APPENDIX D

HASKIN SHELLFISH RESEARCH LABORATORY
OYSTER DREDGE EFFICIENCY STUDY

The inherent efficiency of oyster dredges in survey mode

Eric N. Powell[1]
Kathryn A. Ashton-Alcox[1]
Joseph A. Dobarro[2]
Sarah E. Banta[1]
Meagan Cummings[1]

[1]Haskin Shellfish Research Laboratory
Rutgers University
6859 Miller Ave.
Port Norris, NJ 08349 USA

[2]Rutgers University Marine Field Station
Great Bay Blvd.
Tuckerton, NJ 08087

Abstract

In order to develop a quantitative stock assessment for the New Jersey oyster (*Crassostrea virginica*) seed beds, oyster dredge efficiency was measured on ten different oyster beds in Delaware Bay. Depending on size class and location, mean dredge efficiency for market-size oysters varied from 10.9% to nearly 100%. The sampled beds could be allocated into two groups, one characterized by low dredge efficiency and the other characterized by high dredge efficiency. The low efficiency group, Group 1, had mean dredge efficiencies for market-size oysters that ranged from 10.9% to 19.5%. The high efficiency group, Group 2, had mean dredge efficiencies for market-size oysters that always exceeded 45%.

A strong tendency existed for market-size oysters to be captured with higher efficiency than smaller oysters. In addition, live oysters tended to be captured with higher efficiency than boxes. Although a conclusion cannot be reached

unequivocally, the differential in dredge efficiency observed between Group 1 and Group 2 beds probably represents the difference between dredge efficiencies on beds routinely fished and those not routinely fished. The differential, about a factor of 4.5 for market-size oysters, indicates that variations in bed consolidation may have a large influence on dredge efficiency and may significantly bias estimates of abundance if not taken into account in stock assessments.

Introduction

Dredges are frequently used survey tools. Knowing the efficiency of the dredge is, therefore, paramount in a quantitative estimate of stock abundance. Dredge efficiencies have been evaluated for a number of bottom-dwelling commercial species including scallops, *Placopecten magellanicus* and *Zygochlamys patagonica* (Giguère and Brulotte, 1994; Lasta and Iribarne, 1997), surf clams, *Spisula solidissima* (NEFSC, 2000a), ocean quahogs, *Arctica islandica* (NEFSC, 2000b), and blue crabs, *Callinectes sapidus* (Vølstad et al., 2000).

The stock assessment for the New Jersey oyster seed beds utilizes a standard 1.27-m oyster dredge (Fegley et al., 1994). Quantification of this survey depends upon knowing the efficiency of the dredge under survey conditions. Oyster dredges are not among the most efficient of sampling gear. Estimates of dredge efficiency range between 2% and 32% in survey mode (Chai et al., 1992). As used by the industry in the normal routine of fishing, the dredge efficiency consistently falls into the lower portion of this range (Banta et al., in prep.).

In order to develop a quantitative stock assessment for the New Jersey oyster seed beds, we carried out a series of measurements of dredge efficiency for a standard oyster dredge (Figure 1). Because previous estimates had varied over a wide range, we conducted these measurements on a number of oyster beds covering a range of salinities and degrees of fishery impact to evaluate whether changes in bed environment and fishing history affect dredge efficiency.

Methods

Field program

Dredge efficiency measurements were conducted in summer 1999 and summer

2000 on ten different oyster beds in Delaware Bay. Eight of these were in New Jersey waters and two were in Delaware waters (Figure 2.)

Normally, three separate experiments were conducted on each bed. Time constraints limited the number to less than three in several cases. Each experiment was conducted in an identical manner in the following way.

The oyster boat *F/V Howard W. Sockwell* carried out a 1-min dredge tow using a standard 24-tooth 1.27-m dredge (Figure 1). Tooth length was approximately 44 mm. Mouth opening was 1.27 m *x* 51 cm. The bag consisted of 17 rows of 50.8 mm rings. During the dredge tow, a data logger recorded DGPS position and time at 5-second intervals. A second boat, the *R/V Zephyrus* ran immediately parallel but about 5-m off the oyster boat. A buoy was dropped from the *R/V Zephyrus* at the point immediately opposite dredge deployment and another immediately opposite dredge retrieval as the tow progressed.

