FINAL REPORT

Development of a Fishermen-Based Research Fleet to Contribute to the Management of Quahog Resources in Rhode Island Waters

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ABSTRACT

The quahog (*Mercenaria mercenaria*) fishery is the most valuable fishery in Narragansett Bay, with a dockside value over $5 million. The quahog's complex population and fishery dynamics in combination with aggregated distribution patterns make it difficult to accurately assess the population and thus, properly manage the resource. This work piloted a novel technique that involved commercial shellfishermen using a tablet app to collect quahog data via bullrake sampling year-round, focusing on regions of Narragansett Bay not assessed by the Rhode Island Department of Environmental Management (RI DEM) hydraulic dredge survey. The catch efficiency of the RI DEM hydraulic dredge survey and bullrake sampling were calibrated via in-situ SCUBA observations, enabling direct comparison of fishery dependent and fishery independent data. Preliminary results suggest that quahog density varies at a suite of spatial scales as a result of complex environmental conditions. Furthermore, bullrake sampling appears to document higher quahog densities than the hydraulic dredge survey by accessing a wider variety of areas and habitats within Narragansett Bay. This collaborative data collection program quantified the quahog population and fishery in a novel manner and directly supported efforts to improve the quahog stock assessment. In this way, this project provides an example of how engaging fishermen in standardized fishery dependent data collection can benefit stock assessments. Ultimately, this work fosters a transparent and accurate quahog management system by providing commercial shellfishermen an opportunity to actively participate in the scientific and management process.

INTRODUCTION

The quahog (northern hard clam, *Mercenaria mercenaria*) fishery is the single most valuable fishery in Narragansett Bay, with a dockside value in excess of $5 million in 2017. The fishery supports a fleet of more than 500 active Rhode Island shellfishermen, many of whom have been fishing for decades (ACCSP 2014). Historically, fishermen used dredges to harvest quahogs in Narragansett Bay, but mechanical harvesting was outlawed in the 1950s and hand operated rakes became the primary technique for fishing quahogs, with the bullrake the predominant tool for fishing in waters deeper than 10 feet. Quahog landings fluctuated dramatically during the 20th century, with peaks in the mid-1950's and 1980's more than six times greater than current landings. Since the 1990s, however, quahog landings in Narragansett Bay have been stable at a relatively low level. In recent years, observable changes in quahog abundance have been seen at small spatial scales, particularly in western Greenwich Bay. The cause of these fluctuations is likely a combination of changes in areas open to fishing, fishing mortality, fishing effort, management measures, and environmental conditions impacting recruitment and survival (Fegley 2001). As such, the quahog's complex population and fishery dynamics in combination with aggregated distribution patterns over a variety of spatial scales (less than a meter to 100s of meters) make it difficult to accurately assess the population and thus, properly manage the valuable quahog resource.

Central to the goal of achieving successful sustainable management of the quahog resource is the need to reduce uncertainties in the current quahog stock assessment that are attributable to data limitations and spatial gaps (Gibson 1999). The Rhode Island Department of Environmental Management Division of Marine Fisheries (RI DEM) has utilized a hydraulic dredge and a spatially stratified sampling design to evaluate quahog abundance since the early 1990's, but the number of sampling tows (100-200/year) is limited by time and cost, and the total area surveyed is miniscule (0.001-0.002 km^2/year) compared to the areas fished in Narragansett Bay (~125km^2). Further, the dredge survey is restricted to the 5-30 foot depth range due to vessel and gear limitations, which excludes some of the most productive quahog habitats.

In addition to the assessment data gaps is the inherent distrust that the quahog fishing industry expresses with respect to the data generated through the RI DEM hydraulic dredge survey. Because the dredge apparatus is foreign to many of the bullrakers and far removed from their understanding of effective fishing practices, the shellfishermen are highly suspect of management decisions that are based on RI DEM dredge surveys. Their distrust in the data has previously led to dissatisfaction and open criticism of some management practices.

A new, cost-effective survey technique, that utilizes shellfishermen's time on the water and their ability to use bullrakes to sample in areas not accessible to the RI DEM hydraulic dredge was developed and employed to increase the spatial coverage and accuracy of the quahog stock assessment, and to provide an opportunity for shellfishermen to better understand and have confidence in the overall management process. The project addressed these needs by focusing on two major work components: 1) The development of a formally organized "Quahog Research Fleet" in Narragansett Bay that employed commercial shellfishermen to collect biological quahog data via bullrake sampling for application to the management of the quahog resource; and 2) Assessment and calibration of the catch efficiencies of the RI DEM hydraulic dredge and bullrake sampling through in-situ SCUBA observations and side by side tows. The catch efficiency of the two gear types, bullrake and hydraulic dredge, needed to be assessed and compared to one another in order to correct historic abundance estimates in the stock assessment and apply the Quahog Research Fleet data to management. Dredge-bullrake calibrations were initiated in the summer of 2014, but further work was completed throughout this project to derive a robust calibration index for dredge and bullrake sampling methods in various depths and bottom types (Leavitt et al. 2014).

The work completed through this project built on two earlier efforts between the project team and fishermen. The first building block for the project was the CFRF Lobster and Jonah Crab Research Fleet, which served as a model for enabling fishermen to collect biological and environmental data for application in assessment and management (http://www.cfrfoundation.org/jonah-crab-lobster-research-fleet). The second building block was a project conducted collaboratively by CFRF, RWU, RI DEM, and the Rhode Island Shellfishermen's Association that involved a preliminary evaluation of the catch efficiencies of the RI DEM dredge and bullrakes and the potential application to the quahog stock assessment (Leavitt et al. 2014). Specifically, this effort focused on evaluating the feasibility and data utility of commercial shellfishermen using bullrakes to sample quahogs as a supplement to state dredge surveys. This project demonstrated the efficacy of bullraking by commercial quahoggers and suggested that bullraking could be a viable supplement, or cost-efficient alternative, to hydraulic dredge sampling.

Providing shellfishermen with an opportunity to be active participants in the data collection and stock assessment process and to observe and compare their catch statistics with that of the RI DEM dredge survey will lead to a more open and transparent quahog management system that promotes stakeholder engagement. Improved data to support the quahog stock assessment will, in turn, provide for long-term sustainable management of the resource and economic opportunity for Rhode Island's historic fishing community.

RESEARCH QUESTIONS

Research Question #1: Do bullrake and dredge sampling produce quahog density/distribution data that is comparable/complementary for stock assessment purposes?

> *Hypothesis 1*: With sufficient calibration, bullrake and hydraulic dredge sampling produce equivalent quahog density estimates that can be integrated for stock assessment purposes.

Research Question #2: Does the inclusion of additional data from bullraking sampling significantly reduce variance or affect estimates of quahog abundance and spatial distribution when compared to estimates from the dredge survey alone?

> *Hypothesis 2*: By providing data from areas inaccessible to existing quahog surveys, bullrake sampling reduces uncertainty in overall estimates of quahog abundance and spatial distribution in Narragansett Bay.

Research Question #3: Does sampling at fishermen-selected stations (fishery dependent data) vs. assigned sampling stations (fishery independent data) reveal similar patterns of abundances of quahogs throughout Narragansett Bay?

> *Hypothesis 3*: Fishery independent bullrake sampling sufficiently describes quahog stock structure in Narragansett Bay, and including fishery dependent sampling data does not significantly alter overall abundance estimates or variance

GOALS AND OBJECTIVES

The completed project was aimed at involving commercial shellfishermen in quahog data collection and management by establishing a Quahog Research Fleet modeled after the successful CFRF Lobster and Jonah Crab Research Fleet. Shellfishermen used pre-programmed Android tablets to collect site specific quahog data via bullrake sampling through all four seasons, focused in regions of Narragansett Bay not easily assessed by the RI DEM hydraulic dredge survey. The quahog data collected by bullrake sampling was relayed via WIFI to a central database maintained by the CFRF. Data was ultimately used to augment and improve the management of the quahog stock. To ensure full integration of Quahog Research Fleet data into management, the catch efficiency of bullrake sampling and the RI DEM hydraulic dredge survey was evaluated through side-by-side in-situ comparisons via SCUBA sampling.

The primary goal of the proposed pilot project was to initiate a new era of cooperation and communication among fishermen, scientists, and resource managers that supports a successful, sustainable, transparent, and collaborative management approach for the quahog fishery in Narragansett Bay. To achieve this goal, the project focused on the following objectives: 1) Establish a Quahog Research Fleet that has the knowledge, tools, and legitimacy to contribute to the current RI DEM quahog stock assessment and management plan; 2) Reduce uncertainties in the current quahog stock assessment and promote sustainable management of the quahog resource by addressing existing spatial and temporal data limitations; 3) Develop a model for industry-based data collection that can be duplicated in other fisheries and regions; and 4) Build capacity to involve Rhode Island shellfishermen in coastal monitoring and other types of marine research.

METHODS

Development of Project Steering Committee and Research Fleet

Upon issuance of the RI Sea Grant/URI subaward (April 2016), the CFRF assembled a project steering committee to help develop a scientifically robust and logistically feasible industry-based quahog data collection project. Throughout the first year, the project steering committee helped develop research protocols and approaches, select Research Fleet participants, and review project data. The project steering committee consisted of experts in quahog fisheries science and management as well as a representative from the Rhode Island shellfishing industry. Steering committee members and their affiliations are provided in Table 1.

Name	Affiliation
Anna Mercer	Executive Director, CFRF
Aubrey Ellertson*	Research Associate, CFRF
Thomas Heimann**	Research Associate, CFRF
Jason McNamee	Chief, RI DEM Marine Fisheries
Conor McManus	Biologists, RI DEM Marine Fisheries
Dale Leavitt	Professor, Roger Williams University
Scott Rutherford	Professor, URI Graduate School of Oceanography
Michael McGiveny	President, Rhode Island Shellfishermen's Association
Azure Cygler	Extension Specialist, URI Coastal Resource Center/ RI Sea Grant

*Table 1. Quahog Research Fleet Steering committee members and their affiliated organizations. *Steering Committee member was only responsible for working on project through the first year of the award. **Steering Committee member was added at the start of the second year of the award and worked on the project for the remaining duration.*

The first Quahog Research Fleet steering committee meeting was held on May 9th, 2016. The topics discussed during the steering committee meeting encompassed all aspects of the project including project goals, sampling equipment, participant selection, sampling protocols, and development of the quahog data collection application. The project goals and timeline were discussed to ensure the steering committee was familiar with the intended purpose and time frame of sampling operations.

The first step in Quahog Research Fleet development was the creation of a project briefing document and application form for fishermen interested in joining the Quahog Research Fleet. The briefing document outlined the project timeframe and sampling protocols. Applicants provided information on the fishery in which they participated, annual time spent bullraking, home port, months typically fished, years of commercial fishing experience, history with cooperative research, and vessel information. The application period was open for four weeks during May 2016. Overall, the CFRF received eight applications for the five available spaces in the Quahog Research Fleet.

The initial review of harvester applications was conducted on June 15th, 2016. During the selection process, the project steering committee and the CFRF board of directors provided valuable input on each of the applicants. During the meeting, the project team selected five shellfishermen for participation in the Quahog Research Fleet, based upon areas fished, months fished, and experience with collaborative research. The selected harvesters were notified by mail, email, and phone of their acceptance into the Research Fleet. Once all positions had been accepted, the remaining applicants were notified that the Research Fleet was filled. The CFRF developed work agreements with each Quahog Research Fleet participant, outlining the scope of work, timeline for project, and compensation rates. The Quahog Research Fleet participants were as follows:

- Bo Christensen, Warwick Cove, RI
- David Ghigliotty, Warwick, RI
- Jarrod Goulart, Warren RI
- Gerald Schey, Warwick Cove, RI
- Ernest Wilcox, Wickford, RI

On August 10th, 2016, a Quahog Research Fleet training session was held at the CFRF office in Kingston, RI. All participating harvesters were in attendance, as well as project partners, the app programmer, and some steering committee members (Figure 1). The training session was led by Mercer and Ellertson, and covered the goals and protocols of the project. Fleet participants were familiarized with sampling protocols, and provided in depth instruction for the usage of the data collection application (On Deck Data). During the Research Fleet training, participants were supplied with all sampling equipment, except the sorting racks, which were being constructed by RWU. Each Research Fleet participant signed an “equipment release form” ensuring the proper use and care of their sampling equipment. Training binders were provided to all Research Fleet participants, which included: maps of pre-selected sampling stations, On Deck Data instructions, contact list of all Quahog Research Fleet participants and project staff, sampling protocols, tablet instructions, invoice forms, RI DEM Collector’s Permit, and general support information.

Following the fleet training, the RWU team constructed sorting racks to separate quahogs into size classes (Table 2). The sorting racks were scheduled to be completed by the first week of September; however, the construction took longer than expected. The CFRF staff picked up the sorting racks from RWU, added size class labels, and distributed the sorting racks to Research Fleet participants in October 2016.

On October 19, 2016, the CFRF held a second training session to go over the new sampling equipment and protocols with all Quahog Research Fleet participants. During this meeting, sorting racks and handheld GPS devices were distributed. Ellertson went over all changes made to the On Deck Data app, as well as how to use the handheld GPS devices. The major changes to the app layout and screens were as follows (see Appendix 2 for screenshots):

- Starting Transect
  - Tablet automatically Acquiring GPS start position
  - App prompts user to manually enter starting position (latitude and longitude) from Garmin eTrex 10 GPS device. The GPS format is in Decimal Degrees and requires each harvester to record to five decimal places.
- Addition of "Transect is active" screen
  - This allows the user to know the transect is active and the harvester can start bullraking.
- Stopping Transect
  - Tablet automatically Acquiring GPS stop position
  - App prompts user to manually enter stop position (latitude and longitude) from Garmin eTrex 10 GPS device. The GPS format is in Decimal Degrees and requires each harvester to record to five decimal places.
- Addition of a Summary/ Notes Screen
  - Duration (minutes)
  - Transect length (meters)
  - Bearing (degrees)
  - Area (m^2)
  - Total Live Quahogs (#)
  - Quahog Density (#/m^2)

Research Fleet participants started to collect data more regularly once On Deck Data was revised, sorting racks and GPS units were distributed, and a second training session was conducted.

After sampling had officially gotten underway, the CFRF hosted a Project Steering Committee meeting on April 19, 2017. Due to the multitude of project changes towards the end of the previous reporting period (application updates, addition of hand-held GPS units, etc.) and the commencement of full Research Fleet sampling, the intention was to bring the Steering Committee fully up to speed on the current status of the project and receive feedback on the sampling protocols, equipment, progress, and plans. In addition to reviewing project progress, the Project Steering Committee members provided recommendations for upcoming data analysis.

On June 29, 2017, the CFRF hosted a Quahog Research Fleet meeting to review the sampling equipment, discuss the data collected to date, and review the project timeline with Research Fleet participants. This meeting represented the first Research Fleet gathering since data collection had been fully initiated. The CFRF presented Research Fleet members with a suite of visualizations of the data collected to date and explained the data structure, impact, and implications. During the meeting, Research Fleet members provided feedback on application performance, tablet performance, and general comments on their respective sampling efforts and locations. The CFRF also introduced Thomas Heimann to the Research Fleet as the new Research Associate responsible for running the project.

In July 2017, the CFRF switched the Research Associate responsible for project management from Ellertson to Heimann. Heimann was already working for CFRF as the Research Associate responsible for the Black Sea Bass Research Fleet. The decision to switch the Research Associate working on the Quahog Research Fleet was made strictly for budgetary reasons related to other CFRF projects. Heimann spent much of the summer months of 2017 familiarizing himself with the project sampling protocols and Research Fleet members. Heimann spent multiple days at sea with Research Fleet members getting to know them individually and assisting with sampling. During this reporting period, all other Project Steering Committee and Research Fleet members were retained on the project (Table 1).

In December 2017, Heimann applied for an extension of the Quahog Research Fleet's Rhode Island State Collector's Permits through RI DEM. The permits were granted to cover all of the 2018 sampling year (January 1, 2018 – December 31, 2018). The Collector's Permits were mailed to all Research Fleet participants to keep aboard their fishing vessels at all times. The CFRF also retained copies of all Collector's Permits for reference. The Collector's Permits are required to allow Research Fleet participants to retain sub-legal quahogs onboard for sampling purposes.

The CFRF hosted another Quahog Research Fleet meeting on January 24, 2018. Nearly all Research Fleet participants and Steering Committee members were in attendance. This meeting was the first full gathering of the project team since a full year of data collection had been completed by the Research Fleet. A detailed debrief of the past year's project progress was provided as well as a presentation on the data collected to date. Conor McManus also presented on ways that RI DEM intended to incorporate the Research Fleet data into the quahog management process. To wrap up the meeting, the CFRF screened the first draft of the Quahog Research Fleet documentary and gathered feedback and recommendations for improvement from Research Fleet participants and Steering Committee members.

The work agreements for the Quahog Research Fleet participants were set to expire at the end of January 2018. Mercer drafted an amendment to the work agreements to cover the extended sampling timeline (through December 31, 2019) and received confirmations of acceptance from all Research Fleet participants.

All Research Fleet participants continued sampling with the Quahog Research Fleet through the final award year of the project. Heimann was in contact with Fleet members throughout the sampling year to answer questions, troubleshoot equipment issues, and assist with at-sea sampling when needed.

Through a conversation during a CFRF Board of Directors Meeting, Board member, Jeff Grant (Rhode Island commercial quahogger) shared his thoughts gathered from discussions with current Quahog Research Fleet Members. The common feedback Grant received was that the sampling workload was quite significant and impactful on standard fishing practices during a sampling day. As a result of this conversation, project partners agreed to double the monthly sampling stipend starting in November 2018 and sustain the increased rate through the end of the sampling period in January 2019. Mercer notified all Fleet Members of the increased sampling rate and offered an extended Work Agreement to cover sampling through the end of January 2019. Every Fleet Member accepted the extended work agreement. In December 2018, Heimann prepared an application for Rhode Island Collector's permit renewals for the Research Fleet. RI DEM accepted the application and Collector's Permits were mailed to each Fleet Member to cover sampling through the end of January 2019.

On January 4th, 2019, the CFRF hosted the final full-project Steering Committee and Quahog Research Fleet Member meeting to discuss project results, lessons learned, and plans for the future. Leavitt and McManus also presented their application of dredge and bullrake calibration data as well as ways Research Fleet data has had influence on Rhode Island quahog management. Every Research Fleet Member attended the meeting as well as the majority of the Steering Committee. During the meeting, Heimann notified all Research Fleet and Steering Committee Members of the upcoming distribution of a survey to gather official feedback on the project work. A copy of the survey questions and a summary of the survey responses are provided in the appendix of this report. With the conclusion of Quahog Research Fleet sampling in January 2019, Heimann contacted all Fleet Members, arranged for equipment return, and collected and signed back in all tablets, sorting racks, and GPS units.

Development of Quahog Research Fleet Sampling Protocols and Procedures

The project team (Anna Mercer, CFRF, Aubrey Ellertson, CFRF, Dale Leavitt, RWU, and Conor McManus, RI DEM), in consultation with the project steering committee, developed the Quahog Research Fleet sampling protocols over the course of the first year (2016/2017). Sampling protocols were developed to be scientifically and statistically sound and minimally invasive to the bullraking practices of the Research Fleet members. To accomplish this, the data collected by the Research Fleet needed to be accurate, efficient, and representative of the quahogs encountered.

To achieve maximum temporal and spatial coverage, the sampling protocols call for Research Fleet participants to conduct three bullrake pulls at eight sampling stations per month. Four stations were selected (assigned) by the project team and sampled throughout the year by Research Fleet participants. The other four stations were selected by participant shellfishermen (commercial) and could change month to month at the choice of each Research Fleet Member. The project team employed a stratified random approach, integrating conditional shellfish closures, to select assigned sampling stations within Narragansett Bay. Assigned sampling stations were based upon each Research Fleet participant's home port and typical fishing grounds. Maps and locations (latitude/longitude) of pre-selected assigned sampling stations were provided to each Research Fleet participant. The sampling protocols were originally established as follows: when Research Fleet Members have decided to begin sampling and arrived on location to either an assigned or commercial sampling station, a sampling session is initiated within On Deck Data. Once initiated and the bullrake has hit the bottom, the Fleet

Member is prompted to record the transect starting position (latitude and longitude in decimal degrees). Fleet Members transcribe the GPS coordinates from their provided handheld GPS units. After transcription, the tablet automatically records the date and time and latitude and longitude provided from the internal clock and GPS. Fleet Members then complete a normal bullrake pull and return the bullrake to the vessel once the basket is full. At this time, Fleet Members stop the transect on the tablet which automatically records the internal date and time as well as latitude and longitude from the internal clock and GPS. Fleet Members then manually transcribe their latitude and longitude coordinates from their handheld units as previously completed at the start of the transect. After coordinate entry, Fleet Members record a suite of environmental and gear related data as shown below in points 4 through 15.

1. Date/Time (UTC, automatically recorded)
2. Start Location (latitude/longitude, manually and automatically recorded)
3. Stop Location (latitude/longitude, manually and automatically recorded)
4. Transect Length (automatically calculated from start and stop locations)
5. Transect Bearing (degrees)
6. Depth (feet)
7. Habitat Type (Sand, Sandy Mud, Mud, Sticky Mud)
8. Wind Speed (knots)
9. Wind Direction (Degrees)
10. Stale Length (feet)
11. Rake width (inches)
12. Tooth Length (1, 1-1/4, 1-1/2, 1-3/4, 2, 2-1/4, 2-1/2, 2-3/4, 3, 3-1/4, 3-1/2, 3-3/4, 4 inches)
13. Tooth Spacing (1, 1-1/8, 1-1/4, 1-3/8, or 1-1/2 inches)
14. Rake Weights (pounds)
15. Shell Hash (none or present)
16. Quahog Catch Counts (live and dead)
    a. # Chowder
    b. # Cherrystone
    c. # Topneck
    d. # Littleneck
    e. # Sub-legal

Fleet Members then empty their bullrake baskets into the provided sorting racks. The sorting racks allow for consistent classification of quahog market class (chowder, cherrystone, topneck, littleneck, sublegal) (Table 2). After the sorting process, Fleet Members complete their transect sampling by recording the total number of quahogs in each size class. These market class definitions are what RI DEM currently uses in the quahog stock assessment.

Quahog Market Class	Inches	Millimeters
Chowder	> 1.7	> 44
Cherrystone	1.6 – 1.7	40-43
Topneck	1.4- 1.5	35-39
Littleneck	1.0-1.3	25-34
Sub-legal	< 1.0	< 25

Table 2. Size definitions of the market size classes used for Quahog Research Fleet data collection.

At the start of the project, the CFRF received feedback from Research Fleet participants that conducting three replicates at each location was disruptive on commercial fishing practices, especially with the use of the handheld GPS unit, which was implemented at the end of the first year. To address this concern, the CFRF, RI DEM, and RWU reviewed the Quahog Research Fleet sampling protocols and conducted a power analysis to assess the statistical needs for data application. These efforts revealed that the quality of the Research Fleet's data would not be significantly compromised by reducing the required replicates from three to two. As such, the CFRF advised all Research Fleet participants to conduct only two transect replicates at each assigned and commercial sampling station per month. The total number of locations sampled by each Research Fleet participant every month remained the same (eight), but the total number of transects conducted each month was reduced from 24 to 16. The response to this change in the sampling protocols was very positive and the CFRF did notice a substantial increase of sampling effort at assigned locations as a result.

Early in the reporting period, the CFRF received feedback from Research Fleet participants that the handheld GPS units being used in tandem with the On Deck Data app were very difficult to read while at sea because the screen and font size was small. The handheld GPS units were also logistically cumbersome, as the Research Fleet participants had to juggle an extra piece of equipment while sampling (often in adverse weather). To address this issue, the CFRF team explored alternative methods for the Research Fleet to collect GPS coordinates that would achieve the necessary accuracy and reduce the burden on participant fishermen. Each Research Fleet participant had a mounted GPS unit on their respective vessels used for normal navigation throughout the bay during fishing. The CFRF researched the make, model, and specifications of each Research Fleet Member's boat GPS unit and determined that the accuracies of the boat GPS units were superior or equivalent to the handheld GPS units used by the Research Fleet to date. Thus, to expedite the sampling process and alleviate frustrations, Research Fleet participants were instructed to begin using their boat GPS units to collect the latitude and longitude for each bullrake transect. It is important to note that the internal tablet GPS automatically records the latitude and longitude of each bullrake transect while the fishermen manually records latitude and longitude. The tablet GPS is less accurate compared to the boat GPS units (hence having the fishermen manually enter latitude and longitude), but the location information from the tablet GPS is used to verify sampling locations if an entry error is apparent. This has proven to be an invaluable data auditing tool.

In the fall of 2017, Heimann received feedback from a Research Fleet participant that he was having trouble sampling one of his assigned sampling locations, due to the extended distance from his home port and primary fishing grounds. This issue arose throughout the sampling season as the Research Fleet

Member shifted his typical fishing grounds northward. Heimann consulted with Mercer and McManus and decided that is was best to reassign the sampling location to be closer to the current, typical, fishing grounds of the Research Fleet Member. Given the impending expansion of the Quonset Point Pier, the project team decided to shift the Research Fleet participant's assigned sampling location one strata westward where the pier expansion would take place. Having the Research Fleet participant sample this area will provide added value to the project, as it creates a baseline estimate of quahog density and size composition within the expansion site prior to pier construction. This is especially important because the site is well outside of the depth range covered by the RI DEM dredge survey, and thus, there are no other baseline data to enable the assessment of the impacts of pier construction on the quahog population. Ultimately, Heimann met with the Research Fleet participant to put the new location into his plotter to enable incorporation into his monthly sampling routine.

The final sampling protocol revision during the second year was the implementation of two additional data metrics to On Deck Data and the project database: transect type and replicate number. After preliminary data analysis, McManus informed CFRF that the incorporation of Research Fleet data into the stock synthesis model would be more efficient if the transect type (assigned or commercial) and replicate number (one or two at each sampling location) were included with each record. To address this need, the CFRF worked with the original On Deck Data app programmer to add the ability for Research Fleet participants to record transect type and replicate number within On Deck Data. Heimann also added these fields to the project database. Within the new version of On Deck Data, the addition of transect type and replicate number allows Research Fleet members to select if a bullrake sampling session is at an assigned location or a self-selected (commercial) location and whether it is the first or second transect at a given sampling location. These app revisions allow the project team to better assess fine scale changes in quahog densities (among transect replicates) as well as the overlap of assigned locations with typical fishing grounds. Although both of these metrics could have been evaluated and incorporated post-hoc, having Research Fleet participants collect them at the time of sampling is far more efficient and accurate.

No changes were made to the sampling protocols and procedures during the third year of the project. Ultimately, the final sampling protocols employed by the Research Fleet were as follows: Research Fleet Members arrive on location to either an assigned or commercial sampling station and a sampling session is initiated within On Deck Data. Once initiated and the bullrake has hit the bottom, the Fleet Member is prompted to record the transect starting position latitude and longitude. Fleet Members transcribe the GPS coordinates from their boat GPS units as well as select whether the transect station is either an assigned or commercial station and which replicate number the transect is. After transcription, the tablet automatically records the date and time and latitude and longitude from the internal clock and GPS. Fleet Members then complete a normal bullrake pull and return the bullrake to the vessel once the basket is full. At this time, Fleet Members stop the transect on the tablet which automatically records the internal date and time as well as latitude and longitude from the internal clock and GPS. Fleet Members then manually transcribe their latitude and longitude coordinates from their handheld units like previously completed at the start of the transect. After coordinate entry, Fleet Members record a suite of environmental and gear related data as shown below in points 4 through 17.

1. Date/Time (UTC, automatically recorded)

2. Start Location (latitude/longitude, manually and automatically recorded)
3. Transect Type (assigned or commercial)
4. Replicate Number (1-6)
5. Stop Location (latitude/longitude, manually and automatically recorded)
6. Transect Length (automatically calculated from start and stop locations)
7. Transect Bearing (degrees)
8. Depth (feet)
9. Habitat Type (Sand, Sandy Mud, Mud, Sticky Mud)
10. Wind Speed (knots)
11. Wind Direction (degrees)
12. Stale Length (feet)
13. Rake Width (inches)
14. Tooth length (1, 1-1/4, 1-1/2, 1-3/4, 2, 2-1/4, 2-1/2, 2-3/4, 3, 3-1/4, 3-1/2, 3-3/4, 4 inches)
15. Tooth Spacing (1, 1-1/8, 1-1/4, 1-3/8, or 1-1/2 inches)
16. Rake Weights (pounds)
17. Shell hash (none or present)
18. Quahog Catch Counts (live and dead)
    a. # Chowder
    b. # Cherrystone
    c. # Topneck
    d. # Littleneck
    e. # Sub-legal

Development of Quahog Data Collection Application (On Deck Data) and Database

Upon issuance of the sub-award from RI Sea Grant and URI (April 2016), the CFRF developed work agreements with the tablet application and database developers, Don Coxe and James Finnegan, respectively. Once work agreements were secured, Mercer and Ellertson immediately began working with Don Coxe to conceptualize, outline, program, and vet a specialized quahog data collection application for Android tablets. The app was designed such that the participant shellfishermen are prompted to enter the required data fields in a clear and logical sequence. The app was programmed to automatically record the date, time, and location of sampling events via internal clock and GPS. The existing On Deck Data app for collecting lobster and Jonah crab biological data, developed by the CFRF in 2013, acted as a model for the quahog data collection app.

