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"An assessment of quahog larval supply and distribution in the upper Narragansett Bay with a focus on spawning sanctuaries and alternative area management strategies."

Lead PI: Dr. Dale Leavitt—Roger Williams University

1. How closely did the research team follow the original planned scope of work?

All 5 of the objectives stated in the proposal were addressed in the final report.

Objective 1: Previous reports on the potential areas for spawning activity were collected and reviewed by RIDEM Shellfish Biologist Jeff Mercer.

Objective 2: Standing stock biomass and condition index was assessed using RIDEMs hydraulic dredge and commercial bullrake and diver quadrat sampling. Collaboration between RIDEM and industry partners will hopefully improve understanding regarding stock assessment results

Objective 3: ROMS particle drift models for spring 2006 & 2007 were run for various release points informed by objectives 1 &2.

Objective 4: Model results were compared to surface drifters in spring 2012 & 2013. I found the tracks surprisingly similar despite difference in methodology and interannual variability in environmental conditions. The plankton sampler deployed failed to validate model and drifter studies to actual bivalve larvae. The PI suggests that sampling methods could be modified to ensure capture of larvae and reports anecdotal evidence for the presence of larvae in anticipated areas.

Objective 5: Results from this project will be considered in the development of the RI Shellfish Management Plan. Collaboration between RIDEM and shellfishermen will hopefully improve management and communication.

2. If there were differences between scheduled and completed tasks, did the project team address these and explain why there were differences?

Two differences were stated in the report:

(1) Objective 1 was carried out by project partner RIDEM, instead of the lead PI. This seems like a minor detail as the work was still completed and results integrated into subsequent objectives.

(2) Objective 4 failed to produce expected results. No larvae were collected during field sampling, despite deployment a plankton pump sampler. Pump failure and apparatus problems were experienced in the beginning and then the sampling effort was abandoned after one weak due to lack of larvae collected. The pump was utilized during a time when larvae should be present in high concentration from model predictions. The PI suggests that larvae may be more closely associated with the substrate than previously thought. This failure to produce actual observations of larvae has implications for the utility of the drifter and particle model predictions. Further confidence would be gained in using the ROMs model for management if larvae had been observed in the same tracks or pathways as the model predicted. However, scientific failures often lead to next steps. The PIs have identified a future research objective in their failure to capture larvae where

expected.

3. In the results, analysis, and discussion sections of the report, did the team answer their original research question(s)?

Yes. The research team did a good job presented results organized around each objective.

4. Were analytical techniques appropriately used? Was the experimental methodology statistically sound and supportive of the conclusions drawn?

Yes. I find no problem with the techniques or statistics or conclusions reported. As mentioned earlier, one improvement would have been to attempt other larvae sampling methods instead of abandoning sampling altogether. I also understand the project limitations (money, resources, time) may have prevented the team from finding an alternative solution and perhaps this task warrants additional funding in the future.

5. Was the raw data included in the appendix complete?

Adequate raw data was included in the report. Model projections and other results will be collated in a CD. I was not able to view this CD at the time of my review. It will be important to have all of these data on file.

6. Was the information clearly presented? Were figures and tables appropriately used?

Yes. The report was well written and organized. One minor exception is a formatting problem on page 55 (issues and comments collected during stakeholder meetings) – the text is garbled and difficult to read.

7. In the discussion section, did the team offer comments on results including observations made while conducting the research; explanations of why a particular gear, sampling strategy, or laboratory technique may or may not have worked as anticipated; how project research results may have advanced the knowledge base about the research topic area; and ideas about follow up research?

Yes, the team addressed these concerns in each discussion section for each objective.

Objective 1: No discussion section was included. However, it is obvious that the results of objective 1 were used to inform subsequent objectives.

Objective 2: The team reflects on the GPS technology used on the drifters, its accuracy, and what conclusions can be drawn in relation to the particle model and the behavior of actual larvae. Future efforts are clearly listed and include collaboration with RIDEM and commercial fishermen to improve drifter studies and stock assessment results.

Objective 3: The team makes suggestions regarding the effectiveness of spawning sanctuary locations in Narragansett Bay based on model and drifter results.

Objective 4: The team gives a thoughtful analysis of the caveats of trying to compare model and drifter results and relates it to the hydrodynamics and current management strategies in Narragansett Bay. The team also attempts to explain why no larvae were collected with the sampler and offers suggestions for future research.

Objective 5: The team highlights two significant outcomes from this research and emphasizes the importance of collaboration between research teams and industry partners.

Objective 1 – Introduction:

The northern hard clam, identified locally as the quahog (*Mercenaria mercenaria*), is the basis for an important fishery throughout its range along the Atlantic coast of North America from New Brunswick, Canada to Florida (Harte 2001). The quahog represents the largest commercial fishery for bivalves in the US, with a reported catch of 2,431.8 metric tons (also include pounds so comparison can be made with graph and text of next paragraph) of clams (meat weight excluding shell) having a landed value of $35,312,277 in 2012 (NMFS 2014).

In Rhode Island, the quahog fishery originated with use of the bivalve by Native Americans, prior to the European colonization of the area, and was sustained at a very low level until the 1920’s (Figure 1-1, DeAlteris *et al.* 2000). With the demise of the Narragansett Bay (NBay) oyster fishery in the 1930’s, the shellfish harvesters switched their efforts to the quahog. Fishing pressure dramatically increased through the late 1940’s resulting in a peak quahog harvest of approximately 5 million pounds in 1955 (Figure 1-1). Due primarily to overfishing, quahog harvests rapidly declined during the 1960’s through the early 1970’s. In 1974 the bullrake was introduced into the fishery, leading to increased access to quahogs in deeper waters and a second harvest peak followed by a steady decline in the fishery, primarily due, once-again, to overfishing (DeAlteris *et al.* 2000, McHugh 2001).

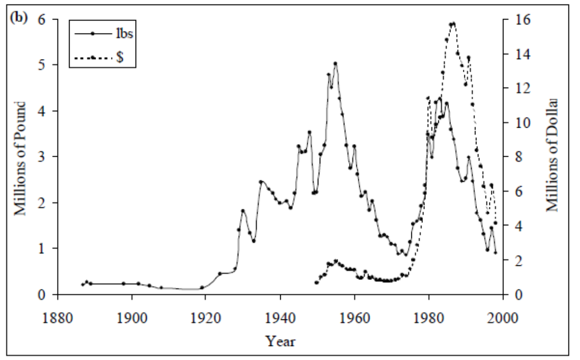
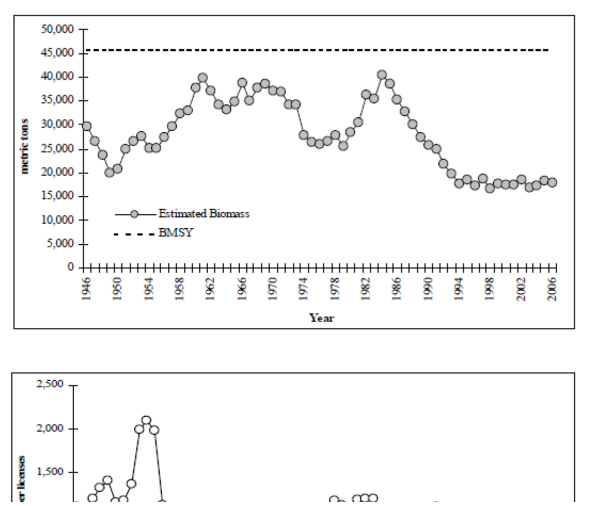


Figure 1-1: Rhode Island quahog production history (from DeAlteris *et al.* 2000).

Following the decline from 1979 to 1995, due to overfishing, the implementation of “precautionary management” by the RI-DEM Marine Fisheries Division resulted in the stabilization of the standing biomass at a level substantially below that needed to provide a sustainable yield (B_{MSY}) (comment – This may not be a good metric for hard clam populations because the most valuable individuals are not the largest. With this price structure in place biomass can remain high while smaller size classes are depleted and thus population replacement can be substantially reduced while biomass remains high. In addition, there is evidence that the largest sizes (greatest biomass) do not necessarily yield the greatest numbers of gametes. Is there any information on the numbers of individuals by the major market sizes (littleneck, cherrystone and chowder) being landed?) (Figure 1-2A, RIDEM 2008). Through management efforts currently in place to rectify overfishing, including entry limitations, management closures, and a rotational harvest/transplant program, the effort was decreased to allow for recovery of the B_{MSY} (Figure 1-2B, RIDEM 2008) resulting in a recent upward turn in RI quahog commercial landings since 2010 (Figure 1-3, Mercer 2013). The recent increase in landings may (if this is “may” then there is a need to make some analysis (collect data?) on which if any of these is responsible for the recovery. Perhaps a portion could be ascribed to each.) originate from management restrictions, including implementation of possession limits and seasons, reduction of fishable areas due to pollution closures, limited number of licenses available and reduction in the number of participants (RIDEM 2009).

Of particular importance to overall quahog management, is that 44.5% of the total quahog



While not exhaustive, this list indicates the large amount of published information currently available to characterize standing stock of quahogs throughout the bay. In addition to the published literature, a series of quahog surveys have been undertaken within NBay by resource management agencies, including the US Fish and Wildlife Service (1951-1957) and RIDEM (1993 to present) (Lazar *et al.* 1994, Ganz *et al.* 1999). An effort of this proposal was to compile the historical information currently available on quahog standing stock distributions throughout the bay to provide a baseline to the quahog survey information collected during this study.

Goals and Objectives of research project:

As a means to initiate this research program, we proposed to compile the past and current quahog standing stock resource assessments from published and grey literature and from surveys by RI-DEM Marine Fisheries for upper Narragansett Bay (NBay) to indicate potential areas for spawning activity.

Methodology:

The overall approach was to compile existing stock assessment information, both in published literature and the data collected by RI-DEM through their hydraulic dredge stock assessment program, which has been collecting stock data since 1994 (with some interruptions - Ganz *et al.* 1999). These data were to be catalogued and used to set the stage for the subsequent stock assessment research proposed as further objectives with the project.

Analysis techniques:

The strategy was to compile existing stock assessment information to provide a historical backdrop to the proposed research. No specific analytical procedures were warranted with this section.

Results:

As this project was launching in 2011, RI-DEM Marine Fisheries restructured their Shellfish Team and added a new staff member, Jeff Mercer. One of Mr. Mercer's primary responsibilities was to oversee the operations of the shellfish stock assessment program. Mr. Mercer also understood the necessity of compiling the existing stock assessment data as his logical starting point to managing the quahog fishery, as we had proposed. With that in mind, Mr. Mercer undertook the same series of analyses that we suggested. Some of his information was included in the introduction to this section of the report and was presented as a component to the 12th Annual Baird Symposium on "The Future of Shellfish in Rhode Island" held on 14-15 November 2013. Rather than duplicate Mr. Mercer's efforts, we selected to defer this aspect of the project to his work such that we could focus our efforts on expanding the data collection aspects to the proposed research.(Compilation of past information was to be a significant part of the analysis. Without this information it is hard to place the current data in a context. This is a significant omission from the report and efforts should be undertaken to have RI-DEM or another group finish this work within the year). Judging from the list above, one has the impression that there is no one time when the entire bay was surveyed. How the distribution of the stock plays into the assessment of the larval distribution data is therefore difficult to assess. If the adult distribution was substantially different, would the spawning time, recruit per adult, or other parameters be different?

