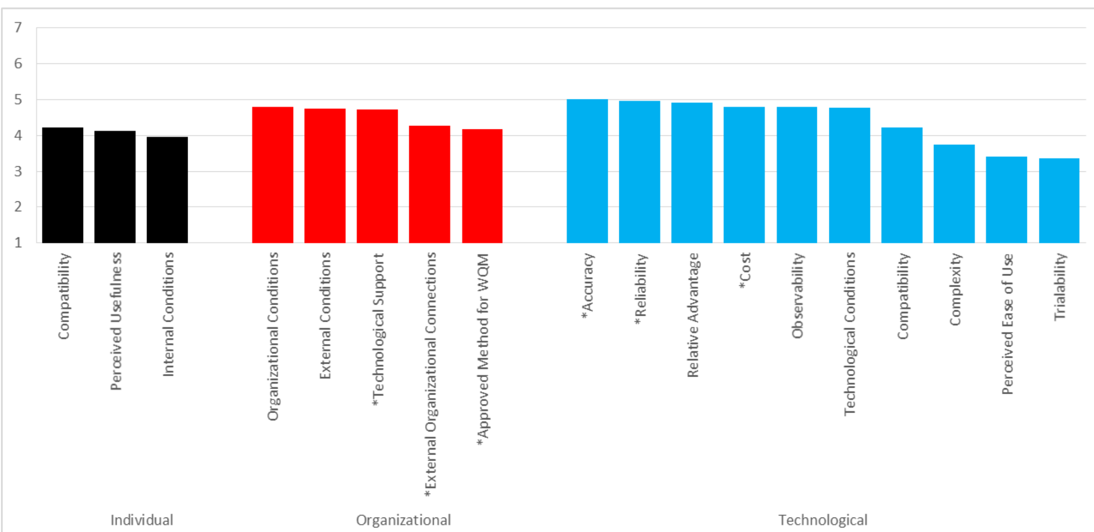

Figure 5. Average rating, on a 7-point Likert scale (where 7=extremely important and 1=not at all important) of framework factors grouped by category (blue=technological factors, red=organizational factors, black=individual factors).

Table 5 shows that the organizational category of factors had the highest average rating (mean=4.44) for the NERRS staff responding to the survey, while the individual category of factors had the lowest average rating of all four categories (mean=4.10).

Table 5. Mean rating of framework categories.

Category	Average Rating	Minimum Rating	Maximum Rating	# of Factors per Category
Individual	4.10	3.96	4.23	3
Organizational	4.44	4.17	4.79	5
Technological	4.39	3.35	5.00	10

When asked to rank the factors, six respondents cited technological conditions as the most important factor influencing their decision to adopt new monitoring technology. Four respondents cited *relative advantage, reliability*, and *accuracy* as the most important factor (Figure 6).

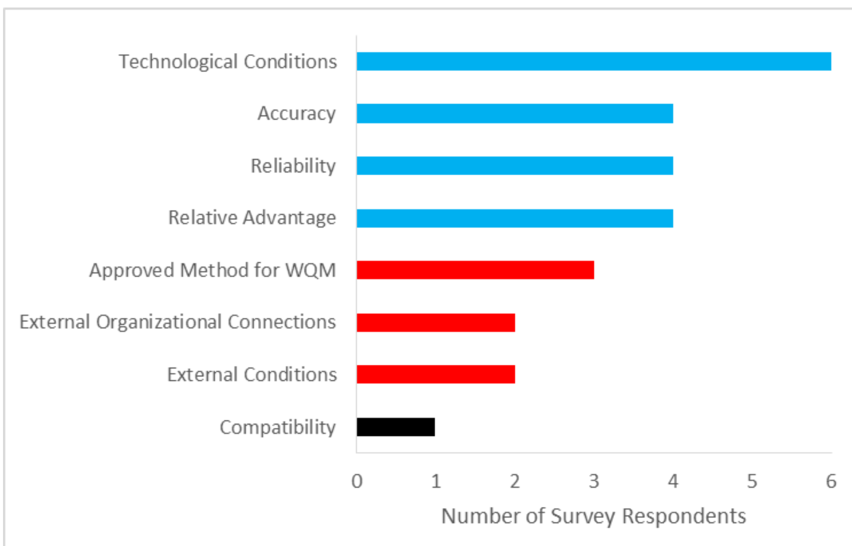

Figure 6. The most important factor when deciding to adopt new monitoring technology according to number of respondents (blue=technological factors, red=organizational factors, and black=individual factors).

4.4.2 Scenarios

Survey respondents were asked to state their likeliness to adopt two very different technologies: (1) a low-cost, handheld nanoscale biosensor that can be used in the field to detect the concentration of specific algae species or other biological components present in a small water sample; and (2) a high-resolution, continuous automated underwater microscope (Imaging FlowCytobot) that can be used to rapidly detect the presence of algae species by analyzing how the cells fluoresce or scatter light. Thirteen respondents stated they were likely to adopt the nanoscale biosensor, while only one respondent stated he was likely to adopt the Imaging FlowCytobot (Table 6).

Table 6. Likeliness of adopting water quality monitoring technology used in survey scenarios.