The first step in app development was preparation of a “Requirements Document”, which outlined all the functionalities, data parameters, and work flows needed (provided in “Other Documents”). The general requirements of the app were: 1) Easily allow shellfishermen to collect data while at sea, 2) Allow the ability to take and collect images, and 3) Store collected data locally, but upload to a CFRF MySQL database over a WiFi signal. The project team worked to mimic and model previous versions of On Deck Data, including four major workflows for quahog data collection and communication: Start a Transect, Collect an Observation, View Data, and Upload Data. The units and ranges for data parameters were selected to be logical for commercial shellfishermen and applicable to scientific analyses. The order of data entry was developed to follow the flow of a typical bullrake event as described above.

With the requirements document in hand, Don Coxe drafted a workflow outline and screen layout, which was reviewed by the CFRF staff (in consultation with steering committee and Research Fleet participants). The CFRF staff communicated edits and revisions to Don Coxe who continuously updated the data collection app. This iterative app development process spanned nearly three months (June - August 2016). Input from the project steering committee and Research Fleet participants proved invaluable during this stage of application development. Insight from quahog biologists on the data parameters needed to calculate density and other essential metrics was essential to ensuring the scientific value of the data. Similarly, input from industry members ensured that effort and gear parameters were collected in appropriate units, and fit into routine fishing operations.

The fully functional beta version of the On Deck Data quahog data collection application was released in August 2016. The beta version of the app was tested rigorously by Mercer, Ellertson, and Coxe for layout, error messages, work flow, and data communication capabilities. Whenever an error message or layout issue was encountered the problem was communicated to Coxe and corrected and then tested again. Beta troubleshooting and testing went through numerous rounds until Mercer, Ellertson and Coxe were satisfied that the application functioned completely as intended.

Coxe then created an alpha version of On Deck Data, which was tested by all Quahog Research Fleet participants during the training session (August 2016). During the training session, fleet members made suggestions for revisions to the app, and Don Coxe worked to complete the suggested revisions in a timely manner.

The Quahog Research Fleet has used On Deck Data since the launch of data collection in August 2016 and has provided ongoing feedback on its functionality and performance. The CFRF staff has worked with Don Coxe to streamline the On Deck Data app according to the shellfishermen's feedback. Over the course of the project, the CFRF remained in constant communication with all Research Fleet participants to troubleshoot any issues that arose.

A major concern of the project team over the course of the project was the GPS accuracy of the tablets (±10 meters). After a series of discussions, it became clear that the project team needed to explore ways to achieve more accurate GPS fixes, since latitude and longitude are used to calculate transect length, which is critical for calculating area sampled, and ultimately quahog density for the stock assessment. The RWU team ran numerous at-sea trials comparing the linear distances derived from tablet GPS fixes and differential GPS fixes. These tests revealed that the Research Fleet would need to use handheld GPS units in tandem with On Deck Data to achieve the accuracy needed. As a result, the CFRF researched and purchased Garmin eTrex 10s, which guarantee an accuracy of less than 3 meters, for each harvester. On Deck Data was revised to prompt manual entry of latitude and longitude from the handheld GPS, while also recording tablet latitude and longitude for comparison. When the handheld GPS proved to be cumbersome for sampling at sea, Research Fleet participants began using their boat GPS units for latitude and longitude entries in On Deck Data. This proved to make the data collection process more efficient and accurate.

Initially, the CFRF expected Don Coxe to also develop the project database and data transmission scripts. The funds allocated for these tasks in the project budget, however, were insufficient for the necessary scope of work. Thus, the CFRF applied for a small cost extension from RI Sea Grant to cover the unforeseen cost associated with the programming of the data transfer and storage system. Once these funds were secured, the CFRF team worked with database programmer James Finnegan to develop the Quahog Research Fleet schema within the CFRF MySQL database as well as write and test the server scripts for wireless data transfer from the On Deck Data app to the CFRF database. The data transfer system and database were completed in August 2016.

While the data collection app and quahog database were under development, CFRF staff researched Android operating system tablets for use by the Quahog Research Fleet. Factors considered during tablet research were: 1) The On Deck Data app is an Android based application, 2) CFRF's Lobster and Jonah Crab Research Fleet have used Google Nexus 9 and 10 tablets successfully in the past, 3) Participants in CFRF's Lobster and Jonah Crab Research Fleet have expressed preference for a tablet that has at least a nine inch screen, and 4) Tablet price must fit within the project's equipment budget. Ultimately, the Google Nexus 9 Android tablet was selected and purchased for the Quahog Research Fleet. The Poetic Revolution Case was selected for the tablets because of its shock protection and resistance to water. In addition, Weatherhawk Windmate (WM-200) anemometers were purchased for the Quahog Research Fleet to record wind speed and direction. The original proposal budgeted for anchors and ropes, which were deemed unnecessary given alternative transect measurement devices. The anchor/rope funds were used for anemometers, sorting racks, and handheld GPS units.

The development of the data collection application (On Deck Data – Quahog) was an ongoing process from the start of the project. The CFRF staff worked closely with Research Fleet participants to receive feedback on the functionality of the application and the utility during routine bullraking practices. As a direct result of the Research Fleet training held in August 2016, Research Fleet members identified a number of parameters that needed adjustment to accurately represent bullraking practices. Coxe, the application developer, was in attendance at the meeting and made all recommended adjustments to the application promptly.

The addition of the Garmin eTrex10 handheld GPS device necessitated several changes within the data collection app layout and design. From August through October 2016, Don Coxe made the recommended changes and distributed versions of the app to the Research Fleet at each step along the way. The CFRF staff communicated app changes and re-trained Research Fleet participants accordingly. CFRF Research Associate, Aubrey Ellertson, also conducted at-sea trainings for three Research Fleet participants (Bo Christensen, Ernest Wilcox, and David Ghigliotty).

The primary tasks related to On Deck Data and database management during the second year of the project were monitoring, troubleshooting, and resolving any issues which arose during sampling or data analysis. Heimann served as the primary database auditor and receives comments from the Research Fleet via in-application submitted notes and verbal communication. Minor data entry errors occurred from time to time such as incorrect recording of depth or manually collected latitude and longitude numbers being mixed. Data auditing is a weekly task to ensure all submitted comments are incorporated and errors rectified.

As noted in the previous section, one major task during the second year of the project relating to both On Deck Data and the database was the incorporation of two new data metrics: transect type and replicate number. Heimann first consulted with Coxe about the feasibility of including these new metrics in On Deck Data as well as the entry location within the user interface. It was determined that the most logical place to add them to On Deck Data was on the "Starting Transect" screen (See Appendix for full screenshots of the final version of On Deck Data).

On the "Starting Transect" screen, fishermen from then onward were required to select whether the transect was an "Assigned Station" or a "Commercial Station". An "Assigned Station" is a bullrake location that was selected by the project team to provide fishery independent data. A "Commercial Station" is a bullrake location that a Research Fleet participant chooses to sample from their typical fishing grounds. In addition to transect type, Research Fleet participants also entered "Replicate Number" on the "Starting Transect" screen. As described in the previous section, the sampling protocols require that Research Fleet participants conduct two replicate transects at each sampling location. Some Research Fleet participants, however, conduct more replicates at their commercial sampling locations (for their own interest or economic incentive). To account for this and provide flexibility going forward, On Deck Data was programmed to provide an option to record up to six replicates even though the sampling protocols only require up to two replicates. The CFRF worked with Finnegan to ensure the server import script and the MySQL database were also revised to include the new fields of transect type and replicate number. Ultimately, Coxe drafted a revised version of the On Deck Data app that incorporated the two new metrics and Heimann tested it thoroughly for both application errors and data upload/database import issues. After the On Deck Data update was proven to be fully functional and error-free, it was released to the Quahog Research Fleet in September 2017.

The addition of transect type and replicate number in the app and database required Heimann to evaluate and back-fill all data collected prior to the update. To do so, Heimann first aggregated all past data for each individual Research Fleet participant and compared all of the beginning latitude and longitude points for each sampling session. Heimann then compared the latitude and longitude points to the assigned sampling locations for each respective Research Fleet participant. Each assigned location represents the center point of a specific RI DEM dredge survey strata and when the dredge samples a specific stratum it aims to sample from the center of point but considers the strata sampled as long as the session occurs entirely within the targeted strata. Applying the same principle to the Research Fleet data, it was assumed the first two sampling sessions occurring within the assigned strata each month (if occurring on the same day) were considered the two replicates at that specific assigned station. This methodology was developed and agreed upon by Heimann, Mercer, and McManus. This method allowed Heimann to assign both transect type and replicate number to all past data. The process for back-filling all past data records with transect type and replicate number was extraordinarily tedious and time consuming, but it ultimately improved the value of the data to the quahog stock assessment.

During the final year of project, the primary task was monitoring the functionality of On Deck Data for any unknown errors as well as updating the tablets in use by the Research Fleet. After feedback from multiple Fleet Members that the batteries in the tablets used in the previous two years of data collection (Google Nexus 9) began to struggle to hold a charge as well as the incidence of multiple accounts of tablet screens freezing, Heimann and Mercer decided that all Research Fleet tablets needed to be replaced. Not only did the Google Nexus 9 become discontinued, but Heimann had also received feedback that the cases used on the Nexus 9 became difficult to operate due to the accumulation of salt and dirt. The CFRF researched new tablet options and purchased Samsung Galaxy Tab A tablets for the Research Fleet. The Samsung Galaxy Tab A had been used successfully by the CFRF Black Sea Bass Research Fleet and was compatible with Otterbox Defender Series cases, which are far superior to the Poetic cases. Heimann delivered the new tablets and cases to all Fleet Members and collected the old Nexus 9 tablets. Well-built cases, with large, tactile buttons were deemed a top priority for sampling equipment. Ultimately, availability of quality cases may be a limiting factor when selecting tablet models as selection often proved sparse. Overall, the Quahog Resaerch Fleet encountered fewer tablet-related issues with the new Samsung Galaxy Tab A tablets, however instances of tablet freezing still occurred from time to time (primarily associated with cold conditions).

Bullrake Catch Efficiency Calibration and Analysis

The bullrake is a basket-like device that has teeth across the bottom cutter bar that digs in and gathers quahogs that reside just below the sediment surface (Figure 1). The length of the teeth varies with the type of substrate at the fishing site as does the overall width of the rake. It is worked across the surface of the sediment by the fisherman in depths up to 50 feet of water from a boat at the surface, by way of attaching the basket rake to the end of a series of interconnected aluminum poles (stales). The overall approach for assessing the catch efficiency of the bullrake was built off a protocol that was developed during earlier work evaluating the bullrake as a stock assessment tool (Leavitt et al. 2014). Calibration of the bullrake included measuring the area covered during the sampling interval (a function of width of the bullrake and length of the sampled track), counting and measuring the sample of quahogs retrieved by the bullrake, counting and measuring the quahogs missed by the bullrake, and calculating the catch efficiency. The methods used for each of these components are described below.

Figure 1. A typical bullrake used by commercial quahog harvesters in Rhode Island (Photo retrieved from https://www.newrivernets.com/nrn/shellfish.htm).

The distance covered during a routine bullrake sampling track was calculated as the width of the bullrake multiplied by the length of the sampled track and was generally less than 30.5 meters (100 feet). Although it varied according to water depth, substrate type and wind/current conditions. To routinely measure the distance that the rake moved across the bottom, having already measured the rake width, we took start and finish position fixes with a global positioning system device (GPS) at the surface on the stale handle, assuming the handle would duplicate the track of the bullrake across the bottom due to the rigid attachment between the rake and the stale handle and provided that the bearing of the rake was consistent between start and finish. The original device utilized for this measurement was a handheld differential GPS (dGPS) with a location accuracy of ±10 centimeters, using post-processed location data (AshTech Mobile Mapper 100, Leavitt *et al.* 2014). With the development of the On Deck Data app, distance measured could be calculated from the data generated by the built in GPS function of the tablet. To evaluate the accuracy of the tablet GPS to measure linear distance via satellite fixes, we ran a series of GPS measurements of known distances on dry land. In evaluating the tablet positioning status, we realized that on average the tablet GPS estimate of linear distance was off by close to 14 feet (Table 3), which would result in significant error in estimating the area sampled by the bullrake. Previous work, comparing a handheld GPS to the known accuracy of the dGPS (± 0.5 ft) (Leavitt *et al.* 2014) and corroborated via a small calibration check within this project (Table 3) indicated that the handheld GPS measurement was within 3 feet of the actual distance. Therefore, the measurement of linear distance traveled by the bullrake was measured routinely with a handheld GPS device or boat GPS unit rather than the built-in function of the tablet.

Measure Device	Distance Measured (ft)	Replicates	Avg Distance Difference (ft)	StDev	Max Difference	Min Difference
Tablet	300	10	15.35	16.58	50.00	0.05
	150	10	21.20	12.29	36.26	4.47
	100	12	11.43	12.09	41.73	0.23
	75	10	14.57	12.82	47.01	5.20
	50	2	15.51	2.81	17.50	13.52
	25	7	5.36	5.10	12.58	0.07
	Average		13.90	5.24		
GPS	100	2	3.84	0.90	4.47	3.20
	50	2	2.10	2.24	3.69	0.52
	Average		2.97	0.95		
dGPS	100	2	0.18	0.17	0.30	0.05
	50	2	1.04	0.11	1.12	0.96
	Average		0.61	0.04		

Table 3. A comparison of linear distance measured with the Android tablet, handheld GPS and differential GPS.

The fisherman would undertake a routine sampling event using the same procedure as if they were commercially fishing. The appropriate rake was selected (overall width and tooth length) to accommodate the substrate type being worked, the stale length was adjusted to allow the proper angle of rake axis to substrate, and the orientation of the surface vessel was arranged such that the wind or current worked in the fisherman's favor in pushing the boat downstream as the digger raked. The fisherman would rake a distance length that was dictated by the degree of filling of the basket attached to the rake (Figure 2). (Commercial bullrakers have an uncanny ability to detect the condition of the rake on the bottom with regards to level of fill and the ability of the rake to properly tend the bottom).

Figure 2. A full bullrake being landed by Quahog Research Fleet participant, Bo Christensen. (Photo Credit: CFRF)

The rake with contents was retrieved to the deck of the boat and dumped onto a sorting table, where the clams were removed from the assorted debris collected. The clams caught were sorted into the 5 market class categories utilized within this study (sublegal, littleneck, topneck, cherrystone, and chowder, Table 2) using a series of sieves or "speed racks" (Figure 3), counted, and recorded. The size categories were designated as listed in Table 4.

Depth	Valve depth (mm)		Valve length (mm)	
Measurements (mm)	Min	Max	Min	Max
Sublegal (Bean)		25	<	50.5
Littleneck	25	35	50.5	67.3
Topneck	35	40	67.3	75.4
Cherry	40	45	75.4	83.3
Chowder	45		83.3	>

Table 4. The valve sizes of the five commercial categories of quahog based on valve depth at the hinge. Length estimates are generated by the relationship of valve depth to length (Length = 3.2553 x Depth$^{0.8518}$, R^2 = 0.8881) as measured for Narragansett Bay.

Figure 3. Dumping the catch onto the speed rack for sorting. (Photo credit D. Leavitt).

As the rake transect was being sampled by the bullraker, a SCUBA diver would mark the start of the transect and the end of the transect on the bottom. Upon completion of the sampling, the transect length was measured directly by the diver to assess the ability of the GPS fixes on the start and stop locations to estimate the distance traveled. In addition, the diver would follow the rake as it moved across the substrate and retrieve any quahogs in the rake track that were missed by the bullrake as it sampled. These missed quahog samples were brought to the surface, measured in the sorting racks and the number in the various size categories of these samples were recorded.

Adjacent to each of the areas sampled by the commercial shellfisherman, a series of three 1-meter quadrats were collected by SCUBA diver and measured in the same way as the fisherman's catch to assess the overall density of the quahogs in the vicinity of the fisherman sampled track.

By comparing the number of harvested quahogs retrieved in the bullrake with the actual number of quahogs in the sampled track (number of retrieved plus missed quahogs), one can derive the efficiency of the sampling device in collecting all of the quahogs that it encounters. Previous work suggests that the bullrake collects quahogs consistently but differently, depending on the substrate type and the skills of the operator (Leavitt et al. 2014). Therefore, each fisherman participating in the study was subjected to a series of calibration transects on various substrates to measure their individual catch efficiency.

Dredge Catch Efficiency Calibration and Analysis

As referenced in the 2014 Sector Management Plan for the Shellfish Fishery (RIDEM 2013), the "RI Division of Fish and Wildlife (DFW) conducts a survey of quahogs in Narragansett Bay on an annual basis that commenced in 1993" (Ganz *et al*. 1999). Both fished and non-fished sections of the bay are sampled. The sampling consists of towing a small hydraulic dredge (0.36 meter sweep, Figure 4) for a distance of 30.5 meters (100 ft) at each station. Pressurized water is delivered to the dredge manifold which dislodges shellfish from the substrate. The dredge is designed to retain legal-sized quahogs (>25.4mm thickness). All species retained in the dredge when hauled are identified and all shellfish are counted and measured, based on the five commercial categories listed in Table 4.

Figure 4. The hydraulic dredge utilized by RI DEM to assess quahog stocks in Narragansett Bay (Photo D. Leavitt).

To evaluate the catch efficiency of the hydraulic dredge, a similar protocol to the bullrake calibration was followed. That included deploying the dredge using the standard protocol outlined above followed by a diver survey of the dredge track to retrieve any quahogs missed by the dredge. A more detailed explanation of this protocol is included below.

As noted above, RI DEM follows a standard protocol for sampling with the dredge that entails deploying the dredge and sampling a 100 foot transect. A slight modification of this protocol was implemented to facilitate the subsequent diver evaluation of the missed quahogs. After the dredge was lowered to the substrate, a diver would free dive to place an anchored buoy at the starting point. Following the completion of the dredge sampling, the dredge was left in place until the diver could place a second anchored buoy at the stop location of the dredge. This protocol modification was necessary due to the lack of visibility in the water immediately after the hydraulic dredge passed. By marking the start and stop points, a SCUBA diver could locate and swim the track to collect missed quahogs after the resuspended sediment had settled back to the substrate or was flushed away. The sampling site was revisited by diver approximately 1 hour following the initial dredge sampling.

Observations by the SCUBA divers revealed that the dredge track formed a characteristic profile, depicted in Figure 5, that we referred to as consisting of a primary track that represents the actual footprint of the dredge and a secondary track resulting from the action of the hydraulic water discharge from the dredge. This profile was most pronounced in the softer substrate types although it could be discerned slightly in sand as well. When swimming the track to collect missed quahogs, the divers noted that recently disturbed quahogs could be identified in both the primary and secondary tracks of the dredge and sometimes could be located at the substrate surface and adjacent to the track itself. Missed quahogs were defined as those quahogs that were located in both the primary and secondary tracks of the dredge. The quahogs collected by divers were returned to the surface, measured, and recorded.

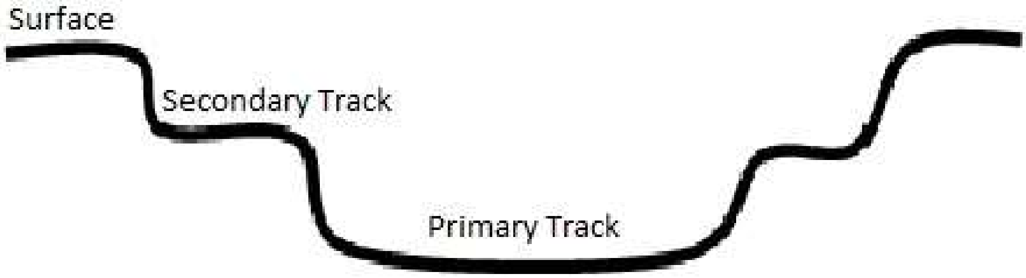

Figure 5. The profile of the RI DEM hydraulic dredge track following sampling.

As with the bullrake calibrations, adjacent to each of the areas sampled by the RI DEM dredge, a series of three 1-meter quadrats were collected by SCUBA divers and measured in the same way as the dredge catch to assess the overall density of the quahogs in the vicinity of the dredge sampled track.

Observed dredge abundance estimates were corrected by including the count of quahogs found in the dredge transect during inspection on SCUBA (N_T) to the total retained by the dredge (N_D), with efficiency estimated as the ratio of the observed dredge abundance to the corrected estimate:

$$\text{Observed Dredge Abundance} = \frac{\mathrm{N_D}}{\text{Dredge Swept Area (m}^2\text{)}}$$
$$\text{Corrected Dredge Abundance} = \frac{\mathrm{N_D} + \mathrm{N_T}}{\text{Dredge Swept Area (m}^2\text{)}}$$
$$\text{Dredge Efficiency} = \frac{\text{Observed Dredge Abundance}}{\text{Corrected Dredge Abundance}}$$

Dredge efficiency estimates ranged between 0 and 1. Efficiency was compared with covariates that were believed to either influence local quahog abundance and/or influence the fishing ability of the dredge. Dredge catch efficiency was modeled using generalized linear mixed models (GLMMS). The GLMM framework allows for covariates to be modeled as fixed or random effects, with random effects providing value accounting for variability among factors of repeated measures, or when randomly selected variables represent are part of a larger population of which the bounds are not completely sampled (Bolker 2009, Deroba 2018). The GLMM was constructed using R package ‘glmmTMB’ (Brooks et al. 2017) with a beta error distribution. Given beta distributions only apply to values within, and not inclusive of, 0 and 1, dredge efficiencies were transformed to account for these observations using the sample size of the dataset (n=45) following Smithson and Verkuilen (2006):

$$\text{Dredge Efficiency}_{\text{Transformed}} = \frac{\text{Dredge Efficiency}_{\text{Observed}} * (\mathrm{n} - 1) + 0.5}{\mathrm{n}}$$

Covariates tested for constructing a model to predict dredge efficiency included bottom type (hard vs. soft bottom), sediment type, depth of sampling, and observed abundance as fixed effects, and the station location as a random effect. Bottom type, sediment, and depth were included to standardize benthic characteristics that influence quahog abundance (Pratt 1953, Pratt et al. 1992, Rice 1992) and may influence dredge efficiency. The observed abundance was included in the modeling to better understand if the dredge efficiency varies depending on the local density of quahogs in the track (e.g. does the efficiency improve at low abundances of quahogs, at higher abundances, or is it relatively the same, Ganz et al. 1994). As a random effect, station was used to indicate that the stations sampled were just random selections from the stock bounds for the quahog population, and that there is some degree spatial autocorrelation between stations regarding their bottom characteristics and quahog abundance, and perhaps efficiency of the dredge. Model predictions for the samples of this study were compared to the observed dredge efficiencies to provide insight into model performance. Model variants using different combinations of these covariates were evaluated, and compared through minimization of the Akaike Information Criterion (AIC; Akaike 1973.)

With the GLMM constructed, the model was applied to the time series data collected by RI DEM. Observed quahog abundance estimates from the dredge survey through time were divided by the model's predicted dredge efficiencies for each sample to estimate the corrected abundances based upon this study's data. Annual average observed and corrected abundance indices were produced to assess how abundance trends compare between the two time series. Time series were constructed for the spatial regions used in the RI DEM quahog stock assessment model: Greenwich Bay, Providence River, and Narragansett Bay Proper.

Quahog Research Fleet Bullrake Data Analysis Methods

Outside of the calibration-specific data analyses led by the RI DEM and RWU project partners, the CFRF began to explore and analyze data collected directly by the Research Fleet. As previously mentioned, all Research Fleet collected bullrake data was submitted and housed within a MySQL database run by CFRF. All data analysis was completed with the statistical language R and ArcGIS.

Various trends and data parameters were monitored throughout the span of the Research Fleet. Specifically, individual and Fleet-wide quahog densities sampled were analyzed by calculating sampled transect area by converting the recorded rake widths used for each transect into meter, and calculating total sampled transect area by multiplying the width of the rake (meter) by the calculated length of the transect from the manually recorded GPS coordinates. Density for each transect was then calculated by dividing the sum of live quahogs sampled from within the transect by the total area, in meters, of the transect resulting in the abundance of quahogs per square meter. Sampled transect densities were monitored throughout the entire project and compared between Fleet Members and ultimately to the RI DEM hydraulic dredge survey to validate the recorded quahog densities.

Further, the mapping of quahog densities sampled by the Quahog Research Fleet alongside the locations of the RI DEM dredge survey was continually completed and updated throughout the project. Once transect density was calculated and assigned to each transect as described above, bubble plots were constructed within ArcGIS to depict the RI DEM hydraulic dredge strata sampled during the same year as the Quahog Research Fleet data was collected. These mapping exercises were used to explore the spatial trends in quahog densities within the Bay and the discrepancy between the densities that the Quahog Research Fleet measured and the densities that the RI DEM dredge survey measured. Fishery dependent (commercial) and fishery independent (assigned) sampling stations densities were compared to one another as well as to the RI DEM dredge densities.

A suite of regressions were run to test for factors influencing quahog density aside from direct transect location. Specifically, a regression was completed to investigate the relationship between quahog density and depth. This relationship was monitored throughout the span of the project as more transect data was collected and became available for analysis. Significance of correlation was tested by Kendall rank correlation tests.

In winter 2017/2018, RI DEM began analyzing the Quahog Research Fleet data to assess the quahog industry's catch rates and size selection. Using the start and end times and total catch from the Quahog Research Fleet transects, RI DEM estimated at what rate the fishermen catch quahogs (# of bushels per hour). The catch rates and size selectivity of the Quahog Research Fleet were compared to those obtained from quahog transplant events to see how the two data sources compared. The Quahog Research Fleet data were directly used for a simulation testing for the impacts of harvesting quahogs in the Providence River, a subpopulation of the Narragansett Bay stock that is unfished and vital in providing larvae for various regions in the Bay. The simulation utilized Quahog Research Fleet-derived catch rates (# of quahogs per minute) that were measurable within the On Deck Data database. While not the stock assessment itself, the simulation was valuable in informing whether certain harvest strategies would be useful for a sustainable quahog fisheries management program.

Throughout the project, RI DEM has been working to revamp the statistical stock assessment modeling framework for Rhode Island's quahog population. Since the inception of this research project, RI DEM has constructed a new quahog stock assessment model that embodies a more refined and appropriate statistical framework, allows for modeling based on market classes for species (like quahog), and the ability to allow mixing between sub groups within a population through recruitment estimates. Based on these benefits, the new assessment approach, Stock Synthesis, was implemented by RI DEM with the assessment approach formally described in the proposal of this work (a depletion-based Biomass Dynamic Model) being abandoned.

The Quahog Research Fleet data can be used as inputs or for comparison purposes to other input data, such as size composition. Current annual proportions of catch by size class for the assessment model are derived from dealer reports (accessed using SAFIS), but there has been some question as to the accuracy of these reports. The Quahog Research Fleet allows for a direct comparison of catch composition of prominent fishers that are believed to represent the industry at-large, and the SAFIS dealer reports. To do so, the catch composition ratios were calculated for each individual Fleet Member as well as on average across the whole Fleet. Catch composition ratios were calculated by dividing the total number of sampled quahogs from each market size class as described above by the total number of sampled quahogs. This was repeated for each individual Fleet Member as well as in aggregate across the entire Fleet. Ratios were then compared against the SAFIS landings size composition ratios provided by RI DEM.

At this point time, the Quahog Research Fleet catch data has not been used as an abundance index within the stock assessment model. With two years of data, there is not a long enough time series to formulate a catch per unit effort (CPUE) index that can be implemented within the model to help tune population abundance trends. While the dredge efficiency work indicated that abundances in bullrake sampling are higher than the dredge on average, there was no clear relationship between the two methods that could then be used to convert the dredge abundance index into a bullrake CPUE one.

Regardless, a comparison between quahog abundances from dredge sampling and bullrake sampling in the same time and space were evaluated to assist with the development of standardized relationship between the two methods.

RESULTS

Bullrake Catch Efficiency

The catch efficiency of the individual diggers and the overall average catch efficiency of the bullrake are provided in Table 5, based on the individual data provided in Table 6.

