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Sampling high biomass but rare benthic animals: Methods for surveying commercial clam stocks using a hydraulic dredge

Daphne Munroe[a,*], Jason Morson[a], Sarah Borsetti[a], Daniel Hennen[b]

[a] Rutgers University, Haskin Shellfish Research Lab, USA
[b] NOAA Northeast Fisheries Science Center, USA

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ABSTRACT

Atlantic surfclams and ocean quahogs are large-bodied clams that inhabit the continental shelf of the Mid-Atlantic. Ecologically, they are the prevailing biomass on the shelf, yet in terms of numerical abundance they are not dominant in the benthic community and clams tend to be patchily distributed. The unusual characteristics of individual clams and their population distribution habits create difficult conditions for estimating overall abundance and biomass. Sampling and survey strategies need to be carefully tailored to these large-bodied, patchily distributed, infaunal animals to prevent undersampling or introduction of bias in surveys. Additionally, to compare data collected across multiple survey projects, consistent and comparable sample collection methods must be used. The ability to compare data across multiple surveys improves regional assessments of status and changes in populations. This paper provides recommendations, based on established best practices, for performing surveys of commercial clam stocks that should improve the quality of the data generated by those surveys and allow for data collected among various surveys and teams to be directly compared.

1. Introduction

The Atlantic surfclam (*Spisula solidissima*) and ocean quahaugh (*Arctica islandica)* are large-bodied clams that live in the sandy soft-bottom habitats along the MidAtlantic continental shelf of the United States. They are important economic resources, supporting fisheries worth more than $50,000,000 USD (Murray, 2016). Ecologically, they are the prevailing biomass on the shelf, yet they do not dominate in terms of numerical abundance (Staff et al., 1985). For example, one square meter of bottom habitat may contain many hundreds of thousands of individual small worms but only one Atlantic surfclam, yet the cumulative biomass of those worms is less than the biomass (shell excluded) of the single clam. Clams tend to be patchily distributed, meaning that there may be dense aggregations in some areas while other areas are relatively sparse. The unusual characteristics of individual clams and their population distribution habits create difficult conditions for estimating overall abundance and biomass. Sampling and survey strategies need to be carefully tailored to these large-bodied, patchily distributed, infaunal animals to prevent undersampling or introduction of bias in surveys (Powell and Mann, 2016; Powell et al., 2017). This paper outlines the vessels, gears, and strategies that are most appropriate for surveying Atlantic surfclams and ocean quahogs.

2. Survey platform

There are a variety of traditional sampling gears commonly used around the world to survey benthic invertebrates. These include sleds and trawls, both designed to primarily target epibenthic organisms, various forms of grabs and boxcores, which are typically best-suited for surveying organisms buried in the benthos, and dredges, which have been used to survey both infauna and epifauna (Flannery and Przeslawski, 2015). More recently, underwater imaging has become a more popular form of surveying benthic invertebrates (Bergman et al., 2009). Acoustic imaging has even proven useful in the detection of organisms that bury within the benthos (Mizuno et al., 2022). Non-extractive survey methods like this can be especially useful when management regulations preclude deployment of extractive survey gears, for instance within a Marine Protected Area. However, most of these methods do not work well for sampling large, patchily distributed, infaunal invertebrates like surfclams and quahogs because they are either designed to only collect organisms on or just below the surface or are too small to cover the area required to collect a representative sample of patchily

* Corresponding author.
E-mail address: dmunroe@hsrl.rutgers.edu (D. Munroe).

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distributed organisms within a survey domain (Powell and Mann, 2016; Powell et al., 2017). A hydraulic dredge, a special type of dredge that samples both epifauna and infauna, is the most effective tool for sampling benthic animals like Atlantic surfclams and ocean quahogs (Fig. 1).