References:

Canario, M.T., and K.A.M. Kovach 1965a. Shellfish survey of the East Passage channel. *Rhode Island Division of Conservation Leaflet No. 16*.

Canario, M.T., and K.A.M. Kovach 1965b. Shellfish survey of the Providence River. *Rhode Island Division of Conservation Leaflet No. 17.*

Objective 2 - Introduction:

Fishery independent data are an important contributor to the development of a fishery management plan and a primary source of these data are research-based stock assessments (Gulland 1983, Cooper 2006). As a biological reference point, a shellfish stock assessment provides information on the spatial distribution of the existing biomass along with the age/size-class distribution and, when compared over time, an estimate of fishing mortality(and its age/size class distribution) and recruitment in the stock (Cooper 2006). In total, stock assessments are critical to the proper management of the commercial fishery.(It is equally important to monitor size specific natural mortality rates (at least of the adults)– this is often the weak point in establishing the dynamics of the population.

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 unfished sections of the bay are sampled. The sampling consists of towing a small hydraulic dredge (0.36 meter sweep, Figure 2-1) 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 survey, the stratified mean density of quahogs in Narragansett Bay has been fairly constant through the duration of the survey typically around 2-3 quahogs per square meter."

Figure 2-1: RIDEM hydraulic dredge used for quahog stock assessment

When utilizing a tool such as the hydraulic dredge for stock assessment, consideration must be paid to the catch efficiency of the equipment. Ganz *et al.* (1999) describe the methods used for measuring catch efficiency of the RIDEM hydraulic dredge employed for quahog stock assessment. Using diver surveys of the dredge track, they estimated that the dredge efficiency was 57.7% and this factor is applied consistently for all substrate types sampled (Ganz *et al.* 1999). However, the capacity of the dredge to sample all substrates consistently is questioned by the commercial quahog fishing fleet in RI. This question is supported to some degree by the variability in the data on catch efficiency on various substrates (Ganz *et al.* 1999). Furthermore, the commercial fleet is not trusting of the assessment data as it sometimes runs counter to their experience while fishing. Therefore, a mechanism that provides fishermen with the opportunity to participate in the stock assessment process would be an important factor in opening lines of communication and trust between the regulatory agency and the fishing fleet in addition to augmenting the annual stock assessment data currently collected by RIDEM. (An alternative would be to have an independent third party do the survey. That way both RIDEM and the industry could criticize and suggest improvements.

In addition to assessing the stock structure, other important biological information can be derived from routine sampling of the population of target species. For example, determining reproductive status of the fished population can aid in predicting reproductive effort and provide insights into the environmental and/or physiological conditions experienced by the species. In RI, Marroquin-Mora and Rice (2008) utilized the condition index of quahogs to investigate the impact stock density may have on reproductive effort at selected sites in NBay. Condition index is a measurement that normalizes the soft tissue content of a bivalve to the size of the animal and is used as a proxy for overall reproductive condition, assuming the main source of soft tissue mass variability in the seasonal cycling of the animal is dependent on gonad development (Crosby and Gale 1990). Monitoring condition index as a proxy for reproductive condition will prove to be useful data when investigating the dynamics of larval dispersal and setting in NBay. (There should be a basic survey that is conducted annually – special studies can be incorporated as time and $ permit. The basic survey should provide the mimimal information about the stock (numbers of individuals by size, a measure of recruitment, a measure of size specific natural mortality, a measure of the size specific removals by the fishery) in various areas of the bay. Without this information on a regular basis, the extra funds expended on special studies have much less value.

There are many instances where development of collaborative stock assessment programs have evolved between the commercial fishing fleet and the agencies tasked with managing the fishery. In the northeast, numerous examples can be found, such as those reported in the Northeast Regional

Collaborative Research Conference, held in Portsmouth, NH in 2011 and the International Collaborative Research Summit in 2013 in Narragansett, RI. Collaborative research constitutes the sharing of the intellectual development of a program and utilizes the intellect of both the scientist and the fisherman to develop the program (Wendt and Starr 2009). By conducting the survey work collaboratively, one can maintain the scientific robustness of the data while promoting the scientific credibility of the information among the fishing community because of their involvement in the design and implementation of the data collection and analysis (Wendt and Starr 2009).

Statement of research question or problem investigated:

In collaboration with the Rhode Island Shellfishermen's Association (RISA), we proposed to develop a means by which commercial quahoggers can participate in the stock assessment program currently managed by RIDEM Marine Fisheries. This involves developing a process by which the bullrake can be used as a stock assessment tool and calibrating the tool in the hands of individual fishermen as well as alongside the traditional stock assessment method used by RIDEM, the hydraulic dredge. As a subset of the data collected through the stock assessment process, we proposed to monitor the reproductive condition of the quahog population at various sites through collecting and measuring quahogs for condition index as a proxy for reproductive status.

Goals and Objectives of research project:

Develop a cooperative assessment of quahog standing stock and reproductive condition in the upper NBay with commercial fishermen through RISA.

Conduct side-by-side quahog stock assessments comparing the efficacy of the RI DEM's standard method (hydraulic dredge) with the commercial bullrake and diver quadrat sampling.

Methodology:

To measure the density and size/age class distribution of a stock of infaunal bivalves, a tool to quantitatively extract the bivalves from a known area of substrate must be developed. With the hydraulic dredge, the width is described as 0.36 m and it is towed a distance of 30.5 m, resulting in an area sampled of 10.98 m^2 (Gibson 2013) tooth or blade length?, bar or mesh size in the collecting bag?. By counting and measuring the quahogs retrieved in the dredge, one can both calculate density (the number of quahogs per m^2) and size class distribution by measuring the individual quahogs caught. In addition to the retrieved catch, it is also necessary to ~~know how many individuals the~~ device missed as it fished, its "catch efficiency". This was done through diver assessment of the dredge track to survey for missed quahogs (Ganz *et al.* 1999). We propose to duplicate this methodology with a bullrake in the hands of a commercial quahogger. (It looks like no consideration was given to compiling data on the numbers of double valve dead clams (boxes) to calibrate the dredge against the bullrake. Calibration should also be done to compare the "catchability" of boxes and live clams, because these may not be the same. While no studies of what boxes of clams actually mean relative to mortality (information is needed on how long they last in various types of sediment and under different temperature conditions), they do provide a measure of mortality. This can be more important than recruitment if mortality rates are high.

The bullrake (Figure 2-2) 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 in the rake. The quahogs were measured along the longest axis (length – anterior/posterior) to the nearest 0.1 mm with a Vernier caliper.

To evaluate the ability of the dGPS to measure the distance the rake travelled across the sediment surface, a diver was deployed to swim the track of the bull rake and to measure the actual distance covered. In addition, the diver picked up any quahogs that were missed and left deposited in the rake track.

Once the sampling protocol was developed and evaluated, the fishing efficiency of individual commercial bullrakers was measured. A minimum of three sampling tracks were monitored by diver on one of two substrate types for each bullraker tested. Hard bottom is described as a combination of sand and mud, often with shell fragments associated with it. Soft substrate was primarily soft mud. On average, the bull rake teeth normally used were between 1 and 1.5 inches for hard substrate and up to 2.5 inches for mud. (are the data recorded with the tooth information? did all the bull rakes have the same width between the teeth? Were the bars on the baskets the same size? What size clam was retained (not retained)? In addition to the sampling completed with the bullrake, three 1 m^2 quadrats(how were these sampled?? Suction sampler??? How deep??) were sampled by diver adjacent to the length of the bullrake track, with all quahogs retrieved for measuring to develop an independent assessment of quahog density at the site.

After "calibrating" the commercial quahogger, a field sampling process was developed that sampled locations that had previously been sampled by the RIDEM hydraulic dredge during their annual quahog survey. The locations (latitude/longitude) and catch were provided to us by Dennis Erkan and Jeff Mercer, on the Shellfish Team within RIDEM Marine Fisheries. A minimum of 5 bullrake transects were sampled at each location identified by RIDEM as a dredge sampling site. The density and size/age class distribution were measured at each site and compared with the data provided by the hydraulic dredge to test the comparability of the two techniques. In addition, one attempt at a simultaneous side-by-side sampling between the hydraulic dredge and a bullrake was undertaken in Greenwich Bay.

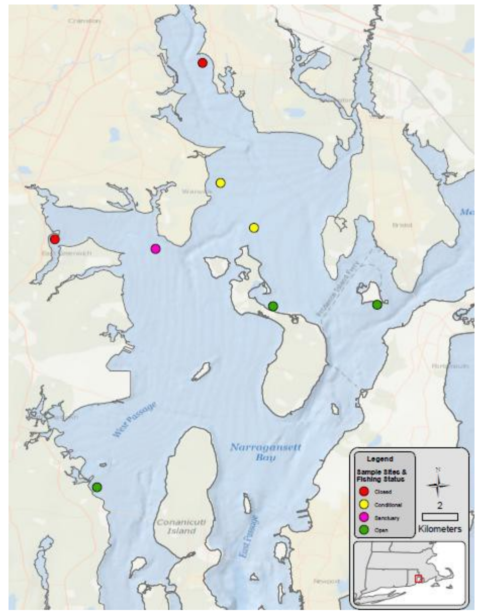
Site	Lat	Lon	Mean Density	SE	Fishing Status
Bissel Cove	41.54200	71.41940	0.7	0.4	Open
Greenwich Cove	41.66933	71.44215	69.0	6.1	Closed
Potowamut sanc.	41.66742	71.38981	6.2	1.1	Sanctuary
Rocky Pt.	41.69900	71.35185	12.3	0.8	Conditional
Providence River	41.76083	71.36716	72.0	2.7	Closed
Conditional Area B	41.67458	71.33950	1.0	0.4	Conditional
Prudence Island	41.63425	71.32703	24.5	6.9	Open
Hog Island	41.63560	71.27815	4.6	1.1	Open
Spawner Sanc. - Transplant	41.66433	71.40163	17.8	0.4	Sanctuary
Spawner Sanc. - Natural	41.66433	71.40163	1.5	0.7	Sanctuary

Table 2-1 and Figure 2-3: Locations of the ten Condition Index sampling sites.

(for this table it would be nice to have the number of samples, Also the units need to be included on the table or in the legend.

During each of the bullrake sampling events, the distance traveled through the transect was measured by dGPS that was post- processed to obtain more accurate location information. In addition, the transect distance was also measured by using a recreational GPS mounted in the boat to compare the distance measured by conventional GPS to that measured by post-processed dGPS.

Initially, we proposed to conduct Condition Index (CI) measurements on quahogs sampled during the stock assessment collections. However, as we advanced in the program, we realized that by collecting repeated samples from the same location(s), it would afford us a better understanding of the reproductive effort and seasonal timing of quahogs in NBay. (Does this mean there is a lot of variability in the gonadal development from site to site?) So we modified the protocol to conduct repeated sampling of quahogs from ten sites within NBay (Table 2-1 and Figure



2-3), including a mix of open and closed sites with varying levels of density associated with them. This study has become the basis for a Master's thesis for a student at URI (Matt Griffin). (if this is finished we need a citation)

Twenty quahogs were collected by diver for CI measurement at each site (on an approximately three-week interval through the active season (April to November) and were returned to the laboratory where they were measured for morphometrics (length, width and depth) to the nearest 0.1 mm using Vernier calipers, weighed for live weight (to the nearest 0.1 g) then shucked to separate the soft tissue from the shell. The wet weight of the soft tissue and shell were measured to the nearest 0.1 mg and the tissues were then dried at 60°C for 48 hours and reweighed. (are they sure that 48 hours is enough to completely dry the tissue of the largest clams?