The dredge haul was brought on board and a one-bushel sample taken for analysis. The remainder of the haul was measured volumetrically and discarded overboard. A buoyed 23-m transect line was dropped from the *R/V Zephyrus* near the first buoy and the line payed out towards the second buoy. Twelve collection sacks were affixed at equal intervals along this line. Divers were then deployed to sample along the transect line using an $0.5\,x\,0.5$-m quadrat (0.25 m^2). A random 0.25-m^2 sample was taken at the location where each collection sack was affixed. Divers attempted to retrieve all of the loose bottom material, including all live oysters and boxes. Collection was facilitated by the use of small hand-held scratch rakes. The divers were instructed to take only the loosely consolidated material on the surface that would normally be taken by the dredge. In most cases, quantitative retrieval was simple because the consolidated portion of the bed was near the surface. In a few cases, unconsolidated shell extended downwards for some distance. In these cases, the diver took the upper portion of the shell until the collection sack was filled.

Laboratory analyses

Each bushel sample and each diver sample was sorted into live oysters, boxes, and shell and other debris and the respective volumes measured. The longest dimension of each oyster and box >20 mm was measured. Swept area was calculated for each dredge tow from the 5-second position logs and the dredge width. The reciprocal of efficiency was calculated as:

$$q = \frac{\left(\frac{\sum_{i=1}^{12} number\ of\ oysters\ or\ boxes\ (diver\ sample)^{-1}}{number\ of\ diver\ samples * 0.25\, m^2}\right)}{\left(\frac{number\ of\ oysters\ or\ boxes\ (bushel)^{-1} * \#\, bushels}{m^2\ dredge\ swept\ area}\right)}$$

Statistical Analysis

Statistical analyses used Spearman's rank correlation and ANOVA on ranked data. When appropriate, differences within the ANOVA were resolved with comparisons that used the least squares means. For some statistical analyses, live oysters and boxes were split into three size classes: juvenile (20-63.5 mm), submarket (63.5-76.2 mm), and market ($\geq$76.2 mm).

Results

Mean values of q for each seed bed are provided in Table 1. Values of q for live oysters ranged from 1.54 (an efficiency of 64.9%) to 11.27 (an efficiency of 8.9%). With one exception, all the size classes of oysters and boxes were correlated with one another (Table 2). The efficiency of collection of shell debris, however, was much more rarely correlated with the efficiency of collection of live oysters or boxes and the correlation coefficients were consistently lower. Divers had difficulty determining when to stop 'digging' out cultch on some beds and this uncertainty in collection resulted in variation in 'catchability' for debris among diver samples.

Visual observation of Table 1 suggests that the sampled beds can be divided into two groups, those with relatively high values of q (low dredge efficiency) and those with relatively low values of q (high dredge efficiency). This observation was confirmed by ANOVA analysis comparing the efficiency of collection of market-size oysters between oyster beds (Table 3). Note that, in general, the beds Arnolds, Cohansey, Over the Bar, Lower Middle, and Ship John, hereafter termed Group 1, are usually significantly different from the beds Shell Rock, Bennies, New Beds, and Egg Island, hereafter termed Group 2, in this analysis (Table 3). Market-size live oysters were not collected at Nantuxent Point, but perusal of the remaining data in Table 1 suggests that, had they been, Nantuxent Point would have fallen within the latter group of beds.

The average values of q for Groups 1 and 2 are shown in Table 4. With the exception of market-size boxes and debris, the efficiency of collection of live oysters and boxes on Group 1 beds is significantly lower (a higher q) than the efficiency of collection of live oysters and boxes on Group 2 beds.

The efficiency of capture of market-size oysters was higher (lower q) than for submarket-size ($P = 0.04$) and juvenile oysters $P = 0.003$). The latter two were not significantly different. The averages recorded in Table 4 also suggest that the efficiency of capture of live oysters is somewhat higher than boxes. In fact, values of q were significantly lower for all live oysters relative to all boxes ($P = 0.002$), live submarket oysters relative to submarket boxes ($P = 0.04$), and juvenile live oysters relative to juvenile boxes ($P = 0.006$). Market-size live oysters and boxes did not differed significantly, although the mean of the former falls well below the mean of the latter, especially for Group 2 beds. Accordingly, boxes were collected with a lower efficiency than live oysters overall.