Digger	Catch efficiency
Christensen, Bo	92.6%
Ghigliotti, Dave	93.9%
Goulart, Jerrod	93.1%
Schey, Gerry	96.1%
Wilcox, Earnest	99.6%
Average	95.1%
StDev	2.9%

Table 5. Catch efficiency of the individual fishermen involved in the study and the average of all five fishermen.

On the whole, the catch efficiency of the five diggers involved in the study was very high (overall 95.1%) with little variability among the fishermen. Furthermore, given the ability of an experienced digger to adjust their equipment and digging technique to the substrate and depth, there were no significant differences (3-way Analysis of Variance) in catch efficiency across these variables (Table 6).

Gerry Schey - 2017

Substrate	Date	Depth	Transect	Start Location		Total in rake	Total present	efficiency	Distance covered	Area Covered	Measured Density	Real Density	Digger Avg Density	Quadrat Avg Density
		(m)		lat	long	(#)	(#)	(%)	(m)	(m^2)	#/m^2	#/m^2	#/m^2	#/m^2
Sand	13-Jul-17	9.1	1	41.40750	-71.21548	86	89	96.6%	27.5	12.6	6.83	7.07	8.98	5.20
			2	41.40743	-71.21551	54	56	96.4%	11.2	5.1	10.50	10.89		
Sand	20-Jul-17	3.0	1	41.40225	-71.24483	42	44	95.5%	32.4	14.8	2.83	2.97	2.84	0.67
			2	41.40226	-71.24465	26	28	92.9%	22.6	10.3	2.52	2.72		
Mud	20-Jul-17	2.4	1	41.40138	-71.24072	81	85	95.3%	8.5	3.9	20.76	21.78	16.88	5.00
			2	41.40133	-71.24073	70	70	100.0%	12.8	5.8	11.98	11.98		
							avg	96.1%	Distance/Area from diver measurement					
							stdev	2.3%						

Dave Ghigliotti - 2017

Substrate	Date	Depth	Transect	Start Location		Total in rake	Total present	efficiency	Distance covered	Area Covered	Measured Density	Real Density	Digger Avg Density	Quadrat Avg Density
		(m)		lat	long	(#)	(#)	(%)	(m)	(m^2)	#/m^2	#/m^2	#/m^2	#/m^2
sand	01-Aug-17	5.8	1	41.67127	-71.34470	44	44	100.0%	6.7	2.9	15.20	15.20	19.40	7.00
			2	41.67119	-71.34492	116	118	98.3%	11.6	5.0	23.19	23.59		
soft	01-Aug-17	7.0	1	41.67012	-71.34348	117	120	97.5%	14.0	6.1	19.33	19.82	15.88	5.67
			2	41.67031	-71.34393	60	66	90.9%	12.8	5.5	10.85	11.94		
soft	03-Aug-17	3.0	1	41.68356	-71.39027	62	62	100.0%	3.0	1.3	47.11	47.11	45.50	6.33
			2	41.68370	-71.39034	26	26	100.0%	1.4	0.6	43.90	43.90		
soft	03-Aug-17	3.4	1	41.68530	-71.39146	40	41	97.6%	8.2	3.6	11.26	11.54	15.56	23.67
			2	41.68513	-71.39099	58	58	100.0%	6.9	3.0	19.59	19.59		
2013														
soft mud w/ shell	04-Oct-13		1	41.67609	-71.42044	26	28	92.9%	9.2	4.2	6.19	6.67	4.22	3.33
			2			9	13	69.2%	9.1	4.1	2.17	3.14		
			3			14	17	82.4%	13.1	6.0	2.34	2.84		
	23-Oct-13		1	41.69062	-71.35572	48	49	98.0%	14.1	7.16788	6.70	6.84	12.15	6.17
			2			68	72	94.4%	8.1	4.12496	16.49	17.45		
							avg	93.9%	Distance/Area from diver measurement					
							stdev	9.7%						

Bo Christensen - 2017

Substrate	Date	Depth	Transect	Start Location		Total in rake	Total present	efficiency	Distance covered	Area Covered	Measured Density	Real Density	Digger Avg Density	Quadrat Avg Density
		(m)		lat	long	(#)	(#)	(%)	(m)	(m^2)	#/m^2	#/m^2	#/m^2	#/m^2
Sand	10-Aug-17	5.1	1	41.68879	-71.35822	44	46	95.7%	14.2	5.4	8.11	8.48	7.89	5.33
			2	41.68894	-71.35884	83	84	98.8%	30.2	11.5	7.22	7.30		
Sticky Mud	10-Aug-17	5.4	1	41.68587	-71.35796	42	44	95.5%	21.4	8.1	5.15	5.40	5.43	0.67
			2	41.68445	-71.35763	51	53	96.2%	25.5	9.7	5.26	5.46		
Sticky Mud	22-Aug-17	5.1	1	41.66685	-71.40335	31	35	88.6%	13.5	5.2	6.01	6.78	9.21	8.00
			2	41.66683	-71.40337	41	48	85.4%	10.8	4.1	9.93	11.63		
Sand	22-Aug-17	5.1	1	41.66673	-71.40308	36	39	92.3%	12.9	4.9	7.31	7.92	5.52	2.00
			2	41.66684	-71.40302	11	15	73.3%	12.6	4.8	2.28	3.11		
2014														
Sand	10-Jul-14	0.0	1			45	50	90.0%	55.6	28.2	1.59	1.77	1.74	2.42
			2			16	17	94.1%	31.7	16.1	0.99	1.06		
			3			20	21	95.2%	26.9	13.7	1.46	1.54		
			4			30	31	96.8%	23.5	11.9	2.51	2.60		
Hard	17-Jul-14	5.8	1			136	144	94.4%	8.2	4.2	32.77	34.70	15.82	12.22
			2			61	62	98.4%	10.7	5.4	11.21	11.40		
			3			38	40	95.0%	8.8	4.4	8.55	9.00		
			4			35	38	92.1%	9.1	4.6	7.55	8.20		
							avg	92.6%						
							stdev	6.2%						

Jerrod Goulart - 2018

Substrate	Date	Depth	Transect	Start Location		Total in rake	Total present	efficiency	Distance covered	Area Covered	Measured Density	Real Density	Digger Avg Density	Quadrat Avg Density
		(ft)		lat	long	(#)	(#)	(%)	(m)	(m^2)	#/m^2	#/m^2	#/m^2	#/m^2
mud w/ shell hash	08-Aug-18	21.6	1	41.67718	-71.31063	36	36	100.0%	32.2	22.0	1.64	1.64	2.92	2.67
		21.2	2	41.67718	-71.31063	82	86	95.3%	25.9	17.7	4.63	4.85		
		21.6	3	41.67718	-71.31063	79	81	97.5%	52.5	35.9	2.20	2.26		
mud	08-Aug-18	20.9	1	41.69319	-71.30802	66	67	98.5%	50.9	34.8	1.90	1.93	1.94	5.67
		21.2	2	41.69319	-71.30802	41	45	91.1%	33.8	23.1	1.78	1.95		
		21.7	3	41.69319	-71.30802	75	77	97.4%	57.7	39.5	1.90	1.95		
hard sand	29-Oct-18	13.6	1	41.70987	-71.29532	4	4	100.0%	1.1	1.2	3.24	3.24	4.59	1.00
		13.5	2	41.70990	-71.29533	18	18	100.0%	4.2	3.0	5.95	5.95		
soft mud	29-Oct-18	18.6	1	41.71246	-71.29597	10	13	76.9%	12.7	10.0	1.00	1.31	1.31	1.33
		16.2	2	41.71268	-71.29582	14	19	73.7%	27.1	14.4	0.98	1.32		
soft mud	29-Oct-18	15.0	1	41.71300	-71.29576	26	27	96.3%	14.8	11.0	2.37	2.46	1.85	n/a
		13.8	2	41.71330	-71.29572	9	13	69.2%	14.2	10.4	0.86	1.25		
							avg	93.1%	Distance/Area from diver measurement					
							stdev	9.8%						

Earnest Wilcox - 2018

Substrate	Date	Depth	Transect	Start Location		Total in rake	Total present	efficiency	Distance covered	Area Covered	Measured Density	Real Density	Digger Avg Density	Quadrat Avg Density
		(ft)		lat	long	(#)	(#)	(%)	(m)	(m^2)	#/m^2	#/m^2	#/m^2	#/m^2
Hard Sand	05-Dec-18	7.7	1	41.60818	-71.41064	61	62	98.4%	8.3	4.6	13.39	13.61	12.54	0.33
		7.9	2	41.60818	-71.41068	32	32	100.0%	5.1	2.8	11.48	11.48		
Mud w/ shell hash	05-Dec-18	8.1	1	41.60811	-71.41075	6	6	100.0%	17.2	9.4	0.64	0.64	4.51	1.00
		8.3	2	41.60810	-71.41045	46	46	100.0%	10.0	5.5	8.38	8.38		
						avg		99.6%						
						stdev		0.8%						

Table 6. Data generated by fishermen calibrations to evaluate catch efficiency of the bullrake. Linear distance sampled by the bullrake was generated by recording Latitude and longitude of

start and stop locations, except in those cases (outlined in red) where the coordinates were not successfully collected and diver measurement of distance was substituted.

Dredge Catch Efficiency Calibration

The multi-geared sampling was conducted at 45 stations throughout Narragansett Bay over 2017 and 2018 (Figure 6). The stations were selected to cover a range of sediment types, depths, local abundances of quahogs, and spatially-explicit fisheries and water quality management. Each sampling station had dredge tows conducted with corresponding dredge transect inspections and quadrat sampling on SCUBA. Bullrake sampling was done opportunistically, with only some of the sampling dates and stations having pairwise bullrake data available (Table 7).

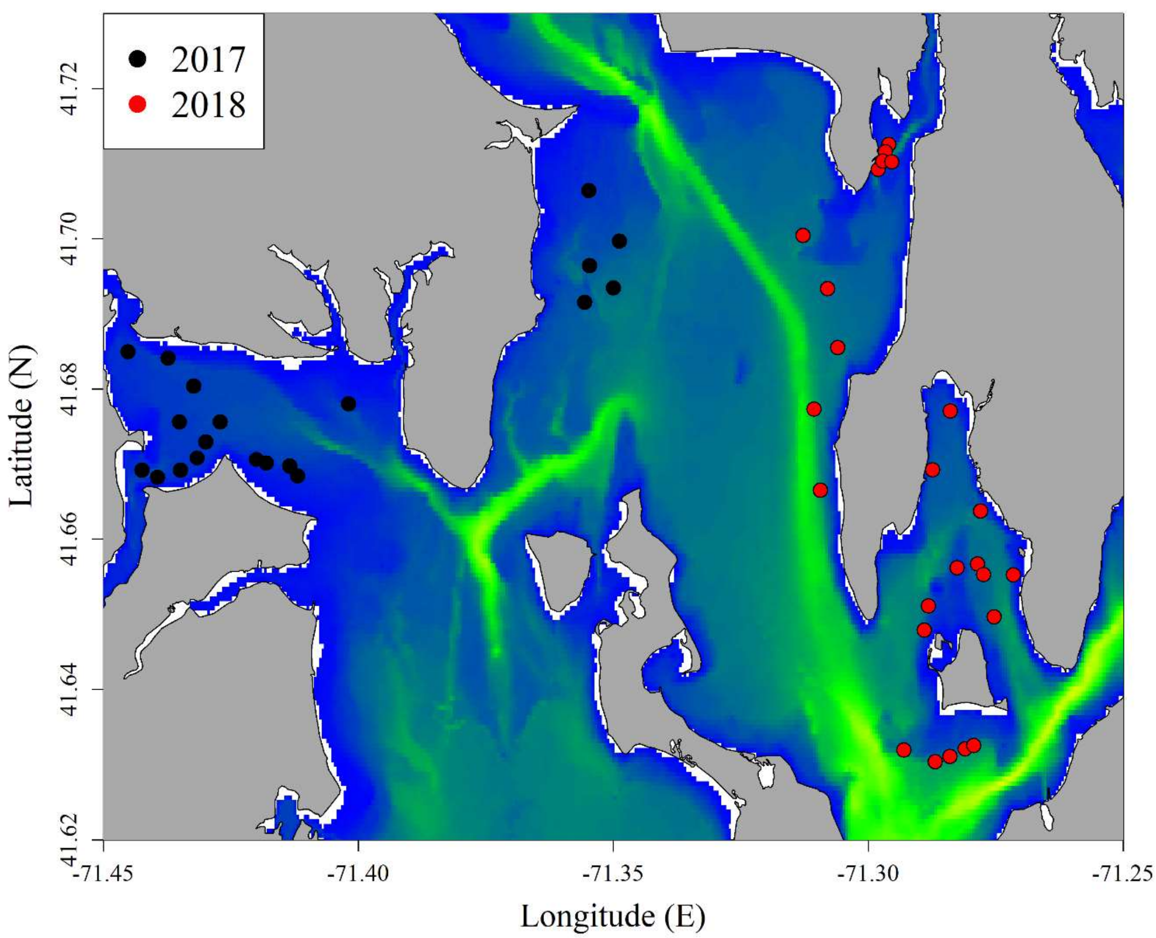

Figure 6. Stations for the multi-gear efficiency sampling in 2017 (black) and 2018 (red). Differences in depth are represented using the color ramp map, with blue indicting shallower depths and green indicating deeper depths.

Date	Dredge Sampling	Dredge Transect Inspection	Bullrake Sampling	Quadrat Sampling
10/6/2017	3	3	3	3
10/11/2017	5	5	-	5
10/18/2017	3	3	-	3
10/19/2017	4	4	3	4
10/27/2017	5	5	5	5
7/30/2018	5	5	-	5
8/1/2018	5	5	2	5
9/17/2018	5	5	-	5
10/5/2018	5	5	-	5
10/19/2018	5	5	2	5

Table 7. Dates and the number of stations sampled for each of the gear efficiency methods.

Over the 45 dredge tows with transect inspections, the average quahog catch efficiency was 0.64 (0.29 standard deviation.) Dredge efficiency did not statistically vary across legal market class sizes, but cherrystone, chowder, and little neck catch efficiencies were statistically different than sublegal quahog catch efficiency (Kruskal-Wallis χ^2 = 16.07, p-value=0.003; Tukey and Kramer significant pairwise tests < 0.05). This finding is driven by the large number of absences of sublegal quahogs found in both the dredge samples and the transect inspection, with resulting efficiencies of 1 (Figure 7.) When evaluating efficiencies by market class of only presence data, the five size classes' efficiencies were not statistically different (Figure 7.)

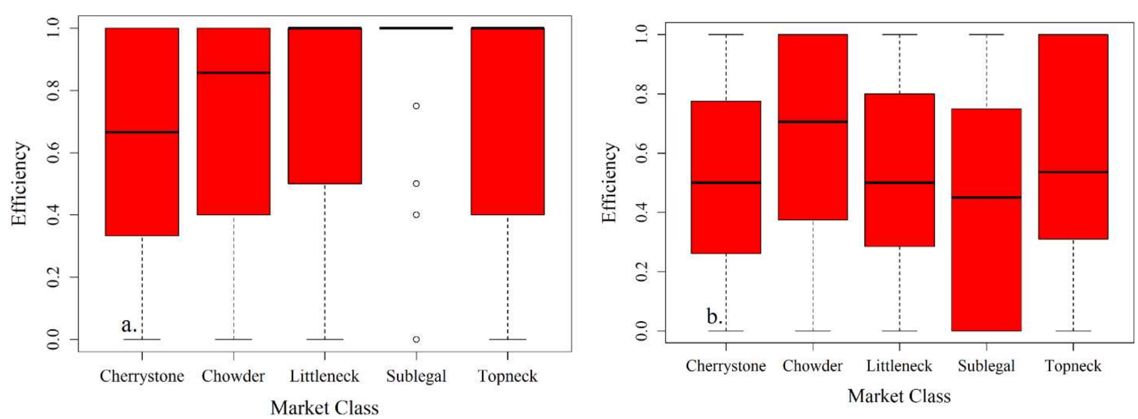

Figure 7. Dredge efficiencies for quahogs by market class. Instances where a given size class was absent in both the dredge catch and transect inspection were considered fully efficient and equal to 1 (left), and instances where market classes were absent in the dredge catch and inspection of the dredge track removed (right), are both presented. Dark lines, box heights, and tick marks indicate 50th, 25-75th, and 0-100th percentiles, respectively.

Dredge catch efficiency varied greatly across and within sediment types, with mean efficiencies by sediment type ranging from 0.44 to 1 (Figure 8.) Hard bottom types had significantly greater efficiencies for total quahog catch than soft sediments (Figure 8.), but not for sediments where the bottom type was not discernible (Kruskal-Wallis χ^2 = 7.49, p-value=0.02). Generally, mud-type sediments had lower catch efficiency than sand-type substrates, but efficiencies by individual sediment type were not significantly different.

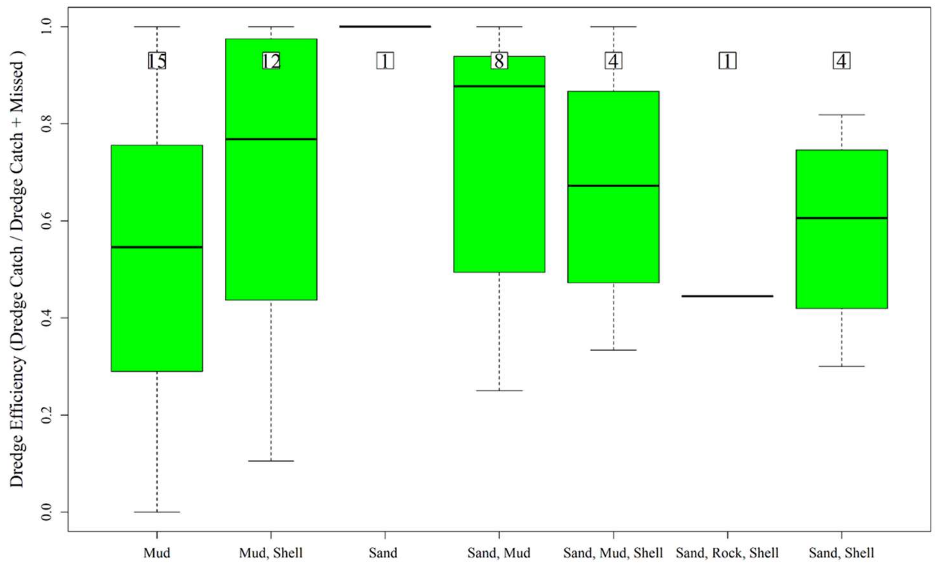

Figure 8. Dredge efficiencies for total quahog catch bottom type. Dark lines, box heights, and tick marks indicate 50th, 25-75th, and 0-100th percentiles, respectively.

Finally, dredge catch efficiency did not indicate a functional relationship with either depth or observed abundance; catch efficiency was highly variability over depth and abundance, particularly at the lower spectrums (Figures 9 and 10)

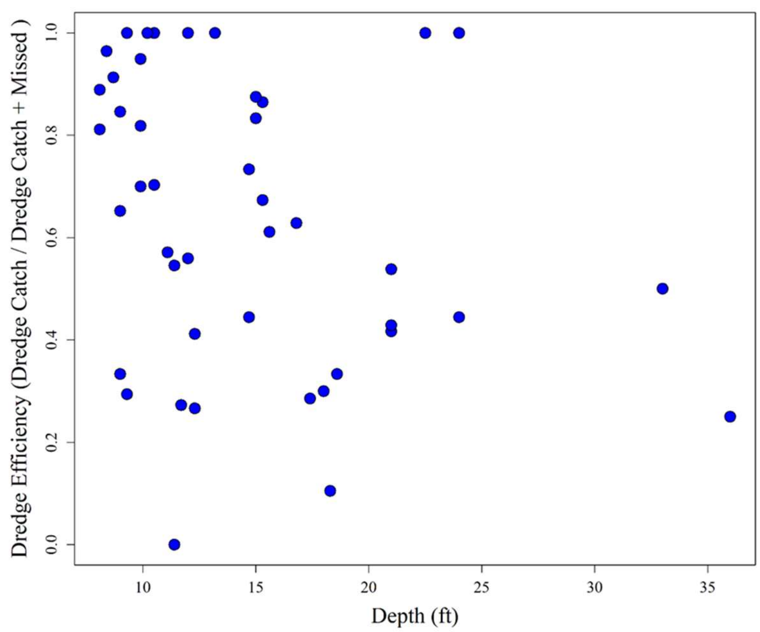

Figure 9. Dredge efficiencies for total quahog catch by depth.

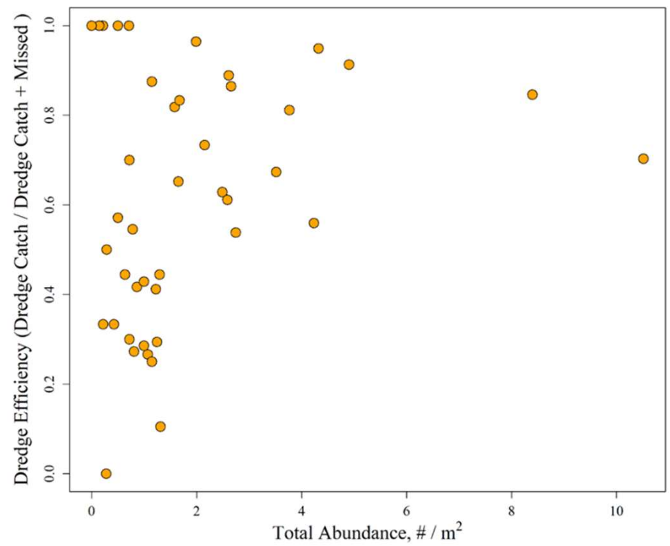

Figure 10. Dredge efficiencies for total quahog catch by abundance.

On average, chowders represented the majority of the catch across dredge, quadrat, and bullrake sampling (Figure 11). The proportion of sublegals was often very small (≤5%), with those of littlenecks, cherrystones, and topnecks often comparable. Correlation between the observed hydraulic dredge and that abundances corrected for by including quahogs missed by the dredge and in the transect was significant (Figure 12).

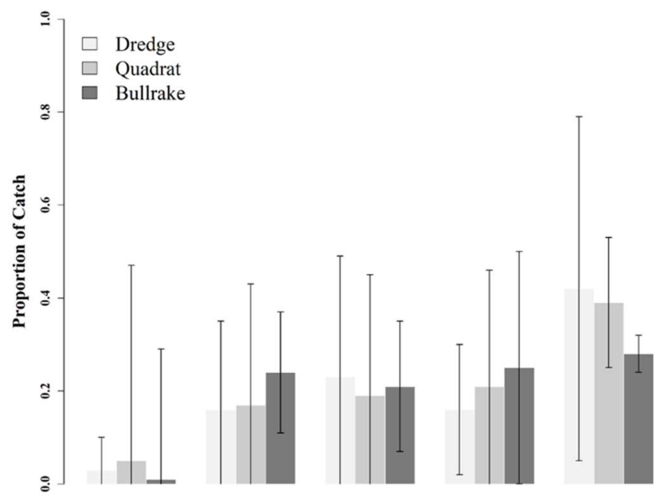

Figure 11. Average proportion of market classes within the samples of each sampling type: the hydraulic dredge, quadrat sampling, and bullrake sampling. Proportions for quadrat and bullrake sampling include the replicates within a station. Bars are average proportions over all data within a sampling type, and bars represent the standard deviation range around the means.

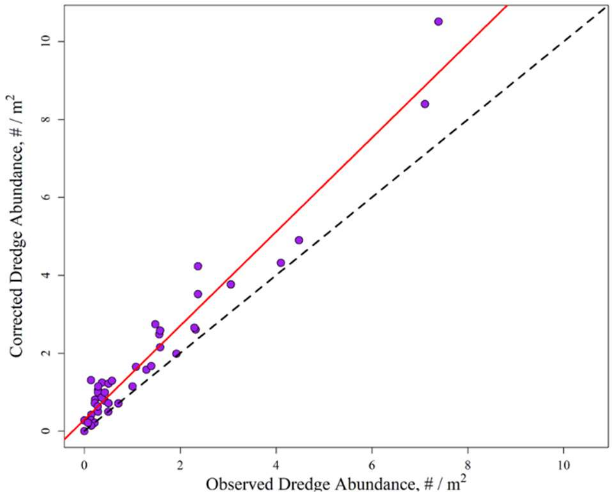

*Figure 12. Observed quahog abundance from the hydraulic dredge compared to corrected abundances based on the transect data. The dark dashed line is the 1:1 line (indicating equal catch between the two abundances), and the red line represents the linear fit predicting corrected dredge abundance based on observed dredge abundance: Corrected Abundance = 1.21*Observed Abundance+0.29 (R2=0.95, p-value<0.001).*

When comparing these corrected dredge abundances to those collected using the quadrat sampling, abundances from the quadrat sampling were typically higher than the dredge (Figure 13.) A similar comparison between corrected dredge abundances and bullrake abundances indicated a parallel finding, with bullrake abundances on average greater than those from the dredge (Figure 14.). However, there was no clear relationship between the two methods and the corrected dredge abundance estimates.

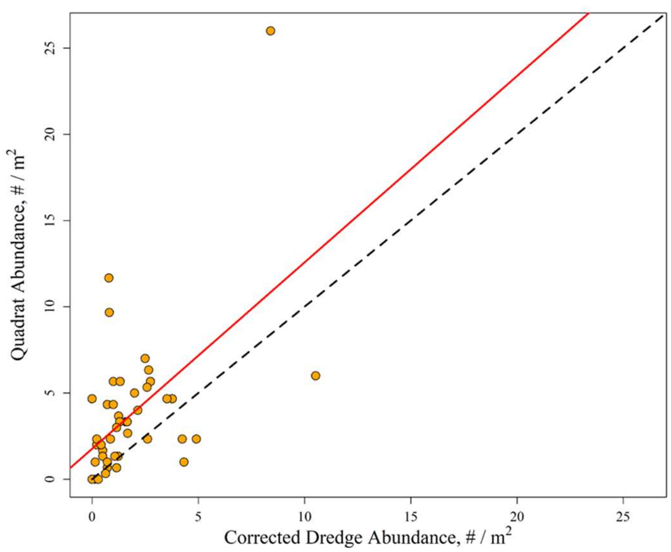

*Figure 13. Corrected quahog abundance from the hydraulic dredge compared to abundances collected using quadrats. Quadrat abundances represent the average abundance across replicates within a station. The dark dashed line is the 1:1 line (indicating equal catch between the two abundances), and the red line represents the linear fit predicting quadrat abundance based on corrected dredge abundance: Quadrat Abundance = 1.08*Corrected Dredge Abundance+1.76 (R2=0.28, p-value<0.001).*

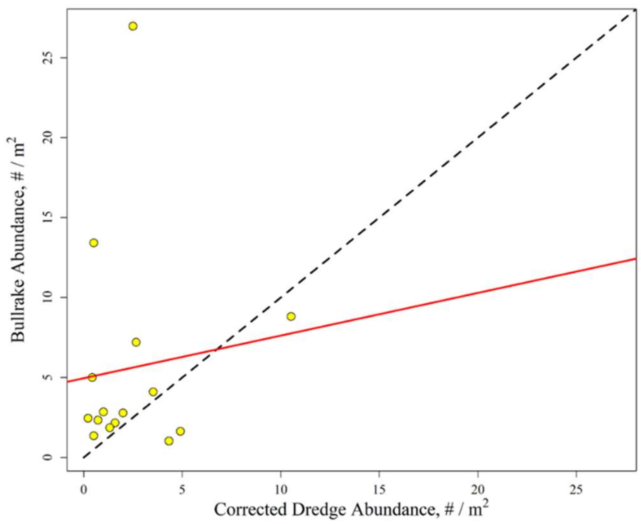

Figure 14. Corrected quahog abundance from the hydraulic dredge compared to abundances collected using bullrakes. Bullrake abundances represent the average abundance across replicates within a station. The dark dashed line is the 1:1 line (indicating equal catch between the two abundances.) The red line represents the linear fit predicting quadrat abundance based on corrected dredge abundance, which was statistically insignificant.

When testing all prospective covariates with the GLMM approach, only bottom type was a significant covariate in predicting dredge efficiency. Depicting this, the model variant only using bottom type had the lowest AIC score (Table 8), which corresponded to a generalized linear model (GLM) without mixed effects. However, for predictive purposes and to incorporate variability of both continuous and discrete variables on dredge catch efficiency, the model variant with all covariates was used for dredge efficiency predictions. When comparing the selected model's predictions to the observed efficiencies, correlation was significant, but relatively weak (R^2= 0.36, p-value < 0.001). Efficiency predictions approximately less than 0.65 were greater than observed, and those over 0.65 were predicted to be less efficient than observed (Figure 15).