Analysis techniques:

Catch efficiency for the bullrake was calculated as the number of quahogs retrieved in the bullrake divided by the total number of quahogs in the track (those retrieved by bullrake plus those retrieved by diver after being missed by the bullrake). This efficiency value was used to adjust the number of retrieved quahogs form the bullrake transects to generate an estimate of total quahogs in the sampled track, similar to the adjustment used for the hydraulic dredge. (if they recorded live and dead animals it would be nice to have the numbers of the dead.

Comparison of the bullrake sampling method to the hydraulic dredge was completed by performing a paired T-test of the densities estimated by the two methods at each location (Zar 2010). The hydraulic dredge samples consisted of one transect while the bullrake sample was the average of five transects.

The quahog tissue/shell weight data were used to calculate CI using formula 1 (Crosby and Gale 1990).

$$CI = [\text{dry soft tissue (g)} * 1000] / [\text{live whole wt. (g)} - \text{wet shell wt. (g)}] \quad (1)$$

Further analysis of condition index data will be forthcoming with the completion of Matt Griffin's Master's thesis.

Results:

Evaluation of the dGPS to measure linear distance (Table 2-2): Initially, we ran a series of land-based transects of known length with the dGPS to compare the post-processed distance measurement with the actual distance. Overall, the average difference between the two measurement techniques was 0.487 feet (0.15 m) with the largest difference being 1.5 feet (0.45 m).

Table 2-2: A comparison of measured land-based transect length to that calculated via post-processed dGPS.

		Measured Length (ft)	dGPS Length (ft)	Difference
Test 1 (7/19)	Trial 1	45.00	44.62	0.38
	Trial 2	45.00	44.48	0.52
	Trial 3	45.00	45.94	-0.94
	Trial 4	45.00	45.07	-0.07
	Trial 5	45.00	44.91	0.09
Test 2 (7/19)	Trial 1	90.00	88.96	1.04
	Trial 2	90.00	89.78	0.22
	Trial 3	90.00	88.94	1.06
	Trial 4	90.00	88.74	1.26
	Trial 5	90.00	89.99	0.01
Test 3 (8/2)	Trial 1	20.00	19.55	0.45
	Trial 2	20.00	19.48	0.52
	Trial 3	20.00	19.63	0.37
	Trial 4	20.00	19.47	0.53
	Trial 5	20.00	18.50	1.50
Test 4 (8/2)	Trial 1	70.00	69.92	0.08
	Trial 2	70.00	69.97	0.03
	Trial 3	70.00	70.22	-0.22
	Trial 4	70.00	70.22	[illegible]

		Measured Length (ft)	dGPS Length (ft)	Difference
Test 6 (8/2)	Trial 1	50.00	49.43	0.57
	Trial 2	50.00	48.72	1.28
	Trial 3	50.00	49.63	0.37
	Trial 4	50.00	49.33	0.67
	Trial 5	50.00	49.82	0.18
Test 7 (8/13)	Trial 1	30.00	28.99	1.01
	Trial 2	30.00	29.51	0.49
	Trial 3	30.00	29.07	0.93
	Trial 4	30.00	29.53	0.47
Test 8 (8/13)	Trial 1	60.00	58.81	1.19
	Trial 2	60.00	59.27	0.73
	Trial 3	60.00	58.89	1.11
	Trial 4	60.00	58.82	1.18
Test 9 (8/13)	Trial 1	90.00	89.39	0.61
	Trial 2	90.00	90.04	-0.04
	Trial 3	90.00	90.06	-0.06
	Trial 4	90.00	89.24	0.76
			Mean	0.487
			StDev	[illegible]

difference in measurement of transect length averaged 0.3 m (SD ± 1.0) comparing dGPS to diver measured transect lengths (maximum difference 1.25 m) while the conventional GPS average difference from the measured length was 0.4 m (SD ± 1.0; maximum difference 1.82 m).

Measure catch efficiency of the bullrake on different substrate types (Table 2-5): Using four different commercial quahoggers, we sampled hard and soft substrate types to measure the ability of the bullrake to catch quahogs (Table 2-5). The overall average catch efficiency (minus the disrupted sampling events, noted in comments section) was 90.8% (SD ± 7.9%) of the total quahogs in the transect path, with the efficiency being a little higher on mud substrate (93.5%) compared to sand substrate (89.3%). (It would be nice to know the dates of the samples. I presume these were done in warmer months when the bay bottom is appreciably softer than in the late winter). Water temperature – if available would also be nice to have. As we progressed into this aspect of the study, it became apparent the commercial quahoggers had an uncanny ability to recognize how the bullrake was fishing on the bottom. As you can see in the comments section of Table 2-3, later in our experience, the quahogger could relate information about the fishing behavior of the bullrake such that they knew when the catch efficiency was being compromised due to some factor influencing the rake's fishing performance.

Table 2-5: Measurements of bullrake catch efficiency collected from four different bullrakers sampling on two substrate types.

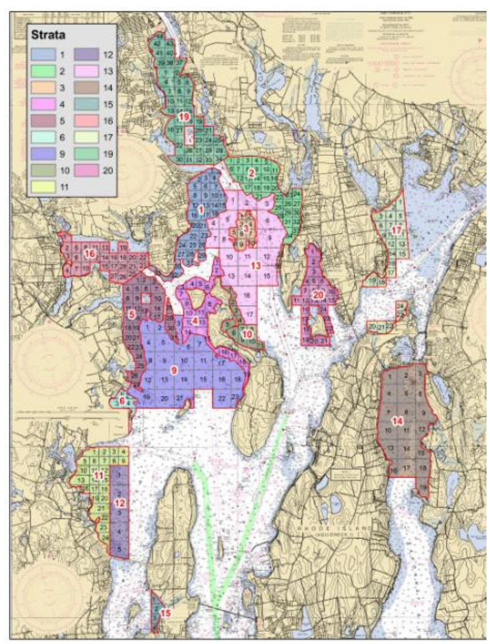
Transect	Quahogger	Location	substrate	Quahogs caught	Quahogs missed	catch efficiency	Comments
1	A	off Allen's Harbor	sand	19	3	86.4%	
2	A	off Allen's Harbor	sand	21	7	75.0%	
3	A	off Allen's Harbor	sand	24	11	68.6%	
4	A	off Allen's Harbor	sand	52	3	94.5%	
5	A	off Allen's Harbor	sand	46	2	95.8%	
6	A	off Allen's Harbor	sand	39	2	95.1%	
7	A	off Allen's Harbor	sand	46	3	93.9%	
8	B	Oakland Beach	sand	24	14	63.2%	inexperienced divers
9	C	Rocky Point	sand	129	14	90.2%	
10	C	Rocky Point	sand	115	12	90.6%	
11	C	Rocky Point	sand	80	15	84.2%	bottom hardened up
12	C	Chepwenoxit	mud	20	2	90.9%	
13	C	Chepwenoxit	mud	50	2	96.2%	
14	C	Chepwenoxit	mud	57	1	98.3%	
15	C	Chepwenoxit	mud	129	8	94.2%	
16	C	Chepwenoxit	mud	97	9	91.5%	
17	D	Sally's Rock	mud	27	3	90.0%	
18	D	Sally's Rock	mud	9	4	69.2%	rake jumped on rock
19	D	Sally's Rock	mud	14	3	82.4%	shell on tooth
20	D	Rocky Point	sand	48	1	98.0%	
21	D	Rocky Point	sand	71	4	94.7%	
		sand avg	89.3%		average	90.8%	
		mud avg	93.5%		stdev	7.9%	

Test the ability of a calibrated bullrake to quantitatively sample quahog density in the field (Table 2-6): Once we had worked with the fisherman on performing a stock assessment transect in the field and had measured their catch efficiency, we undertook a series of transects on two substrate types to gauge the fishermen/bullrake's ability to estimate quahog standing stock density. Using the diver collected quadrat data as the baseline, we compared the density estimated by the bullrake, based on area sampled, number of quahogs collected in the rake and the catch efficiency, to that of the quadrats. The bullrake sample estimated the average density measured at thirteen sites to be 7.22 quahogs/m^2 (SD ± 4.45) compared to the diver quadrat estimate of 6.63 quahogs/m^2 (SD ± 2.58). Resulting in a difference of 0.59 quahogs/m^2 (SD ± 2.99). There was a small and insignificant difference in the quahogger's ability to sample on different substrate types (mean difference of 1.91 quahogs/m^2 (SD $\pm$ 2.97) on sand and -0.95 quahogs/m^2 (SD $\pm$ 2.38) compared to the diver quadrats. (Are any of these significantly different?)(IF the bullrake technique is to be used the authors should develop a sheet describing how to do the claibrations, what information is required etc.)

Table 2-6: A comparison between quahog density measured by diver collected 1- meter quadrat compared to density measured by bullrake.

Transect	Locations	Fisherman	Substrate Type	Area sampled w/ bullrake (m^2)	density measured by bullrake (quahogs/m^2)	catch efficiency	total density (adjusted for avg efficiency) (quahogs/m^2)	avg density measured by diver quadrat (quahogs/m^2)	Bullrake density - Diver density (quahogs/m^2)
2-1	Allen's Hbr	A	sand-mud	6.66	7.81	94.5%	8.35	8.00	0.35
2-2	Allen's Hbr	A		7.30	6.30	95.8%	6.73	7.00	-0.27
2-3	Allen's Hbr	A		8.74	4.46	95.1%	4.77	4.00	0.77
2-4	Allen's Hbr	A		7.30	6.30	93.9%	6.73	6.33	0.40
4-1	Rocky Point	C	sand	8.40	15.35	90.2%	16.41	8.00	8.41
4-2	Rocky Point	C		8.27	13.91	90.6%	14.87	13.00	1.87
5-1	Chepwenoxit	C	soft mud	16.94	1.18	90.9%	1.26	6.00	-4.74
5-2	Chepwenoxit	C		16.30	3.07	96.2%	3.28	3.50	-0.22
5-3	Chepwenoxit	C		16.53	3.52	98.3%	3.76	5.00	-1.24
5-4	Chepwenoxit	C		16.57	7.97	94.2%	8.52	6.00	2.52
5-5	Chepwenoxit	C		15.79	6.29	91.5%	6.72	8.50	-1.78
6-1	Sally's Rock	D	soft mud	9.33	2.90	90.0%	3.10	3.33	-0.23
7-2	Rocky Point	D	sand	7.16	8.74	94.7%	9.34	7.50	1.84
					overall average	93.5%	7.22	6.63	0.59
					standard deviation	2.6%	4.45	2.58	2.99
					on sand	93.6%	9.60	7.69	1.91
					SD	2.2%	4.39	2.72	2.97
					on mud	93.5%	4.44	5.39	-0.95
					SD	3.3%	2.67	1.92	2.38