Hydraulic dredges were developed in the 1940′s for use in the growing clam fishery (Parker, 1971). These dredges use high-pressure jetted water at the leading edge of the cage-style retention chamber to fluidize the bottom and collect clams with limited damage and minimal bycatch (Smolowitz and Nolk, 1982; Serchuk and Murawski, 1997; Moschino et al., 2003; Gaspar et al., 2013). These dredges tend to be large and heavy, requiring specialized vessels containing hauling winches, customized retrieval platforms, and large pumps that supply pressurized water to the dredge through large rubber hoses (Fig. 1). Because they are equipped with and can handle a hydraulic dredge, it is common to perform science experiments and surveys using commercial clam fishing vessels (Rambaldi et al., 2001; Morello et al., 2005; Hennen et al., 2016). Hydraulic dredges have been effectively used in other parts of the world to quantitatively evaluate shellfish communities (Peharda et al., 2010) and survey clam biomass and abundance (Hughes and Bourne, 1981; Hauton et al., 2007) as well as being the platform of choice used to survey surfclam and quahog stocks in the MidAtlantic (Northeast Fisheries Science Center (NEFSC), 2022). The large size of the dredge enables it to efficiently sample a large area, and the hydraulic jets allow collection of buried macrofauna, making commercial clam fishing vessels with hydraulic dredges the most effective sampling tool for quantitatively sampling sparse or patchy large-bodied clams.

One challenge to using a commercial hydraulic dredge to sample surfclams and ocean quahogs is that pre-recruit sized clams (those not yet recruited to the fishing gear) are poorly retained (Sala et al., 2017). These commercial dredges are designed to have very little bycatch and to have a specific size-selectivity that allows only larger, older clams (shell length >120 mm and ages >4–6 years in surfclams (Chute et al., 2016), and length >80 mm and ages >60–90 years in ocean quahogs [Pace et al., 2017)) to be retained while smaller clams and unwanted debris pass through the gaps between bars in the retention cage. One workaround that allows a commercial dredge to catch small pre-recruit clams in a survey is to line the dredge with wire mesh, which effectively reduces the spacing in the retention cage to the size of the holes in the mesh. A lined dredge retains almost everything it encounters, including a great deal of bottom sediment and shell hash (Hennen et al., 2016), making processing and sorting the catch an arduous task. Therefore, using a lined dredge to retain smaller clams comes at a cost in terms of survey efficiency because the dredge fills quickly, so only very short (30–45 s long) tows can be made, restricting tows to a relatively small area and necessitating increased sampling effort to achieve similar coverage. Additionally, the mass of catch retained by a lined dredge can create an unsafe condition for ship operation because of the weight being hauled by the winches. The liner itself can also be easily ruptured or pulled loose and requires frequent inspection and repair between tows, further slowing the survey process. The costs and benefits of this strategy in a survey should be carefully considered with respect to the overall goals of the survey.

3. Sample collection

Sampling station locations should be selected in advance, randomly within the survey region. In cases when pre-selected tow locations prove unsuitable during the survey (e.g., they are located over buried cables), the tow location should be moved to a suitable location within one nautical mile of the initial randomly selected location. Each tow should be standardized. This is typically done by holding scope and manifold pressure constant, and towing for a set amount of time at a constant towing speed (vessel over ground). For example, the U.S. federal clam survey performs tows using a standard commercial hydraulic dredge with a 3:1 scope and manifold pressure of 135 psi that is towed for 5 min at a speed of 3.0 knots (target tow distance 500 m (Northeast Fisheries Science Center (NEFSC), 2017)). The target tow distance is rarely equal to the bottom that is sampled because the dredge will begin fishing some time after set out (the dredge begins fishing the bottom when it begins towing on the hawser tow line), and will continue fishing for some time during haul back as the haulback wire engages, and may lift away from bottom contact during a tow due to surface waves and/or uneven bathymetry (Weinberg et al., 2002). At a minimum, the location of the start and end of each tow should be recorded; however, depth and tilt sensors can be used to accurately estimate the total area fished to adjust to the realized swept area as the amount of additional bottom contact time will vary with several conditions, including water depth, towing scope, weather, bottom roughness, and inclination (Weinberg et al., 2002). More detail about use of tilt sensors and manifold pressure sensors can be found in Appendix 11 of Northeast Fisheries Science Center (NEFSC), 2017.