Model	Fixed Effects				Random Effects	AIC	ΔAIC	Degrees of Freedom
	Bottom Type	Sediment	Depth	Observed Abundance	Station			
1	x					-12.6	0	4
2	x	x				-6.4	6.2	10
3	x	x	x			-4.6	8.0	11
4	x	x	x	x		-3.2	9.5	12
5	x	x	x	x	x	-1.2	11.5	13

Table 8. GLM and GLMM variants tested for predicting dredge catch efficiency, with 'x' denoting the variable's inclusion in the model.

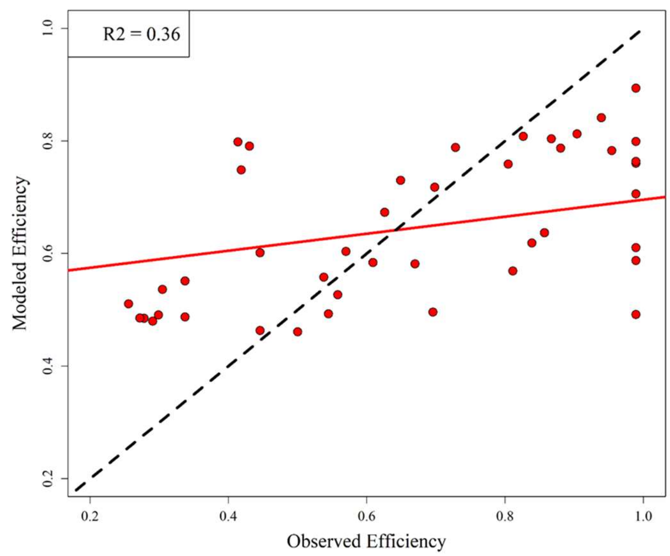

Figure 15. Observed dredge efficiency for catching quahogs compared to the predicted efficiency from the best-fitting model. The red line represents the linear fit between the two data (with the correlation of determination presented), and the dark dashed line is the 1:1 line.

With corrections applied to the quahog abundance time series data, average annual abundances increased for all years except for 2003 in Greenwich Bay (Figure 16). Increases in abundances through time and region varied based on the sampling that occurred in the given year, but reached up to 2-3 times larger the original abundance in some instances. Despite varying increases in abundance through time, the abundance trends for each region remained predominantly the same when applying the dredge efficiency corrections to samples. Providence River remained to have the highest overall abundance trend through time, with Greenwich Bay and Narragansett Bay Proper indices remaining of similar magnitude (Figure 16).

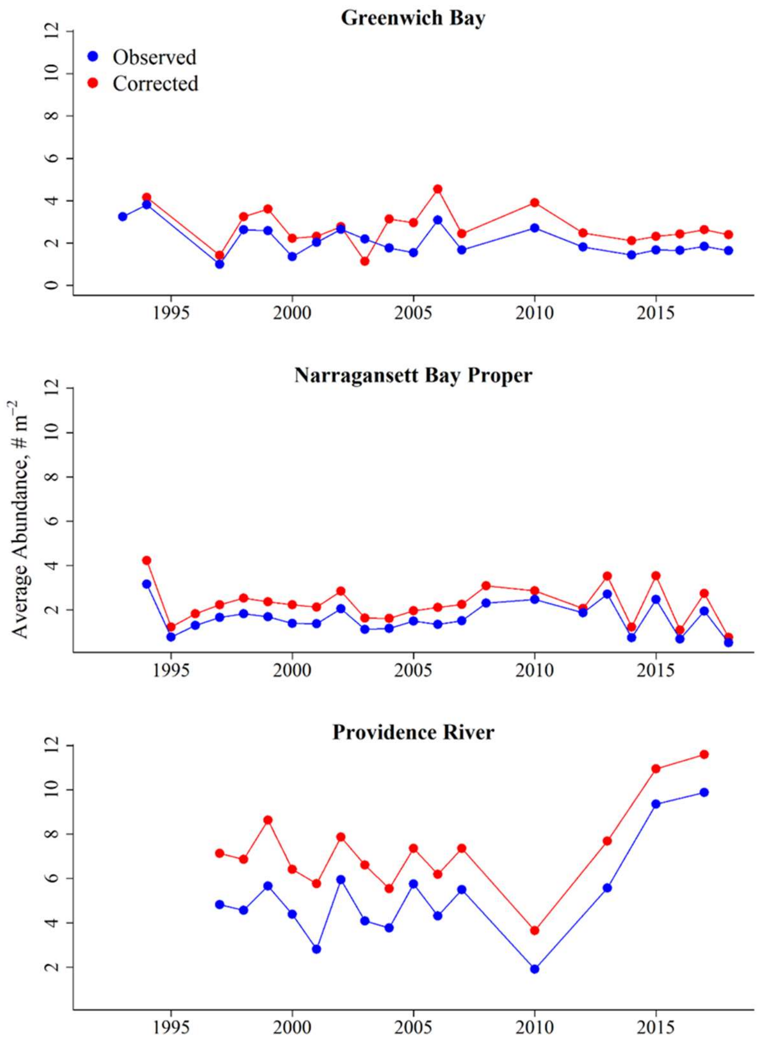

Figure 16. Time series of quahog dredge abundance from RIDEM DMF's survey for the three regions currently modeled for stock assessment (Greenwich Bay, Narragansett Bay Proper, the Providence River) for abundances currently used ('Original') and those corrected for based on the dredge efficiency model ('Corrected').

<u>*Quahog Research Fleet Bullrake Data Analysis*</u>

Quahog Research Fleet data collection officially began on September 1, 2016; however, the majority of the Research Fleet did not start actively sampling until November 2016. This delay in sampling was primarily due to sorting rack construction, GPS accuracy issues, and edits and adjustments to On Deck Data (detailed above). In addition, the weather during the winter months is unpredictable, which limits shellfishermen's ability to operate regularly.

During the first year of the project (February 1, 2016 to January 31, 2017), a total of 3,643 quahogs were sampled by the Quahog Research Fleet from 34 locations throughout Narragansett Bay (Figure 17). Of the quahogs sampled, 10.2% were chowders, 13.6% were cherrystones, 18.8% were topnecks, 51.5% were littlenecks, and 5.9% were sub-legal. A variety of habitat types were sampled by the Quahog

Research Fleet, with 32.8% of samples from sand, 37.5% of samples from sandy mud, 21.9% of samples from mud, and 7.8% of samples from sticky mud. The mean depth sampled was 17.1 feet.

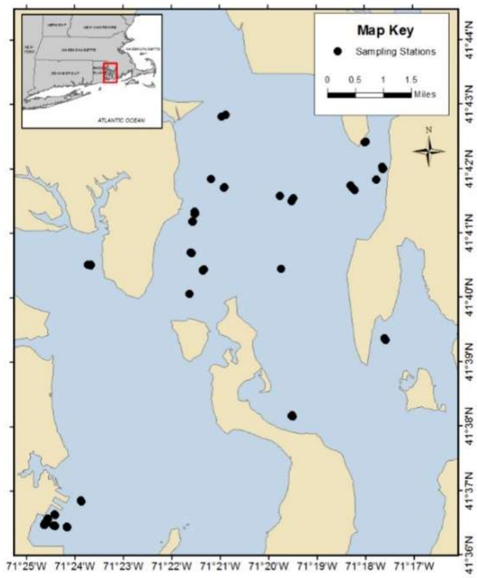

Figure 17. Map of Research Fleet transect locations through the first year of data collection (n=34).

With On Deck Data and sampling equipment fine-tuned, the Quahog Research Fleet exhibited a substantial increase in sampling effort during the second year of sampling. Specifically, during year 2, the Quahog Research Fleet sampled a total of 34,527 quahogs from 613 sampling sessions representing 250 unique locations throughout Narragansett Bay (Figure 18).

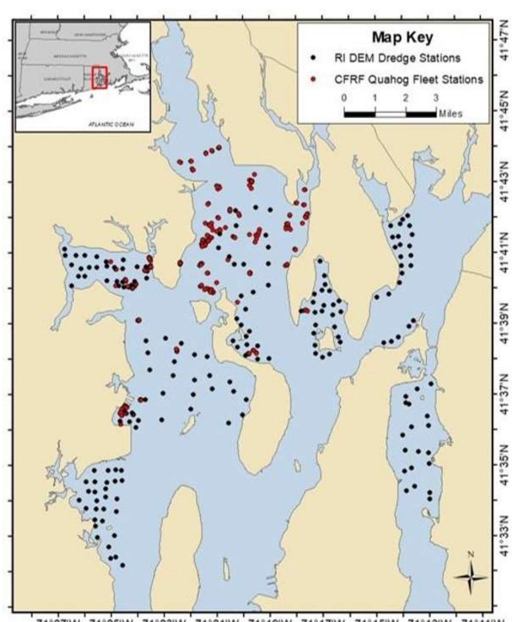

Figure 18. Map of Research Fleet transect locations (n=613) through the end of the second year of sampling. Red dots represent transect locations and black dots represent RI DEM dredge stations.

Of the quahogs sampled by the Research Fleet during year 2 of the project, 11.2% were chowders, 14.2% were cherrystones, 21.8% were topnecks, 48.6% were littlenecks, and 4.2% were sub-legal. A variety of habitat types were sampled by the Quahog Research Fleet, with 17% of samples from sand, 23% of samples from sandy mud, 28% of samples from mud, and 32% of samples from sticky mud. The mean depth sampled was 15 feet.

In addition to the routine sampling by the Quahog Research Fleet during year 2 of the project, the CFRF worked with RI DEM to arrange days for directed sampling in the Providence River, which was slated to be opened to quahog fishing in 2018. In October 2017, the CFRF accompanied Quahog Research Fleet participants on sampling trips to the Providence River alongside the RI DEM dredge. These efforts provided data about the quahog population structure in the Providence River as well as a unique opportunity for the Research Fleet participants to get a glimpse of the quahog resource that may soon be accessible for harvest. During each sampling day in the Providence River, CFRF staff joined Research Fleet participants on their boats and assisted with the collection of bullrake data at locations determined by RI DEM. The CFRF was responsible for notifying enforcement about the sampling efforts and for organizing and communicating the data to RI DEM. All of the quahogs sampled in the Providence River were returned to the water to adhere to current regulations. RI DEM ultimately utilized the data from the Research Fleet transects from within the Providence River to estimate catch rates of bullraking in the Providence River (as described in the previous section). The estimated catch rates were considered a minimum estimate for potential harvesting rates of bullrakers operating in the newly opened, high quahog density area. With this information, RI DEM was able to develop management schemes for the Providence River by applying the estimated catch rates to targeted number of opening days to ultimately estimate a targeted total removal.

During the third year of the project, the Research Fleet sampled a total of 468 transects accounting for a total of 20,155 quahogs (Figure 19). The catch composition of the quahogs sampled in year 3 was 9.6% chowder, 11.2% cherrystone, 19.7% topneck, and 53.7% littleneck. Similarly to previous years of data collection, the Research Fleet sampled quahog transects from a variety of substrate types with 26.3% of transects completed in mud, 6.2% in sand, 15.6 % in sandy mud, and 51.9% in sticky mud.

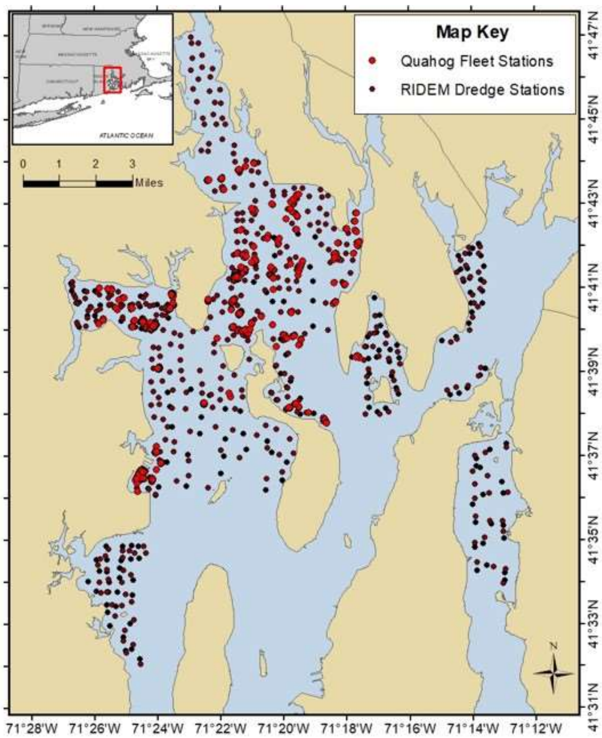

Figure 19. Map of all transect locations through the final year of sampling by the Research Fleet (n=1,055). Red dots represent Research Fleet locations and black dots represent RI DEM dredge sampling locations from the same time frame.

Over the course of the project, the Quahog Research Fleet completed a total of 1,055 transects accounting for 53,866 quahogs. The quahog catch composition from the entire project was 10.3% chowder, 12.9% cherrystone, 20.8% topneck, and 51.1% littleneck. The aggregate habitat coverage by the Research Fleet was 27.3% mud, 12.7% sand, 21.7% sandy mud, and 38.2% sticky mud.

An important output of the Quahog Research Fleet was an estimate of quahog density in areas not covered by the RI DEM dredge survey. Overall, quahog densities sampled by the Research Fleet had a mean of 6.5 quahogs per meter^2, a maximum of 98.3 quahogs per meter^2 , and a minimum of 0 quahogs per meter^2 (Figure 20). In comparison to quahog densities sampled by the RI DEM hydraulic dredge during the same time frame, the Research Fleet had a higher mean and maximum compared to the RI DEM hydraulic dredge (Figure 21). Specifically, the RI DEM dredge measured a mean quahog density of 1.6 quahogs per meter^2 and maximum of 69.2 quahogs per meter^2 (Figure 21). Both the Quahog Research Fleet and RI DEM dredge sampled areas with zero quahogs. Although instances of high quahog densities, similar to Quahog Research Fleet sampled densities, were present in the RI DEM dredge dat, the Research Fleet had a higher proportion of higher density transects Specifically, 16.5% of all Quahog Research Fleet sampling locations exhibited densities greater than 10 quahogs per meter^2, where as only 2.4% of the RI DEM dredge sampling locations exhibited densities greater than 10 quahogs per meter^2. This trend holds true even when the commercial sampling data (fishery dependent data), which are derived from areas targeted for fishing and, thus, expected to exhibit higher quahog densities, are removed from the analysis (Figure 22).

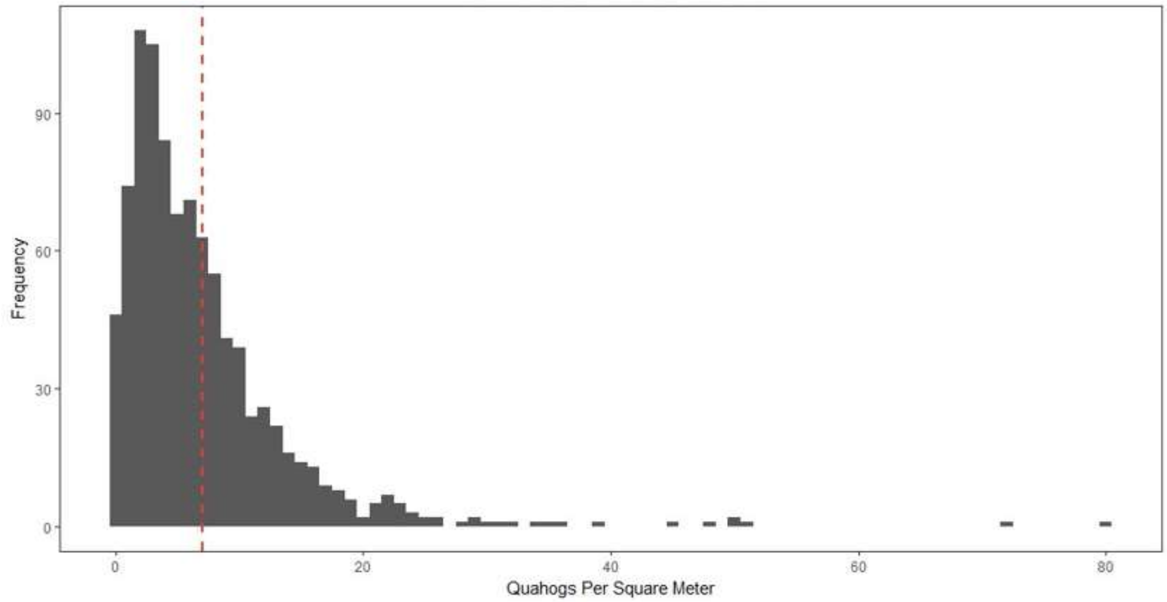

Figure 20. Histogram of all transect densities throughout the data collection period of the Quahog Research Fleet. Quahog density is binned to the nearest whole number. Red-dashed line represents the mean quahog density from all transects (6.5 quahogs per meter^2)

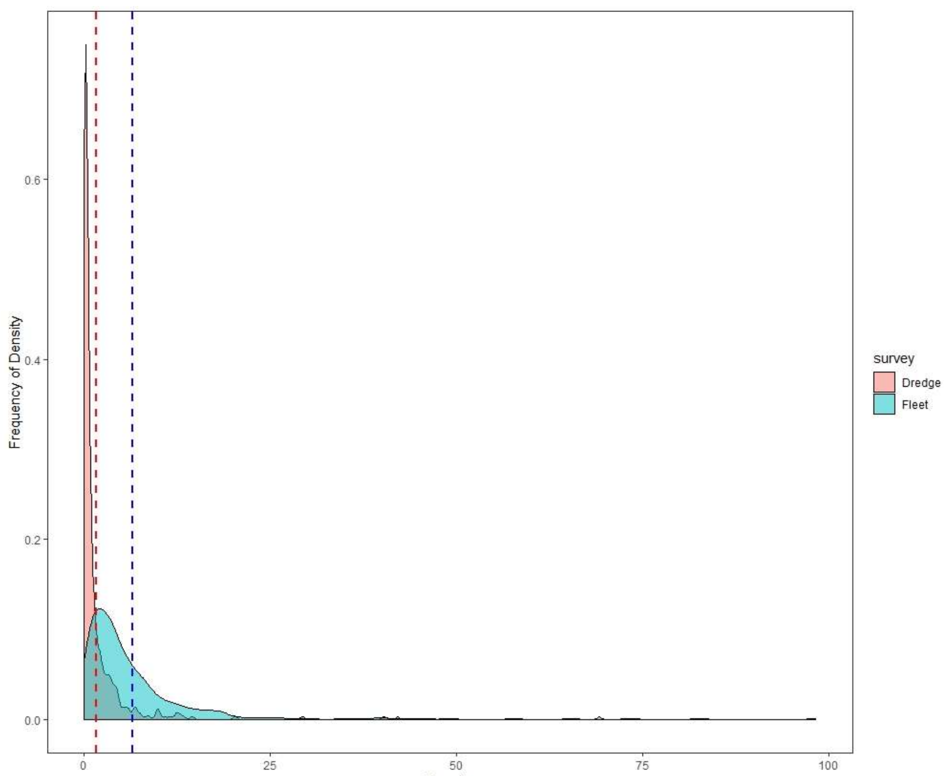

Figure 21. Density plot of the recorded transect densities separated by the Research Fleet (blue) and the RI DEM hydraulic dredge (pink) survey. The red dashed line represents the RI DEM dredge mean density (1.64 quahogs per meter^2) and the blue dashed line represents the Research Fleet mean density (6.5 quahogs per meter^2)

When comparing standardized fishery independent data from the Quahog Research Fleet (assigned sampling stations) to the RI DEM dredge survey, the Research Fleet data documents higher quahog densities throughout the Bay (Figure 22). This trend is likely a combination of the lower efficiency of the RI DEM dredge (as described in the previous section) as well as the fine-scale variability in quahog density throughout the Bay.

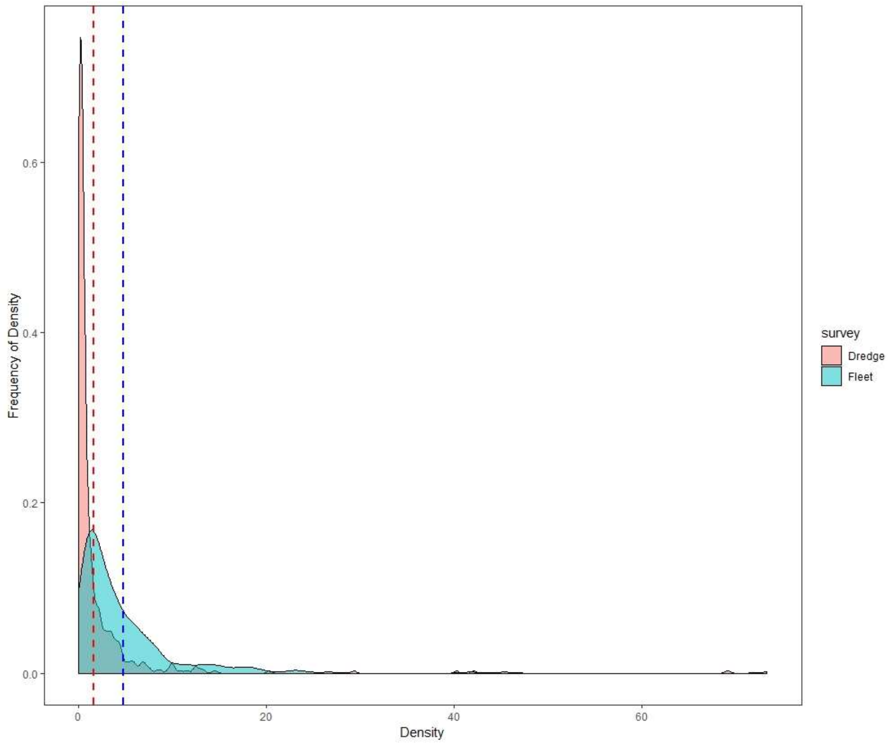

Figure 22. Density plot of the recorded transect densities separated by the Research Fleet fishery independent, assigned, locations (blue) and the RI DEM hydraulic dredge (pink) survey. The red dashed line represents the RI DEM dredge mean density (1.64 quahogs per meter^2) and the blue dashed line represents the Research Fleet mean density (4.75 quahogs per meter^2)

When comparing the Quahog Research Fleet data from fishery dependent and fishery independent sampling locations (the commercial vs. assigned locations, respectively), the expected trend was that the fishery dependent (commercial) sampling locations would have a higher mean density then the fishery independent (assigned) locations (as described above). The Research Fleet data confirmed this expected trend, with the commercial stations having a mean of 6.74 quahogs per meter^2 and the assigned locations having a mean of 4.75 quahogs per meter^2 (Figure 23). More specifically, 19% of the fishery dependent (commercial) sites sampled by the Quahog Research Fleet exhibited high quahog densities (> 10 quahogs per meter^2), whereas only 11% of the fishery independent (assigned) sites sampled by the Quahog Research Fleet exhibited high densities. The total range of quahog densities sampled at the Research Fleet's assigned and commercial sites, however, were similar (Assigned: 0-75 quahogs per meter^2, Commercial: 0-100 quahogs per meter^2).

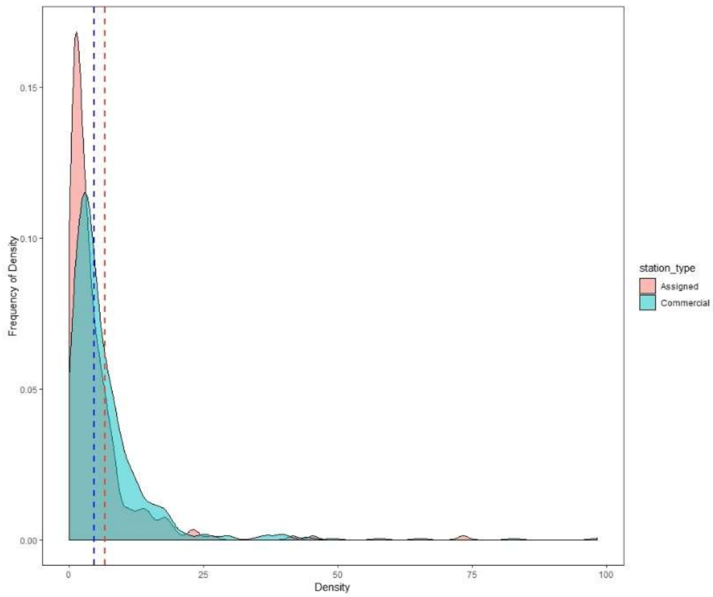

Figure 23. Density plot of the recorded transect densities separated by the Research Fleet fishery dependent, commercial, locations (blue) and the Research Fleet fishery independent, assigned, locations (pink). The red dashed line represents the commercial station mean density (6.74 quahogs per meter^2) and the blue dashed line represents the Research Fleet mean density (4.75 quahogs per meter^2)

To address the hypothesis that the Quahog Research Fleet, and the quahog industry state-wide, was capable of accessing higher density quahog beds in the areas outside of the depth range of the RI DEM dredge, the CFRF ran a suite of regressions and significance of correlation tests between quahog density and depth. While there was a general trend towards higher quahog densities at deeper depths, the relationship between quahog density and depth was not significant (Figure 25). This was likely due to the high level of variance in quahog density at intermediate depths and the relatively small sample size from shallow (<10 feet deep) and deep (>20 feet deep) waters. To further explore this trend, the same regression and significance test was completed on data from deeper than 20 feet (Figure 26). This analysis resulted in a significant positive correlation between depth and quahog density in areas deeper than 20 feet (Figure 26, P-value = 0.0006, Tau: 0.184).

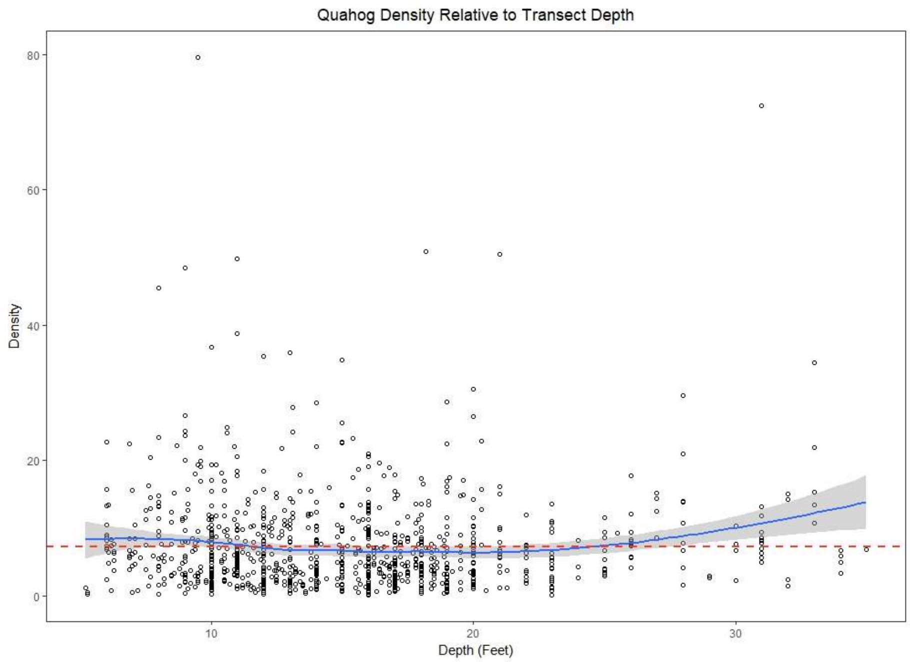

Figure 25. Regression plot of quahog density in response to depth of transect. The red-dashed line represents the mean quahog density (6.5 quahogs per meter[2]). The blue line is a Loess-smooth fit trend line and the gray shaded area represents the 95% confidence interval. Kendall rank correlation test showed no significance (p = 0.277)

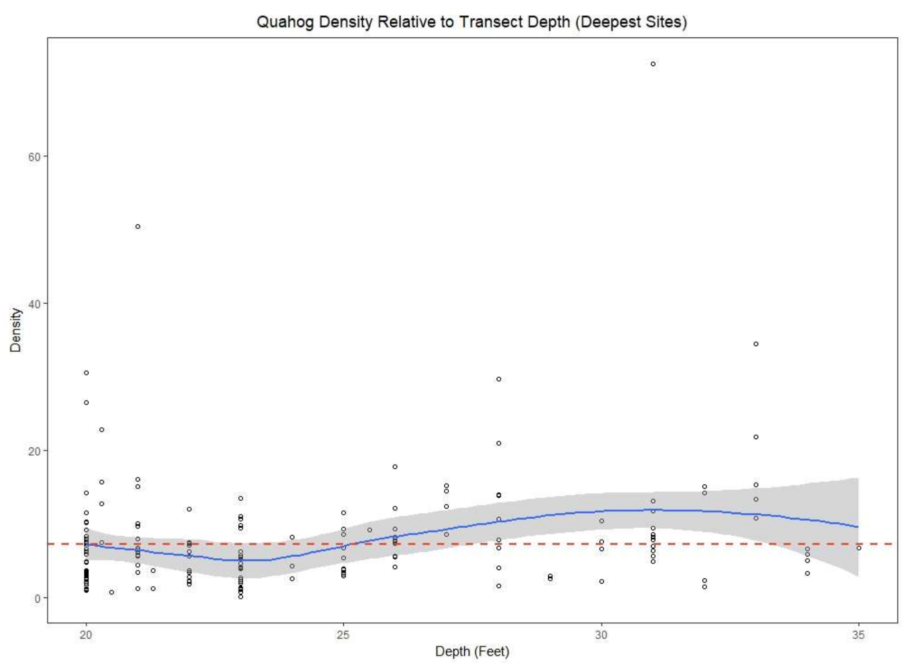

Figure 26. Regression plot of quahog density in response to depth of transect for the deepest transect sites beyond 20 feet of depth. The red-dashed line represents the mean quahog density (6.5 quahogs per meter[2]). The blue line is a Loess-smooth fit trend line and the gray shaded area represents the 95% confidence interval. Kendall rank correlation test showed a significant positive correlation of density in response to depth (p = 0.0006, Tau-value = 0.184).

