Efficiency of a scientific clam survey dredge and strategies for an improved experimental efficiency approach

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Introduction

A central tenet of sustainable fisheries management is the ability to evaluate stock status and detect changes in stocks over time. Commonly, stock surveys are used to achieve these goals, and the success of fishery-independent surveys relies of the use of unbiased sampling gear and an understanding of the efficiency of that gear relative to the stock available to capture (Cadrin et al., 2016). Estimates of survey gear efficiency allow absolute abundance to be inferred from observations of catch per unit effort and provide catchability estimates for stock assessment models (Delargy et al., 2023).

Estimating gear efficiency empirically can be challenging, costly, and time-consuming (Nakayama et al., 2023). These experiments can be easier to perform for sedentary benthic species such as clams or oysters (Hennen et al., 2012; Morson et al., 2018) that, in contrast to mobile species, presumably do not redistribute in space over the course of the experiment. Nonetheless, precise knowledge of spatial coverage of each sample and the total area sampled for a given experiment is difficult to assess in real time (Walter et al., 2007) and model processing often is done after an experiment is complete leading sometimes to experimental efforts that fail to produce efficiency estimates once data processing is complete. Methods to improve the confidence in data integrity and experimental success in real time would improve the data provided by these experiments and support more efficient use of resources.

Pair-wise comparison of catch volume and size composition among survey platforms can serve as an efficient means to evaluate relative gear performance and to support estimates of efficiency (Nakayama et al., 2023). Indeed, paired tow data can also be used to infer dredge efficiency of one gear for which efficiency is unknown from the known efficiency of the other gear (Fifas et al., 2004; Delgary et al., 2023). Additionally, a comparison of towed gears with varying mesh sizes can support inferences about how effectively different mesh sizes retain size classes of catch (Millar and Fryer, 1999).

Hydraulic dredges jet water along the leading edge of a box dredge to fluidize sediments and harvest clams (Serchuk and Murawski, 1997; Gaspar et al., 2013). The width of the gap between bars composing the box serves as the 'mesh' size that retains catch. These dredges are specialized fishing gear that require dedicated fishing boats to operate them; therefore, scientific experiments and surveys targeting commercial clam stocks often conduct operations cooperatively aboard commercial vessels (Rambaldi et al., 2001; Hennen et al., 2016, NEFSC, 2017). Hydraulic dredges are used extensively to sample benthos and study shellfish communities (Peharda et al., 2010) and to survey clam population biomass and abundance (Hughes and Bourne, 1981; Hauton et al., 2007). Given their large size, hydraulic dredges can sample benthic macrofauna over large areas of the bottom, making them an effective tool for quantitative surveys of patchy large-bodied clams.

The U.S. federal surfclam (*Spisula solidissima*) fishery was the first federal commercial fishery management plan (FMP) established (Adelaja et al., 1998), and since FMP establishment in 1977 the surfclam stock has been assessed using quantitative fishery-independent surveys (Hofmann et al., 2018). These surveys occur on commercial vessels and use hydraulic dredges with experimentally derived efficiency estimates (Hennen et al., 2016). This report details results from experiments aimed at quantifying the performance of a novel surfclam survey platform designed as a modified commercial dredge to be used for scientific surveys. The dredge is based on a design conceived by fishery partners and architectural drawings funded by the NSF Science Center for Marine Fisheries (SCEMFIS). The catch performance of the science dredge was evaluated with direct comparison to the dredge used to collect long-term datasets used in federal management of the surfclam stock (NEFSC, 2017). In addition, a series of depletion experiments were performed using the new NJ RMI - SCEMFIS dredge to estimate capture efficiency using strategies that can improve the efficiency and reliability of such experiments for other platforms. The results presented will allow integration of the data collected on this new survey platform to be used to make absolute clam abundance estimates and to integrate data with previously collected datasets.