Likelihood of Adopting Technology	nanoscale biosensor (Number of respondents)	Imaging FlowCytobot (Number of respondents)
Extremely Likely	3	0
Likely	10	1
Neutral	7	9
Unlikely	5	10
Extremely Unlikely	1	6

Survey respondents were more likely to adopt the nanoscale biosensor than the Imaging FlowCytobot. Seven respondents stated that they do not have a need for the nanoscale biosensor and three respondents stated they do not have the financial resources to buy an instrument like this. Respondents also mentioned that adoption of the nanoscale biosensor is dependent on characteristics such as reliability, affordability, and the “the instrument's performance relative to other instruments that are available.” Eight respondents stated they do not have the financial resources to purchase the FlowCytobot and eight respondents stated they do not have a need for an instrument like this as their reasons for low likelihood of adoption. Two respondents already adopted the Imaging FlowCytobot at their respective reserves. Three respondents stated that cost was the limiting factor when adopting an instrument like the Imaging FlowCytobot. In both scenarios, a couple of respondents mentioned that in order to adopt a new technology, the NERRS or collaborating researchers must be conducting the type of research that requires this type of technology. Additionally, in response to adopting new technology used to monitor water quality, three respondents noted that they are required to follow NERRS standard operating procedures or acquire approval from management, and therefore, are limited in terms of the instruments they are permitted to use.

Observability was the only factor that was statistically significantly different between respondents not willing to adopt the nanoscale biosensor and those who were willing to adopt it ($U=9.00$, $n_1=4$, $n_2=13$, and $p=0.034$) (Figure 7). Respondents who were not willing to adopt the nanoscale biosensor rated observability higher than those who were willing to adopt the nanoscale biosensor, when comparing mean ranks.

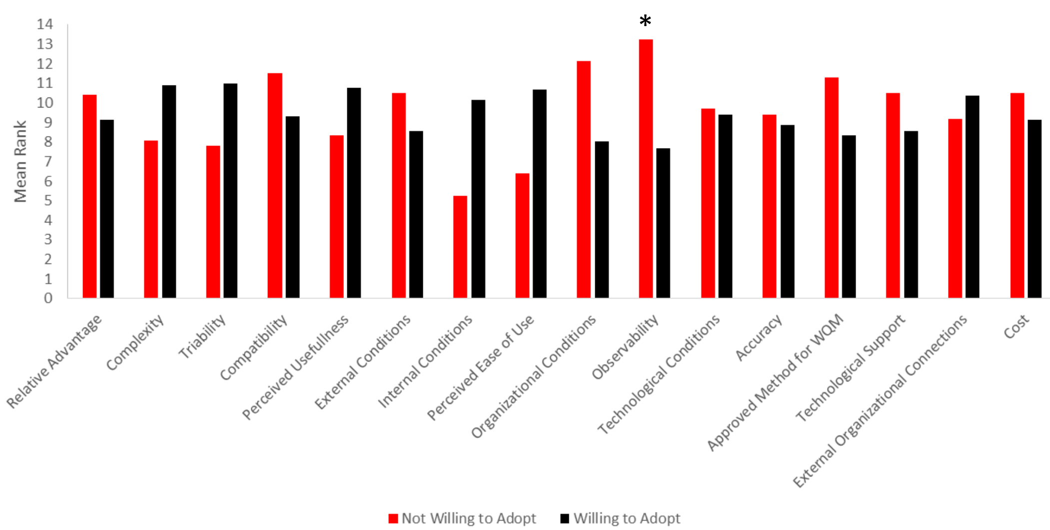

Figure 7. Mean rankings of factors affecting monitoring technology in coastal management. Observability was statistically significant ($p<0.05$) and is denoted with an * ($U=9.00$, $n_1=4$, $n_2=13$, and $p=0.034$)

5. DISCUSSION

5.1 Overview

Factors within the technological and organizational categories were found to be most influential for successful adoption of water quality monitoring technology in coastal management. *Technological conditions, accuracy, reliability, external organizational conditions,* and *approved method for water quality monitoring* were important factors for both RI coastal managers and NERR researchers. Factors influencing coastal managers' and water quality monitors' decision to adopt new technology seem to be specific to this user group, which is not surprising as coastal managers have certain needs, experiences, and preferences. Key findings from the study suggest,

- The most influential factors in an individual's decision to adopt new monitoring technology are related to technological and organizational conditions.
- Factors deemed important by coastal managers and water quality monitors do not necessary align with other studies on technology adoption.
- There is limited diversity in technologies used for water quality monitoring.
- Technology developers and water quality monitoring program directors can utilize findings from this study to develop more applicable and targeted technology and water quality monitoring programs.