To address the Research Question about whether the Quahog Research Fleet (and quahog industry as a whole) is able to access areas with high quahog abundances outside of the RI DEM dredge survey strata, the CFRF mapped the quahog densities measured by the Research Fleet and the RI DEM dredge between 2016 and 2018 (Figure 27). This mapping exercise reveals that the Quahog Research Fleet documents high quahog densities outside the RI DEM survey strata, namely in the coves of Greenwich Bay, the coves around Quonset and Fry's Pond Cove, the eastern shoreline of Warwick Neck, and the Warren River. This provides quantitative evidence that the RI DEM dredge survey neglects some areas that are important to the quahog population and fishery.

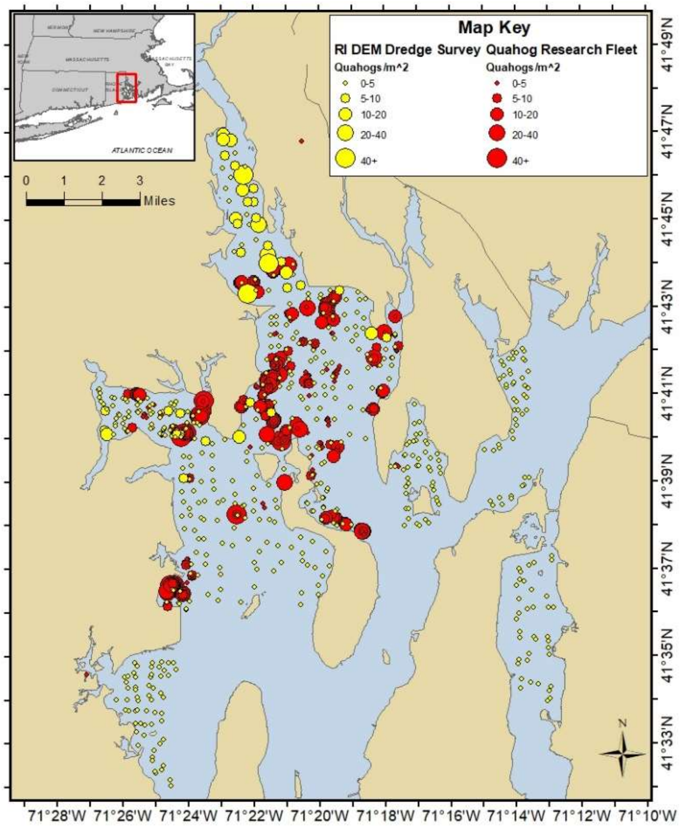

Figure 27. Map of quahog densities sampled by the Quahog Research Fleet (red circles) and the RI DEM hydraulic dredge survey (yellow circles). Circle size corresponds to quahog density (e.g. larger circles = higher quahog densities).

In addition to revealing high quahog densities outside of the RI DEM dredge survey strata, the Quahog Research Fleet also documents different quahog densities than the DEM dredge in some areas where sampling coverage overlaps. Specifically, the Quahog Research Fleet documents higher quahog densities than the RI DEM dredge survey in Greenwich Bay, off Rocky Point and Warwick Neck, along the north shore of Prudence Island, and off the north shore of Colt State Park (Figure 27). These discrepancies are likely due to the lower efficiency of the RI DEM dredge as well as fine-scale differences in quahog density throughout the Bay. With that said, there are areas in Narragansett Bay that the RI DEM dredge and the Quahog Research Fleet document similar quahog densities, including the central Upper Bay, Providence River, and Usher Cove (Figure 27).

As noted earlier in this report, there are uncertainties regarding the accuracy of SAFIS (landings) data for quahogs, especially in regard to the size structure of quahog catch. To address this question, the CFRF completed a comparison of quahog catch composition data from the Research Fleet and SAFIS reports. The SAFIS landings data serves as an important part of the current quahog stock assessment model, providing the size (which is converted into age) of total removals of quahogs from the different areas of Narragansett Bay (Greenwich Bay, Upper Bay, Narragansett Bay Proper). Ultimately, accurate size and age of total removals allows for the model to asses the mortality at age and how, if propagated throughout time due to annual landings, it can impact total adults, spawning stock biomass, and recruits. Currently, SAFIS serves as the only source of size and age of removals data in the quahog stock assessment model.

A side-by-side comparison of quahog size structure (by market class) from SAFIS and the Quahog Research Fleet revealed significant differences (Figure 28). Specifically, the reported SAFIS quahog landings exhibit a much higher composition of littlenecks than the Research Fleet data. The Research Fleet catch composition, which also favoring littlenecks, was more evenly distributed amongst the various size classes. A variety of reasons for these differences are possible, including variability in fishing practices and target size classes between shellfishermen.

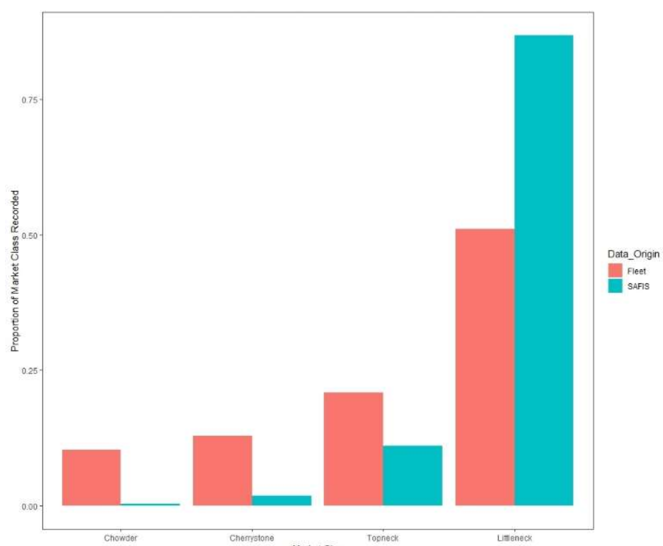

Figure 28. Proportion of catch composition of each market class separated by Research Fleet recorded data (pink) and SAFIS landings report provided by RI DEM (blue). Each bar represents the proportion of total catch accounted for by each market size class.

To investigate variability in quahog harvest practices between shellfishermen, individual quahog catch compositions were developed for each Research Fleet member (Figure 29). This exercise suggests there is significant variance between individual shellfishermen in regards to quahog catch composition. While some shellfishermen are clearly targeting the smallest (and most valuable) size class of quahog (littlenecks), others prefer to harvest more evenly across the size classes. As described in the previous section, no trend was found between bullrake configuration and size classes of quahogs targeted. This suggests the differences between individual Research Fleet member's catch composition is likely driven primarily by site specific variation in size classes of quahogs present.

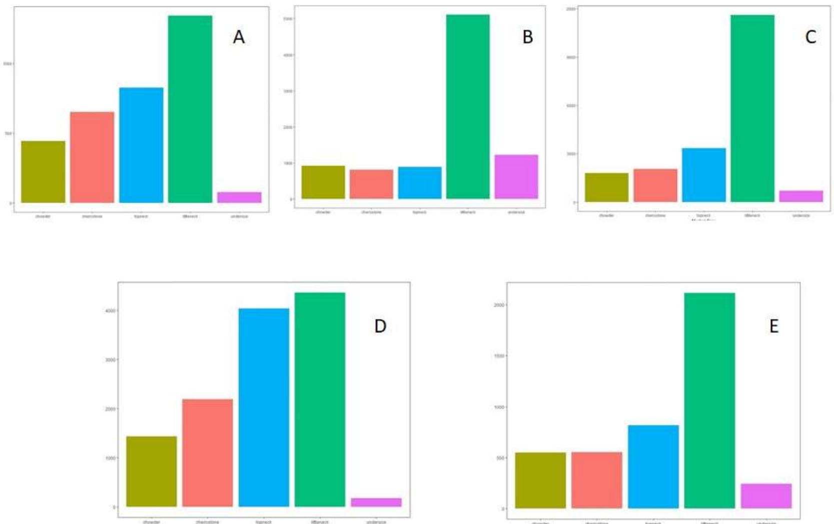

Figure 29. Catch composition of each Quahog Research Fleet member through the entirety of bullrake sampling. Each plot with a unique letter (A, B, C, D, and E) represents an individual Fleet Member. Each bar represents a specific harvested size class of quahog and is the same in each plot from left to right; chowder, cherrystone, topneck, littleneck, and undersize.

DISCUSSION

<u>*Quahog Research Fleet Development*</u>

The work completed during this project tested the efficacy of the "Research Fleet" approach, which engages fishermen in collecting biological data to inform stock assessments, in the Rhode Island quahog fishery. Ongoing feedback on sampling protocols from both shellfishermen and scientists proved to be invaluable to developing an efficient and effective program. That said, if the Quahog Research Fleet were to continue for the long-term, a variety of technological and logistical modifications would need to be adopted. A suite of recommended modifications are detailed below, and include: 1) reduction in number of metrics collected in the app, 2) use of tablets with a high-accuracy GPS, and 3) increase in stipend amount to participant shellfishermen. Overall, the small-boat, single-operator nature of the quahog fishery introduced technical and logistical challenges that require creative solutions, some of which are hindered by the current capabilities of hand-held technology.

One of the shellfishermen's major critiques of the Quahog Research Fleet's sampling protocols was the length of time required to complete the monthly sampling and the meager compensation. The lengthy data collection process was, in part, due to the large suite of metrics (habitat, gear, catch, ect) that were selected by the shellfishermen and scientists at the start of the project so as to capture all the factors that may impact quahog catch. After analyzing the project data, the suite of metrics collected by the Research Fleet could be winnowed to a quarter of what they are now and the value of the data would remain strong.

In the other Research Fleets operated by CFRF (lobster, Jonah crab, black sea bass), nearly all participating fishing vessels are operated by multiple people, which means that the sampling workload is easier to accomplish as sampling and data entry can be split and assigned to different crewmembers. However, in the Quahog Research Fleet all fishing vessels are single operator. The presence of only one individual on the boat requires all work (both commercial fishing and data collection) to be completed by the same individual. Occasionally, this proved to be problematic when issues arose, either directly with sampling equipment or externally related to the environment. Overall, a reduction in the suite of data collected would be necessary for continuation of the Quahog Research Fleet.

Most of the other areas identified for improvement by participant shellfishermen were related to the physical and technological specifications of sampling equipment, including sorting racks and tablets. Due to the small size of commercial quahog boats, deck space is considered a premium and each digger's vessel had different space constraints. Thus, participants noted that the sorting racks constructed by RWU were often too large and would get in the way of commercial fishing operations. In the future, each individual Research Fleet participant should be consulted to provide exact desired dimensions of sorting racks and other sampling equipment that requires deck space.

One of the major sources of frustration during sampling was the transcription of latitude and longitude coordinates from the external mounted boat GPS, which was necessitated by the low-accuracy of the internal tablet GPS units. Although easier to transcribe from compared to the previously-used, hand-held GPS units, transcription from any external source into a tablet is less than ideal and introduces the potential for entry error which requires another step of data auditing. A new tablet technology that will likely become available in 2019, however, significantly improves GPS accuracy to within 10 centimeters. With recent restrictions lifted by the Federal Communications Commission, GPS units within the United States are being made capable of accessing all global positioning satellites owned by the United States, Russia, Japan, and the European Union. The current GPS technology in the Samsung Galaxy Tab A tablets used by the Research Fleet only accesses the United States and Russian satellites, which does not provide the needed accuracy. Identifying and using tablets with internal GPS units capable of maintaining the needed accuracy are a top priority for improving the Quahog Research Fleet. Using tablets that have the required GPS accuracy would eliminate the added time commitment of transcribing latitude and longitude coordinates, eliminate the possibility of data entry error from this data field, and overall would streamline the sampling procedure. For this reason, it is recommended that higher-end tablets with better hardware capabilities be located and invested in. On a single-operator fishing vessel participating in data collection, having properly functioning sampling equipment at all times is a necessity as the slightest issue can quickly impact and halt all fishing.

Ultimately, successful implementation of the Quahog Research Fleet was centered around proof of concept: Were shellfishermen able to organize and work collaboratively with scientists and managers to address scientific issues facing their fishery? Conversely, were scientists and managers receptive to the concerns of the industry and able to adequately address issues while working towards a common, shared, goal? In both of these instances the Quahog Research Fleet to be successful. Through analysis of the survey results, every single participating Research Fleet participant thought positively that the project was worthwhile, successful, and improved their relationship with management. Further, every Research Fleet participant believed the data collected throughout the project both improved the database available for the quahog stock assessment and management and increased their trust in the process. Overwhelmingly, the comments received by shellfishermen participating in the Research Fleet share the common theme of feeling valued and heard by management. Further, involving shellfishermen in the calibration of the hydraulic dredge and taking steps to correct for the lower efficiency in the stock assessment, developed trust in the process and improved the relations between industry and management.

Gear Calibration

Similar to previous work, the RI DEM hydraulic dredge was found to not always sample all quahogs in the sampling area, with average efficiency across the samples found to be 0.64. Earlier work evaluating the efficiency of hydraulic dredge sampling in Narragansett Bay was found to be 0.57 (Ganz et al. 1999). Efficiencies were most correlated to the bottom type, with hard bottoms having a higher efficiency (0.76, 0.23 standard deviation) on average than soft sediments (0.50, 0.30 standard deviation). These efficiencies indicated a stronger discrepancy between hard and soft bottoms than previously reported by Ganz et al. (1999), but their work also identified shell and sand as a bottom type classification, where this research considered those as sediment types. While sediment type did not indicate there was a significant difference between mud and sand, this difference is likely manifested in the hard and soft bottom type analysis. Ganz et al. (1999) noted that the hard bottoms in Narragansett Bay usually represent packed sand, and soft bottoms are typically mud. While previous work has indicated that efficiency varies with local quahog density (Ganz et al. 1994), this study did not.

Efficiencies of legal quahog market classes indicated that the dredge samples these sizes equally well. While sublegal quahog catch efficiency was high based on the dredge and SCUBA transect inspections, these findings are elevated by the large number of instances where both the dredge and divers inspecting the transect found zero sublegals and efficiencies equated to one (Figure 2.) Possible hypotheses for low catch of sublegal abundances could be gear selectivity (either loss of sublegal abundances through the mesh or deeper than the dredge scar), or these small individuals were blown away from the sampling area due to the hydraulics of the dredge. The similar market class catch compositions by dredge and SCUBA and lack of sublegals found in the dredge scar during transect inspections indicate that the mesh gear selectivity hypothesis may not be true. While the quadrat and bullrake sampling caught more sublegals than the dredge, the fewer sublegals than older individuals from these techniques draws further questions as where legal quahogs settled in the area originate from. Smaller hard clams have been found to be more active (Chesnut 1952) and found deeper in sediments (RISG 2014) than larger clams, but it remains unclear if sublegal quahogs reside deeper than the dredge scar or quadrat excavating.

On averages alone, the quadrat and bullrake sampling appeared to catch more quahogs than the dredge survey. This finding may be in part due to the differing swept areas by each gear type. Quahog distribution has often been described as superdispered or contagious, following a negative binomial distribution (Saila and Gaucher 1996, Russell 1972.) The larger swept area of the dredge (~14 m^2) compared to that of the quadrats (3 m^2) may explain this discrepancy, with the dredge representing a more integrated sample of the local standing stock with a larger swept area. Bullrake swept areas were much more variable, as they were conducted until the rake felt full. This approach may lend itself to more efficient sampling and ensure that either a rake head or rear cage of a hydraulic dredge does not overfill before the end of a tow and cause clam spillage (Meyer et al. 1981). Continued comparative work with industry on assessing bullrake and dredge catch comparisons would improve these inferences, as the sample size for these comparisons is currently small (n=15). The benefits of using an industry fleet to sample with bullrakes include prospective improved efficiency, ability to sample shallower and deeper depths, and including industry in the scientific process of data collection for management. However, the current drawbacks include the gear variability that quahoggers use between sites and loss of standardization (e.g. changes in rake head width, rake tooth length, stale length, weights) and the ability to ensure accurate distance or area swept calculations. An alternative solution may be to change the blade of the hydraulic dredge by site to increase efficiency and not keep the blade standardized, which has been found to improve dredge efficiency for sampling other shellfish (Meyer et al. 1981).

The adjustments in time series hydraulic dredge survey data using this efficiency information have more appropriately quantified Northern quahog abundances in Narragansett Bay. Improving the abundance estimates also aids in addressing longstanding concerns from the commercial fishing industry that the state's hydraulic dredge survey does not accurately depict the local standing stock of legal sized quahogs. While abundance estimates have improved through this work, based upon the dredge efficiency model and predicted abundances, the overall trends in abundance remain the same, suggesting that the interannual composition of environmental factors used to infer dredge efficiency have largely been the same. Further, the dredge efficiency corrections will improve estimates in the Narragansett Bay quahog population size from stock assessment models, but likely will not affect our understanding of the population trajectories.

This work serves as an example of scientists, managers, and industry members collaboratively addressing fisheries questions and improving the fisheries science and management. The dredge efficiency estimates and pair-wise sampling conducted through this study provided insight into the efficiency of a longstanding hydraulic dredge survey, and what other gear types may be suitable for use in the future via supplementary fisheries-independent data or an industry-based index of abundance (e.g. catch per unit effort.) By incorporating commercial quahoggers into the sampling procedures and data collection, this research improved both their understanding of how survey data are used by scientists and the working relationship between industry and managers. The findings of this research have direct applications, as they can be used to correct dredge catchability issues prior to stock assessment modeling.

Quahog Research Fleet Transect Data

All of the trends and relationships identified during analysis of Quahog Research Fleet data and comparison to the RI DEM dredge survey data confirmed initial hypotheses and supported calibration results. The Quahog Research Fleet consistently sampled higher densities throughout Narragansett Bay then the dredge survey. This was in part due to the higher efficiency of the bullrake compared to the hydraulic dredge across various substrates as previously discussed. However, the Quahog Research Fleet consistently recording high densities in depths typically outside the depth range of the RI DEM dredge and outside the sampled strata (in coves). Further, the Quahog Research Fleet exhibited the ability to target areas with high quahog densities through their commercially-selected sites and adapt their fishing practices quickly to meet their typical catch efficiencies when targeting previously unfished, assigned, sampling locations.

The correlation between depth and quahog density has increased in strength throughout the duration of Quahog Research Fleet sampling. This suggests that further sampling may reinforce the positive correlation between depth and quahog density. The presence of a positive correlation between depth and density may explain the perception that the quahog industry has of being able to record significantly higher densities then the dredge, as the depth at which the correlation is detected is outside the depth range of the dredge. The trend towards higher quahog densities at deeper depths, however, may be related to fishing pressure. Specifically, the Quahog Research Fleet exhibited lower fishing pressure at the deepest depths. If this trend is persistent throughout the entire quahog fishing fleet, total quahog removals would be lower in deeper waters throughout Narragansett Bay, in essence allowing deeper quahogs beds to reach higher densities.

Although the Quahog Research Fleet data was not used as an index of abundance in the stock assessment (due to the limited time series), it still made tremendous impact on quahog management in Rhode Island. Through the analysis of catch rates and catch composition, the Quahog Research Fleet was able to directly contribute to components that either informed stock assessment parameters or developed novel management strategies. In addition, the Quahog Research Fleet provided quantitative validation of long-held beliefs by the quahog fishing industry, including high quahog densities outside areas traditionally surveyed. Ultimately, the utility of the shellfishermen-based supplemental survey to the RI DEM hydraulic dredge will continue to grow as the time-series expands.

Most importantly, the Quahog Research Fleet provided proof of concept that an industry-led Research Fleet of commercial shellfishermen can contribute to, and execute, a scientifically rigorous sampling program to monitor quahogs throughout Rhode Island waters.

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APPENDIX

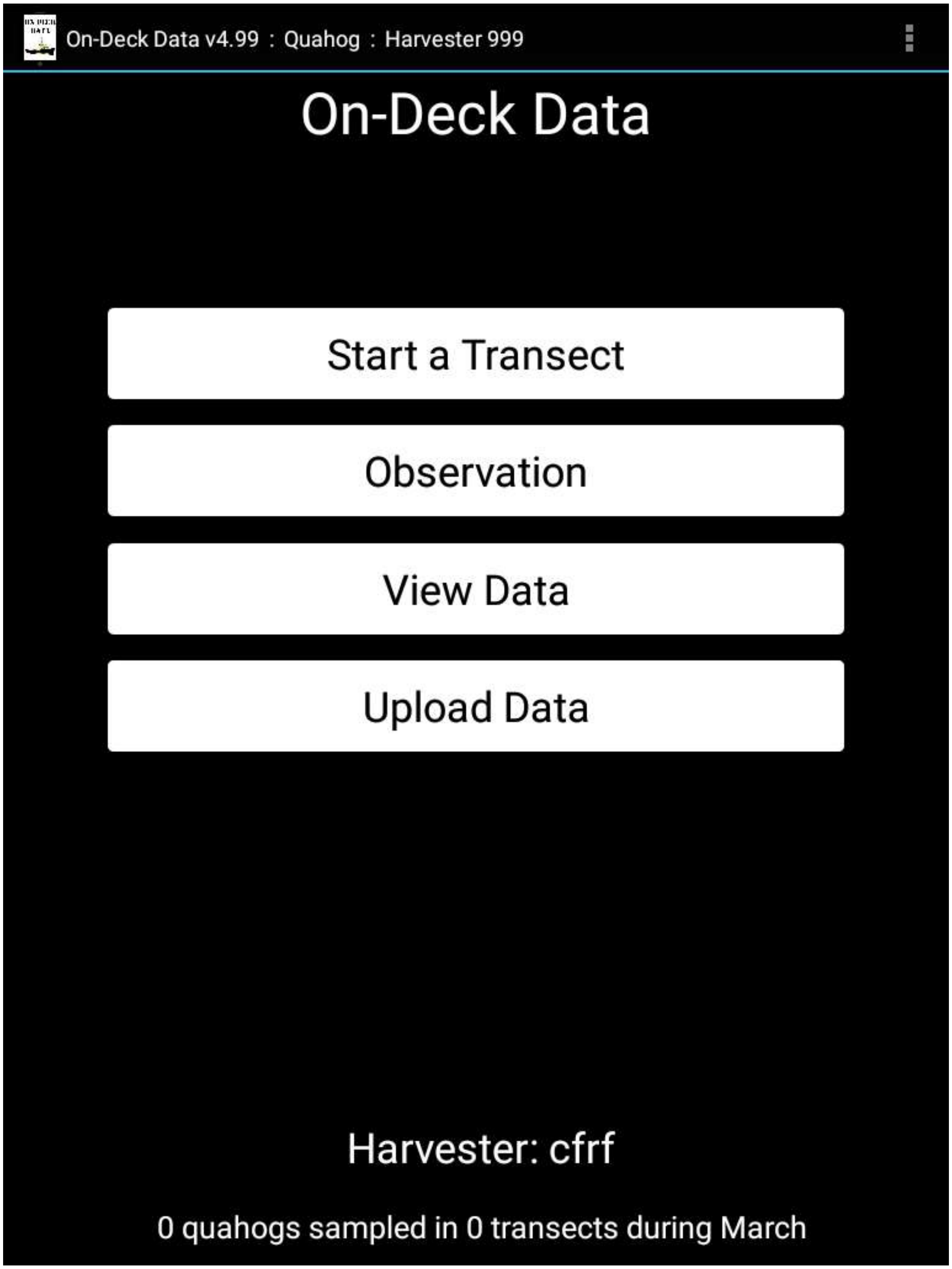


Figure 1. Home screen of On Deck Data. This screen is used to access all components of On Deck Data.

Figure 2. Drop down selection menu is opened by tapping on the icon in the top right of the home screen. This menu was only used by CFRF staff as it allowed access into configurations setting of On Deck Data which were password protected.

Figure 3. To record a transect a bullrake transect, users would select “Start a Transect” from On Deck Data home screen, if selected users were prompted to confirm the initiation of transect.

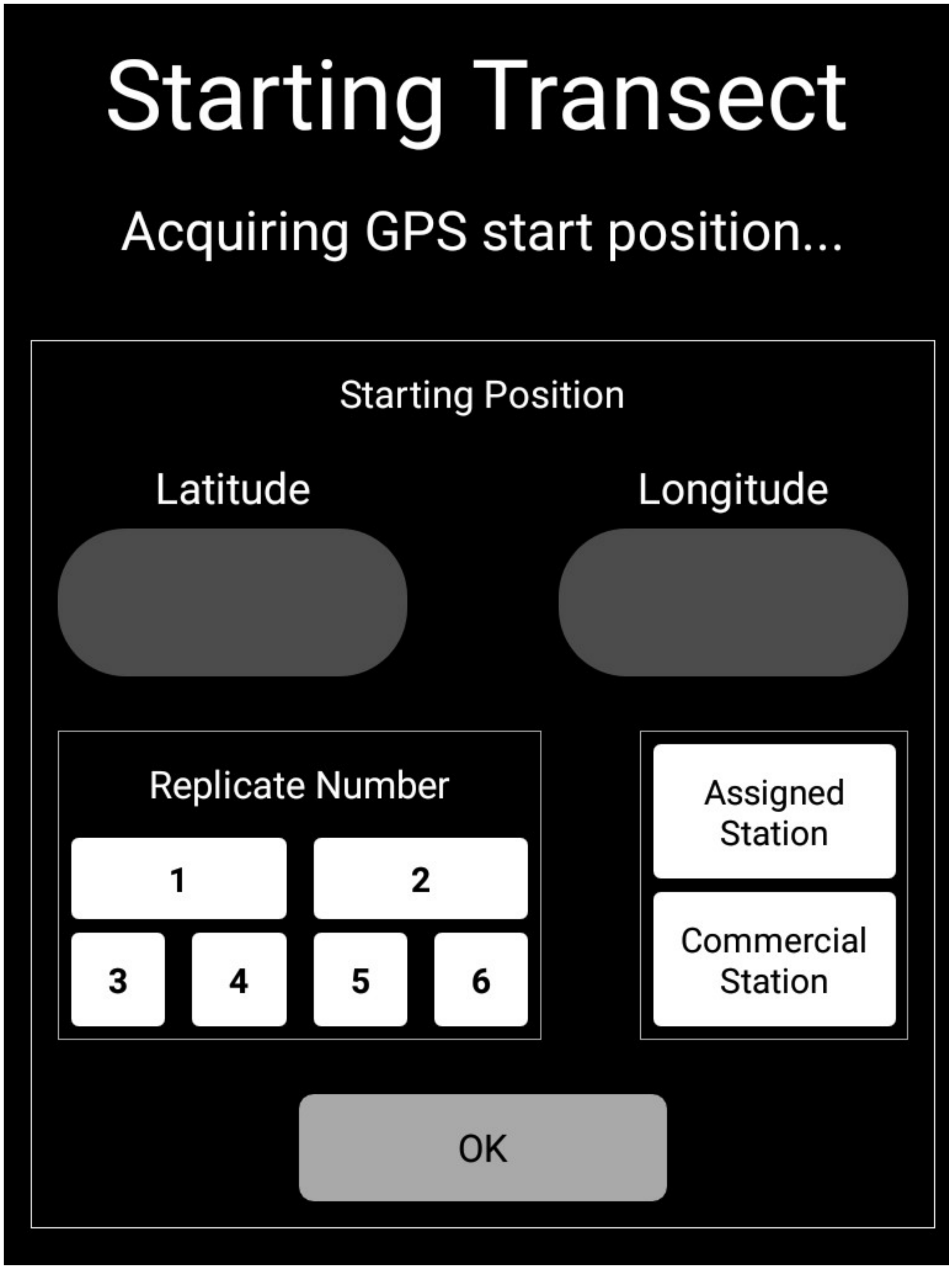


Figure 4. Once transect start confirmed, users were asked to manually input latitude and longitude coordinates from their vessel mounted GPS unit. Selecting the gray oval under each opens a keypad for number entry. Station type and replicate number are simply tapped for selection.