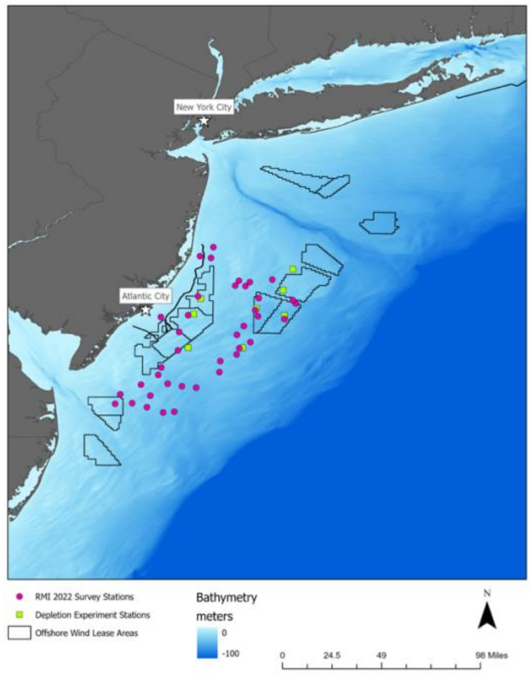
Methods

Paired Surveys Experiment

Fishery cooperative surveys for surfclams were conducted between August 18-22, 2022, on two fishery survey vessels, the *F.V. E.S.S. Pursuit* and the *F.V. JoeyD*. At 48 m (157 ft.) long, the *E.S.S. Pursuit* is a larger vessel than the 30 m (99 ft.) long *F.V. JoeyD*. The *E.S.S. Pursuit* also can carry two 4 m wide dredges (only one was used in this survey), with a bar spacing on the dredge that is 3.5 cm (1.375 in.), and a manifold pressure at depth of 130 pounds per square inch (PSI) on average. In contrast, the *F.V. JoeyD* carries a single 2.5 m wide dredge with narrower than normal bar spacing at 2.0 cm (0.8 in.), and a manifold pressure at depth of 160 PSI on average. The *E.S.S. Pursuit* has a catch efficiency, established using previous depletion experiments, of 0.67 (NEFSC, 2017); the *F.V. JoeyD* has no previously known efficiency estimated.

Each vessel collected surfclam samples using standardized hydraulic dredge tows at 39 survey stations off the coast of New Jersey in water depths ranging from 13 to 48 m (Figure 1). At each station, each vessel conducted a 5-minute tow at approximately 3 knots following standard protocols used in the NOAA federal clam survey (NEFSC, 2017; Munroe et al., 2023). For all tows, a tilt sensor (Star Oddi DST tilt) was fixed to each dredge and continuously measured pitch, roll, and yaw of the dredge, and a GPS was used to record vessel speed and location during each tow. These recorded data were used to evaluate the bottom area contacted during each tow to estimate swept area per tow. A pressure sensor (MadgeTech PR1000) attached to the manifold recorded water pressure within the dredge manifold to ensure water pressure remained consistent for each tow.

Figure 1: Locations of the survey stations occupied in 2022 by both vessels (pink circles) and the 2023 depletion stations (green circles). Offshore wind lease areas outlined with black polygons for reference.



The catch from each tow was sorted by species on deck and the total volume (in bushels) of surfclams caught was measured. A subsample (1 bushel) of the surfclam catch was counted (number of individual clams per bushel), and the shell lengths of all surfclams in the subsample were measured to the nearest 0.1 mm using a digital length board (SciElex Measuring Board). The subsample was expanded to total catch per tow by multiplying the subsample by the total volume caught. The total count of clams and observed length frequencies were used to estimate the meat weight of the surfclams in each tow using an established allometric weight-at-length relationship for surfclams (Marzec et al., 2010). Total catch and total biomass were then corrected to the area sampled in each tow (swept area) to standardize among the two different dredge sizes. The swept-area catch (number of clams per area sampled) and the swept-area biomass (wet weight in grams per area sampled) from the two vessels were compared pairwise across all 39 stations using a paired t-test to evaluate the relative catchability among platforms. The length frequency caught across all 39 stations was compared among the two survey platforms using a Kolmogorov–Smirnov test, and the selectivity ratio (*S*) at length (*L*) among the two survey platforms was calculated as the ratio of the catch per unit effort (CPUE) at length of the two surveys following Kotowicki et al. (2017):