The two groups of beds differ in average salinity. Group 1 beds are upbay of Group 2 beds. However, the intensity of fishing also follows the salinity gradient. Visual inspection of samples showed that oysters were much more clumped in samples from Group 1 beds as a consequence of the much lower frequency of dredging that has historically occured on these beds. Clumping and reef consolidation might decrease dredge efficiency. If so, a correlation might exist between the amount of dredging on the bed during the preceding year and our measurement of dredge efficiency. We evaluated the significance of dredging using Spearman's rank correlations between the number of bushels taken per bed in 1999 and 2000 versus the measured value of q. The number of bushels taken is a reasonable surrogate for the total swept area of dredging (Banta et al., in prep.). All correlations were negative in accordance with the hypothesis that a higher value of q (lower dredge efficiency) should coincide with lower harvest rates. However, only the correlation with market-size live oysters was significant.

Discussion

Oyster dredge efficiency varied over a wide range among the oyster beds sampled in Delaware Bay. The range measured encompasses dredge efficiencies higher than those recorded by Chai et al. (1992) in Chesapeake Bay. In that study, dredge efficiencies varied from 2% to 32%. In this study, depending on size class and location, mean dredge efficiency for market-size oysters varied from 10.9% to nearly 100%. High efficiencies are achieved when the dredge is used in survey mode, with short 1-min tows that do not result in the complete filling of the dredge. The oyster fishery, as it routinely fishes, rarely achieves a dredge efficiency above 5% (Banta et al., in prep.) because the tows are longer and the dredge is routinely full when retrieved.

The range of efficiencies measured is large. Extreme values, whether high or low, probably are due to patchiness in the sampled area. Diver samples were not taken from the dredge tow path, but rather along a transect run parallel and close to the dredge tow path. Nevertheless, the sampled beds could readily be allocated into two groups, one characterized by low dredge efficiency and the other characterized by high dredge efficiency. The low efficiency group, Group 1, had mean dredge efficiencies for market-size oysters that ranged from 10.9% to 19.5%. The high efficiency group had mean dredge efficiencies for market-size oysters that always exceeded 45%.

A strong tendency existed for market-size oysters to be captured with higher efficiency than smaller oysters. Presumably, a greater tendency exists for the smaller oysters to pass between the dredge teeth or through the rings of the collection bag and, thus, not be collected. Dredge efficiencies were particularly low for juveniles, many of which may be attached to smaller pieces of cultch that are poorly sampled. Very likely, dredge samples routinely result in a significant bias against juveniles. In this study, market-size oysters were captured with about twice the efficiency of juveniles.

In addition, live oysters tended to be captured with higher efficiency than boxes. The difference was highly significant, particularly in Group 2 beds where boxes tended to be captured with an efficiency of about one-third the efficiency of living oysters. Several possible reasons exist for the lower capture efficiency of boxes. (1) Collection by dredge may result in disarticulation. This possibility is not supported by experiments designed to evaluate this source of disarticulation, however (Powell et al., in prep.). (2) Some boxes taken by divers may be deeper in the reef than the dredge normally samples. Efficiency of collection of debris was significantly correlated with efficiency of collection of total boxes in accordance with this hypothesis (Table 2), however the efficiency of collection of debris was also correlated with some live-oyster variables. Thus, a conclusive explanation for the variation in efficiency of capture between boxes and live oysters is not provided by the present analyses.

Box counts are routinely used as a method to estimate mortality rates in shellfish populations (Merrill and Posgay, 1964; Fegley et al., 1994; Christmas et al., 1997). The differential in dredge efficiency measured in this study could result in a significant bias in the live:dead ratio and a significant underestimation of mortality rate from box counts if diver collections are unbiased.