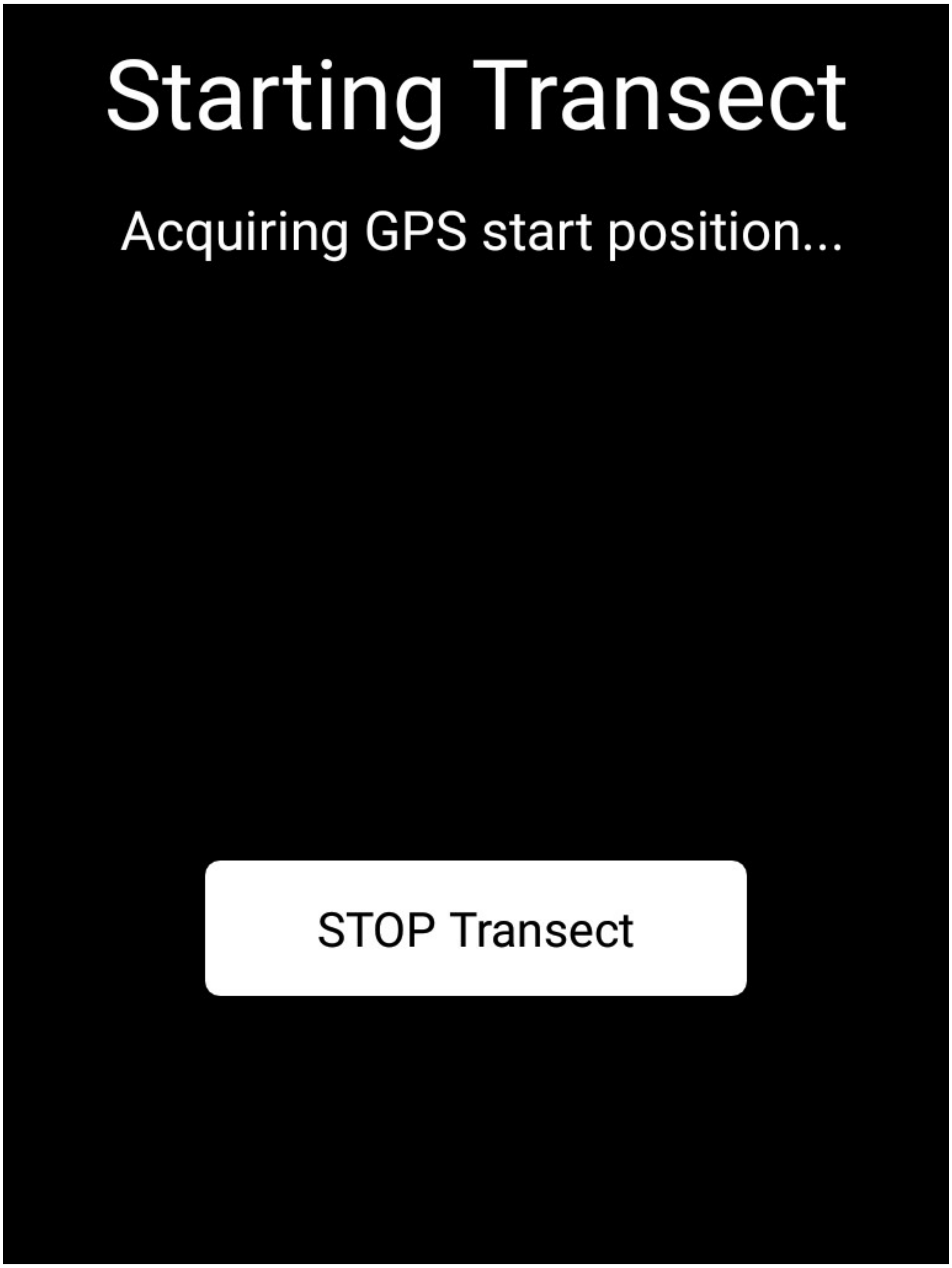


Figure 5. This screen is displayed to inform users a transect is currently underway. During this screen the internal GPS from the tablet automatically acquires a fix and records it in the background.

Figure 5. Once “stop transect” is selected from the previous screen, users are prompted to manually input latitude and longitude coordinates from the vessel mounted GPS in the same manner as starting transect coordinates were recorded. During this time the On Deck Data automatically fixes and records the latitude and longitude from the internal tablet GPS.

Figure 6. Users are prompted to take a photo of their catch still in the bullrake. Selecting “Take Photo” opens up the tablets camera.

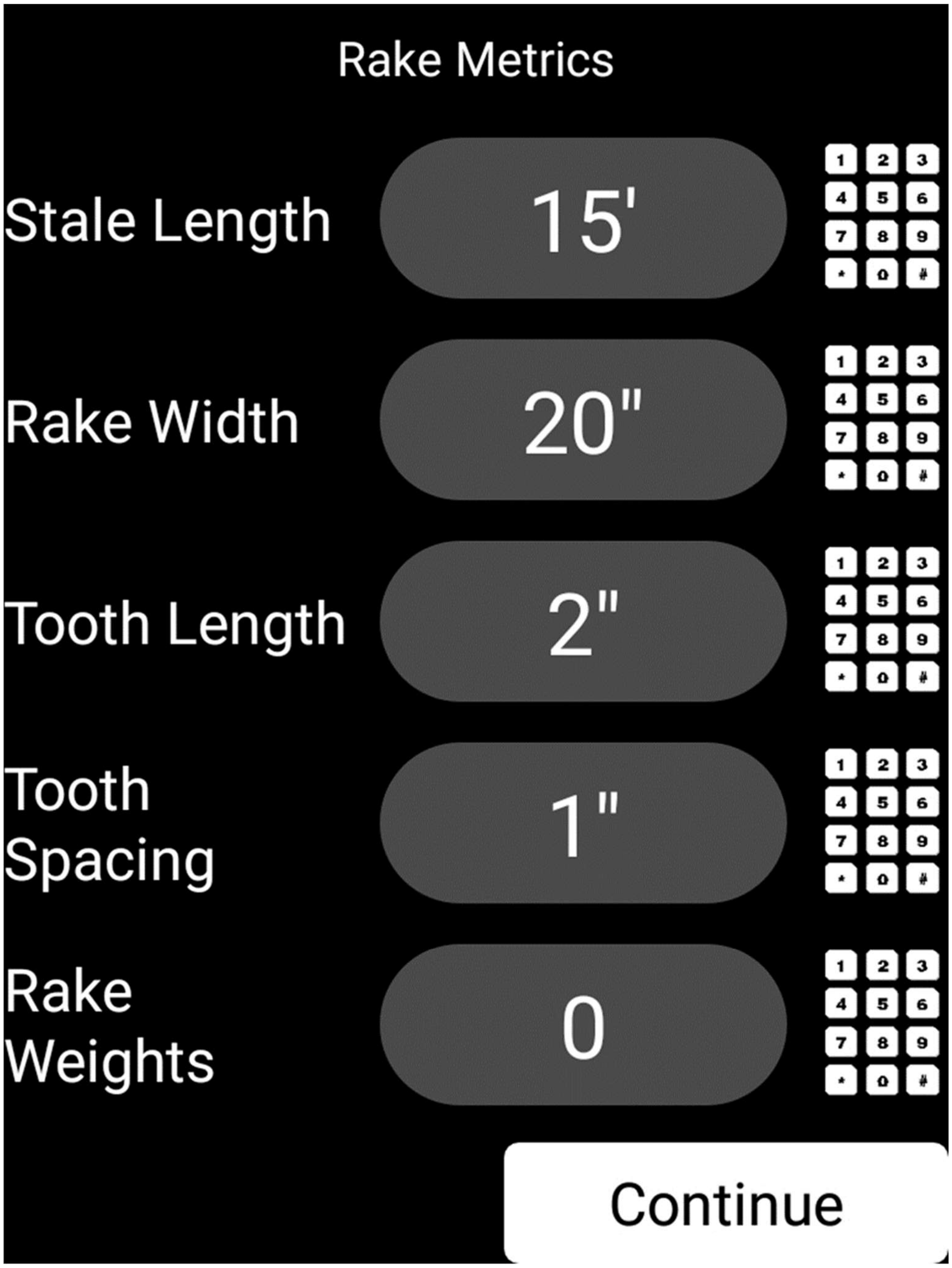


Figure 7. After a photo is save, users are prompted to record the rake metrics from the bullrake used to complete the transect. Stale length, rake width, and rake weights are recorded by tapping the field to access a keypad. Tooth length and tooth spacing are recorded by tapping each field and selecting from a list of prerecorded options provided by the Research Fleet before On Deck Data development. All metrics on this screen are saved between each sampling session and remembered for the next session.

Figure 8. Users are prompted to record environmental data from the transect site. Bottom type and shell hash are recorded by simply tapping the screen. Selecting depth and wind speed are recorded via a number pad which opens when each field is tapped. Wind direction is recorded by selecting an option from a compass which opens when field is tapped.

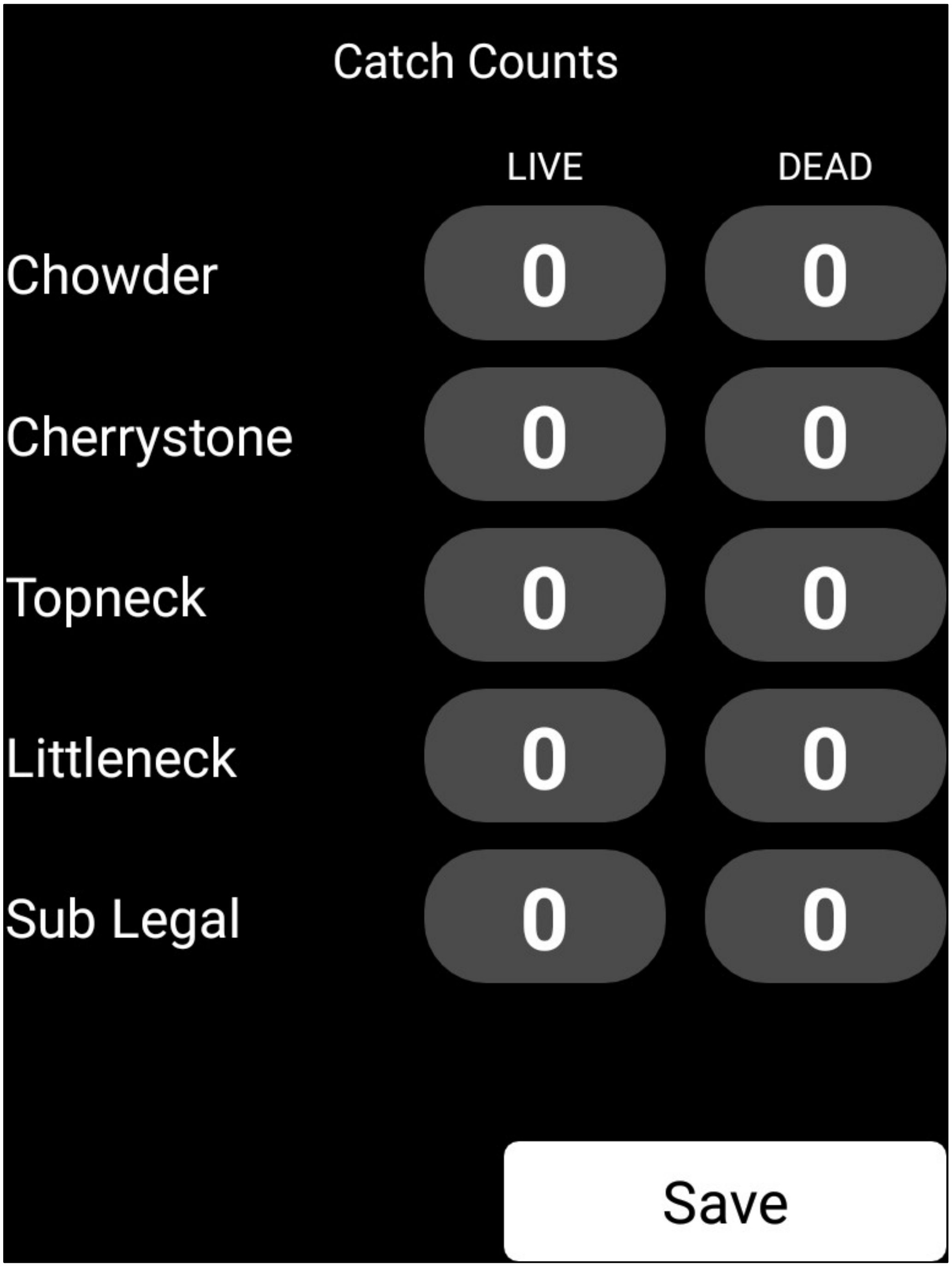


Figure 9. After pressing continue after recording the environmental data and all quahog catch has been sorted via the sorting racks, users are prompted to record the total number of both alive and dead quahogs from each market size class.

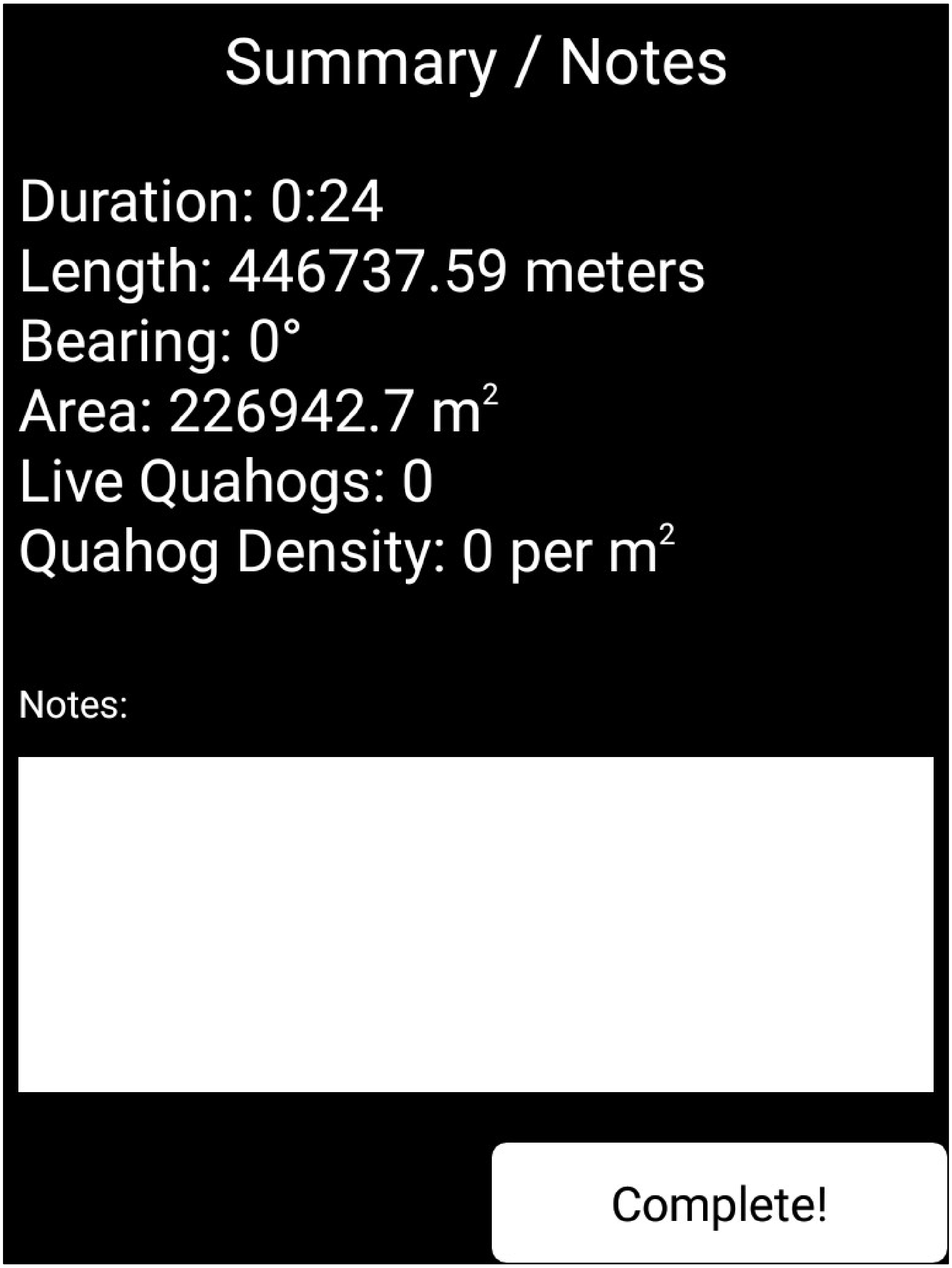


Figure 10. After saving the total quahog counts in the previous screen, users are prompted with a summary screen which details the above information from the past transect. Users are also able to record notes from the transect by tapping in the blank box to access and in-application keyboard. Once reviewed and any desires notes saved, tapping "Complete1" finishes the sampling session and returns users to the homescreen of On Deck Data.

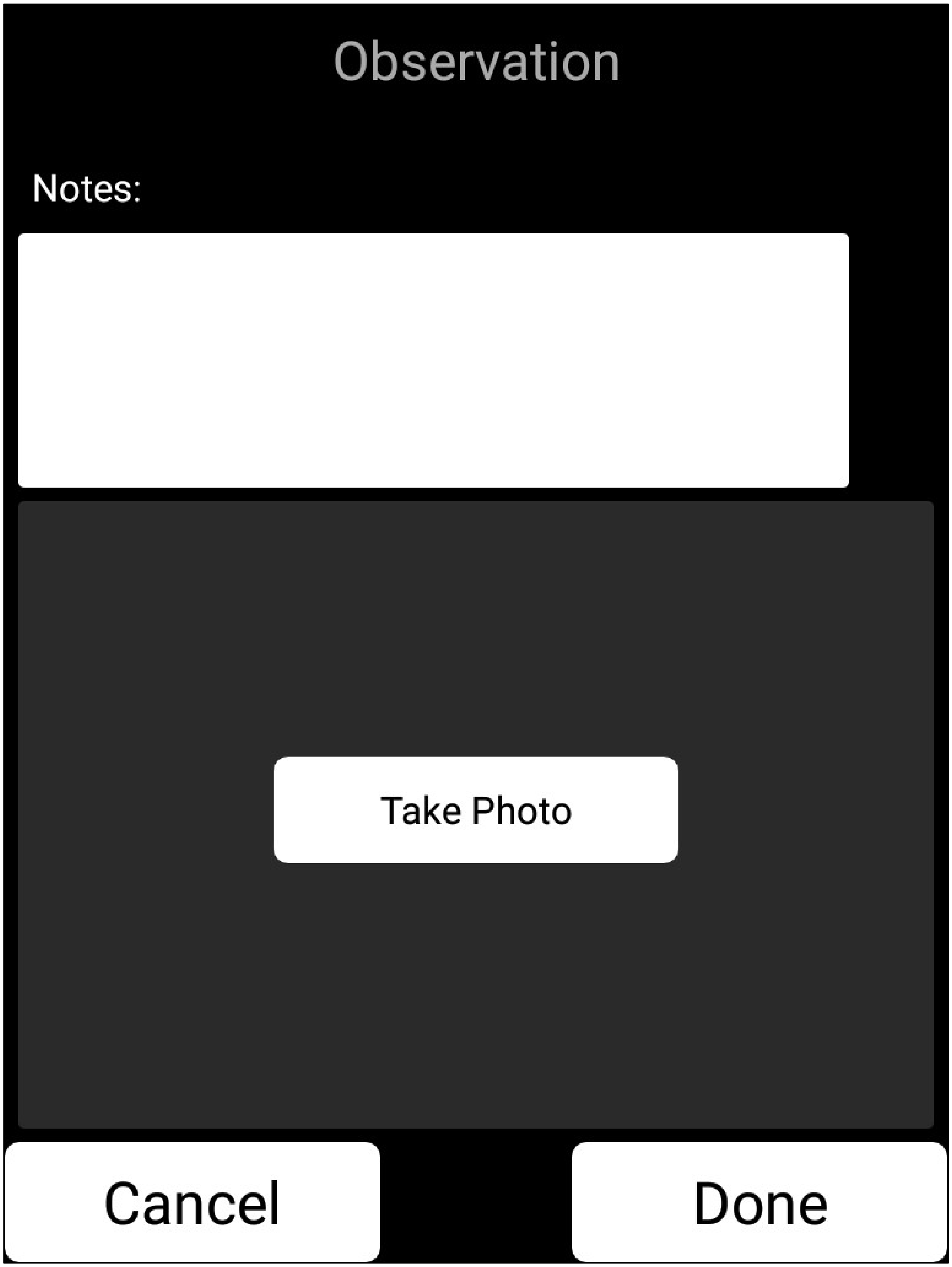


Figure 11. If desired, users may record an observation by selecting “Observation” from the home screen of On Deck Data found in Figure 1. of this appendix. If selected users may access the in-application keyboard by selecting the notes box as well as access the table camera by selecting “Take Photo”. Pressing “Done” saves any information entered on this screen and returns users to the On Deck Data home screen while selecting “Cancel” immediately returns users to the home screen.

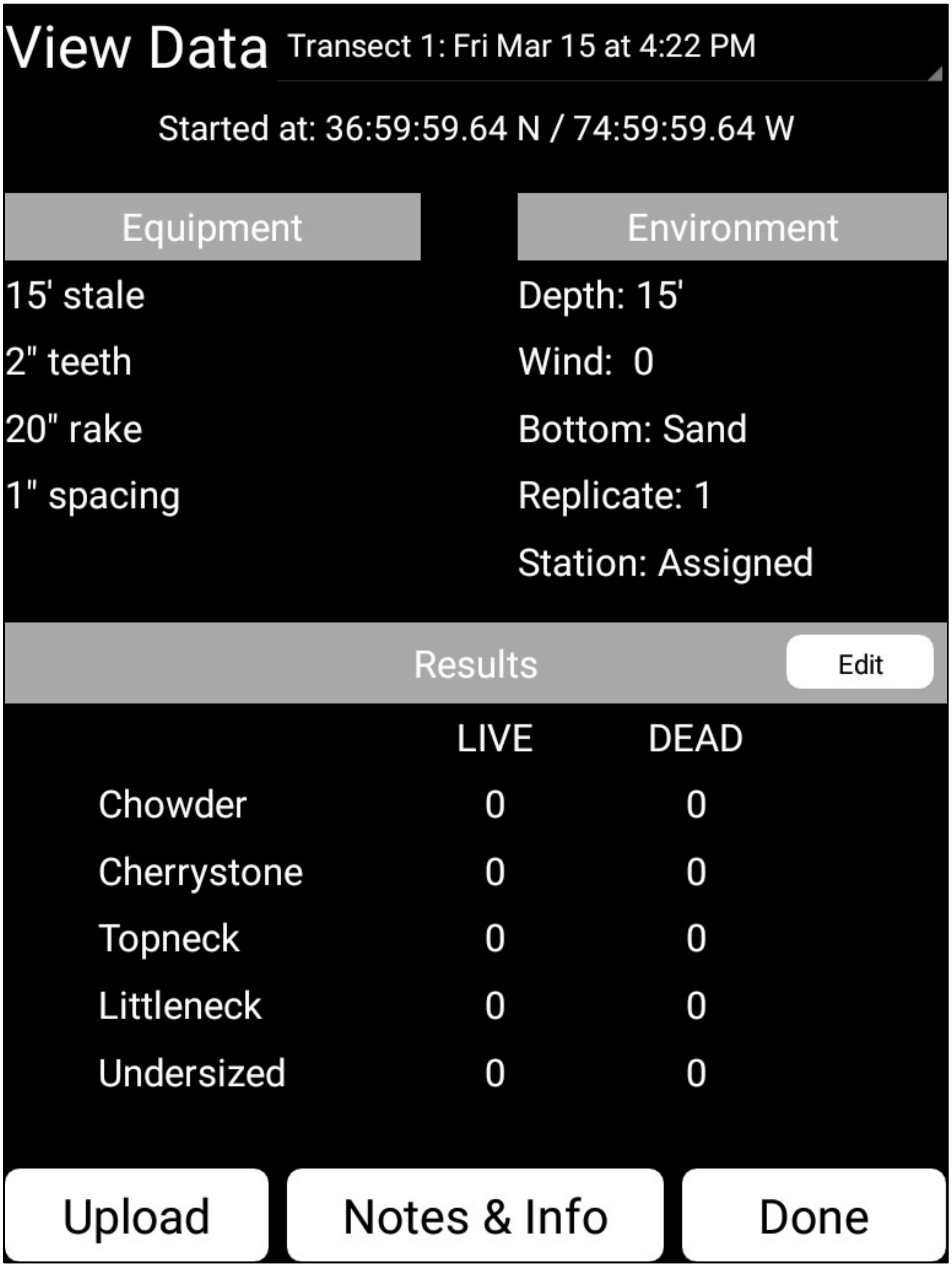


Figure 12. If “View Data” is selected from the On Deck Data home screen, users are prompted with the above information from their oldest completed transect currently stored on the tablet. Users may edit the total quahog counts by selecting “Edit” next to the Results tab and inputting number via a keypad as previously mentioned.

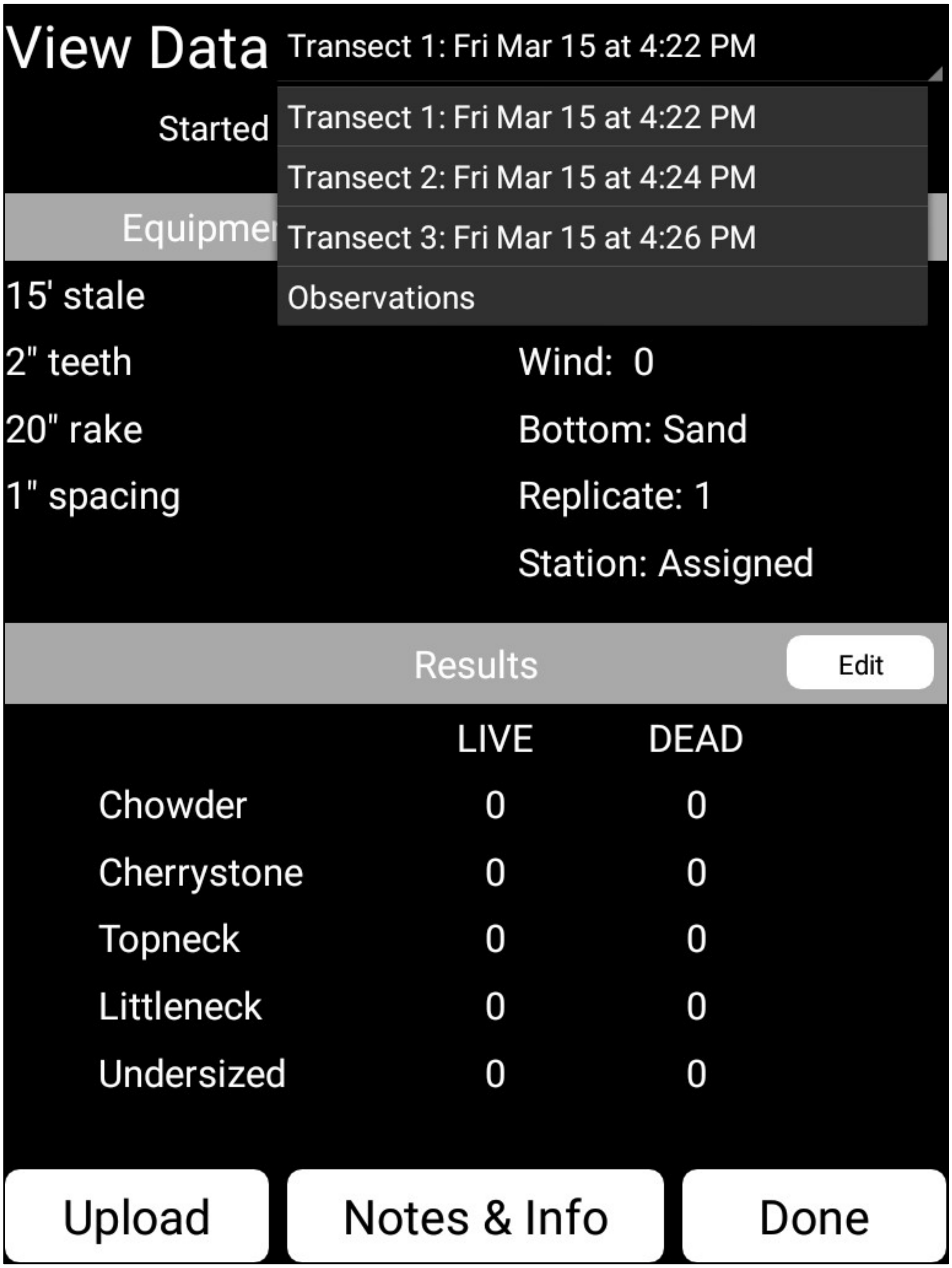


Figure 13. To access other transects, users tap on the transect date displayed in the top right of the screen and select which transect they would like to view from a drop down list.