5.2 Ubiquity of the YSI Multiparameter Sonde

The YSI Multiparameter Sonde was the most widely used monitoring technology by respondents of this study. Although many other tools and technologies were mentioned as being used in water quality monitoring, those other technologies were used in novel circumstances or were used in addition to the YSI meter. With the YSI meter being used by 75% of RI interview respondents and 81% of NERRS survey respondents, there does not seem to be much variation in the types of technology used for water quality monitoring. This suggests that coastal managers prefer technologies that are capable of measuring more than one parameter, like the YSI Multiparameter Sonde, which is capable of measuring water quality parameters simultaneously, such as pH, dissolved oxygen, and temperature. With a long list of water quality parameters to measure, coastal managers might prefer to reduce the amount of tools needed to monitor by using one technology that is capable of measuring several parameters. As the respondents noted in the interviews, the YSI Multiparameter Sonde was a way for users to reduce the number of instruments used in the field, increase productivity, and reduce costs associated with buying several instruments to measure different parameters.

Understanding preferences of coastal managers and other individuals involved in monitoring will enable technology developers and investors supporting new technology advancements to develop monitoring technology that better fits the needs and demands of coastal managers, potentially leading to more useful, directed technology and, ultimately, better data. Merging the gap between researchers and technology developers can lead to more credible, focused, and accurate data (McNie, 2007).

5.3 Expanding the Framework

Findings from both the interviews and surveys suggest that the original framework of factors (Table 1) that was developed from general technology adoption and acceptance theories, such as DIT, UTAUT, and TAM, does not seem to fully capture all of the drivers of technology adoption in coastal management. Additional factors (*technological reliability, cost, durability*, *external organizational connections, technological support, accuracy,* and *approved method for water quality monitoring*) were cited by interview respondents as important in their decisions to adopt new water quality monitoring technologies. Interview respondents even described several of these additional factors as the most important factors when deciding to adopt new technology. In order to accurately explain why certain water quality monitoring technologies get adopted by individuals involved in coastal water quality monitoring, the framework of factors affecting decisions to adopt would need to be expanded (Table 7).

Table 7. Expanded framework of predictors of successful technology adoption in coastal management (based on Crann et al. 2015; Davis 1989; Rice and Pearce 2015; Rogers 2003; interviews in this study). Factors that emerged out of the interviews but were not found in the literature are denoted by asterisk.

Predictor Category	Predictors of Technology Adoption
Technological	Technological Conditions
	Relative Advantage
	Complexity
	Trialability
	Observability
	Perceived Ease of Use
	*Accuracy
	*Reliability
	*Cost
	*Durability
Individual	Perceived Usefulness
	Internal Conditions
	Compatibility
Organizational	External Conditions
	Organizational Conditions
	*External organizational Connections
	*Approved Method for Water Quality Monitoring
	*Technological Support

When testing the expanded framework within the NERRS context, some factors were more difficult to measure than others. For instance, some factors represent personal qualities, such as a respondent's values and experiences, while others were external to a respondent, such as resources provided by the organization. *Perceived usefulness* was one of the factors that was more difficult to assess because it represents an individual's attitude toward a tool that does not tend to be explicitly discussed. During the interviews, when discussing technology that is currently being used for monitoring, it is assumed that the technology indeed helps the researcher perform his/her job; however, determining the degree to which perceived usefulness informed their decision making process was difficult to assess. *Compatibility* was also difficult to assess as it refers to the values and experiences of the potential technology user. Understanding the core values of the respondent came out when discussing what she/he perceived to be the most influential factors when deciding to adopt a new monitoring technology, but it was more difficult to parse out how the values of the user affect the adoption of a specific monitoring technology.

5.4 Most Influential Factors

The most influential factors for both RI coastal managers and NERRS researchers were related to the technological capabilities of the technology and organizational conditions of the organization/agency in which the individual works. Across the interviews and surveys, similar factors emerged as being most influential in an individual's decision to adopt a new monitoring technology, which suggests there are similarities among the needs and preferences of RI coastal managers and NERRS staff included in this study.

5.4.1 Technological Category

Several factors within the technological category were cited as the most important factor(s) when deciding to adopt a new monitoring technology. *Technological conditions* was cited as the most important factor by the highest number of interview and survey respondents. *Technological conditions* refer to the ability of the technology to measure environmental conditions, such as water temperature, dissolved oxygen, pH, etc. The importance of *technological conditions* to coastal managers suggests that they are particularly interested in adopting technology capable of collecting data that reflects the dynamic, complex nature of coastal environments. Additionally, many respondents also cited *reliability* and *accuracy* as the most important factors when adopting new technology. These findings suggest that coastal managers and water quality monitors are particularly concerned with the technological capabilities of the technology, highlighting the importance to the coastal management community of sound science and accurate and reliable data.

It was surprising that *perceived ease of use* and *trialability*, factors considered to have considerable influence on technology adoption in general (Crann et al. 2015; Renaud and van Biljon' 2008), were not considered important factors by respondents in this study. Perhaps this is due to the particular characteristics of the sample in this study. Coastal managers and individuals responsible for water quality monitoring have experience dealing with complex, scientific instruments and datasets. Interview and survey respondents in this study are well educated and have high levels of technical training, characteristics that likely distinguish them from the general public. As noted above, theories of technology adoption developed for the general public may not be entirely applicable to this sample. Coastal managers may not be as concerned about *perceived ease of use* and *trialability* because they feel comfortable applying their prior knowledge, skills, and experience to using an unfamiliar technology. To potentially increase the probability of a technology being adopted, technology developers should prioritize producing accuracy and reliable technology over easy-to-use devices.