Why Group 1 beds yielded such low dredge efficiencies in comparison to Group 2 beds cannot unequivocally be identified. Group 1 beds are all upbay of Group 2 and, thus, exist at lower average salinities. Unfortunately, Group 1 beds also have been impacted less over the long-term by dredging because effort in the Delaware Bay oyster industry also follows the salinity gradient, with lower effort on the lowest salinity beds (HSRL, 2000; Fegley et al., 1994). We attempted to assess the influence of dredging using catch data for 1999 and 2000, without much success. However, whether the catch data for the year prior to sampling is the correct estimator of the effect of dredging is questionable. Visual observation, for example, shows that oyster clumps are larger and contain more living oysters on these upbay beds. These clumps, very likely, are more firmly attached to the underlying bed than are the oysters on Group 2 beds. Greater bed consolidation on the upbay beds (Group 1) would reduce the effectiveness of the teeth in scraping shell material up into the dredge and, consequently, reduce dredge efficiency.

Oystermen normally report that catch rates are lower on beds that have not been fished for a time and that catch rates improve after repeated dredging over a few days. Very likely, this repeated dredging breaks the bottom up and results in a substantial increase in the efficiency of capture. Although the conclusion cannot be reached unequivocally, it seems most likely that the differential observed between Group 1 and Group 2 beds represents the difference between dredge efficiencies on beds routinely fished and those not routinely fished. The differential is large, about a factor of 4.5 for market-size oysters, indicating that variations in bed consolidation may have a large influence on dredge efficiency and may significantly bias estimates of abundance if not taken into account in stock assessments.

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Legends for Tables

Table 1. Mean values of q (the reciprocal of dredge efficiency) for each of the size classes of live oysters and boxes, total live oysters, total boxes, and debris. Debris includes cultch and other debris. Dash indicates situations where diver sampling did not provide an adequate catch of that variable to permit an estimate of dredge efficiency.

Table 2. P-values from Spearman's rank correlations between the efficiency of capture of the various groupings of live oysters, boxes, and debris.

Table 3. P-values from comparisons of least squares means for the efficiency of capture of market-size live oysters among the sampled beds. No market-size oysters were collected at Nantuxent Point, hence this bed is not included in the table. Boxed area delineates the comparisons between Group 1 and Group 2 beds discussed in the text.

Table 4. Mean values of q (the reciprocal of dredge efficiency) for each of the size classes of live oysters and boxes, total live oysters, total boxes, and debris for two groups of beds. Group 1 contains Arnolds, Cohansey, Over the Bar, Lower Middle, and Ship John. Group 2 contains Bennies, Shell Rock, Nantuxent Point, Egg Island, and New Beds. Debris includes cultch and other debris. P-values record the results of ANOVA analysis comparing the two groups with respect to the variable listed as the column heading. NS, not significant ($\alpha = 0.05$).

Table 1

	Live oysters				Boxes				
Oyster Bed	Juveniles	Submarkets	Markets	Total Live	Juveniles	Submarkets	Markets	Total Box	Debris
Group 1									
Arnolds	10.30	2.22	6.46	9.26	10.05	8.81	10.04	9.74	7.47
Cohansey	12.80	7.96	7.81	11.27	17.62	50.54	11.40	18.83	37.23
Over the Bar	9.63	5.88	5.14	7.61	6.81	12.58	5.58	7.33	6.93
Lower Middle	9.33	7.69	6.23	8.80	8.09	7.92	13.40	8.31	15.26
Ship John	10.16	12.06	9.15	10.40	12.79	9.91	13.17	11.88	50.12
Group 2									
Shell Rock	4.16	2.84	1.99	3.70	5.37	4.55	2.44	4.71	12.45
Nantuxent Pt.	3.86	1.98	–	3.30	2.32	2.48	–	1.98	6.06
Bennies	2.57	2.31	1.17	2.32	6.70	4.01	5.48	5.58	5.20
New Beds	2.04	3.12	0.64	2.13	2.88	2.08	–	2.71	9.65
Egg Island	–	–	2.22	1.54	15.41	6.00	20.31	16.99	14.47