$$S_{L,JoeyD,Pursuit} = \frac{CPUE_{L,JoeyD}}{CPUE_{L,Pursuit}}$$

Depletion Experiments

From August 15-18, 2023, eight locations were used to conduct separate depletion experiments (Figure 1) on board the *F.V. JoeyD*. These depletion experiments provide data that can be used to directly estimate dredge efficiency (Rago et al., 2006; Hennen et al., 2012; Wilberg et al., 2013; Poussard et al., 2021). The locations of the experiments spanned a range of depths from 25 to 43 m (82 to 141 feet), bottom types, and clam abundances because capture efficiency of fishing gears is known to vary with these parameters (Wilberg et al. 2010; Delargy et al., 2023). At each depletion experiment location, a target area (50 m wide by 500 m long, that follows the local bathymetry to produce tows that are relatively level) was identified and mapped onto the vessel's chart plotter so that tows could be made repeatedly in one location until the location was deemed 'depleted' of clams. For each tow, the catch was sorted by species, the total volume of surfclams was measured and the number of clams in a one-bushel subsample was counted. For tows catching less than one bushel, all clams were counted. In each experiment, the first tow and every third tow after the first, shell lengths in a one-bushel subsample were measured. A GPS receiver (ArrowGold GNSS) was used to record location every 2 seconds at a resolution of <0.5m; location information of each tow was passed to ArcGIS and ArcPy after each tow to evaluate tow overlap. Tow overlap was estimated by setting a buffer distance in ArcGIS of 1.25 m on either side of each tow track to make a polygon for each tow, then summing the total areas of overlapping tows (polygon overlap) and dividing by the total area occupied by all tows combined. The addition of tow-by-tow estimation of tow overlap has not been used in previous clam depletion experiments to our knowledge.

Three conditions were monitored after each tow to determine whether the location had been 'depleted': the depletion of catch volume, the depletion of catch abundance (number of clams caught), and tow overlap. Depletion of the catch volume and abundance was evaluated (1) relative to the highest catch observed in the experiment and (2) using a depletion curve fit to the time series of the catch. When the catch (both volume and number caught) dropped below 20% of the highest catch observed, and the slope of the depletion curve was below 20% of the maximum slope, the catch was considered depleted. Additionally, the tows were considered sufficiently overlapped when 80% of all area towed was overlapped by a minimum of two, and possibly more, tows. When all three of these conditions were met, the experiment was considered complete. Previous depletion experiments have used catch volume of 20% of the highest catch observed as a rule-of-thumb to determine experiment completion (Hennen et al., 2012); however, our approach to require depletion by volume, abundance, curve fitting, and spatial overlap is novel and provides greater assurance of experimental success.

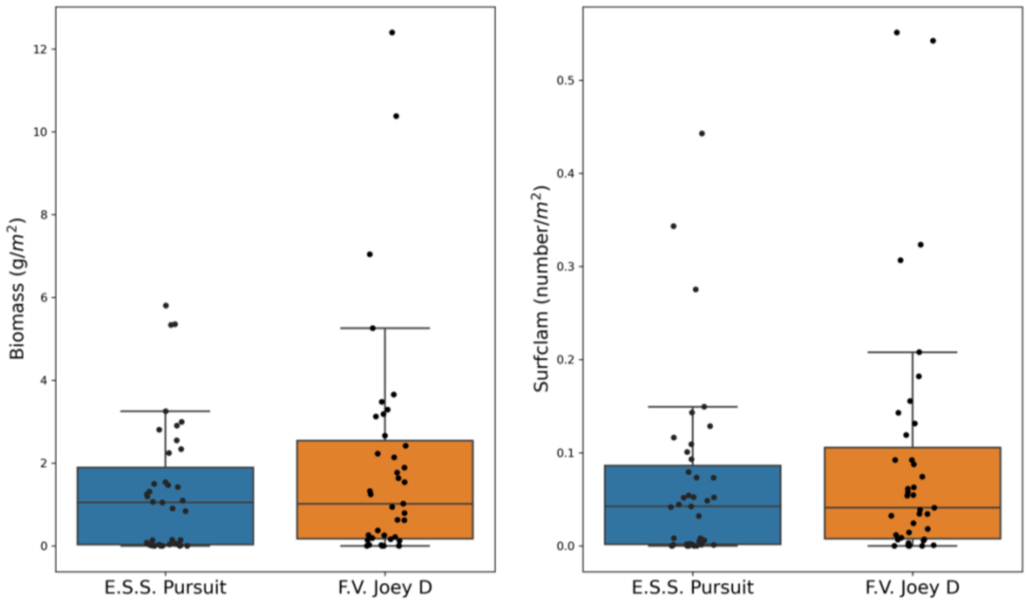
The catch and tow track location data for each experiment was used to estimate the dredge capture efficiency for each experiment following Hennen et al. (2012). In this analysis, a sequential hit matrix for the area covered by each tow was used to estimate the amount of bottom contacted by the dredge repeatedly over the course of a given experiment. The matrix that was used for each experiment had a spatial resolution of 1.0 cm and encapsulated all tow locations. For each tow track, the number of grids in the hit matrix that are contacted by the dredge was evaluated and the number of times that a given grid is contacted across all tows was calculated. A Patch-model (Rago et al., 2006) was then used to estimate clam density and dredge efficiency for each experiment.