If using a standard commercial surfclam dredge (~3.5 m wide) and maintaining a target tow distance of approximately 500 m (as detailed above), a single sampling station should cover ~1600 m^2. How many stations to sample in a survey should be tailored to the abundance and patchiness of the clam resource in the area to be surveyed. The optimal station density for a given survey area can be estimated from prior data (Cochran, 1977). Data resources that can be used to optimize clam survey strategies include prior federal, state, or independent surveys. These data sources can provide an estimate of the expected data variability that can be used in a power analysis to evaluate the sample number required to estimate overall abundance. An example from a recent study done off the coast of New Jersey demonstrated that in an ~32 million m^2 area of patchily distributed surfclams, collecting

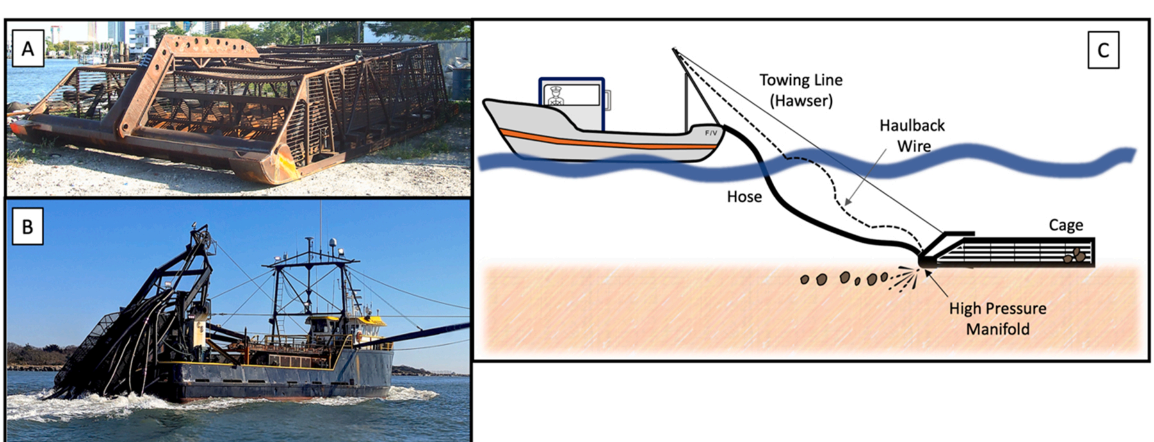

Fig. 1. Hydraulic surfclam dredge (A) and vessel (B) and schematic of how the vessel and dredge operate when fishing (C); not drawn to scale.

between 8 and 15 random samples with each sample accessing 0.001 % of the total domain to be surveyed (or, in combination, tows covering 0.008–0.015 % of the total study area) provided a median abundance approaching that of the true mean abundance (Powell et al., 2017). The optimal sampling strategy will vary with clam abundance and patchiness of the area to be surveyed and should be customized to that area. For cases in which the clam distribution changes spatially across the area to be surveyed, stratification of the survey area, based on abundance, habitat, sediment type, depth or other characteristics generating known changes in clam distribution, can further improve allocation of survey effort and overall survey results (Jacobson and Hennen, 2019).

Each tow should be assigned a unique tow identification name, and the following metadata associated with the tow should be recorded: station identification, latitude and longitude at the start and end of the tow, time at the start and end of the tow, water depth, manifold pressure, vessel speed, and weather conditions. To avoid bias caused by gear saturation, the catch from tows that are retrieved with a full or nearly full dredge should be re-towed for a shorter duration because a full (saturated) dredge will not allow the gear to continue collecting catch (Smolowitz and Nolk, 1982; Rago, 2005). The reduced duration for the repeat tow should be clearly noted on the tow metadata sheet, and the repeat tow should be made at a location that will avoid towing over the original catch.

The entire catch from each tow should be sorted by species and the total volume of each species measured (Northeast Fisheries Science Center (NEFSC), 2017). Standardized tows that are designed not to fill the dredge means that for most tows, the dredge is retrieved with relatively little catch in the dredge. When that catch is emptied into the hopper or deck of the vessel (which often involves dropping it from a height), the shell breakage rate tends to be higher than the breakage that would result from retrieving a full dredge load as would be the case during normal fishing operations. In that way, these 'survey-mode' tows tend to have a higher breakage rate than fishing practices do. Breakage rates or bycatch in the fishery would therefore have to be evaluated in a cooperative (e.g., dockside monitoring) manner, and not in a survey like the one we are describing here. The volume of debris (dead shells, rocks, etc.) relative to target catch may also be of interests, in which case the volume of debris should also be measured. A random subsample of a standard volume from the catch can be used to count the number of clams per volume. The counts from the volumetric subsample can then be scaled using the total catch volume to estimate total number of clams from a given tow. Shell lengths (the longest shell axis) of each clam in the subsample should be measured to estimate length frequency of the catch (Fig. 2). The subsample can also be used to measure meat weights (the total weight of the body of the clam without the shell) if biomass is of interest. If meat weights are to be collected, the individual clam shell length, whole weight (complete animal) and viscera weight (the body tissue only without the shell) must be recorded for each individual clam. Finally, shucked shells can be retained for further data collection such as aging or other shell measurements as desired. All station data including environmental variables, catch volumes, volumetric counts, length frequencies, and other metrics measured, should be recorded for each tow.