For some respondents, *observability* was considered an important factor, although it was not the most important factor. As the NERRS survey findings demonstrated, respondents who were not willing to adopt the nanoscale biosensor rated *observability* higher than respondents who were willing to adopt the nanoscale biosensor. This indicates that respondents who prefer to see the benefits of a device before adopting it were not willing to adopt the biosensor, suggesting that these respondents did not necessarily see any benefits of using the biosensor. If developers of the nanoscale biosensor want to increase the likelihood of adoption, they might consider ways to clearly demonstrate the benefits of this tool to potential users.

5.4.2 Organizational Category

Factors within the organizational category were considered important across both interviews and surveys. *External conditions* and *approved methods for water* *quality monitoring* greatly affect the decision to adopt new monitoring technologies in coastal management. *External conditions* was rated as the most important factor in the organizational category and greatly influenced an individual's decision to adopt new monitoring technology. For nearly all respondents, *external conditions* affect the rate at which technology is adopted as financial resources are generally necessary to adopt new technology and resources to adopt new technology were limited. Grants provided opportunities for coastal managers to adopt new technologies; however, respondents were primarily responsible for seeking financial resources outside of their organization in order to cover the costs of new monitoring technology investments and maintenance. The limited amount of resources available and the uncertainty that comes with applying for grants tend to make coastal managers more hesitant to adopt new technologies, preferring instead to prolong the life of their current technologies. This could potentially slow the rate of technology adoption in coastal management.

While 69% of NERRS researchers stated they are willing to adopt innovative technologies but are never the first to do so (i.e. early majority adopters), most relied on the YSI Multiparameter Sonde, a well-established tool for water quality monitoring. Perhaps coastal managers and water quality researchers do not feel like they need to go out and try an innovative technology as they already have a method of water quality monitoring that has been shown to be accurate and useful. While coastal managers and NERRS researchers state that they are willing to use innovative technology, they do not necessarily do so frequently, as seen by the ubiquity of the YSI Multiparameter Sonde.

RI interview and NERRS survey respondents stated that the *approved methods for water quality monitoring*, including approval of a protocol, standard operating procedures, or technologies, affect whether or not a technology or method is implemented. Utilizing approved methods and instruments is a way to standardize the data, ensure quality assurance, in order to develop policies using sound science and data. Considering whether the technology is an approved method of water quality when deciding to adopt this technology emphasizes the importance coastal managers place on producing quality data.

5.5 Management Implications

This study found that individuals involved in coastal water quality monitoring place more importance on the technological capabilities of the instrument over other characteristics. Coastal managers and water quality monitors prefer technologies that are accurate, low-cost, multi-purpose, and reliable. Technology developers should consider certain characteristics for this particular user group when developing new technology. Applying the information learned in this study, technology developers can prioritize certain characteristics when developing new monitoring technologies that are more applicable and useful to coastal managers.

Factors influencing the rate of technology adoption of coastal managers and water quality monitors do not necessarily align with those in the framework developed from the technology adoption literature. Coastal managers and NERRS researchers prefer low-cost technologies that are considered approved methods for water quality monitoring and that are able to measure environmental conditions accurately and reliably. While some studies have found that complexity and ease of use are important factors in technology adoption (e.g., Renaud and van Biljon 2008; Crann et al. 2015), findings from this study show that in a professional water quality monitoring setting, these factors do not seem to be that important, likely because coastal managers are technically trained and have advanced scientific understanding.

The findings from this study and other studies on technology adoption demonstrate that factors that influence technology adopt vary based on the needs and preferences of the user population. This information will be useful to a variety of stakeholders including technology developers, researchers, and coastal managers/water quality program directors. For instance, technology developers should consider the particular needs and preferences of coastal managers if they would like to get this user group to adopt their technology. In addition, researchers studying technology adoption might consider modifying the existing technology adoption theories, so that they are applicable to unique user groups. Finally, coastal managers/program directors can use this information to develop water quality monitoring programs tailored specifically to this particular user group.

This study identified key factors that influence coastal managers' and water quality monitors' decision to adopt new technology. However, it is worth noting that factors identified as important for coastal managers might not apply to other technology users involved in coastal management, such as citizen scientists. The needs, experiences, preferences of these non-scientists may be different from those of the program scientists or other staff involved in monitoring. For instance, citizen scientists are typically not technically trained and therefore, may not be able to utilize complex technologies as easily as coastal managers and their staff do. Complexity might be a barrier to successful technology adoption in these types of coastal monitoring programs. Individuals who invest in the development of new water quality monitoring technologies will need to consider the needs, experiences, and preferences of the individuals that will be using the technology.

6. Conclusion

This study contributes to existing technology adoption literature by addressing how and why technology is adopted within a coastal management context. This study investigated current technologies used to monitor water quality in RI and at NERRS and perceptions on innovative technologies, such as the nanoscale biosensor. This information aids in understanding the needs and preferences of RI coastal managers and water quality monitors across the country.