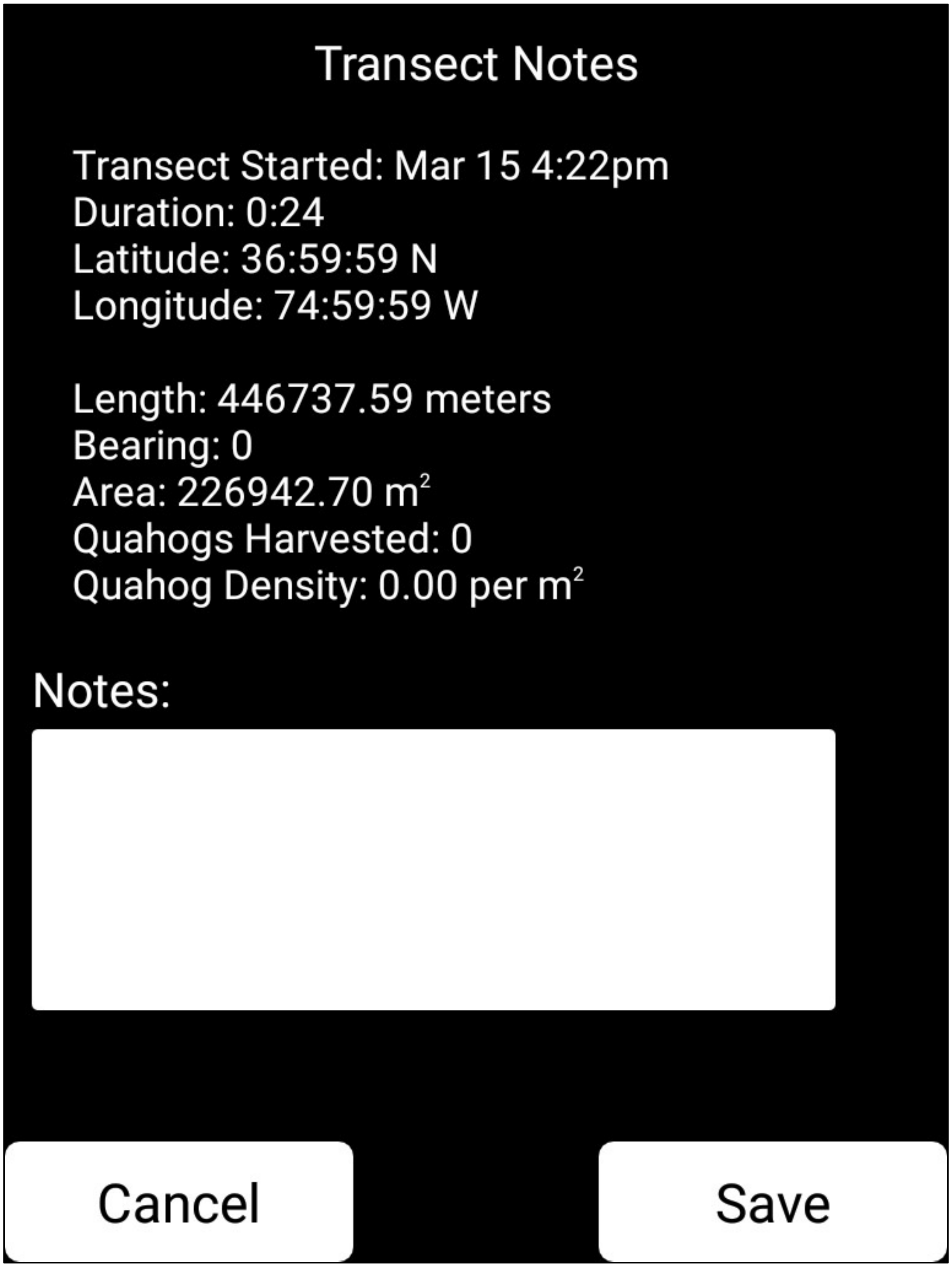


Figure 14. If desired, users may also add additional notes (or edit previously recorded notes) for a transect by selecting “Notes & Info” from the bottom center of the “View Data” screen. This allows users to access transect summary data and any notes previously saved with the transect.

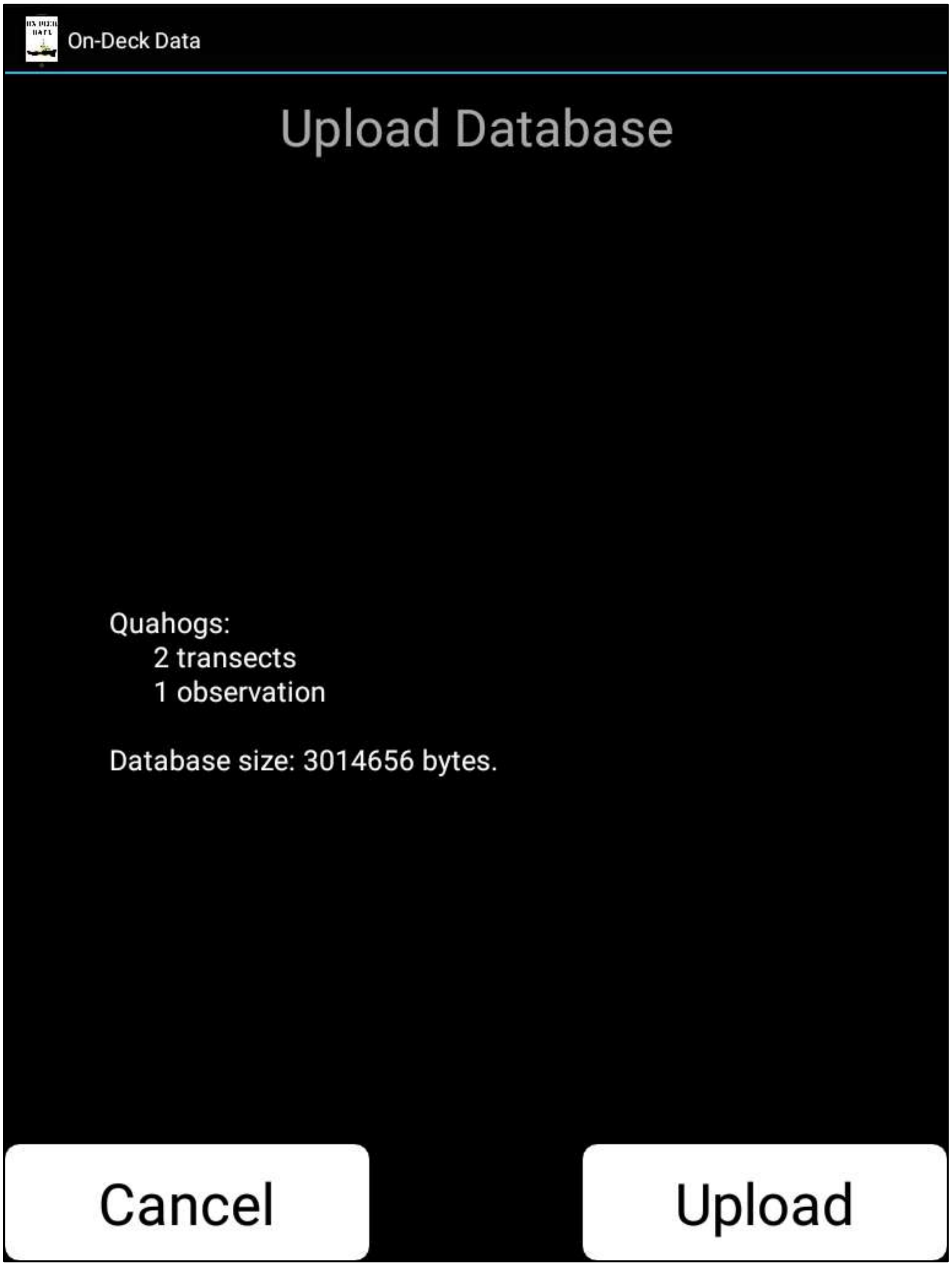


Figure 15. Once connected to WiFi, users may upload any data stored on the tablet by selecting “Upload Data” from the On Deck Data home screen. If selected, users are prompted with the above summary of any data stored on the tablet and the database upload size.

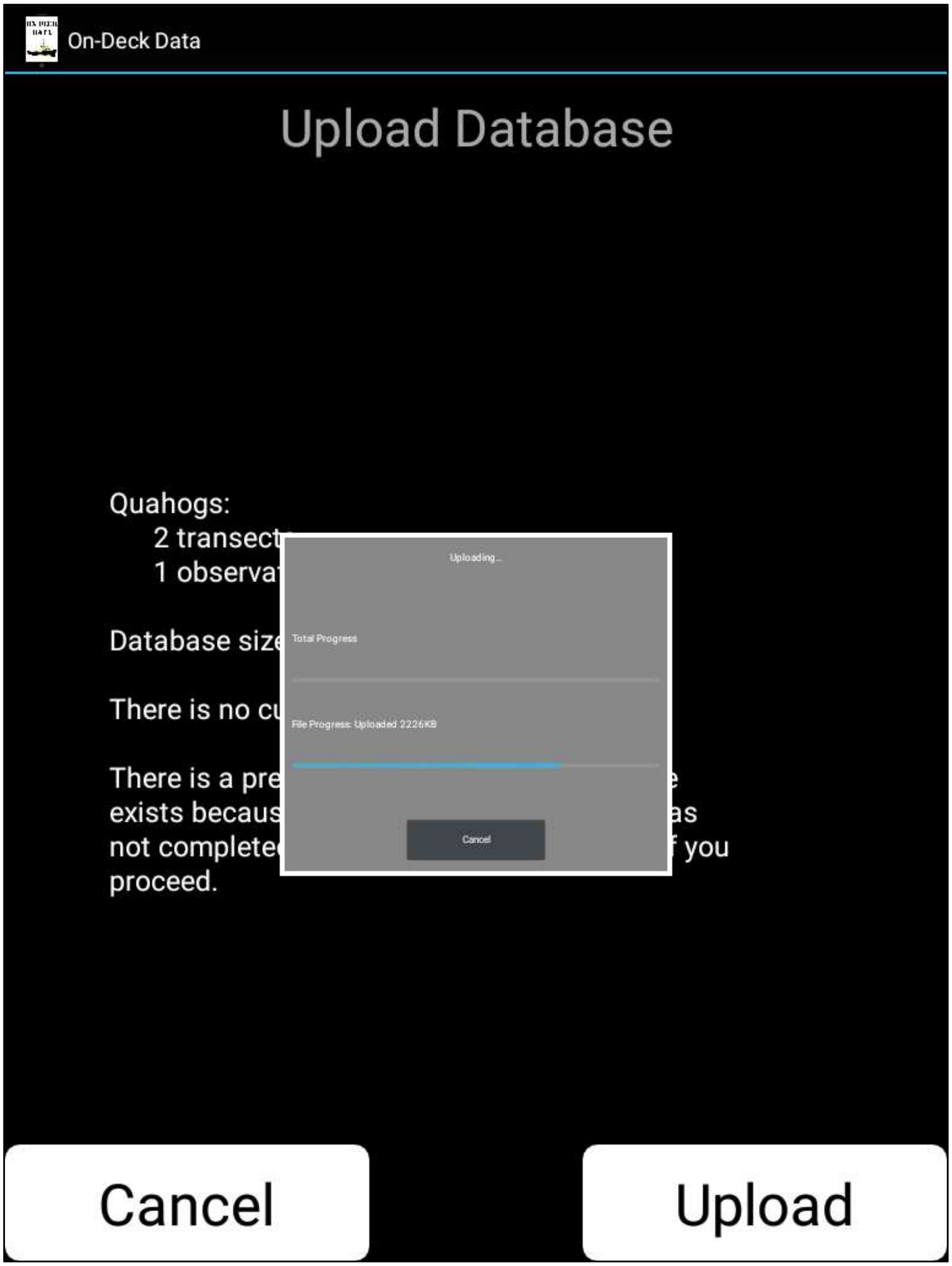


Figure 16. Users review the upload data summary and then select "Upload" to initiate the upload process. Once begun, users are prompted with this window showing the status of the upload.

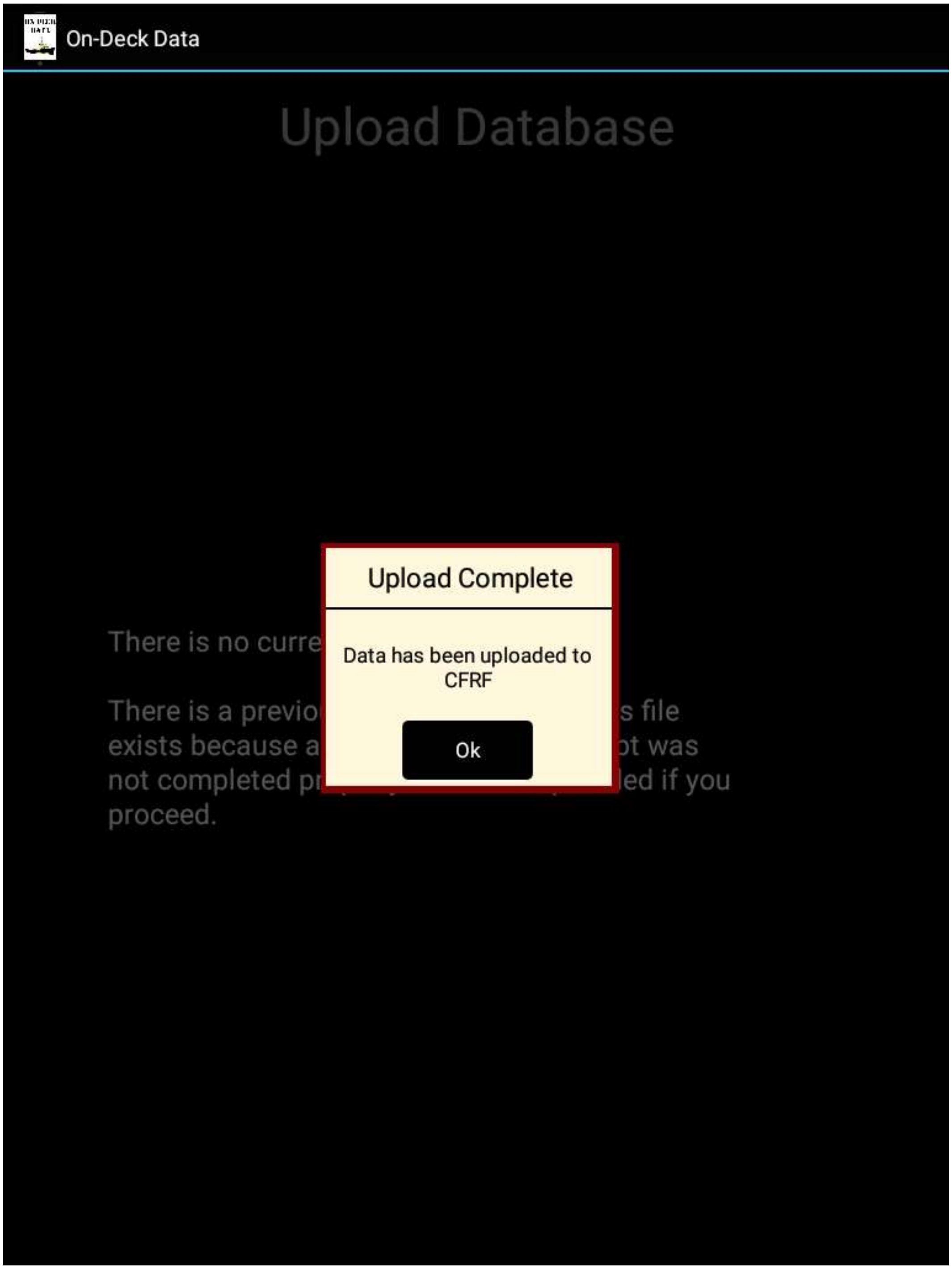


Figure 17. Once the upload is completed, users are prompted to confirm upload is complete by selecting "Ok".

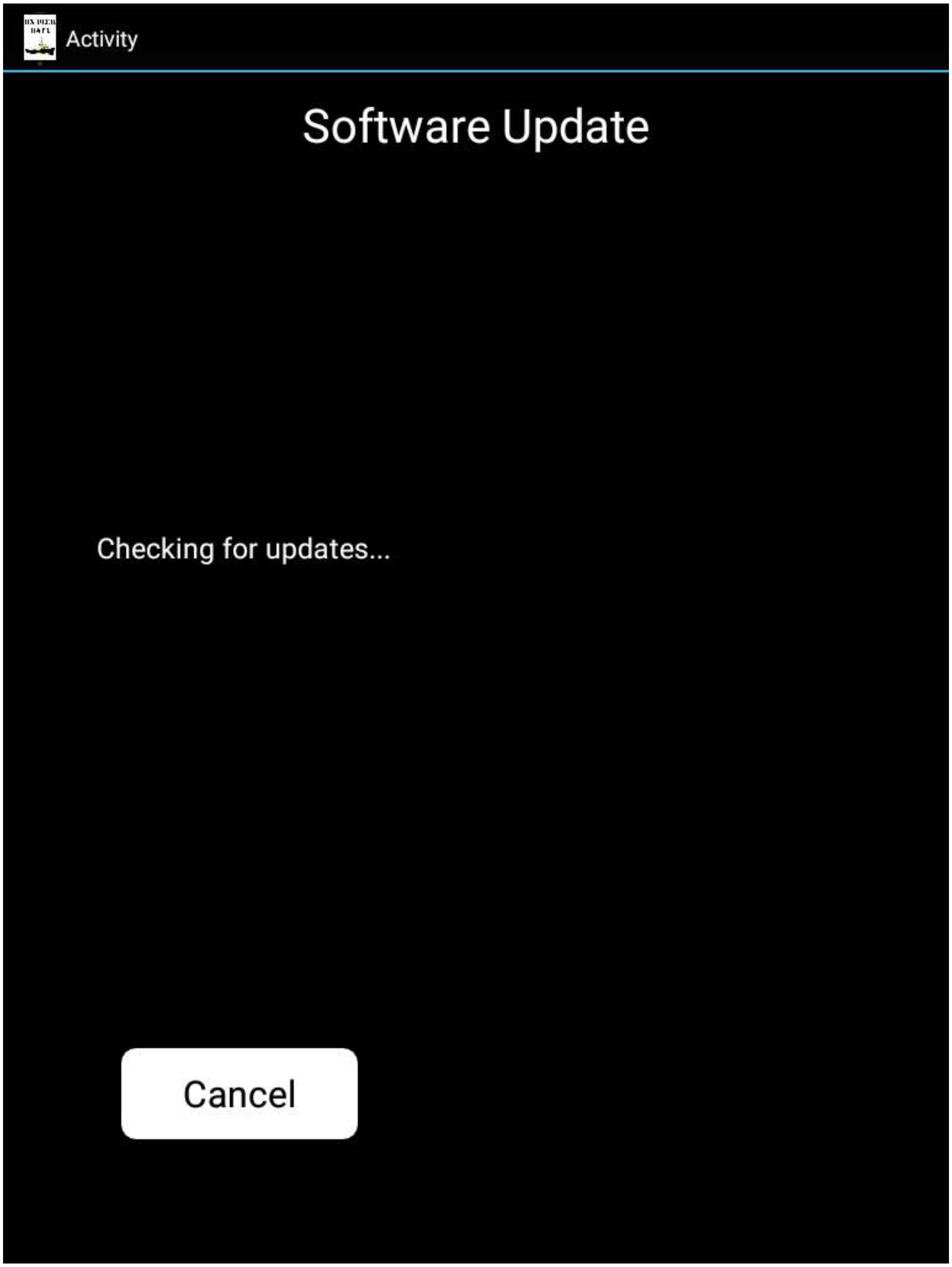


Figure 18. Once upload confirmation is complete, On Deck Data automatically searches the server which data was uploaded to for any applicable application updates.

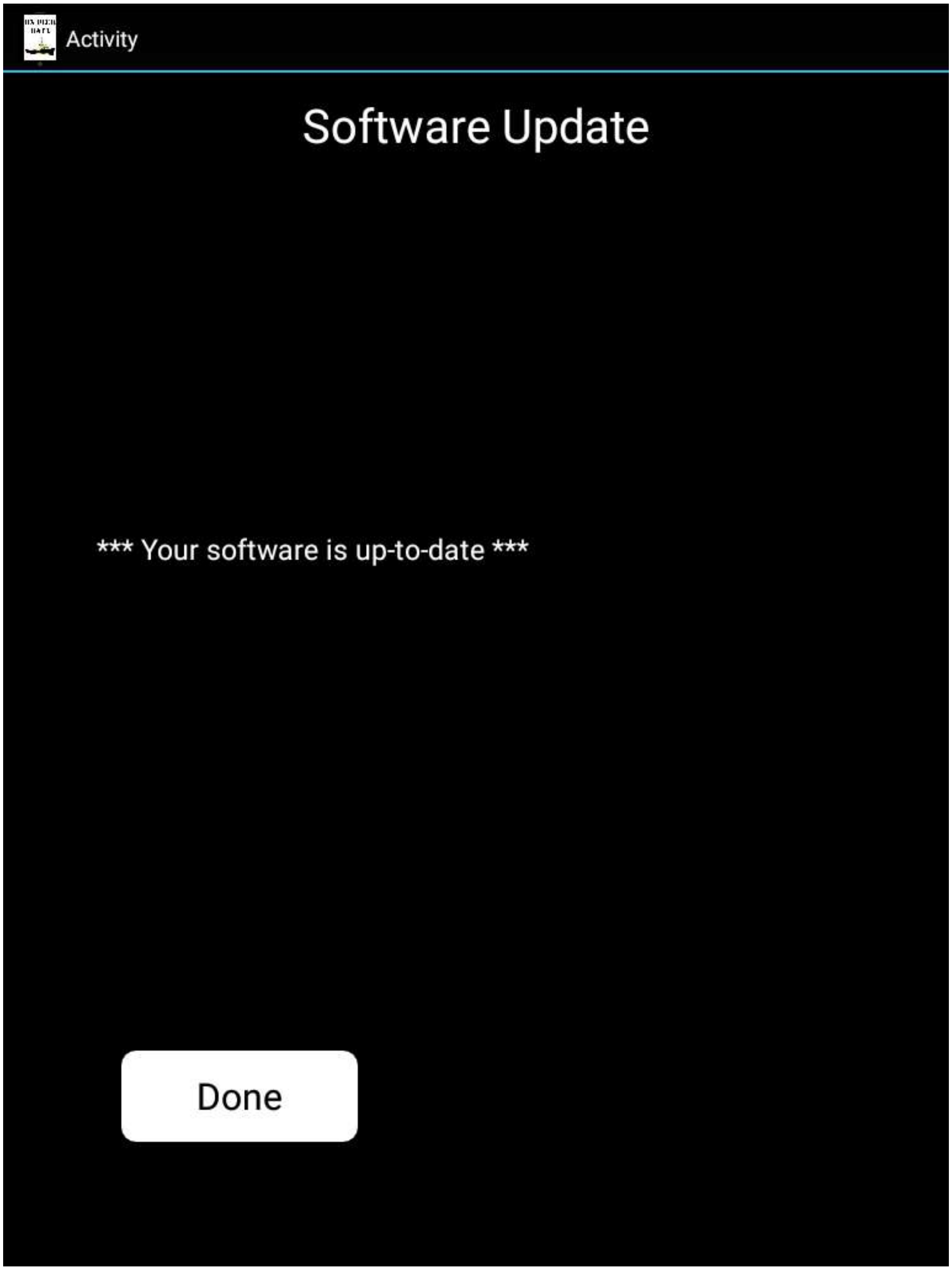


Figure 19. If no updates are found, the user is notified their software is up to date and selecting “Done” returns users to the On Deck Data home screen. If an update is found, it is automatically downloaded and installed.

Quahog Research Fleet Completion Survey

Project: Development of a Fishermen-Based Research Fleet to Contribute to the Management of Quahog (*Mercenaria mercenaria)* Resources in Rhode Island Waters

1) *Did the equipment and research protocols work well throughout the course of this project (If "No", please explain)?*
    - Yes, very well (17%)
    - Somewhat (50%)
    - No (33%)
    - Comments:
      "Tablet was a problem – freeze ups a couple of times lost transects all together", "The first model of tablet had a few issues, other then that everything worked very well", "The tablet froze up in the middle of transects occasionally, punching in lat/lon was worse part", "As talked about before, tablets froze up", "I heard some of Fleet had issues with tablet and entering lat/lon took a lot of time"

2) *Overall do you feel that the CFRF Quahog Research Fleet project has been worthwhile (If "No", please explain)?*
    - Yes, very much (100%)
    - Somewhat
    - No
    - Comments:
      "We got a lot of data, hopefully it is helpful into the future", "Hopefully will continue through state funding"

3) *Do you feel that the Quahog Research Fleet has been successful (If "No", please explain)?*
    - Yes, very much (83%)
    - Somewhat (17%)
    - No
    - Comments:
      "I think there should have been changes in assigned transect locations more frequently",

4) *How was working with CFRF staff?*
    - Excellent (100%)
    - Very good
    - Good
    - Poor
    - Comments:
      "Everyone was great to work with and helpful when things went wrong. CFRF was able to fix just about everything with just a phone call", "Nothing but positive things to say about staff interactions"

5) *How was working with RI DEM staff?*
    - Excellent (67%)
    - Very good (17%)
    - Good (17%)
    - Poor
    - Comments:
    "Overall I should score this higher but had issues coordinating with the dredge boat, Conor was excellent to with however and always available", "I did not have much contact with them directly", "Was great other then not being able to sample more areas in the Providence River"

6) *How was working with Roger Williams University staff?*
    - Excellent (100%)
    - Very good
    - Good
    - Poor
    - Comments:
    "Was amazed to see the amount of people who were involved to work together, it was fun and eye opening to be a part of",

7) *Do you feel that the data collected throughout this project helped improve the quahog database that are used for stock assessments and management plans (If "No", please explain)?*
    - Yes, very much (83%)
    - Somewhat (17%)
    - No
    - Comments:

    "More data has to be better. Fishermen input is important!", "Yes, very much, we have been trying to get RI DEM to listen for years", "As said before, the areas assigned were not historically productive areas so it would represent fishable areas better if our assigned stations changed"

8) *Do you feel that the quahog and calibration data collected by the Research Fleet has increased your trust in the quahog assessment and management?*
    - Yes, very much (50%)
    - Yes, somewhat (50%)
    - No
    - N/A
    - Comments:

    "Yes, it should what I had suspected. The dredge efficiency was much more variable then previously thought", "Will have to see how the state will ultimately implement what we helped provide",

9) *Do you feel that your time spent with the Research Fleet improved your relationship with management?*
   - Yes, very much (60%)
   - Yes, somewhat (40)
   - No improvement
   - Worsened

   "Yes somewhat, however my relationship with RI DEM was already good to begin with", "I have always had a great relationship with RI DEM"

10) *Do you feel that this project has served as a good example of how fishermen can contribute data that improves fisheries science and management (If "No", please explain)?*
    - Yes, very much (100%)
    - Somewhat
    - No
    - Comments:

    "I think it is important to have fishermen involved, we're out there every day seeing and doing things people who aren't out there don't get to see. We also have the most to lose if bad decisions are made", "This program gave fishermen ownership over the data and it was for a species that fishermen previously had no input in data collection"

11) *What was your favorite part of the project?*

"Really didn't have a favorite part, thought the whole project was great", "The variety of areas being tested", "Working with the CFRF on the first day out on the water with the tablet and helping start this whole project, going up north into the Providence River with Anna sampling and seeing how good it is up there", "The state being willing to let us show them how much stock we see out there in the Bay"

12) *General comments/reflections (optional)*

"The tablet program tended to be more complicated than a single fisherman to deal with", "Thought the CFRF staff was very professional, enjoyed the whole project. The work was a very long time coming and overall appreciate the work we have done", "Great to see everyone working together", "I'm ready for the next phase", "I wish the state would account for the undersized quahogs during assessment and management, the Research Fleet began to show how many undersized quahogs are out there which is the future of the industry", "Listening to all the guys trying to use their tablets with wet hands"

CFRF Quahog Research Fleet – Sampling Protocol

General Description:

- The CFRF, in partnership with RWU and RI DEM, developed the Quahog Research Fleet to engage shellfishermen in the collection of biological and environmental data from Narragansett Bay throughout the year. The data collected by the Research Fleet will be used to compare quahog densities to other collection techniques and provide additional information for the quahog stock assessment. The project is focused on collecting fishery dependent data using electronic recording and transmission techniques and maintaining communication among all participants.
- Data is collected at sea, stored in Android tablets, and relayed to a database (at CFRF) via wireless internet once a shellfishermen returns to shore and has access to the internet.