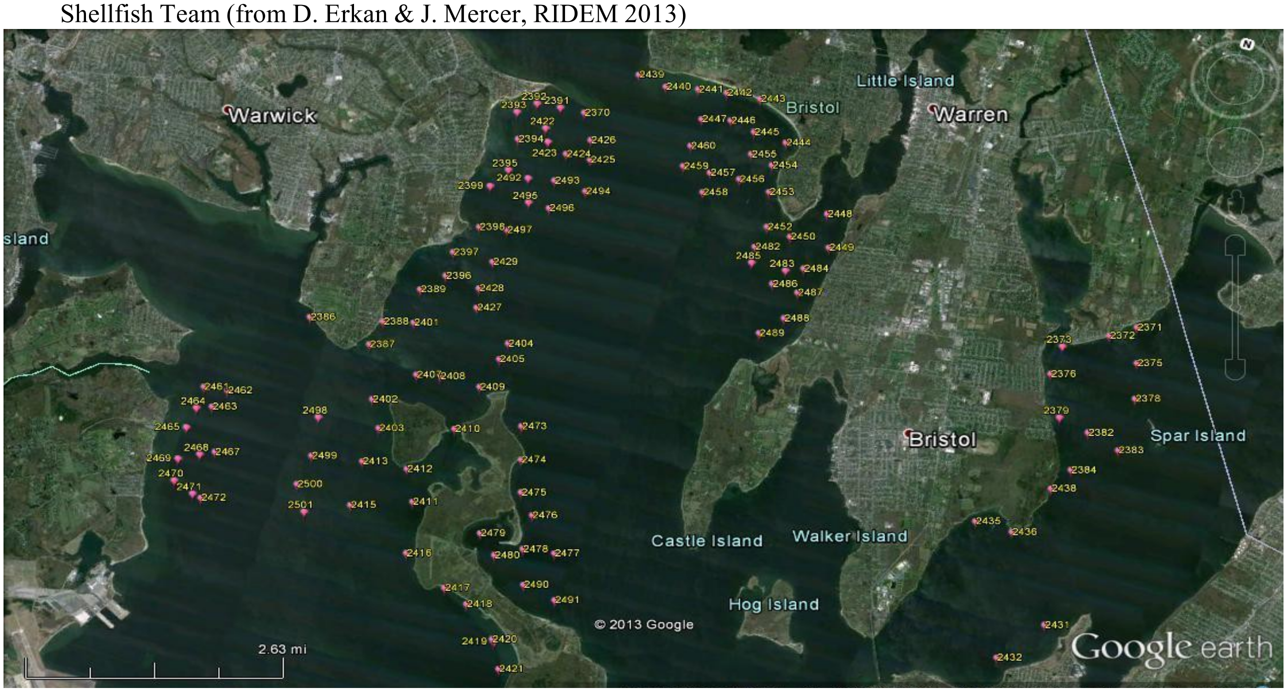
Conduct bullrake surveys at sites sampled by the 2013 RIDEM hydraulic dredge survey (Figures 2-5,6,7 and Table 2-7): RIDEM has adopted a stratified random sampling protocol for monitoring quahog stocks in NBay where the strata are focused on areas with high densities of quahogs that are frequently harvested (Figure 2-5, Gibson 2013). Through collaboration with RIDEM Marine Fisheries, the 2013 dredge sampling data were shared with this project to allow us to duplicate quahog transects at specific locations for comparing the bullrake sampling method to the hydraulic dredge. The sites sampled in the 2013 RIDEM quahog dredge survey are represented in Figure 2-6. We were able to sample ten of those sites, which had previously been sampled by the dredge, with a commercial quahogger who was familiar with the bullrake sampling protocol. The results of the comparisons are included in Table 2-5 and Figure 2-6. The average density across the ten sites as measured by the hydraulic dredge was 5.32 quahogs per m^2 (SD $\pm$ 6.59) compared to the density measured by the bullrake of 6.04 quahogs per m^2 (SD $\pm$ 4.95) (Table 2-7). (were the bullrake and dredge samples adjusted for catch efficiency? When compared by a Paired T-test



the sampled

On one occasion (date – see note above), we were able to coordinate schedules between the commercial bullraker, the science/diver team and the RIDEM dredge team to allow a side-by-side comparison between the dredge and the bullrake. On very soft substrate (near Sally's Rock), the dredge measured an adjusted sample density of 1.11 quahogs per m^2, compared to the bullrake adjusted measured density of 1.99 quahogs per m^2 (SD $\pm$ 1.07) (Table 2-7). (so are these different?)

Figure 2-6: Locations of the sample sites for the 2013 quahogs stock survey completed by the RIDEM Marine Fisheries Shellfish Team (from D. Erkan & J. Mercer, RIDEM 2013)



RI-DEM Tow ID	Density as measured by Dredge	Dredge adjusted for 57.7% efficiency	Average Density as measured by Bull Rake	StDev	Substrate type
2389	8.86	15.36	9.37	2.22	hard bottom
2393	0.46	0.80	0.12	0.11	hard bottom
2424	11.65	20.19	13.73	6.87	very hard bottom
2429	1.90	3.29	8.05	4.60	moderate hard bottom
2445	0.25	0.43	0.77	0.70	soft mud
2448	3.69	6.40	6.63	3.99	soft sticky mud
2453	0.46	0.80	0.43	0.33	soft sticky mud
2484	0.27	0.47	3.21	2.13	soft sticky mud w/ shell
2485	2.96	5.13	11.80	6.41	hard w/ shells
2496	2.62	4.54	10.37	1.74	moderate hard bottom
GB adjacent	0.64	1.11	1.99	1.07	soft mud w/ shell
average	3.07	5.32	6.04		
stdev	3.80	6.59	4.95		

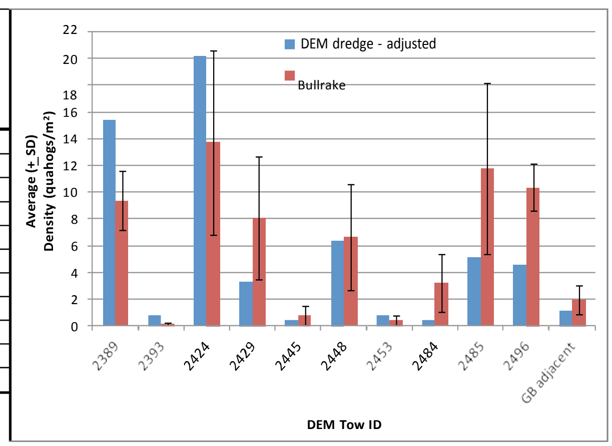
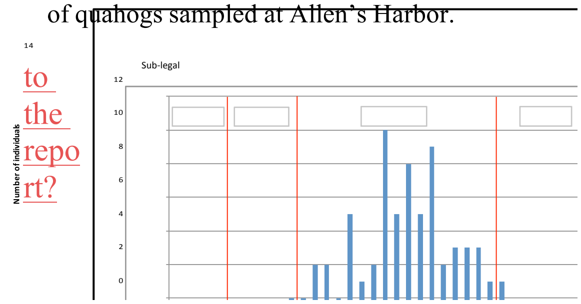


Table 2-7 and Figure 2-7: A comparison of quahog densities sampled by RIDEM hydraulic dredge and a bullrake.

Determine the size/age frequency distribution of quahogs sampled (Figure 2-8): At each site, it is possible to construct a size-frequency histogram that describes the population characteristics of that site. The data in Figure 2-8 represent the quahog population sampled at an Allen's Harbor location, where the size classes have been separated into the commonly used market designations of Littleneck (49-61 mm length), Cherrystone (61-95 mm), Chowder (>95 mm), and Sub-legal (<49 mm). Are all the data going to be appended

Figure 2-8: Size/age frequency distribution of quahogs sampled at Allen's Harbor.



to the report?

the stale is in the same orientation when marking the finish point. Depending on the length of the stale (i.e. the depth of water where fishing), failure to do this can lead to significant error in measuring the distance the rake covered on the bottom, up to 4 m of the transect length under severe conditions (14 meter stale length deflected 60^{o}) (Figure 2-11).

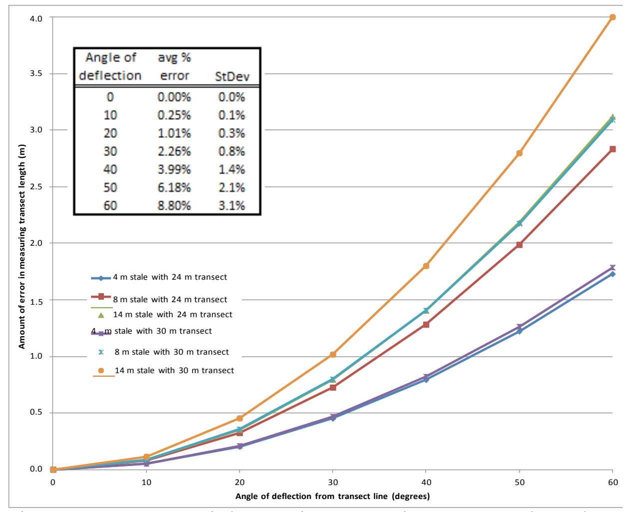


Figure 2-11: Potential error in measuring transect lengths if stale angle is deflected from the direction of the transect.

Although it was initially suggested that using a dGPS would be important in achieving the level of accuracy required for sampling, subsequent preliminary evaluation of a conventional GPS unit proved to be nearly as accurate (0.3 m compared to 0.4 m average difference between the respective GPS measurements and the diver measurement; Table 2-4). While Wieh *et al.* (2009) reported a dGPS accuracy at approximately the same level as found in this study (0.79 m average versus our worst case measurement of 0.79 m), they suggested that some handheld recreational GPS units could come within a meter or less of matching the dGPS measurement. Therefore, it may not be necessary to invest in a high cost dGPS ($3-5,000 for a complete set-up) if a suitable recreational unit (estimated cost of $2-400) can be used. As a component to the conclusion of this study, this spring we propose to test a suite of handheld GPS units available to the investigators to see if they can approach the level of accuracy demonstrated with the dGPS, following a protocol similar to what has been employed in the current study. (The authors should provide a written protocol so any subsequent use of GPS and bullrakes is standardized)

Understanding catch efficiency of a harvest device is instrumental in using that device as a tool for stock assessment. Estimates of biomass are inversely related to the estimated catch efficiency of the hydraulic dredge so any inaccuracies in estimating catch efficiency can directly influence the biomass estimates used to determine harvest allowances (Thorarinsdo´ttir *et al.* 2009). The catch efficiency of the hydraulic dredge currently used by RIDEM to sample quahog populations in NBay was carefully measured when the device was first introduced to collect quahog samples in 1994 (Lazar *et al.* 1994, Ganz *et al* 1999). The value of 57.7 to 67.5% efficiency measured for the RIDEM dredge is significantly lower than some estimates of other hydraulic dredges used for harvesting infaunal clams (92% for an ocean quahog dredge in shallow water - Thorarinsdo´ttir *et al.* 2009; >90% for a Stimpson's surf clam dredge – Lambert & Goudreau 1995; 90.1% for dredging razor clams – Hauton 2007) but similar to estimates for American (66% - Rago *et al.* 2006) or Japanese (63% - Nashimoto 1994) surf clam dredges. Lazar *et al.* (1994) noted problems with replication of the dredge sampling in areas with densities higher than 5 quahogs per meter^2. RIDEM currently does not do replicate sampling as a component to their annual quahog stock survey. It has been 20 years since catch efficiency was last assessed on the RIDEM hydraulic dredge and there have been changes made to the dredge, suggesting that it should be recalibrated in the near future with a defined protocol for testing the catch efficiency on a regular basis in the future. (I agree with this statement – and it should be tested on different bottom types in different areas of the bay. This is expensive, but doing a little each year or every other year would mitigate the costs.)