Drawing from three general technology adoption theories (*DIT, UTAUT,* and *TAM*), a framework of factors that influence water quality monitoring technology in coastal management was developed and tested. Findings from this study suggest that influencing factors found in general technology adoption theories are not sufficient at explaining why individuals adopt new water quality monitoring technologies. Therefore, the framework was expanded to include factors that emerged from interviews with RI coastal managers.

Technology development will continue in the coming years. Climate change poses new threats to coastal ecosystems and coastal managers, and water quality monitors will need to find effective methods to quantify environmental changes. The changing marine environment necessitates changes in policies and regulations and scientists need to produce information that can be useful to decision makers (McNie 2007). By understanding the factors that greatly affect an individual's decision to adopt new technology, technology developers can increase the likelihood of adoption by developing technologies that are more targeted and applicable to the user group. Developing and investing in monitoring technology that is low cost, capable of measuring environmental variables of interest, accurate, and reliable, can aid in better environmental management that is driven by science. Additionally, coastal managers/program developers should consider how individuals perceive and use technology in the field in order to develop better water quality monitoring programs.

Appendices

Appendix A: Interview protocol

The following protocol serves as a guide for the interviews. Interviews should be hour-long conservations between the interviewer and the participant.

I. Opening

Describe the general purpose of the research study and the role of the participants.

The purpose of this study is to explore what individuals involved in water monitoring think about technologies in coastal management. This project focuses on how and why certain technologies are used in coastal management.

Explain confidentiality and get consent form signed. Discuss risks and benefits. Ask for questions.

Your part in this study is confidential. None of the information will identify you by name. Scientific reports will be based on group data and will not identify you or any individual as being in this project. There are no anticipated risks from participating in this study. If you are not comfortable answering any of the questions asked, you may refuse to answer and/or refuse to participate any further. There will be no direct benefits to you for taking part in this study. Do you have any questions before we begin?

II. Main Interview

I would like to talk with you today about water quality monitoring technologies used in coastal management. I am mostly interested in your thoughts on water quality technology and the reasons why you've chose to use them. We have divided the interview into three sections beginning with current water quality monitoring technologies, then we will talk about new monitoring technologies, and finally we will talk about future technological needs.

Background:

What is your title and responsibilities here at [name of organization/agency]?

How long have you been at this job? At this position?

Section 1: Existing technologies & factors that affected adoption

In general, what are some aspects of water quality you study?

(Probe for monitoring technology capability at addressing issues)

What percentage of your time would you say you spend on water quality monitoring or water quality related issues?

In your opinion, what do you think about the current water quality conditions in Rhode Island's waters (both marine and fresh water)?

- How do you think these conditions compare to conditions in the past 15-20 years ago?

We would like to learn more about the tools you use to monitor water quality…. What tools do you use to monitor water quality?

I'm going to ask you some questions about each of the tools that you say you use. (Follow up questions for each technology the participant listed):

- Tell me a little more about when you started using {name specific technology}.
    - Would you say this technique for monitoring had been around for a while or was it innovative? *(probe for timing of when innovation is adopted: innovator, early adopter, early majority, late majority, laggard)*
- What is [name specific technology] used for?
- Why did you chose this tool?
    - Would you prefer to use a different monitoring technology?

(Technological)

What are some of the features of this tool that you like/dislike?

- Before you started using this tool for your own work, how familiar were you with it? *(trialability and observability)*
- How easy is it to use? *(perceived ease of use)*
- How does it compare other similar monitoring technologies? *(relative advantage)*
- How well does this technology work with other technologies you use? *(compatibility)*
- In what ways does [name specific technology] affect how your work gets done? *(perceived usefulness, internal conditions)*

How well does this technology measure the current environmental conditions? *(compatibility)*

- What do you think about its ability to measure those conditions? *(technological conditions)*
- Does this tool measure the variables you need it to? *(perceived usefulness)*

You've discussed a lot of reasons for using this tool, **is there anyone characteristic** that was most important in deciding to use it?

(Organizational)

We would like to know a little more about how your organization supports the use of technology.

- How would you describe the amount of resources reserved for new monitoring technologies? *(external conditions)*

- Who has control over which technologies are used for monitoring? *(organizations conditions)*

(Individual)

We would like to know a little more about how you use technology in your daily life, including work. (*probe for general technologies: smart phone, handheld devices, computers, etc.)*

- What do you think about technology in general? *(probe for attitudes and perceptions of technology in general)*
- What types of technologies do you use regularly?

Section 2: Innovative, emerging technologies & factors that affect adoption

We are working engineers at URI and RWU who are developing new technologies for water quality monitoring and we are interested in learning more about what you think of these new types of technologies.

I would like to talk with you about a few of these new technologies:
Are you familiar with any water quality monitoring technologies that use new monitoring techniques such as Lab on a Chip technologies such as environmental sample processors, visualization technologies such as Imaging Flow Cytobot, or autonomous nutrient sensors such as ISUS?

- How much do you know (how familiar) about these technologies or others that I didn't mention?
- What do you think of these kinds of technologies? *(probe for attitudes, initial perceptions)*
- Do you use them?
    - Have you considered using them? Why or why not?