Bullrake Sampling Minimums:

- The goal for each participant shellfishermen is to sample quahogs via bullrake at eight stations per month throughout the year.
- At each station, participant shellfishermen will conduct two independent bullrake pulls.
- After each bullrake pull, participant shellfishermen will use the On Deck Data app to record the stale length, rake width, tooth length, spacing between teeth, depth, habitat type, presence or absence of shell hash, wind direction, and wind speed.
- Immediately after each bullrake pull, participant shellfishermen will use the On Deck Data app to take a photo of their catch and record the number of live and dead quahogs in each market class that were caught. A sorting rack will be provided to each participant shellfishermen to help sort the quahogs into market classes.
- Shellfishermen must sample 8 sampling stations a month to receive the $200 per month stipend.
    - The monthly stipend will be pro-rated if shellfishermen complete a portion of the required sampling.

Bullrake Sampling Locations:

- Four sampling stations will be selected by CFRF, RWU, and RI DEM to maximize spatial coverage of the bay and fill in areas not sampled by the RI DEM hydraulic dredge survey.
- Four sampling stations will be selected by participating shellfishermen at locations within their typical fishing grounds.

Bullrake Sampling Strategy:

- All information will be recorded in the pre-programmed tablet application, On Deck Data.
- The location will be recorded before each bullrake pull.
    - *Note: Location will be automatically recorded at the beginning and end of each bullrake pull via internal tablet GPS.*

- The depth, habitat type, rake configuration, wind direction, and wind speed will be recorded after each bullrake pull.
- After completing each bullrake pull, participant shellfishermen will use the On Deck Data app to take a photo of their catch. A sorting rack will then be used to separate quahog catch into market classes. Participant shellfishermen will then record the number of live and dead quahogs in each market class (chowder, cherrystone, top neck, little neck, sub legal) in On Deck Data.
- When sampling is complete, the On Deck Data app will provide participant shellfishermen with a summary of their catch, including the total number and density of quahogs.
- Upon returning to the dock, data will be uploaded via WIFI to a central database at CFRF.

Quahog Sampling Session Data Parameters:

- Rake Metrics
  - Stale Length (Feet)
  - Rake Width (Inches)
  - Tooth Length (Inches)
  - Spacing Between Teeth (Inches)
- Date/Time (automatically recorded)
- Location (automatically recorded)
- Depth (Decimal Feet)
- Habitat (Sand, Mud, Sandy Mud, Sticky Mud)
- Wind Direction (Cardinal Direction)
- Wind Speed (Knots)
- Shell Hash (Yes/No)
- Rake weights (Pounds)

Quahog Biological Data Parameters:

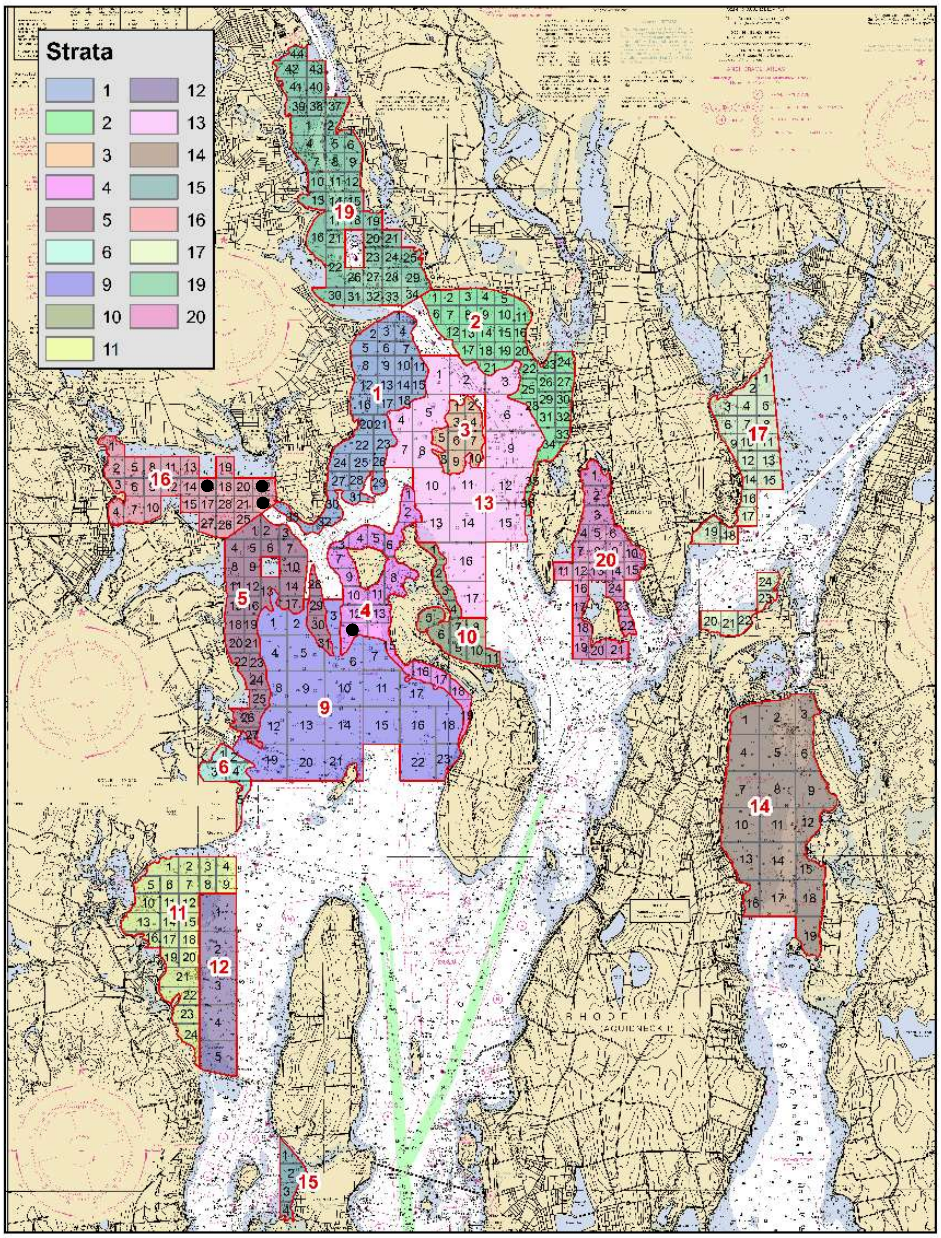
- Chowder (# Alive/ Dead)
- Cherrystone (# Alive/ Dead)
- Top Neck (# Alive/ Dead)
- Littleneck (# Alive/ Dead)
- Sublegal (# Alive/ Dead)
- Notes

CFRF Quahog Research Fleet – Selected Sampling Stations

Harvester: Bo Christensen

Time Period: August 2016 – August 2017

RI DEM Strata-Grid Cell	Latitude	Longitude
4-14	41.640	-71.367
16-16	41.675	-71.413
16-22	41.675	-71.395
16-23	41.672	-71.396

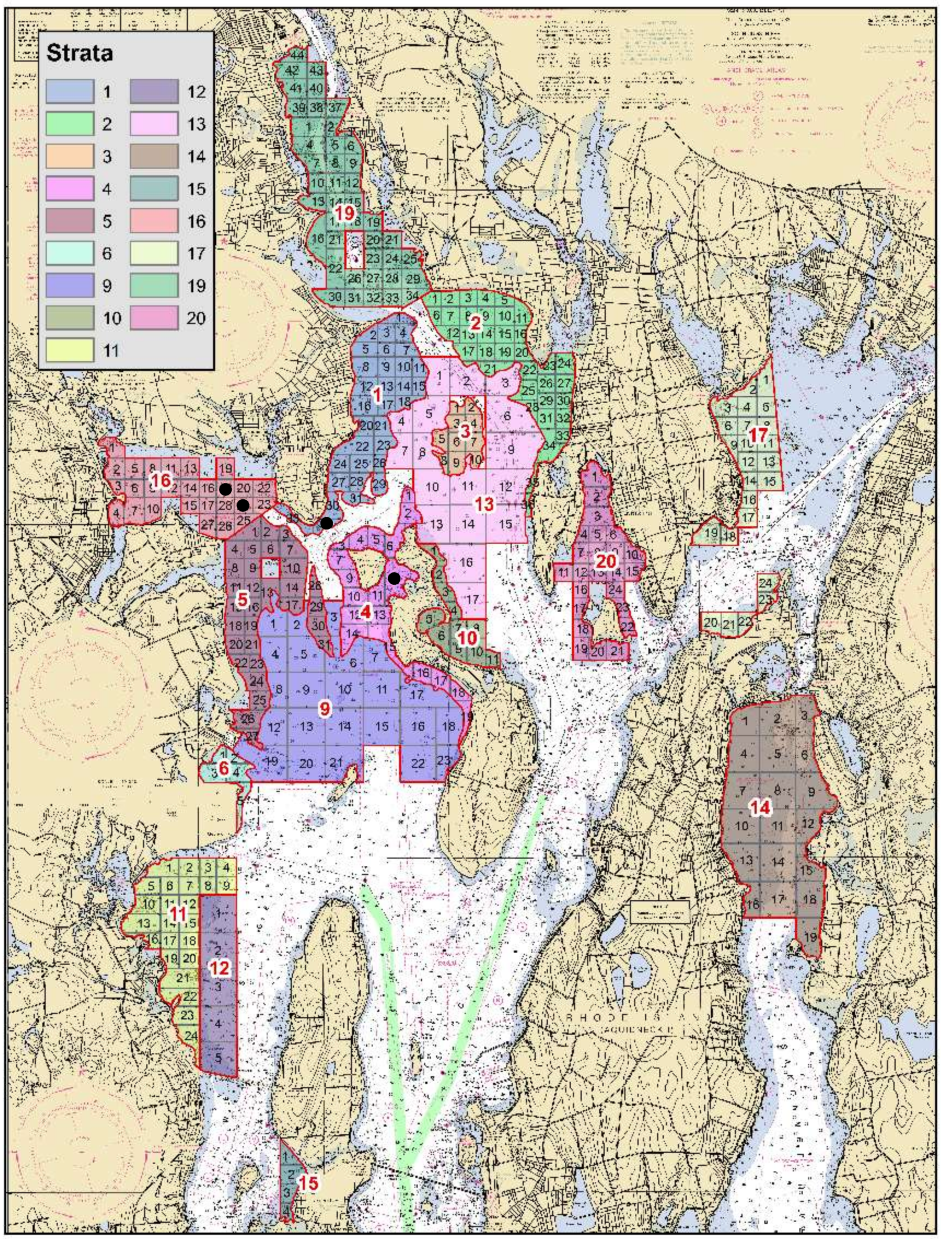


CFRF Quahog Research Fleet – Selected Sampling Stations

Harvester: Dave Ghigliotty

Time Period: August 2016 – August 2017

RI DEM Strata-Grid Cell	Latitude	Longitude
1-32	41.667	-71.375
4-8	41.654	-71.352
16-18	41.676	-71.408
16-21	41.671	-71.401

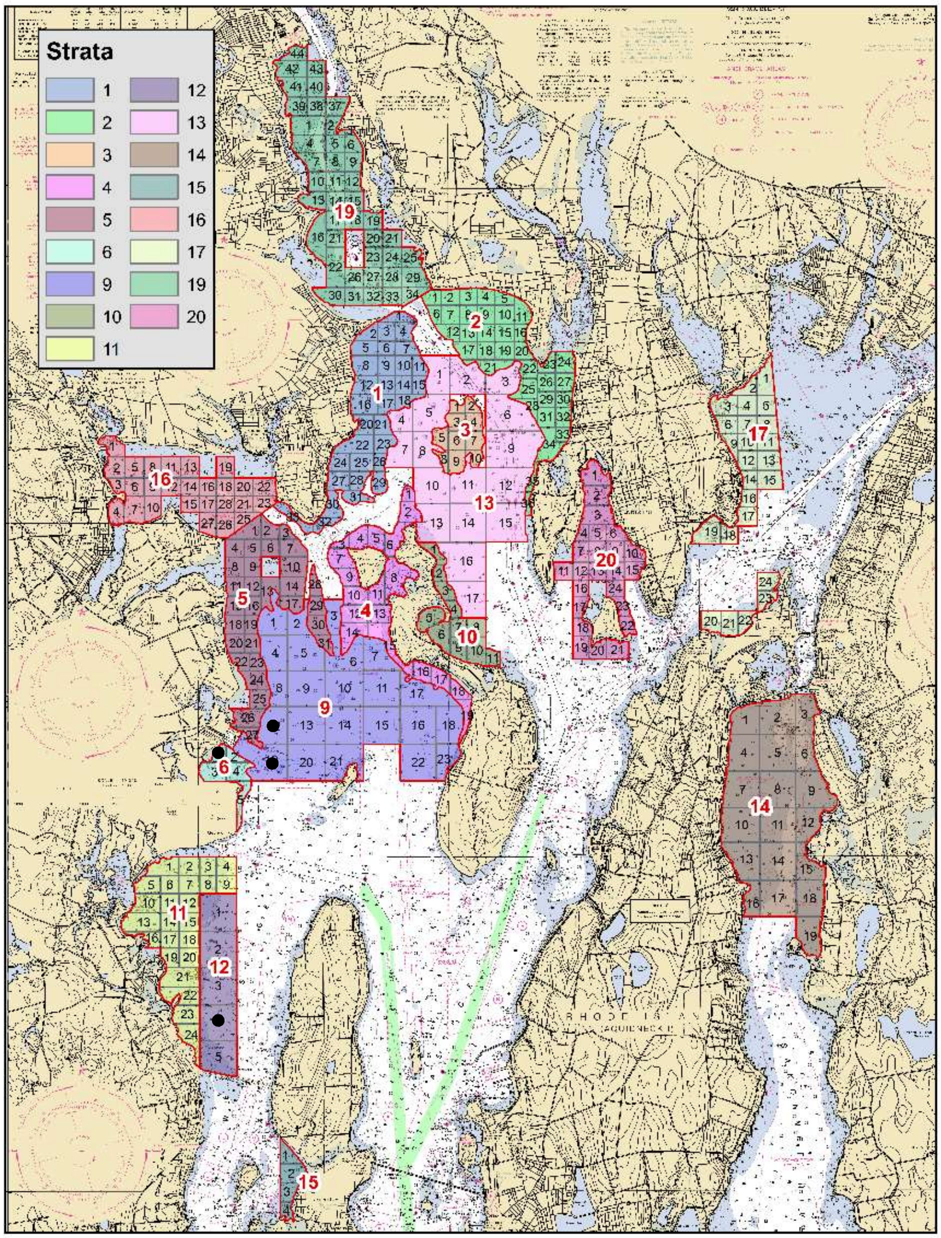


CFRF Quahog Research Fleet – Selected Sampling Stations

Harvester: Ernest Wilcox

Time Period: August 2016 – August 2017

RI DEM Strata-Grid Cell	Latitude	Longitude
6-1	41.61040	-71.40703
5-27	41.61400	-71.39800
6-2	41.60700	-71.40272
12-4	41.53800	-71.41500

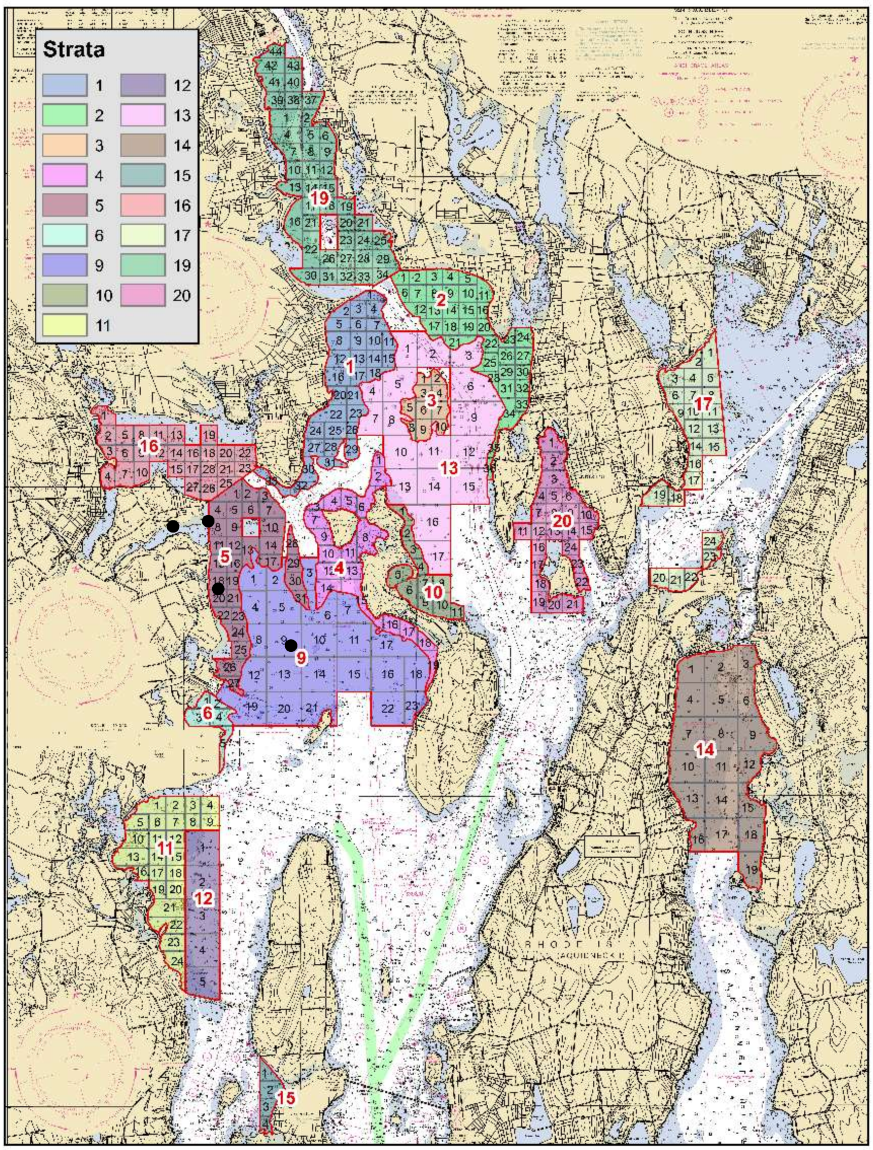


CFRF Quahog Research Fleet – Selected Sampling Stations

Harvester: Gerry Schey

Time Period: August 2016 – August 2017

RI DEM Strata-Grid Cell	Latitude	Longitude
5-12	41.651	-71.399
5-31	41.637	-71.375
16-25	41.668	-71.401
16-27 (x)- not fishable	41.667	-71.413
16-28 (new site)	41.670866	-71.407711

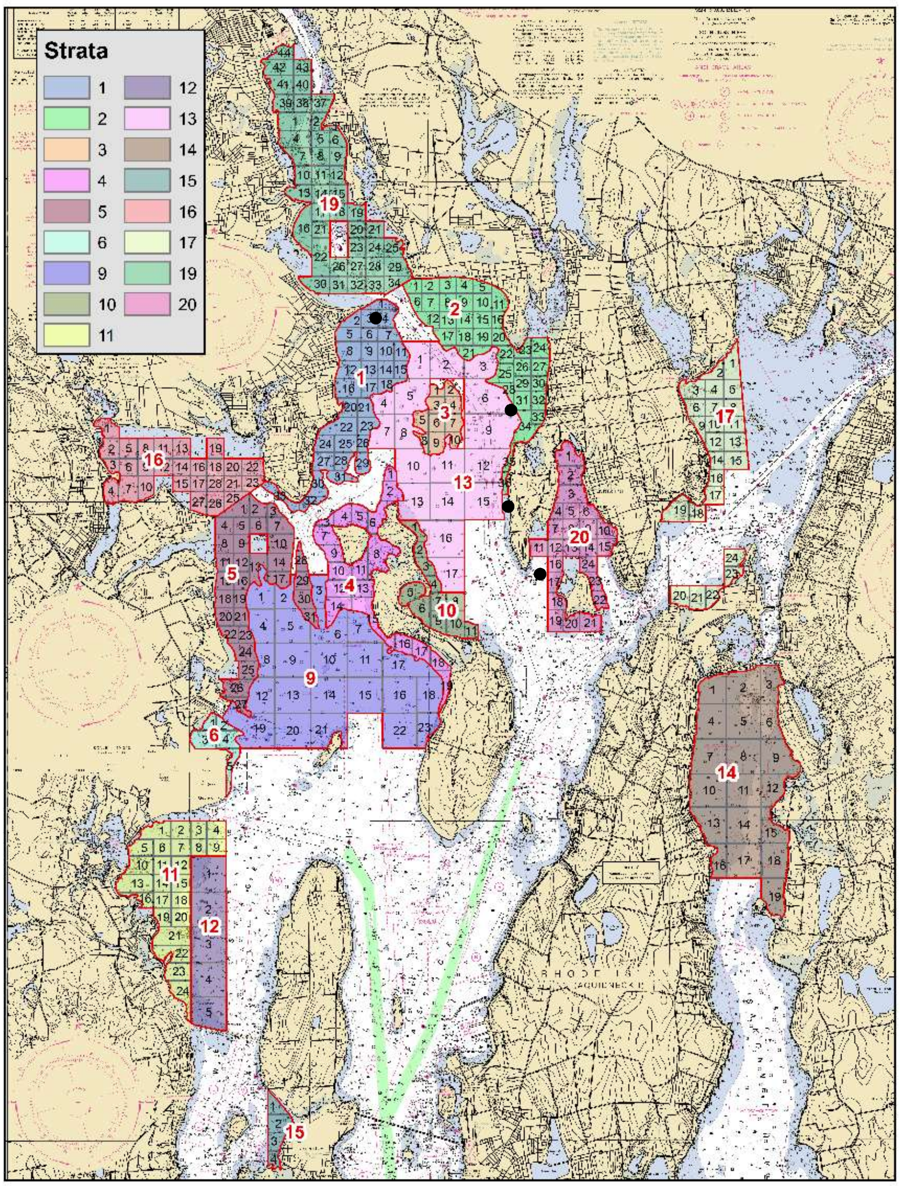


CFRF Quahog Research Fleet – Selected Sampling Stations

Harvester: Jarrod Goulart

Time Period: August 2016 – August 2017

RI DEM Strata-Grid Cell	Latitude	Longitude
1-1	41.718	-71.348
2-28	41.696	-71.305
2-36	41.669	-71.307
20-11	41.655	-71.297



CFRF Quahog Research Fleet – Video Documentary Script

I. Introduction & statement of problem

[Introduction to the Quahog fishery– establish cultural/economic value; State the issue with the existing RI DEM survey and stock assessment and push to develop a stock synthesis, focusing on under/unsampled areas by the dredge survey]

- *Despite being the smallest state in the Nation, Rhode Island boasts over 400 miles of coastline, much of it falling within Narragansett Bay.*
- *A productive, expansive estuary, Narraganset Bay covers 147 square miles, including an expansive network of small bays and coves that act as prime habitat for the Northern Quahog.*
- *The quahog has been an integral part of the Rhode Island identity and Narragansett Bay ecosystem for hundreds of years.*
- *The quahog fishery is the single most valuable fishery in Narragansett Bay, with a dockside value of nearly $8 million in 2016. The fishery supports a fleet of more than 500 active Rhode Island shellfishermen, many of whom have been fishing for decades.*
- *The management of the quahog fishery is primarily informed by data from a hydraulic dredge survey that covers only a small portion of Narragansett Bay every year due to cost and gear constraints.*
- *The quahog fishing industry has long distrusted the dredge survey as it fails to sample in some of the most productive quahog habitats, possibly leading to inaccurate estimates of the quahog population and mismanagement of the quahog fishery.*
- *The Commercial Fisheries Research Foundation, in collaboration with members of the quahog fishing industry, scientists at Roger Williams University, and fisheries managers at the Rhode Island Department of Environmental Management, developed a solution to this problem in 2016: The Quahog Research Fleet.*
- *The Quahog Research Fleet employs commercial shellfishermen to collect quahog data from across Narragansett Bay throughout the year to supplement the dredge survey and, ultimately, ensure the long-term sustainability of the historic quahog fishery.*

II. Solution – CFRF Quahog Research Fleet – team effort to solve the problem

[Fishermen getting involved to help solve the problem, so that they can sustain the historic fishery and fishing businesses can plan for the future]

- *The Quahog Research Fleet is approached collaboratively to maximize the impact of all partners' contributions and to ensure successful application of collected data to quahog management.*
- *The five shellfishermen participating in the Quahog Research Fleet use a specialized tablet app and standardized sorting racks to accurately and efficiently record biological and fishery data from their quahog catch in areas and times of year that are not accessible to the dredge survey. To ensure data quality, participant shellfishermen follow*

  - *scientific sampling protocols, including wireless data transfer, and the CFRF audits the quahog database regularly.*
  - *The data collected by the Research Fleet is essential to increasing the spatial and temporal coverage of the dredge survey and accuracy of the quahog stock assessment.*
  - *An important component of the project is calibrating the catch efficiency of each Quahog Research Fleet participant as well as the dredge survey. Calibrations are needed to standardize the data collected by the Research Fleet to the dredge survey to allow both data sets to be used in the quahog stock assessment and management process.*
  - *For the calibrations, a team of scientific divers follow behind each shellfishermen's bullrake, counting the number of quahogs missed by the rake. The total number of quahogs caught and missed are enumerated to calculate the catch efficiency. The same standardized method is applied to the dredge survey.*
  - *Since its inception in late 2016, the Quahog Research Fleet has sampled over 22,000 Quahogs throughout Narragansett Bay, providing a novel perspective of the quahog resource and fishery.*
  - *Ultimately, the Quahog Research Fleet provides an opportunity for shellfishermen to contribute to and have confidence in the quahog stock assessment and management process.*
  - *The Quahog Research Fleet has begun addressing the data needs surrounding quahogs in Narragansett Bay and will contribute to the sustainable management of this valuable resource for many years to come.*

IV. Conclusions

- *The Commercial Fisheries Research Foundation has stepped up to provide an opportunity for scientists, fishermen, and managers to work as a team to develop management measures that are based on sound science.*
- *Even more, the Quahog Research Fleet has provided an opportunity for fishermen to contribute directly to the assessment and management of the resources that their livelihoods directly depend upon.*
- *Ultimately, the CFRF's work has built trust, increased transparency, and created a community of collaboration, which is at the heart of the CFRF's mission.*
- *In the future, the CFRF hopes to expand the Research Fleet to include more fishermen and expand spatial coverage to ensure the long-term sustainability and prosperity of the resource, and the fishing communities and seafood consumers that depend upon it.*
- *The Commercial Fisheries Research Foundation will be reporting out its findings from this project in the winter of 2018. For more information, follow along on the Foundation's website at www.cfrfoundation.org*

CREDITS:

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David Ghigliotty
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RI DEM Team:
Conor McManus, Principal Biologist
Dennis Erkan, Principal Biologist

RWU Team:
Dale Leavitt, PhD, Professor
Matt Griffin, Technician

Put in credits at the end: Project funded by RISG

List of Shots:

- Quahogger actively bullraking (close up from quahog boat, wide shot from dive boat, aerial from drone)
  - Digging on the bottom
  - Hauling up rake
  - Dumping catch onto table/sorting racks
  - Changing gear configuration around (swapping rakes, adding weights, increasing stale length)
- Quahogger using sorting racks
  - Dumping catch onto racks
  - Pulling racks apart to count the sorted quahogs
- Quahogger entering data into tablet
- Up close still of quahogger's face
- Quahog boats pulling into dock
- Worn down rail on Quahog boat
- Divers preparing to enter water
- Divers rolling off boat
- Divers descending
- Quahogger talking to Roger Williams and CFRF staff