4. Selection of control stations

When hydraulic dredge sampling is conducted with the purpose of experimentally evaluating changes in clam abundance or size distribution at an impact site (e.g., before-after-control-impact experiments), careful consideration should be made about how to select control areas. Suitable control locations should occupy habitats similar to those in the impacted area; habitat considerations include comparable depths and bottom sediment types (Fay et al., 1983). Control areas should also be of approximately the same spatial footprint and contain initial (before) clam population demographics as similar as possible to the impacted area to be studied. Prior information from federal clam surveys and commercial fishing activity should be used to help inform decisions

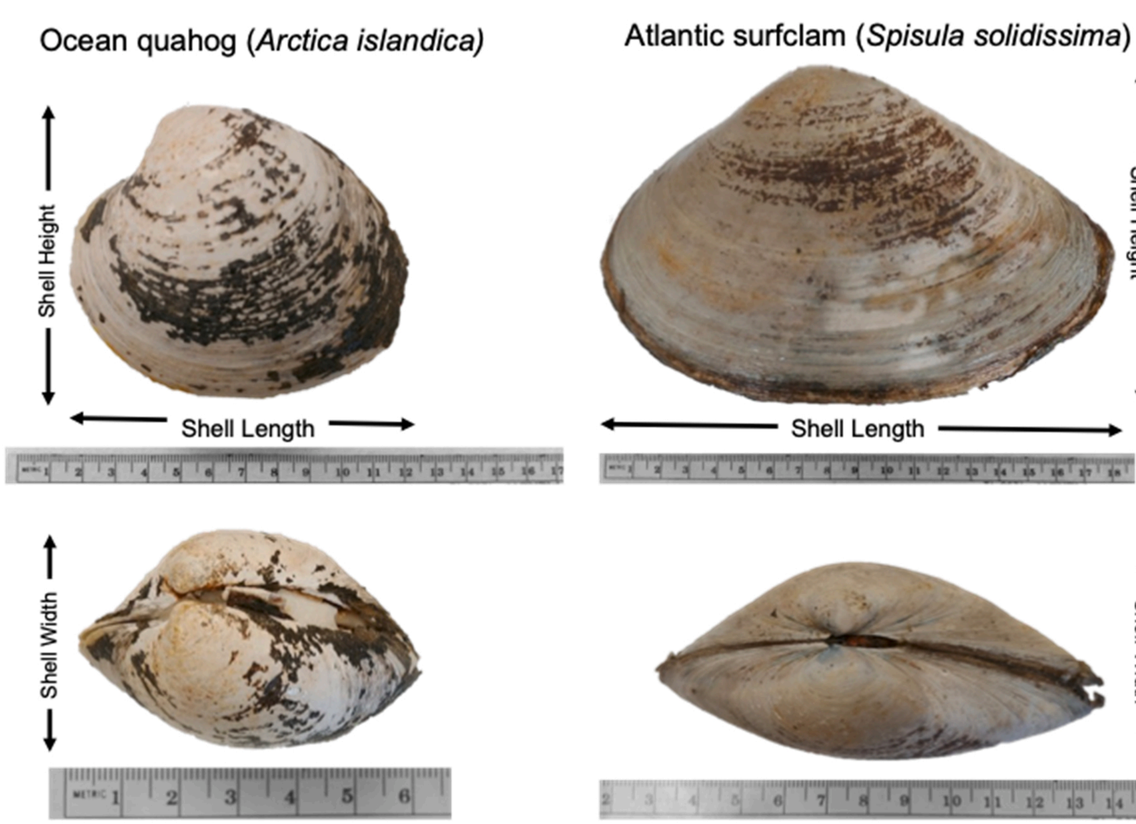

Fig. 2. Morphological shell measurements (mm) for ocean quahogs and Atlantic surfclams. Shell length is the longest shell axis and shell height is the umbo (hinge) to the growing edge. Shell width is the thickness of the shell at its widest across both valves.

about clam populations in the impacted area and select appropriate control areas.