Results

Paired Stations

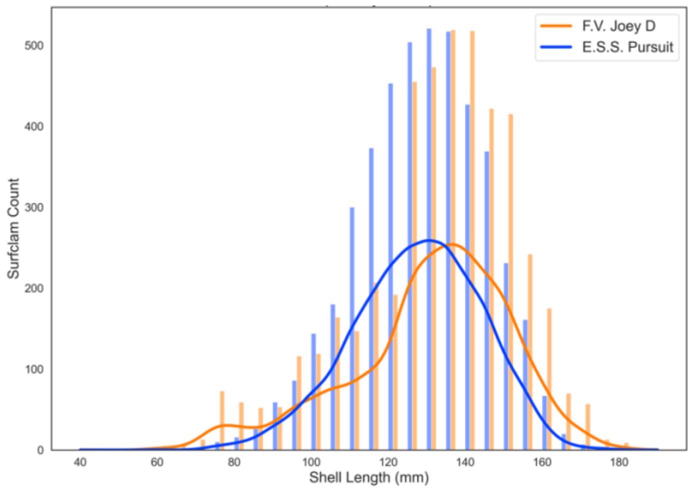
Across the 39 stations sampled in the 2022 survey, the *E.S.S. Pursuit* observed an average of 0.066 surfclams/m^2 ($\pm$ 0.097 st. dev.), and an average of 1.30 g/m^2 ($\pm$ 1.59 st. dev.) and *the F.V. JoeyD* observed an average of 0.092 surfclams/m^2 ($\pm$ 0.13 st. dev.), and an average of 1.96 g/m^2 ($\pm$ 2.74 st. dev.) per station. No significant difference was observed among the paired number of surfclams/m^2 (t-statistic=1.69, p=0.10, n=39) nor biomass/m^2 (t-statistic=1.79, p=0.081, n=38; one extreme outlier pair removed prior to analysis) observed by the two survey platforms (Figure 2).

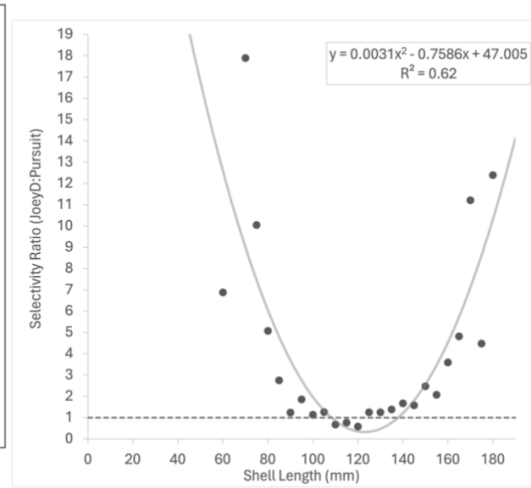
Figure 2: Boxplots of catch biomass (left) and abundance (right) for each tow (black circles) for the E.S.S. Pursuit (blue) and the F.V. JoeyD (orange).



The shell length size frequency of the catch among the two platforms differed significantly (K-S = 0.13, p<<<0.0001, d.f.= 38). The surfclam sizes caught by the *F.V. JoeyD* represented a wider range of sizes than that of the *E.S.S. Pursuit*, with both smaller and larger surfclams observed (Figure 3). The size selectivity ratio of the *F.V. JoeyD* relative to the *E.S.S. Pursuit* varied by clam size with the *F.V. JoeyD* showing higher selectivity for surfclams <90mm and >145mm (Figure 3).