The nanoscale biosensor that is currently being developed a URI will be a low cost, handheld device that will be used in the field to detect the concentration of algae or other biological components present in a water sample. The biosensor will utilize electromagnetic radiation in order to detect a range of wavelengths given off by algae species.

- What are your immediate thoughts of this technology?
- Would you consider using this technology in your current position? Why or why not?
- What types of applications do you think this device would be useful for?
- Can you describe some of the characteristics of a device like this that would get you to use it?

Section 3: Technological gaps & future needs

How would you describe the changes of water quality instruments or research methods over the last 10-15 years? (*probe for changes in technologies over the years)*

What are some, if any, environmental conditions you think are important to measure now or in the future that you are unable to using current monitoring technologies? *(probe for scale of variables, specific conditions/variables)*

What would you like to see in water quality technology in the future?

Is there anything else that you would like to share with me on emerging monitoring technologies applicable to your area?

Appendix B: Online survey instrument

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Research Description

You are invited to participate in a web-based online survey on water quality monitoring technology use. This is a research project being conducted by Nelle D'Aversa and Dr. Tracey Dalton from the University of Rhode Island. It should take approximately 15-20 minutes to complete. You must be at least 18 years old to be in this research project.

This study will explore the perceptions of coastal managers and individuals involved in water quality monitoring on current and new monitoring technologies as tools for coastal management within the National Estuarine Research Reserve system. This project aims to understand how and why certain technologies are used in coastal management and to explore the social, individual, contextual, and organizational factors that influence use of water quality monitoring technology.

Confidentiality:
Your survey answers will be sent to a link at SurveyMonkey.com where data will be stored in a password protected electronic format. Survey Monkey does not collect identifying information such as your name, email address, or IP address. Therefore, your responses will remain anonymous. **No one will be able to identify you or your answers, and no one will know whether or not you participated in the study.**

Decision to quit at any time:
The decision to take part in this study is up to you.**You do not have to participate. If you decide to take part in the study, you may quit at any time**. Whatever you decide will in no way negatively affect you. If you wish to quit, simply inform Dr. Tracey Dalton at (401) 874-2434 or dalton@uri.edu of your decision.

Rights and Complaints:
If you are not satisfied with the way this study is performed, you may contact Dr. Tracey Dalton at (401) 874-2434 or dalton@uri.edu or Nelle D'Aversa at (908) 399-7756 or ndaversa@uri.edu, anonymously, if you choose. In addition, if you have questions about your rights as a research participant, you may contact the URI office of the Vice President for Research and Economic Development, telephone: (401) 874-4328.

Electronic Consent:
By clicking the "next" button you are consenting that you are 18 years of age or older, read and understood the information above and you voluntarily agree to participate in this study.

1

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*1 What percentage of your time in your current position would you say you spend on water quality monitoring or water quality related issues?

- ◯ 100%
- ◯ Between 75% and 100%
- ◯ Between 50% and 75%
- ◯ Between 25% and 50%
- ◯ Less than 25%
- ◯ 0%

*2 Are you actively involved in water quality monitoring at your Reserve? (select all that apply)

- ☐ I am the primary person responsible for collecting water quality samples
- ☐ I am one of many people responsible for collecting water quality samples
- ☐ I am frequently in the field collecting samples
- ☐ I am occasionally in the field collecting samples
- ☐ I am the primary person responsible for analyzing water quality samples in the lab
- ☐ I am one of many people responsible for analyzing water quality samples in the lab
- ☐ I do not actively collect data
- ☐ I oversee the water quality programs at my Reserve
- ☐ I read and review water quality reports

Other (please specify)

[ ]

* 3 In your opinion, what do you think about the current water quality conditions within/surrounding your reserve?

- ◯ Severely degraded
- ◯ Average
- ◯ Pristine

Other (please specify)

____

* 4 How do you think these conditions compare to conditions in the past 15-20 years?

- ◯ Declining
- ◯ Stable
- ◯ Improving

* 5 In general, what are some aspects or variables of water quality studied or monitored at your Reserve?

____

* 6 What instruments are used to monitor water quality at your Reserve?

____

* 7 Of the instruments you listed in the previous question, which tool do you use **most** frequently?

____

* 8 When the instrument mentioned in Question 7 was first used at your Reserve, would you say this technique for monitoring had been around for a while or was it innovative?

- ◯ This instrument was very innovative
- ◯ This instrument was relatively new
- ◯ This instrument was around for a long time but there were multiple ways to measure this variable
- ◯ This instrument was around for a long time and was the only way to measure this variable

3

* 9 How frequently does your Reserve purchase or acquire new water quality monitoring equipment?

- Frequently
- Occasionally
- Rarely
- Never

* 10 When was the last time new water quality monitoring instrument/technology was purchased or acquired at your Reserve?

- Within the last 6 months
- Within the last 2 years
- Within the last 5 years
- Within the last 10 years
- More than 10 years ago

* 11 In terms of using new technology in your life (at home, at work, etc.), how would you describe yourself?