Table 2

	Submarket live oysters	Market live oysters	Total live oysters	Juvenile boxes	Submarket boxes	Market boxes	Total boxes	Debris
Juvenile live oysters	0.0013	0.0001	0.0001	0.0001	0.0001	0.0048	0.0001	0.1289
Submarket live oysters		0.0022	0.0005	0.0007	0.0008	0.0073	0.0002	0.0003
Market live oysters			0.0001	0.0001	0.0001	0.0019	0.0001	0.0167
Total live oysters				0.0001	0.0001	0.0047	0.0001	0.1128
Juvenile boxes					0.0001	0.0003	0.0001	0.0231
Submarket boxes						0.0030	0.0001	0.0136
Market boxes							0.0001	0.3216
Total boxes								0.0174

Table 3

	Cohansey	Over the Bar	Lower Middle	Ship John	Shell Rock	Bennies	New Beds	Egg Island
Arnolds	0.5529	0.5360	0.6912	0.2775	0.0310	0.0057	0.0207	0.1967
Cohansey		0.2597	0.3290	0.5651	0.0100	0.0019	0.0093	0.0972
Over the Bar			0.7895	0.1312	0.1478	0.0356	0.0645	0.4315
Lower Middle				0.1590	0.0645	0.0121	0.0351	0.3017
Ship John					0.0061	0.0014	0.0057	0.0539
Shell Rock						0.3778	0.3680	0.7253
Bennies							0.7784	0.3337
New Beds								0.3111

Table 4

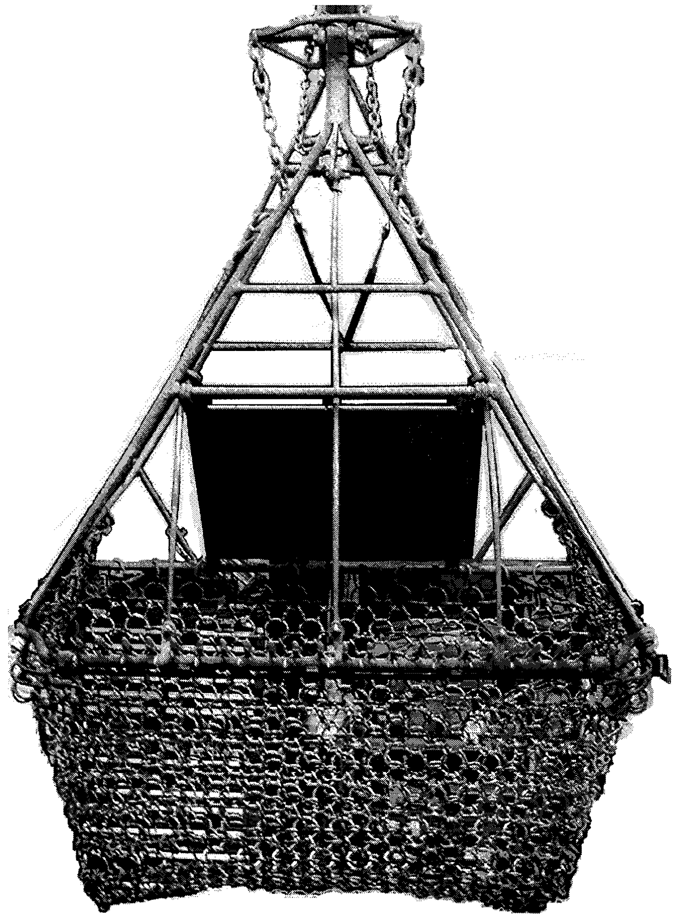
	Live oysters				Boxes				
Oyster Bed	Juveniles	Submarkets	Markets	Total Live	Juveniles	Submarkets	Markets	Total Box	Debris
Group 1	10.46	6.89	6.93	9.40	11.26	18.98	11.00	11.47	21.49
Group 2	3.33	2.57	1.54	2.83	6.78	4.03	8.85	6.50	9.55
P-value	0.0009	0.04	0.0001	0.0002	0.04	0.0008	NS	0.02	NS