Figure 3: Histograms of surfclam sizes caught in each 5 mm size bin across all 39 stations in 2022 (left) for the E.S.S. Pursuit (blue) and F.V. JoeyD (orange). The solid line overlaid on the histogram shows the smoothed distribution across all sizes. Selectivity ratio of the F.V. JoeyD relative to the E.S.S. Pursuit for each 5 mm size bin shown with black dots (right), with an exponential curve fit to the data (grey line) and the 1:1 ratio line shown with the dotted horizontal line.

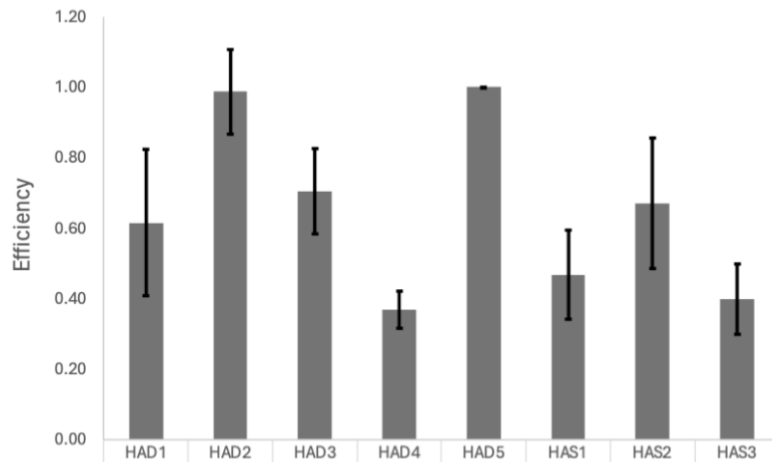




Dredge Efficiency

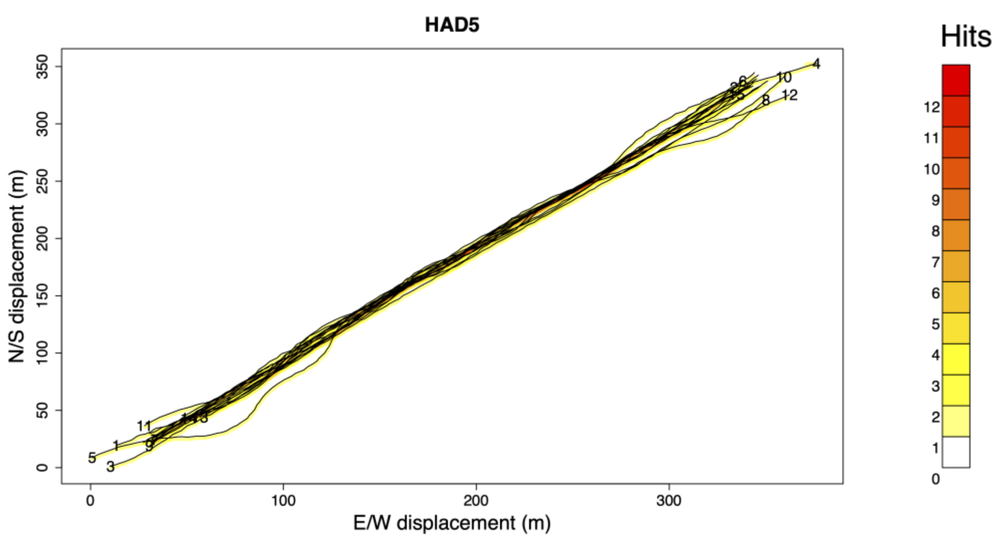
All eight depletion experiments performed provided data sufficient to derive an efficiency estimate (Figure 4). Across the eight depletion experiments performed, the number of tows required to complete the experiments ranged from 14 to 29 (median=16, mean=19; Figure 4), and the maximum number of hits in each hit matrix ranged from 10 to 21 (median=13, mean=14; Figure 4, 5). Efficiency estimated by the experiments ranged from 0.37 to 0.99 with an average efficiency across all experiments of 0.65 (± 0.24 st.dev.).