- I am always thinking of ways to develop a new technology. Uncertainty and failure about a new technology do not prevent me from innovating.
- I ususally use a new technology before most people and I am the person to go to for advice when considering using new technologies for the first time
- I am willing to use a new technology but I'm never the first to do so
- I am usually skeptical of new technologies and the uncertainty about new technologies must be reduced before deciding to use them
- I am usually the last to use a new technology and only do so when the technology is known to not fail

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The following questions seek to understand the importance of factors that affect the decision to use new technologies for monitoring water quality.

* 12 Please rate the following factors on a scale of 1 to 7, **where 1 is not at all important and 7 is extremely important**, that you consider when deciding to use an instrument to monitor water quality at your Reserve.

	1 = Not at all important	2 = Low importance	3 = Slightly Important	4 = Neutral	5 = Moderately important	6 = Very Important	7 = Extremely important
A. The instrument is better than its precursor	○	○	○	○	○	○	○
B. The instrument is relatively difficult to understand and use	○	○	○	○	○	○	○
C. There is an opportunity to trial the instrument before deciding to purchase it	○	○	○	○	○	○	○
D. Other organizations use this instrument for water quality monitoring	○	○	○	○	○	○	○
E. The instrument is consistent with my existing values and past experiences	○	○	○	○	○	○	○
F. The instrument will enhance my job performance	○	○	○	○	○	○	○

	1 = Not at all important	2 = Low importance	3 = Slightly Important	4 = Neutral	5 = Moderately important	6 = Very Important	7 = Extremely important
G. My organization provides adequate resources to support the purchase of the new instrument	◯	◯	◯	◯	◯	◯	◯
H. The instrument is cost effective	◯	◯	◯	◯	◯	◯	◯
I. The instrument is compatible with my work style	◯	◯	◯	◯	◯	◯	◯
J. The instrument requires little to no effort to use	◯	◯	◯	◯	◯	◯	◯
K. Technical support is available to assist with any problems that arise with the instrument	◯	◯	◯	◯	◯	◯	◯
L. The instrument has been shown to be reliable	◯	◯	◯	◯	◯	◯	◯
M. The instrument is compatible with existing tools and technologies at my organization	◯	◯	◯	◯	◯	◯	◯
N. The outcomes of using the instrument are clear	◯	◯	◯	◯	◯	◯	◯
O. The instrument has been shown to be accurate	◯	◯	◯	◯	◯	◯	◯
P. The instrument is approved for water quality monitoring by a regulatory agency	◯	◯	◯	◯	◯	◯	◯
Q: The instrument is able to measure targeted conditions	◯	◯	◯	◯	◯	◯	◯

6

* 13 Of all of the factors listed in the previous question, **please rank the top 3 most important factors** that influence your decision to use a new water quality instrument.

	Factors that influence your decision to use new water quality monitoring technology
Most important factor:	
Second most important factor:	
Third most important factor:	

* 14 Who makes decisions about which technologies are used for monitoring at your Reserve?

- ◯ Yourself
- ◯ Direct supervisor
- ◯ Co-worker
- ◯ Other (please specify)

* 15 How would you describe the amount of resources available at your Reserve for new monitoring technologies ?

- ◯ Plentiful (resources are not a concern)
- ◯ Adequate (meets our needs)
- ◯ Limited (very few resources available)
- ◯ None (no resources available)

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*16 Engineers at the University of Rhode Island and Roger Williams University are working to develop a new technology for water quality monitoring. The nanoscale biosensor that is currently being developed will be a low cost ($200-300), handheld device that can be used in the field to detect the concentration of specific algae species or other biological components present in a small water sample. In the field, the biosensor can utilize electromagnetic radiation in order to detect specific algae species based on their wavelengths. The device will provide *in situ*, periodic, rapid detection of algae concentration, algae species identification, and possibly other relevant information.

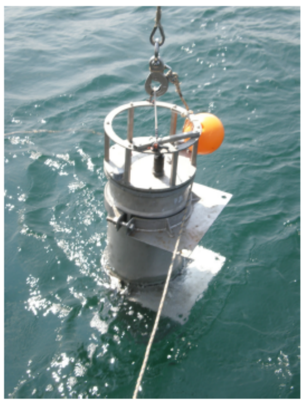
If this product became available, how likely are you to buy this technology within the next 5 years?

- Extremely unlikely
- Unlikely
- Neutral
- Likely
- Extremely likely

*17 If you are not likely to buy the Nanoscale Biosensor, why not?

- Do not have a need for an instrument like this
- Do not want an instrument like this
- Satisfied with current monitoring instruments available
- Do not have the financial resources to buy an instrument like this
- Other (please specify)

* 18 The Imaging FlowCytobot was developed at Wood's Hole Oceanographic Institute in 2003 and is a automated underwater microscope that can be used to rapidly detect the presence of algae species by analyzing how the cells flouresce or scatter light. The Imaging FlowCytobot can be deployed in both freshwater and saltwater and provides long term, high-resolution measurements of algae abundance and cell properties. Continuous measurements and photographs of the cells captured by the Imaging FlowCytobot provide information on a variety of temporal scales and daily estimates of cell growth rate. The Imaging FlowCytobot can operate without external maintenance for at least two months (Seltenrich, 2014).