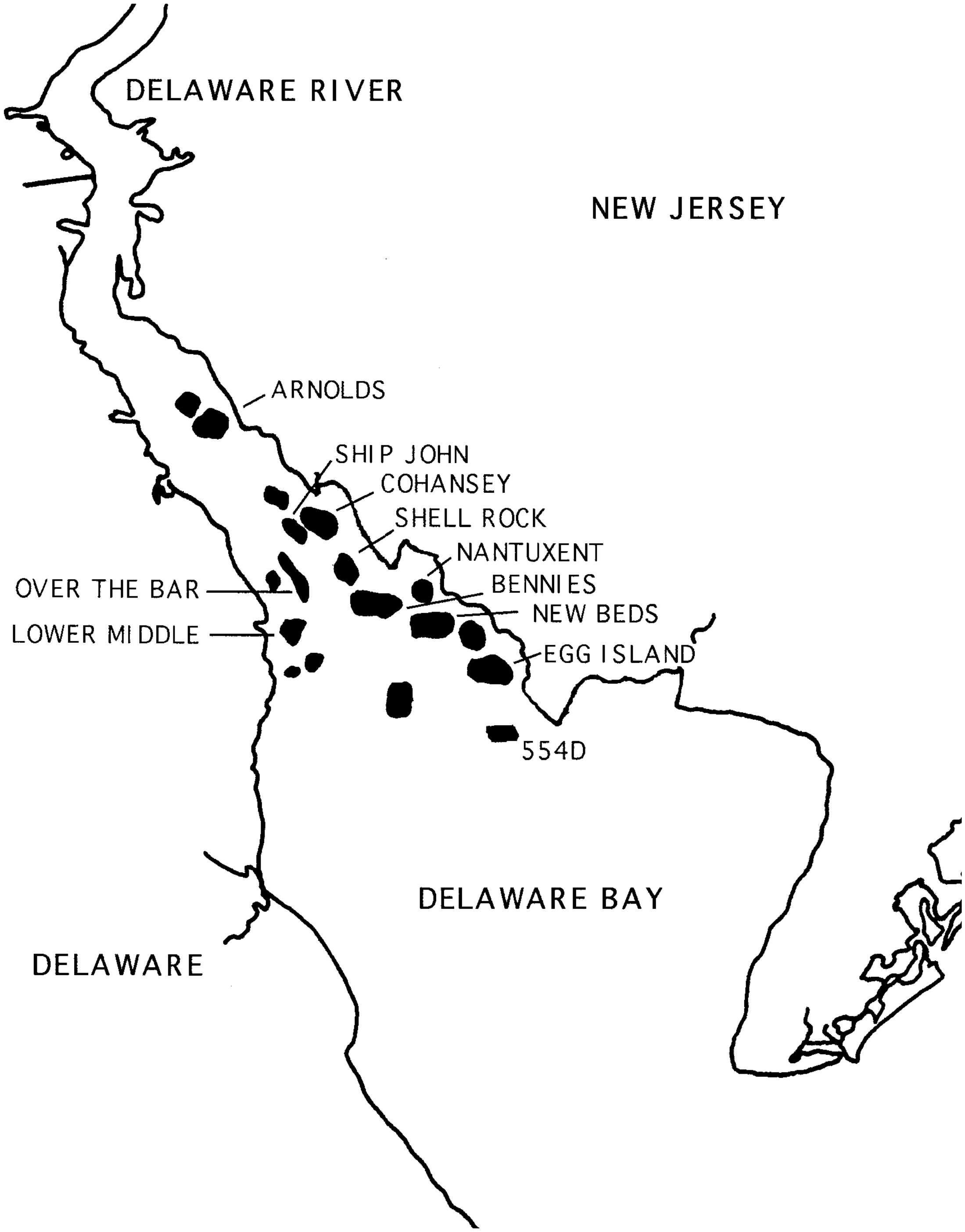
Legends for Figures

Figure 1. A standard 1.27-m New Jersey oyster dredge.

Figure 2. Location of the ten oyster beds where dredge efficiency measurements were conducted in survey mode. Banta et al. (in prep.) obtained estimates of dredge efficiency under commercial use from New Beds.

Figure 1




DELAWARE RIVER
NEW JERSEY
ARNOLDS
SHIP JOHN
COHANSEY
SHELL ROCK
NANTUXENT
BENNIES
NEW BEDS
EGG ISLAND
OVER THE BAR
LOWER MIDDLE
554D
DELAWARE BAY
DELAWARE