Figure 4: Efficiency estimated from each depletion experiment; error bars show the standard deviation of each estimate. Table below the x-axis shows the number of tows required to complete the experiment, the maximum catch (number of surfclams), and maximum number of hits estimate by the hit matrix for each experiment.



	HAD1	HAD2	HAD3	HAD4	HAD5	HAS1	HAS2	HAS3
Efficiency	0.62	0.99	0.71	0.37	1.00	0.47	0.67	0.40
Tows	14	16	16	29	15	23	15	21
Max Catch (n)	240	342	189	539	208	34	252	47
Max. Hits	11	12	13	21	13	16	10	15

Figure 5: Overlapping track data from one of the depletion experiments with color scale indicating the number of tow hits for each grid. This experiment required 15 tows to achieve depletion and had a maximum of 13 hits.



Discussion

In general, the two survey platforms evaluated in these experiments perform relatively similarly in terms of overall dredge efficiency with similar average efficiencies estimated for both using depletion experiments; the *E.S.S. Pursuit* previously estimated to be 0.67 and the *F.V. JoeyD* estimated to be 0.65 herein. The two survey platforms show no statistical difference in volume of clams caught; however, size selectivity differs with the *F.V. JoeyD* catching the smallest and largest size classes of surfclams more effectively than the *E.S.S. Pursuit*. These slight differences in the amount and sizes of catches among the two survey platforms could be related to several factors including the relative sizes and weights of the dredges relative to vessels (*F.V. JoeyD* is a smaller boat with a heavy but small dredge), differences in the manifold pressure used while sampling, and differences in the ability of captains in operating vessels.

Commercial gears can benefit from being size selective, yet survey platforms aim to observe the entire population and benefit from being less size-selective, retaining catch reflective of a range of the population (Kotwicki et al., 2017). In this study, the size frequency of the catch retained by the *F.V. JoeyD* represents both smaller and larger animals, whereas the size frequency in the *E.S.S. Pursuit* catch follows a nearly normal distribution centered on 130mm clams. Dredges designed as scientific sampling tools have been shown to catch smaller sub-market size classes better than commercial dredges (Fifas et al., 2004). The narrower bar spacing of the *F.V. JoeyD* likely generates some of this difference in size frequency of the catch. The difference in size selectivity of the two gears suggests that the *F.V. JoeyD* is more effective for unbiased sampling of a given population and supports the evidence for a dome-shaped selectivity of the *E.S.S. Pursuit* (NEFSC, 2017).

We did not attempt to spatially overlap the exact tow locations of the paired tow experiments. Rather, we made similarly standardized tows at the same target location. Given that clams are not homogeneously distributed in the bottom, the paired catches could have varied due to differences in the clams available for each occupied tow track; however, we would expect this to occur at random across the platforms and stations. Indeed, for each paired tow, the catches were sometimes higher for each platform almost equally, and trends in catch volume among the platforms were consistent in that for stations with high catch, both tended to see high catches and for stations with low catch, both tended to see low catch. At one station out of the 39, both survey platforms observed zero catch.

Estimating gear efficiency from a depletion experiment has certain challenges, one of which is the assumption that the location of the vessel is a reliable proxy for the position of the gear (Wilberg et al., 2013). Positional uncertainty translates to uncertainty in the hit matrix that is not explicitly accounted for in the patch model. The *F.V. JoeyD* probably has less positional uncertainty because the dredge is heavier than most commercial dredges due to the additional steel used to make smaller bar spacing, and therefore likely tracks the boat position much more closely than most gears. In addition, we used real-time track observations to improve our understanding of how well tows in each experiment overlapped as tows were made, making the experiments more efficient. Across all eight depletion experiments performed, all were successful in deriving an estimate of efficiency, thus our strategy should serve as a way to improve future experiments aiming to evaluate gear performance.

The availability of multiple survey platforms with known efficiency allows data comparison among platforms, supports integration of datasets over time, and offers platform redundancy. Increased capacity for data comparison and integration will support our ability to investigate regional patterns in stock biology and status that go beyond that available from a single survey platform, helping us understand the dynamics of these ecologically and commercially important stocks in a time of changing ocean conditions and uses.

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