How likely are you to buy and use this instrument in your current job?

- Extremely unlikely
- Unlikely
- Neutral
- Likely
- Extremely likely

* 19 If you are not likely to buy the Imaging FlowCytobot, why not?

- ◯ Do not have a need for an instrument like this
- ◯ Do not want an instrument like this
- ◯ Satisfied with current monitoring instruments available
- ◯ Do not have the financial resources to purchase an instrument like this
- ◯ Other (please specify)

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Demographic
s

To ensure representation among our respondents, we ask the following questions. All answers are anonymous and confidential.

20 How would you describe your current position at your Reserve?

21 How long have you been working at this Reserve? (Please indicate months or years)

22 What is your age?

23 What is your gender?

24 What is the highest degree or level of school you have completed?

- High school graduate, diploma or the equivalent (for example: GED)
- Some college credit, no degree
- Associate's degree
- Bachelor's degree
- Graduate or Professional degree
- Doctorate degree

(25) In which region is your Reserve?

- ◯ Northeast region
- ◯ Mid Atlantic region
- ◯ Southeast region
- ◯ West Coast region
- ◯ Great Lakes region
- ◯ Caribbean region
- ◯ Gulf of Mexico region

(26) Thank you for take time out of your day to complete the survey. If you would like to share any additional information regarding water quality monitoring technologies, please use the following space to do so.

Appendix C: Water quality parameters monitored by interview and survey respondents

Parameters	Mentioned by Interview Respondents	Mentioned by Survey Respondents
Physical and Chemical Parameters		
Water temperature	X	X
Dissolved oxygen (DO) saturation (%) and concentration (mg/L)	X	X
Salinity	X	X
pH	X	X
Turbidity	X	X
Water clarity	X	X
Fluorescence	X	X
Specific conductance	X	X
Chlorophyll	X	X
Water depth	X	X
Density of the water column	X	
Chloride	X	
Length of exposure to low oxygen events	X	
Total suspended solids (TSS)		X
Volatile suspended solids (VSS)		X
Water level		X
Silicate		X
Phycocyanin		X
Partial Pressure of carbon dioxide		X
Particulate organic carbon (POC)		X
Photosynthetically active radiation (PAR)		X
Nutrient, Metal, and Pollution Parameters		
Nitrogen (particulate organic nitrogen, nitrate, nitrite, and ammonia)	X	X
Mercury	X	
Phosphate		X
Orthophosphate		X
Inorganic nutrients		X
Microplastics		X
Nutrient concentrations at the inflow to and outflow from the estuary		X
Biological Parameters		
Plankton abundance	X	X
Biological response to nutrients	X	
Harmful algal blooms	X	

Bacterial concentrations using an Enterococci as the bacterial indicator	X	
Zooplankton		X
Blue-green Algae (PhycoErythrin)		X
Drift macroalgae and attached microalgae		X
Hypoxia events/zones		X
Submerged aquatic vegetation production		X
Other Parameters		
Freshwater timing		X
Saltmarsh vegetation		X
Changes in salt marsh blue carbon storage		X
Long-term changes related to climatic oscillations (PDO, ENSO)		X
Meteorological conditions (Barometric Pressure, Air Temperature, Precipitation, Wind Speed, Wind Direction)		X
Watershed loading		X
Watershed health/buffering		X

Appendix D: List of all instruments used by interview and survey respondents for water quality monitoring

Water Quality Monitoring Instrument	Mentioned by Interview Respondents	Mentioned by Survey Respondents
YSI Multiparameter Sonde (various models including: 6920, 6820, 6600, 6500, 2600, 2030, 90, 85, EXO 1 and 2, Pro Plus, ProDSS)	X	X
Flourometer (various brands, including Turner)	X	X
Thermometer	X	X
Secchi Disk	X	X
Onset HOBO data loggers	X	X
Refractometer	X	X
Grab samples	X	X
Seabird Profiling CTD	X	
Quantitative PRC (QPCR)	X	
Westco Smartchem Discrete Analyzer	X	
FlowCam	X	
Eureka Water Probe (models unknown)	X	
Salinometer	X	
Hydrolab Multiparameter Data Sonde	X	
GPS	X	
Integrated tube sampler	X	
Microscope	X	
Integrated Fixed-Film Activated Sludge (IFAS)	X	
pH and Alkalinity Meter	X	
EPA Bacteria Kit	X	
Cyanoscope	X	
Dissolved Oxygen Kit	X	
Segmented Flow Nutrient Autoanalyzer	X	
Underwater Video Camera	X	
Rain Gauge		X
Analytical Balance		X
SEAL Autoanalyzer 3 HR		X
Isco Automatic Water Sampler		X
Niskin Water Sampler		X
Imagine FlowCytobot		X
Kestrel Weather Meter		X
LiCor LI-1400 Datalogger		X
Onset Water Level Data Logger		X

Densitometer		X
Periphytometer		X
Onset Conductivity Data Logger		X
Onset Temperature Data Logger		X
Meterological Station		X
SAMI-CO_2 Ocean CO_2 Sensor		X
pH Sensor (brands: Durafet and SeapHOx/SeaFET		X

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