Catch efficiency for the bullrake is a less studied parameter. As measured in the current study, the average catch efficiency of the bullrake, in the hands of an experienced individual, was calculated to be 90.8% (SD $\pm$ 7.9%, Table 2-5) if the situations where something interfered with the rake are discounted. This value is somewhat lower than the 100% efficiency observed by Glude and Landers (1954) or Peterson *et al.* (1983) when fishing quahogs greater than 48 mm in length (23.6 mm depth)

Using the bullrake to measure stock density is a reasonable means to gather that data. Although the adjusted? (rather than repeating "adjusted" throughout the report, perhaps a general statement that all densities for all gear types are adjusted for catch efficiency – unless otherwise noted) density estimates provided by the bullrake are close to baseline (7.22 quahogs/m^2 measured by diver quadrat versus 6.99 quahogs/m^2 for the bullrake), the difference may lie in the baseline measurement rather than the bullrake. The quahog is described as a having a clumped or superdispersed distribution pattern (Saila and Gaucher 1966, Lazar et al. 1994). This means that if you observe one quahog in a location then there is a higher probability that you will find another. One means to ensure the samples you collect better represent the actual quahog density of the area is to sample a larger surface area. When sampling by diver, three replicate 1 m^2 quadrats are sampled adjacent to each transect whereas when sampling with the bullrake, we sampled between 6 and 16 m^2 of area per transect (Table 2-6). Therefore, using the diver collected quadrat may not be the best baseline for comparison unless one samples as many quadrats as surface area covered by the bullrake. This is not practical from a time and effort standpoint. (Another possible calibration would be with a hydraulic patent tong).

Following calibration of the commercial quahogger, we sampled ten sites that had previously been sampled by the RIDEM hydraulic dredge and we ran one simultaneous side-by-side measurement. The density measured by the commercial quahogger was similar to the density sampled by the dredge (5.32 quahogs/m^2 measured by the dredge and 6.04 quahogs/m^2 by the bullrake). A paired T-Test analysis of the density measurements demonstrated that there was no difference between the two sampling techniques. The largest variation in this relationship between sampling methods seemed to be when the quahog density was relatively high (Table 2-7 and Figure 2-7). As noted by Lazar *et al.* (1994), the RIDEM dredge had problems with quahog densities above 5 quahogs/m^2, where the variability of replicated dredge tows was exceedingly high and followed no discernible pattern. Further comparisons between the dredge and the bullrake will be completed this spring to continue to analyze the comparability between the two techniques.

Although not investigated in detail because we do not have the size distribution data from RIDEM from their sampling , the bullrake stock assessment provides the same capacity for characterizing the size/age class distribution at specific sites as the information generated by the dredge. These data provide a tool to look at the stock structure of local populations to measure impact of fishing pressure (e.g. Rice *et al.* 1989), to expand our knowledge of reproductive potential (Peterson 1983), to assign economic value to the resource (Kraeuter *et al.* 2008) or for a number of other applications. The data should be included in an appendix. In addition, any information on numbers and sizes of dead paired valves should be included.

As a proxy for reproductive effort, the condition index measurement offers insights into the level of gonadal development in quahogs as well as the seasonal timing of spawning events (Doall *et al.* 2008). The condition index data from 2012 and 2013 (Figures 2-9 and 2-10) suggest that the spawning cycle in NBay for those years resulted in larval releases from late May through the month of June. The timing observed in the present study reflects that reported by other shellfish researchers (Marroquin-Mora and Rice 2008)) and will be used to set the larval release times in the ROMS model developed under Objectives 3 and 4 of this study.

Wilson (1999) describes four different models of collaboration between fishermen, policy managers and scientists, with the "competing constructions" model being most relevant to the current effort in developing a collaborative stock assessment process. Wilson explains competing constructions as resulting from competition between different pictures of the resource that are constructed by interest groups that compete with each other in the fisheries policy arena. In RI, the RIDEM quahog stock assessment survey is routinely criticized by commercial quahoggers as not accurately representing the actual stocks as they are in the bay. The oft cited evidence of this revolves around dredge surveys that were conducted in Greenwich Bay just prior to an opening, where the shellfish biologist remarked that the dredge survey indicated no substantial catch of quahogs could be anticipated based on the survey while the fishermen were supported for an extended period of time thereafter on the extensive quahog beds that were available. This one situation has completely eroded

The goal of these experiments is to take advantage of the traditional fishermen's knowledge and their skill in catching quahogs to evolve collaborative efforts of the fishermen into the "community science" model described by Wilson (1999). the. With this collaboration, "fisheries science appears in the context of fisheries co-management and/or community development. These programs will often both defer to the knowledge of professional scientists and respect traditional ecological knowledge. They also take into account the competing constructions of various stakeholder groups and use collaborative science as a way to resolve and move beyond these disputes. They are characterized by an open discourse about all the aspects of the scientific problems." By including RISA and other fishermen in the stock assessment process, the level of data collection can be amplified, the data are available for all users, the trust and confidence of the fishermen about the data will be increased, and the management process becomes more transparent and collaborative.

Summary of conclusions:

- The bullrake, in the hands of an experienced fisherman, with an appropriate protocol for measuring distance is a valid assessment tool that can deliver data to be used for quahog fisheries management.
- Sampling quahog stock density with the bullrake is relatively simple and can be conducted with relatively inexpensive equipment.
- Developing a community science approach to quahog stock assessment could bring local fishermen into the quahog management process and allow for a more interactive and collaborative management strategy.

Future efforts:

- Following consultation with RIDEM concerning the results from this work, we will focus the remainder of the study (through to 30 June 2014) on addressing the following questions:
    - Continue to "calibrate" quahoggers through our collaboration with RISA for inclusion in the stock assessment program,
    - Investigate the potential for using a recreational GPS in lieu of the expensive differential GPS currently used in the study,
    - Continue to conduct side-by-side assessments of sampling with both the RIDEM hydraulic dredge and the bullrake.
- Longer term goals, in collaboration with RIDEM, includeDeveloping a standard set of protocols for the fishermen to follow if they are sampling for stock assessment purposes.
    - Developing a means to integrate RISA and other commercial fishermen into the stock assessment process for RIDEM Marine Fisheries (i.e. a research fleet), starting with assigning areas that will be specifically surveyed by fishermen, primarily because of inaccessibility with the dredge and boat.
    - Look into mechanisms to compensate the quahoggers for their participation in a "research fleet" approach to stock assessment.
    - Expand on our understanding of the influence of water depth, sediment type and fishing style on catch efficiency of the bullrake. (and the hydralulic dredge??)

References:

Cooper, A.B. 2006. A Guide to Fisheries Stock Assessment – From Data to Recommendations. NH Sea Grant College Program, Durham, NH. 44 pgs.

Crosby, M.P. and L.D. Gale. 1990. A review and evaluation of bivalve condition index methodologies with a suggested standard method. J Shellfish Res 91:233–237.

Doall, M.H., D.K. Padilla, C.P. Lobue, C. Clapp, A.R.Webb, and J. Hornstein. 2008. Evaluating northern quahog (=hard clam, *Mercenaria mercenaria* L.) restoration: Are transplanting clams

Objective 3 – Introduction:

One method to characterize larval dispersal patterns in specific coastal embayments that has proved to be very successful is the use of hydrodynamic models to predict movement of larvae from their release point to their final settling destination. Movement of planktonic bivalve larvae results from a combination of hydrodynamic processes, where they were spawned, the behavioral positioning of the larvae in the water column, and the duration of the larval period (Roegner 2000, North *et al.* 2008). The Regional Ocean Modeling System (ROMS) is an internationally recognized hydrodynamic model that has been applied to a number of different coastal embayments to investigate larval bivalve dispersal patterns (Chesapeake Bay, North *et al.* 2008; Delaware Bay, Narvaez *et al.* 2012; San Diego, CA, Rasmussen *et al*. 2006).

The ROMS is a 3-dimensional hydrodynamic model that was developed by the coastal modeling group at Rutgers University (Haidvogel *et al.* 2008). The model solves the set of primitive hydrodynamic equations under the hydrostatic and Boussinesq approximations. It is a free surface model with a terrain-following vertical coordinate and uses orthogonal curvilinear coordinates in the horizontal that allow for variable spatial resolution. The details of the model algorithms are described in Shchepetkin and McWilliams (2005). The model can be driven by imposed tidal forcing, surface momentum and heat fluxes, and by river runoff. In addition to the dynamically active temperature and salinity fields, the model can simulate an arbitrary number of passive (not influencing fluid density) tracers that can be used to estimate water property exchange (e.g. Kremer *et al.* 2010).

The ROMS model has been adapted for Narragansett Bay by the present University of Rhode Island Graduate School of Oceanography ROMS Group (comprised of Kincaid and Ullman) as well as several other present and former graduate students and has been used in a number of prior studies (Sullivan and Kincaid 2001, Bergondo 2004, Rogers 2008, Bergondo and Kincaid 2007, LaSota *et al.* 2007, Kremer *et al.* 2010). The implementation most relevant to this proposal was developed as part of a recent study investigating the processes influencing summertime hypoxia in the Bay where ROMS was used to provide estimates of the physical exchange of hydrographic and biological properties between the coarse elements of a two-layer ecological box model of the Bay (Kremer *et al.* 2010). A high-resolution model grid of the Bay, with horizontal spatial resolution of approximately 50-100 m in the upper Bay and 15 vertical levels, was nested within a coarser grid, which included the Bay and extended out onto the continental shelf south of the Bay mouth. At its open southern boundary, the coarse grid model was forced with tidal constituents from the Eastcoast Tidal Constituent Database (Mukai *et al.* 2002) and climatological temperature and salinity fields. The model was additionally forced by actual freshwater discharges from the eight rivers gauged by the United States Geological Survey (USGS) and from several sewage treatment facilities as well as by surface fluxes derived from meteorological measurements in the NBay region (see Kremer *et al*. 2010 for details). The output of the coarse resolution model was used to force the high-resolution model, using the same river and meteorological forcing, at its southern open boundary at the Bay mouth. Vertical mixing in both models was parameterized using the Generic Length Scale closure scheme (Umlauf and Burchard 2003, Warner *et al.* 2005). Model skill, as assessed using in situ current and hydrographic time series measurements, was generally high in the mid- to upper-Bay region (Balt *et al.* 2014 (in preparation)).

Statement of research question or problem investigated:

Taking advantage of the development of the ROMS for Narragansett Bay, we used our developing knowledge of quahog bivalve behavior and distribution in the bay, the ROMS characterization of the hydrodynamics of the bay, and measured observations of fecundity of specific populations in the upper Bay to predict the distribution of post-metamorphic quahog juveniles. There have been a few studies describing bivalve larval occurrence and distribution in portions of NBay (Landers 1954, Rice and Goncalo 1995, Butet 1997). But these data are very incomplete with respect to tracking quahog larval distributions because of their limited sampling and the degree of difficulty in separating *M. mercenaria* larvae from other bivalve larvae. Thus we performed a numerical study of

Particles released from the Providence River location, the northernmost site considered, are distributed widely throughout the Bay after 10 days of drift. There are somewhat more particles in the West Passage than in the East Passage. Due to its location in the northern part of the Bay, relatively few particles are lost to the coastal ocean (34% and 20% in 2006 and 2007, respectively).