5. Dredge calibration

Surveys can be conducted using hydraulic dredge gear that is not calibrated; however, these dredges do not collect all of the clams in the area towed in a given pass. The gear is inefficient to some degree and retains clams differently by size (i.e., is size-selective) by design. Because of these inefficiencies, abundance data collected and reported from uncalibrated gear will provide relative abundance information, not absolute abundance. Relative abundance can be used as an index to compare among stations, areas, and years for surveys performed with the same gear, representing a conservative estimate of the absolute abundance of clams. If absolute abundance is a desired outcome of a survey, the gear must be calibrated to allow calculation of the absolute abundance of clams at each station. The following sections provide guidance about how a dredge can be calibrated.

5.1. Efficiency

Capture efficiency of survey gear (the fraction of clams caught by the gear relative to the total on the bottom), and the catchability coefficient (the inverse of capture efficiency) (Morson et al., 2018), are used to convert the catch observed by the gear to the true abundance on the bottom and are an important source of uncertainty in stock assessments (Thorarinsdóttir et al., 2010). Efficiency can be estimated directly using depletion experiments (Latsa and Iribarne, 1997; Gedamke et al., 2004; Rago et al., 2006; Hennen et al., 2012; Wilberg et al., 2013; Poussard et al., 2021). Capture efficiency of many types of fishing or sampling gear will vary spatially (Powell et al., 2002, 2007; Doray et al., 2010; Marenghi et al., 2017) and temporally (Walters and Martell, 2004; Powell et al., 2007), likely due to changes in abundance, stock area, the environment, and the sampling gear itself (Wilberg et al., 2010). For this reason, it is important to perform depletion experiments in multiple locations that occupy habitats with different clam densities. To conduct depletion experiments, hydraulic dredge tows can be made repeatedly within a specified area until enough overlapping tows have been made to estimate efficiency. A rule of thumb used in real-time is to continue repeat tows until the catch drops below 20 % of the initial catch volume (Hennen et al., 2012). The total density of clams before the experiment (the total on the bottom) can be estimated from the rate of decline in catch as the area is repeatedly fished (Rago et al., 2006).

5.2. Selectivity

The bar spacing of the retention box in a hydraulic dredge is the primary means by which the catch is sorted by shell size (Sala et al., 2017). The sizes selected for in a given dredge may vary if the bar spacing varies, so an evaluation of the sizes selected for can help inform gear performance. Simultaneous sampling of the dredge used for the survey and another gear that is assumed 100% efficient is a method commonly used to estimate size-selectivity or catchability of shellfish survey dredges (Powell et al., 2002, 2007; Mann et al., 2004; Singh et al., 2014; Morson et al., 2018). Examples of gear that could be assumed 100 % efficient are scientific hydraulic dredges that allow bar spacing to be altered such that it retains very small clams (Hennen et al., 2016), a dredge with a liner (e.g., wire mesh) that retains all size classes (Smolowitz and Nolk, 1982), or divers who hand collect clams (Smolowitz and Nolk, 1982; Morson et al., 2018). The length frequencies of the catch using the two gears can be compared to evaluate the size selectivity of the survey dredge. The bycatch collected by an 100 % efficient gear could also be evaluated to estimate abundance or biomass of non-target species that may be disturbed from sediments during fishing operations.

6. Comparisons between multiple survey platforms

Since size selection, efficiency, catchability and spatial coverage often vary between gears and vessels, it is often advantageous to pool data from multiple surveys or vessels to index abundance or biomass (e.g., Serchuk and Wigley, 1989). To directly compare surfclam and ocean quahog abundance and distribution data collected on multiple cooperative fishing vessels, platforms could be cross-calibrated against one another by occupying the same survey stations at nearly the same time (paired-gear experiments) to obtain information about relative capture efficiency and relative size selectivity for each platform (Miller, 2013; Thorson and Ward, 2014; Kotwicki et al., 2017). With that information, indices from multiple vessels could be pooled and used collectively to make a single index. Alternatively, multiple indices can be combined using models such as the Conn method (Conn, 2010), VAST (Thorson, 2019), hierarchical modeling, or dynamic factor analysis.

CRediT authorship contribution statement

Daphne Munroe: Conceptualization, Writing – original draft preparation, Writing – reviewing and editing. **Jason Morson**: Writing – reviewing and editing. **Sarah Borsetti**: Writing – reviewing and editing, Visualization. **Dan Hennen**: Writing – reviewing and editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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