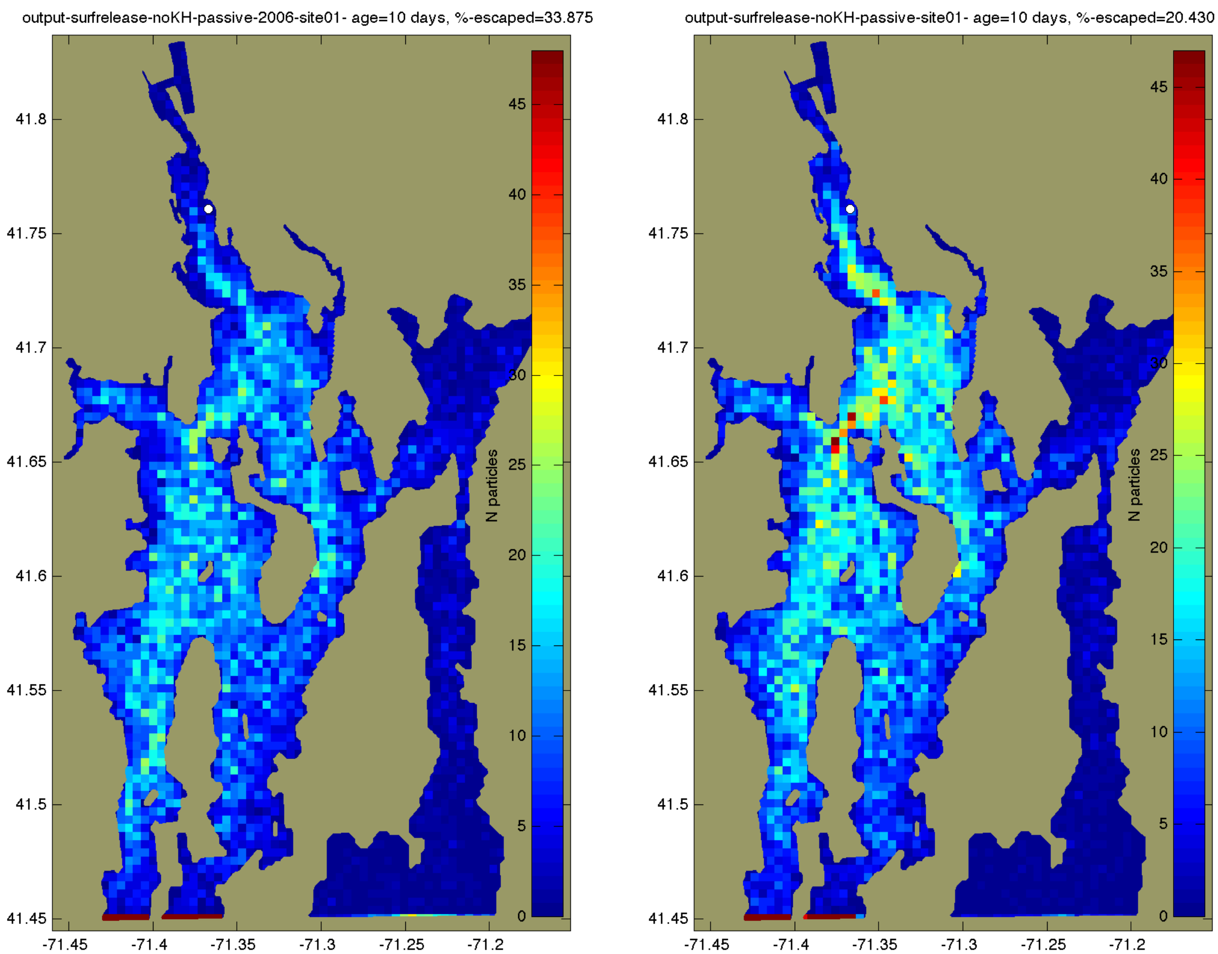


Figure 3-4. Number of particles as a function of position within the Bay 10 days after release from the Providence River site for 2006 (left) and 2007 (right). The white dot indicates the release location.

On the figure below you provide an estimate of the % lost from the bay. Why not for this figure as well?

Rome Point, the release site closest to the Bay mouth, is not surprisingly a poor site from the standpoint of larval retention. A small number of particles remain within the lower East and West Passages after 10 days, but most particles escape the Bay. The percentage of particles lost to the coastal ocean is 95% in 2006 and 96% in 2007. so for this site the timing of spawning relative to the flood and ebb cycle and the spring and neap cycle could be important in increasing or decreasing the retention.

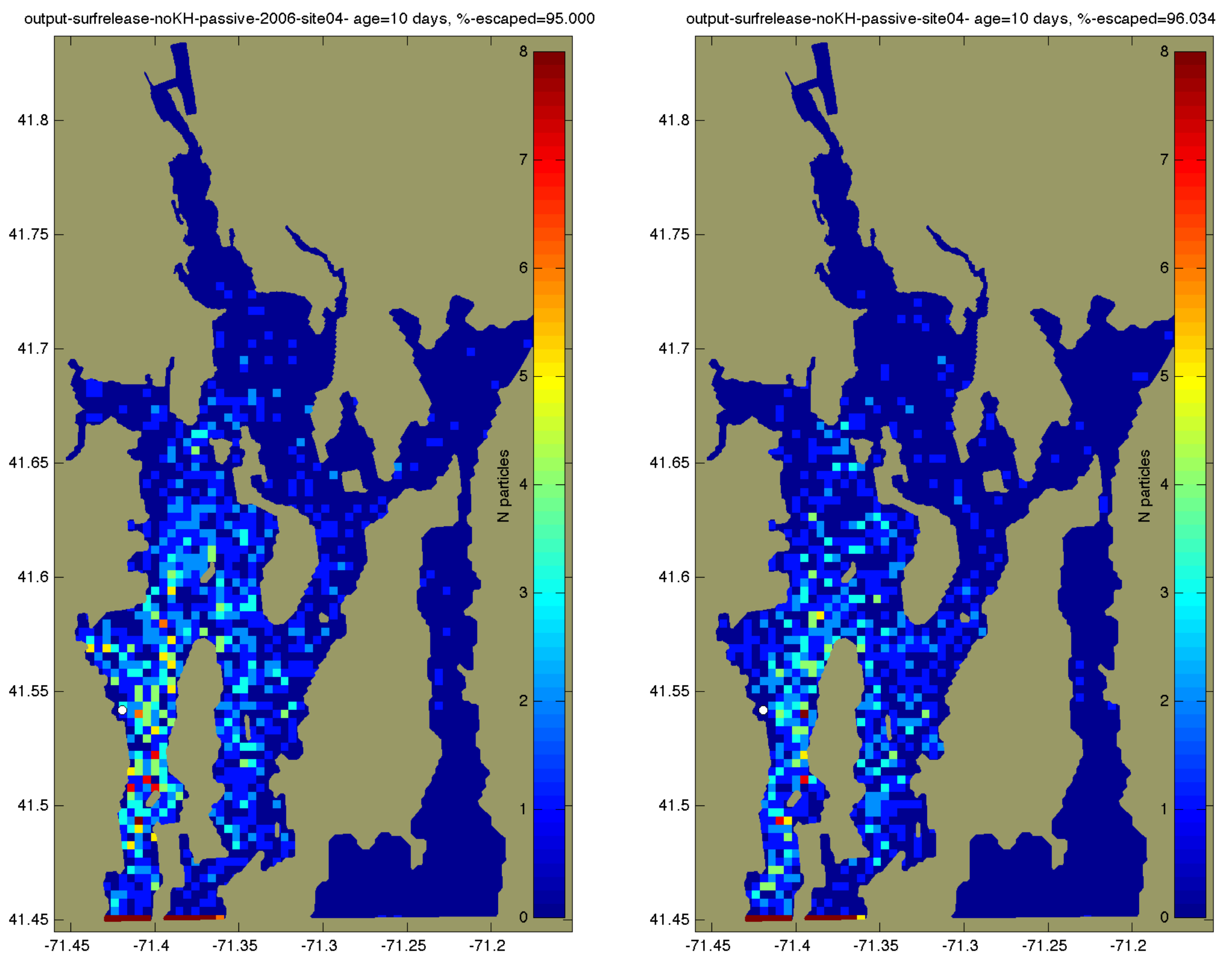


Figure 3-7. Number of particles as a function of position within the Bay 10 days after release from the Rome Point site for 2006 (left) and 2007 (right). The white dot indicates the release location.

swimming speed decreases linearly with time, becoming downwards during the second half of the larval period. Figure 3-10 shows a comparison of the 10-day larval distribution for larvae released from the Providence River site with and without swimming behavior. The distributions are very different, with many more larvae escaping the Bay when behavior is included (53% lost as compared to 20% loss with no behavior). There is also an odd aggregation of particles near shorelines, which is under investigation at this time. To understand the increased loss of larvae when upward swimming behavior occurs early in the larval stage, Figure 3-11 shows the mean (and 1 standard deviation about the mean) depth and height above bottom for larvae in the two cases. When larvae exhibit swimming behavior, they tend to be found closer to the surface than when larvae are passive (even though the larvae are released at the surface, with no behavior they tend to be mixed downwards by turbulent diffusion). Larvae near the surface tend to be advected southwards in the estuarine circulation, thus more larvae near the surface results in greater export of larvae from the Bay. What would happen if the larvae are swimming upward only a portion of the time (ie – no preference at night?)

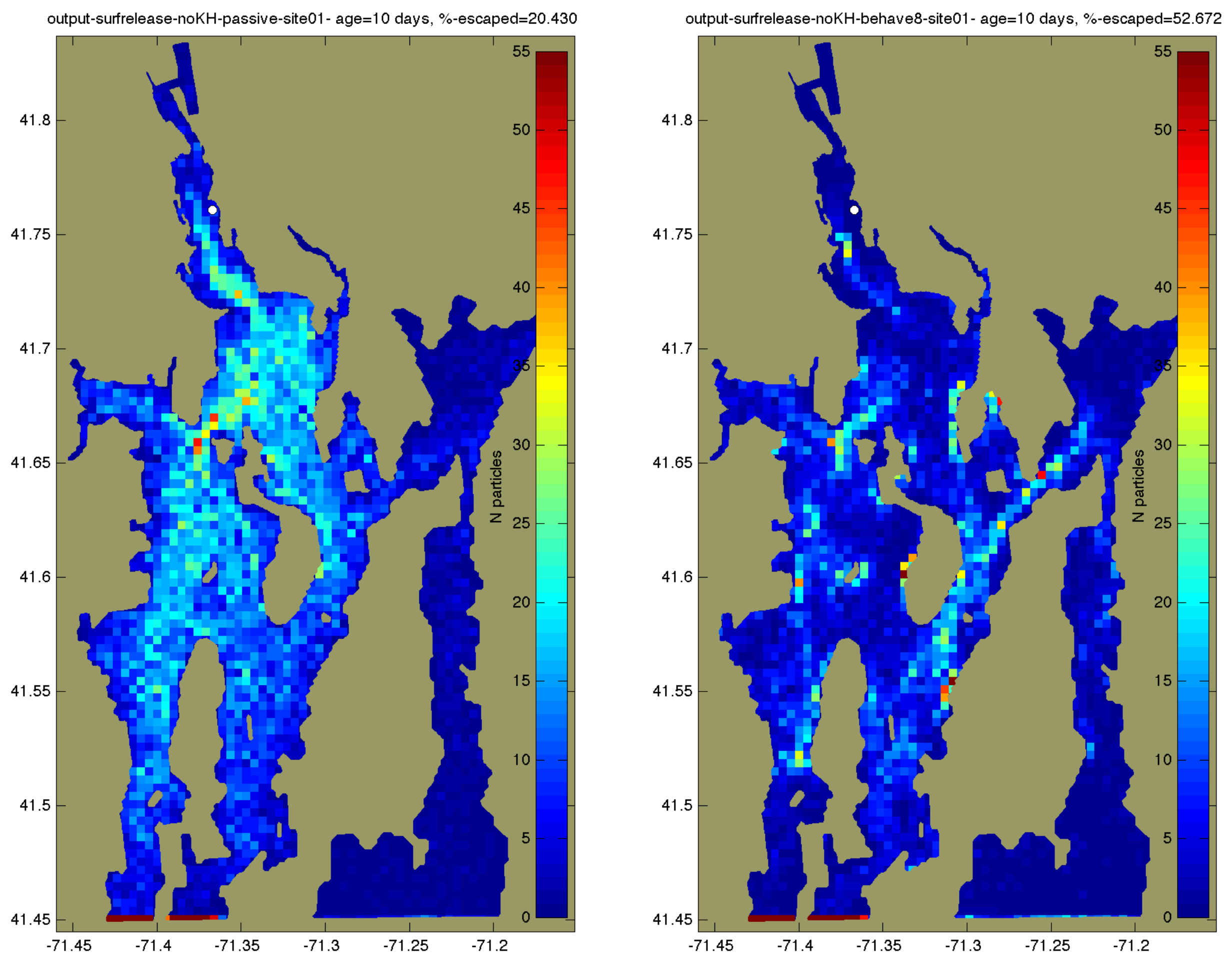


Figure 3-10. Comparison of the number of particles as a function of position within the Bay for particles released at the Providence River site (white dot) during 2007 for larvae with no swimming behavior (left) and larvae with the swimming behavior shown in Figure 3-3 (right). The percentage lost is 20% for the case of passive larvae and 53% for the case of swimming larvae.

within NBay where quahog larvae may be aggregated prior to settlement due to prevailing wind and water movement. To verify the projected model simulations, we will ground truth the model forecasts using a combination of surface drifters, to physically track the movement of passive particles in the bay, and surveying for late-stage competent quahog larvae in the near-bottom environment.

Goals and Objectives of research project:

Using the results of the model, validate predicted larval settlement sites through a combined effort of surface drifter deployments and monitoring for the occurrence of quahog larvae, identified with a polarized laser video plankton sampler (LIHDaT).

Methodology:

Drifters

There are several existing designs for low-cost drifters (e.g. http://gisweb.wh.whoi.edu/ioos/drift/driftdesign.html) and we initially chose a design ("Roger", Figure 4-2) that proved unsatisfactory after it frequently ran aground within 12 hours of deployment. We modified the design repeatedly, concluding with one designed to track water movement one-meter below the surface and with minimal windage (Figure 4-3). These routinely would remain adrift for up to seven days before either running aground or leaving the Bay. The final design is easily adapted to track currents at deeper depths by using a taller mast and we successfully deployed several three-meter versions of the drifter during the summer of 2013.

Figure 4-2: A photo of the original "Roger" drifter design.

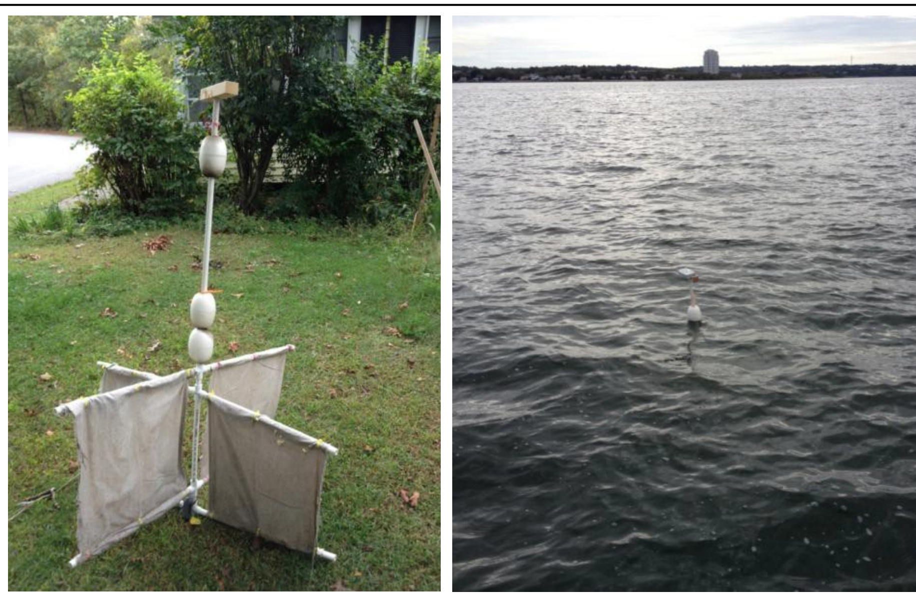


Figure 4-3: Final "Roger" drifter design on land (left) and while deployed (right). The center of the canvas sail is approximately one meter below the upper-most white float. When deployed, only the top of the drifter is emergent. Mounted at the top of the mast is a GPS/cell phone unit for data collection and transmission.

the bottom (Figure 4-5). To sample, the pump frame was lowered to the bottom on site and the pump output was brought to the surface through a length of 1" diameter Tygon tubing. At the boat side, the pump effluent ran through an inline flowmeter (GPI Turbine flowmeter) then discharged into a 200 μm Why was this selected? A 150 net would give more assurance that nothing is missed. plankton net. 100 gallons of seawater was sampled at each location and sampling event (how was this determined?. The material retained on the plankton net was placed in a capped bottle, placed on ice and returned to the laboratory. Upon return to the laboratory, the plankton sample was concentrated on a 100 μm screen and transferred to a 100 ml plastic bottle, where it was preserved in 1% buffered formalin with a small amount of Borax to buffer the overall solution (LIHDaT preservation protocol). At this time, the samples were preliminarily inspected for bivalve larvae with a dissecting microscope to ensure the presence of larvae.

Figure 4-5: The bottom tending plankton pump for sampling at an elevation of 0.5 m off the bottom.

Identification and enumeration of bivalve larvae in the sample would be completed by the LIHDaT instrumentation in collaboration with the Aquinnah Wampanoag Water Quality Laboratory in Aquinnah, MA. The preserved samples were to be shipped to the lab where they would be processed and analyzed.

Analysis techniques:

Drifter:

Drifter tracks were downloaded from the FoxTrax website and compiled at RWU using the Generic Mapping Tools (GMT) software. The completed tracks were plotted on a map of NBay and the patterns were evaluated visually for comparison to the projected larval transport patterns predicted by the ROMS model. Similarities and dissimilarities were noted with the feedback going to the modeling team for analysis and discussion on methods to refine any inconsistencies between model projections and drifter tracks.

Quahog Larval Sampling:

The total number of quahog larvae collected with each sample were to be compared over time and between sites using a two-way ANOVA with time and location being the two independent factors.

Results:

Drifters

After several design modifications and refinements, we implemented a low-cost version of the Davis-style drifters to investigate the near-surface current movements in Narragansett Bay with regard to potential larval source locations. Dubbed the "Roger", the drifters were deployed on 49 different occasions during the late spring,

Release Date	Location (number drifters released)	Release Date	Location (number drifters released)
31-May-12	Hog Island (2)	20-May-13	Hog Island (1)
5-Jun-12	Hog Island (2)	24-May-13	Hog Island (1)
11-Jun-12	Greenwich Cove (2)	26-May-13	Hog Island (1)
11-Jun-12	Hog Island (1)	4-Jun-13	Hog Island (2)
11-Jun-12	Spawner Sanc. (3)	11-Jun-13	Hog Island (3)
18-Jun-12	Hog Island (1)	17-Jun-13	Spawner Sanc. (4)
18-Jun-12	Spawner Sanc. (2)	17-Jun-13	High Banks (1)
19-Jun-12	Hog Island (2)	24-Jun-13	High Banks (2)
19-Jun-12	Spawner Sanc. (1)	24-Jun-13	Spawner Sanc. (2)
11-Jul-12	Rocky Point (1)	1-Jul-13	Rocky Point (4)
11-Jul-12	Sabin Point (2)	2-Jul-13	Spawner Sanc. (1)
25-Jul-12	Sabin Point (1)	3-Jul-13	High Banks (1)
25-Jul-12	Rocky Point (2)	9-Jul-13	Rocky Point (4)
1-Aug-12	Rocky Point (2)	9-Jul-13	High Banks (1)
7-Aug-12	Rome Point (1)	15-Jul-13	Sabin Point (2)
10-Sep-12	Rome Point (2)	15-Jul-13	Spawner Sanc. (1)
29-Sep-12	Spawner Sanc. (2)	15-Jul-13	Rocky Point (2)
1-Oct-12	Spawner Sanc. (2)	18-Jul-13	Sabin Point (1)
2-Oct-12	Hog Island (2)	22-Jul-13	Hog Island (1)

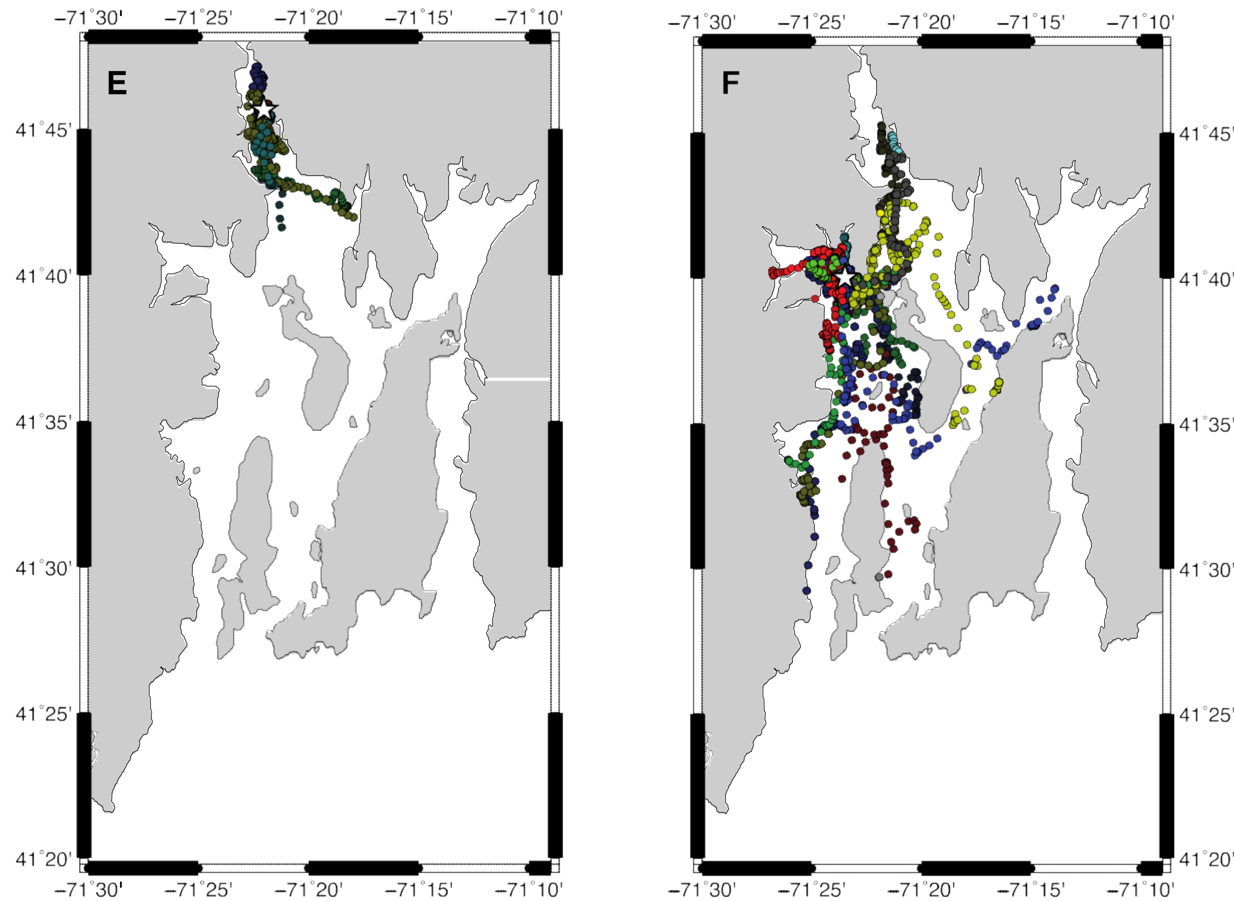


Figure 4-6 (continued). Maps showing tracks for all drifters release from Sabin Point (E) and the Spawner Sanctuary (F). Each color represents an individual drifter track and the white star denotes the release location.

than a week (Table 4-4) and were inspected quickly following each sampling interval. The sampling program was abandoned after one week due to a lack of bivalve larvae in any of the samples collected up to that point. Why wasn't a plankton net attempted to see if it was an equipment issue or simply a timing issue?

Discussion:

Drifters

We can compare the drifter tracks (Objective 4) to the locations of passive particles released in the ROMS simulations (Objective 3) as a means to validate the ROMS results. This is not a direct comparison because the drifters were released from late spring through early fall 2012 and 2013, whereas the model results are based on forcing (e.g. wind and freshwater) during the late spring of 2006 and 2007. Thus the conditions experienced by the particles in the model and the drifters can be quite different. In addition, particles were released in the model at all stages of the tidal cycle, across two precipitation events (2007) and observed wind conditions in May and June of 2006/2007. The advantage of the model is that the particle locations depict an integrated result across a wide range of wind and tidal conditions, something that cannot be done with physical drifters. Finally, drifters often run aground prior to the 10-day results obtained in the model. Unfortunately, the drifters do not perfectly mimic microscopic larvae. On the other hand, the spatial resolution of the model does not approach that of the real world. Nonetheless, the drifter-model comparison is instructive with regard to the general trends.

Generally, the model results and drifter results are very similar, strikingly so in some cases. One example is the results from Rocky Point releases (Figure 4-7). Here, the northward extent of the

Quahog Larval Sampling:

Our inability to capture bivalve larvae in the plankton pump sampling we conducted was a surprising result. Microscopic analysis of the plankton samples revealed a wide variety of larval stages of other marine invertebrates, indicating that the dearth of bivalve larvae was a real phenomenon rather than a failure of the equipment or protocol to collect larvae (see note above about the plankton net). In addition, bivalve larvae were assumed present in the system. Based on previous work by Jeff Mercer (RIDEM personal communication), he indicated that bivalve larvae could be retrieved by plankton net tows within the water column at almost any time during the summer months at many locations in NBay, including spots close to our designated sampling sites. Mercer's observations are supported by three reports of quahog larval distribution in NBay that report larvae present in the bay during the interval sampled in this study (Landers 1954, Rice and Goncalo 1995, Butet 1997). However, all three studies sampled larvae either much higher in the water column (1.6 m deep) or at the surface (0.3 m deep).

Two sampling factors most likely contributed to the lack of bivalve larvae in the bottom plankton samples. These are the plankton net mesh size (150 μm (above you said 200) and/or the location of the pump (0.5 m off the bottom). Quahog larvae approach a size of 170 to 240 μm in length as they approach competency while they start their development as trochophores between 50 to 90 μm (Loosanoff and Davis 1950, Landers 1954). Therefore, the plankton net used in the current study was selected to target only those individual larvae that were large and therefore assumed to be near metamorphosis. Other studies sampling quahog larvae in NBay used much smaller mesh nets (60 to 90 μm; Landers 1954, Rice and Goncalo 1995, Butet 1997) allowing them to sample the entire range of quahog larval stages. With mortality estimates approaching 95% over the course of quahog larval development (Butet 1997), the absolute numbers of competent quahog pediveligers is much less than the numbers of earlier stage larvae captured in the field. Therefore, by only selecting the larger pediveligers in the quahog larval population, we are sampling a much smaller proportion of the larval population than the previous researchers. Nevertheless, one would anticipate collecting reasonable levels of competent larvae, as all three previous studies were able to collect late stage quahog veligers in the same area we sampled during the sampling interval that we covered (Julian days 212 to 219), albeit that they were sampling higher in the water column. This is particularly reasonable, considering that we sampled 4 times as much water (or more) as the previous studies.

By focusing our samples to the level of 0.5 m from the bottom, we were working from the assumption that late developing bivalve larvae tend to swim at or near the substrate as they become competent to metamorphose (Bayne 1965). It is often stated that as bivalve larvae become competent, their swimming behavior, as well as their overall buoyancy, tends them to swimming at the substrate water interface, especially under flow conditions (Johnsson 1991). It is reported that they proceed to "bounce" along the substrate as they are seeking appropriate habitat within which to settle (Keough and Downes 1982, Butman 1986, Butman *et al.* 1988). Under some circumstances, when water flow exceeds certain thresholds, they become incorporated in the substrate hugging boundary layer flow (Pawlik *et al.* 1991, Johnsson 1991). Although the direct evidence is not available, the results from this exercise suggest that the competent bivalve larvae are not located in the depth profile of 0.5 m above the sediment surface. Therefore, they are either swimming higher in the water column or are more closely associated with the sediment surface as they explore their future habitat (you didn't include two other possible reasons. 1for some unknown reason they weren't present or 2. perhaps weren't captured with the pump sampler). In which case, we were not able to sample them with the plankton pump that we developed. Further studies are required to address this question.

Summary of conclusions:

- Drifter
    - We designed a drifter that, when deployed in Narragansett Bay, was able to collect data and not run aground for 5-10 days post-deployment.

    - Drifter tracks (49) were collected from six release points that corresponded to particle release points utilized in the ROM model for tracking quahog larval distributions in NBay.
    - On the whole, the results of the drifter deployment supported the particle distribution patterns generated by the ROMS.
    - There may be areas in the ROMS model (i.e. Greenwich Bay) where work is needed to improve the ability of the model to forecast particle transport from hydrodynamic forces.
- Quahog Larval Sampling
    - A plankton pump was developed to sample plankton at the level of 0.5 m from the substrate surface.
    - The pump was utilized at 7 sampling sites on 5 sampling days that corresponded to a time interval when late-stage quahog larvae should be present in the water column and where model projections indicated that the locations would either have high or low concentrations of larvae in the vicinity.
    - No bivalve larvae were collected at any of the locations during any of the sampling attempts.
    - The results of a lack of competent quahog larvae in the sample suggest that the late-stage pre-metamorphic larvae may be more closely associated with the substrate than previously thought. (This cannot be a conclusion from this effort. There are other possible reasons that you did not eliminate.)

References:

Arnold, W.S., G.L. Hitchcock, M.E. Frischer, R. Wanninkhof and Y.P. Sheng, 2005. Dispersal of an introduced larval cohort in a coastal lagoon. Limnol. Oceanogr. 50: 587-597.

Bayne, B. L. 1965. Growth and the delay of metamorphosis of the larvae of *Mytilus edulis* (L.). Ophelia 2(1): 1-47

Becker, D.S. 1978. Evaluation of a hard clam spawner transplant site using a dye tracer technique. *Special Report New York State University (SUNY)*, Feb. 1978. Stony Brook, NY. 42 pgs.

Bergondo, D.L. 2004. Examining the processes controlling water column variability in Narragansett Bay: Time series data and numerical modeling. *Doctoral dissertation,* Graduate School of Oceanography, University of Rhode Island, 136 pp.

Bergondo, D. and Kincaid, C. 2007. Development and Calibration of a Model for Tracking Dispersion of Water from Narragansett Bay Commission Facilities. *Narragansett Bay Commission Annual Report*.

Butet, N.A. 1997. Distribution of quahog larvae along a north-south transect in Narragansett Bay. *M.Sc. Thesis*, University of Rhode Island, South Kingston, RI. 85 pgs.

Butman, C.A. 1986. Larval settlement of soft-sediment invertebrates: some predictions based on an analysis of near-bottom velocity profiles. In: Nihoul, J.C.J. (ed.) Marine Interface Ecohydrodynamics. Elsevier, Amsterdam, 487-513

Butman, C.A., J.P. Grassle, and C.M. Webb. 1988. Substrate choices made by marine larvae settling in still water and in a flume flow. Nature, Lond. 333:771-773.

Davis, R. 1985. Drifter Observations of Coastal Surface Currents During CODE: The Method and Descriptive View. J.Geophys.Res.,90,4756-72.

Deshieneks, M.E., E.E. Hofmann, J.M. Klinck, And E.N. Powell. 1996. Modeling the vertical distribution of oyster larvae in response to environmental conditions. Mar. Ecol. Prog. Ser. 136:97-110.

Erskine, A.J., S. Snyder, M. Southworth, K. Hudson, J. Shen, and R. Mann. 2005. So how far do oyster larvae disperse? A dye study simulation. *J. Shellf. Res.* 24[2]:647.

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"An assessment of quahog larval supply and distribution in the upper Narragansett Bay with a focus on spawning sanctuaries and alternative area management strategies."

Lead PI: Dr. Dale Leavitt—Roger Williams University

1. How closely did the research team follow the original planned scope of work?

I found the work conducted to track the original proposed plan of work quite well. To jump ahead to question 2, their first stated goal (re: reviews of stock assessments) was transferred RI DEM, but the authors gave a reasonable rational as to why what was, and they also provided some useful background information even in the absence of that goal actually being worked on -

2. If there were differences between scheduled and completed tasks, did the project team address these and explain why there were differences?

Please see above in question 1

3. In the results, analysis, and discussion sections of the report, did the team answer their original research question(s)?

I think they did, and fairly comprehensively. In fact, I appreciated the arrangement of this report, which laid out the original objective, the work conducted, the findings, and the summary information in an easy-to-follow format. There were many parts to this project, and the report makes it easy to follow each segment.

4. Were analytical techniques appropriately used? Was the experimental methodology statistically sound and supportive of the conclusions drawn?

While I'm not a stock assessment or hydrodynamic expert by any means, the methodology indicates to me that the investigators were cognizant of proper techniques, and I liked the reinforcing activities: the comparisons between the bullrakes and the dives even included an offset for the distance between the handle and the basket of the bullrake, and the drifters seemed to generally corroborate the findings of the particle modeling.

The lack of quahog larvae is as much of a mystery to me as it was for the investigators. I would not have anticipated a zero result there. The equipment seemed appropriate, but since I would have guessed that at least some larvae would have been retained/observed, I would strongly urge a thorough walk-through of their sampling equipment and process. Even if the sampling location a little above the sediment were somewhat off, I'd assume that some larvae are present in that zone.

5. Was the raw data included in the appendix complete?

I did not see any raw data included in the package I was sent.

6. Was the information clearly presented? Were figures and tables appropriately used?

Yes, very much so, and credit to the grant program organizers in requiring a clear and thoughtful layout for the final report.

7. In the discussion section, did the team offer comments on results including observations made while conducting the research; explanations of why a particular gear, sampling strategy, or laboratory technique may or may not have worked as anticipated; how project research results may have advanced the knowledge base about the research topic area; and ideas about follow up research?