DELAWARE RIVER MAIN CHANNEL DEEPENING PROJECT DELAWARE BAY WINTER CRAB SURVEY –2002-

Prepared for

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ABSTRACT

The U.S. Army Corps of Engineers conducts maintenance dredging in areas of the Delaware River main channel with depth less than 12.2 m (40 ft), and plans to deepen sections of the channel with depths between 12.2 m (40 ft) and 14.3 m (47 ft). The dredging material would be used to support the Kelly Island wetland restoration project. Resource agencies have raised concerns that dredging during winter may have a significant negative impact on the blue crab stock residing in the lower bay. Blue crabs are vulnerable to dredging during winter because they largely are inactive and bury themselves in the bottom sediment from November through March. Mature female crabs favor deeper waters in the lower bay. Dredging could harm the blue crab stock and the fishery if a significant portion of the population over-winter in the part of the navigation channel that is affected. The blue crab supports a valuable winter dredge fishery in Delaware and New Jersey. The total reported landings from December 2000 through March 2001 winter were 26,534 bushels.

Versar conducted a swept area survey during February 2002 to quantify the number and fraction of over-wintering blue crabs that would be impacted by channel dredging. The survey covered the same spatial area as the 2001 winter survey, limited to the Delaware Bay south of the 39º N 20' parallel, excluding tributaries and shallow waters. Using stratified random sampling, 195 sampling sites were selected for sampling of crabs to estimate abundance, with focus on the navigation channel. The navigation channel was further classified into five sub-areas based on dredging categories. A total of 120 stations were allocated to the navigational channel, with stratified random selection of sites in sections of the channel that have previously been dredged and in sections that have never been dredged. Sampling was conducted from a Delaware fishing vessel equipped with a commercial dredge widely used in the winter blue crab fishery. For this study, the dredge was lined with a 12.7 mm nylon mesh to retain young-of-year crabs with carapace width greater than 15 mm. Versar estimated that 22% of the crabs present in the path of the dredge are caught, on average; the catch efficiency was 11% in habitat with oyster shells and 33% elsewhere. After statistically adjusting for the dredge catch efficiency, the density of blue crabs in the navigation channel was estimated at 3.60 live crabs per 1000 m^2, which is significantly lower density than the estimated 21.87 live crabs per 1000m^2 for the overall study area. The density of blue crabs overall, as well as for the navigation channel was significantly lower than the previous year. Sections of the channel that had been previously been dredged had a density of 0.96 live crabs per 1000 m^2, as compared to 3.96 crabs per 1000 m^2 in sections of the channel that never have been dredged. Only a small fraction (0.22 %) of the blue crab population in the lower Delaware Bay resides in the navigation channel during winter (0.13% for the sections slated to be dredged). The winter mortality during this season was negligible. The winter-population was estimated at 30.37 million live crabs for the entire study area, and 66,977 crabs for the section of the navigation channel included in this study. The absolute abundance of fully recruited crabs (120 mm and greater CW) in the study area was 19.77 million crabs, and 47,021 crabs for the navigation channel (0.24% of the total). The estimate for the fully recruited

stock did not significantly differ from the 1979-1999 average (25.05 million) based on modified DeLury model assessments.

The blue crab sampling in the channel covered bottom habitats that have previously been subject to maintenance dredging, as well as areas that have not previously been dredged. The estimated mean absolute density in previously dredged areas (0.96 crabs per 1000 m^2) was lower than the mean density in areas that never have been dredged (3.96 crabs per 1000 m^2), but the difference is not statistically significant at the 5% -level. For the small section of the channel scheduled to be dredged during winter (9.86 km^2) the estimated density was 4.02 crabs per 1000 m^2, and the absolute abundance of live crabs across size and sex groups was 39,635 crabs. The number of crabs in the potentially impacted area constitutes about 59% of the live crabs that were hibernating in the channel, and 0.13% of all the crabs hibernating in the lower Delaware Bay. This study suggests that the planned navigation channel deepening during winter will have negligible impact on the hibernating blue crab stock because only a small area with relatively low density of crabs will be affected.

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1.0 INTRODUCTION

The blue crab (*Callinectes sapidus*) is found from Nova Scotia through the East and Gulf coasts of the United States, and into the West Indies. Commercial and recreational fisheries for this species exist in many states, including New Jersey, Delaware, and the Carolinas. The largest fishery for the blue crab, both today and historically, is on Chesapeake Bay in the states of Maryland and Virginia. The blue crab supports the most valuable fishery in Delaware, with an average commercial catch of 50,000 bushels of hard shells and peelers per year; the pot fishery accounts for the majority of the total landings. A dredge fishery for blue crabs occurs from December 15 to March 30 in the lower Delaware Bay, targeting fully recruited crabs (carapace width 120 mm) that over-winter in deeper waters (depth > 10 m) with relatively high salinity. Mature females are dominant in these waters, and make up the vast proportion of blue crabs residing in the lower Delaware Bay. At the onset of winter, mature female blue crabs migrate to the mouth of the estuary and burrow into deep-water sediments where they remain until spring, whereas young-of-year (< 60 mm) females and male crabs of all size classes tend to burrow near their foraging habitat in shallow water. The distribution of blue crab in Chesapeake Bay during winter exhibits a similar pattern, with mature females being dominant in deep waters close to the mouth of the Bay (Van Engel 1958, Schaffner and Diaz 1988, Sharov et al. 2001). Blue crabs in the Chesapeake Bay are largely inactive and bury themselves in the bottom sediment from November through March (Van Engel, 1958); thus, they are less likely to escape the dredge by swimming. Orth and van Montfrans (1987) reported negligible catches in bottom trawls during winter, further supporting the premise that crabs are buried in the substrate. The successful blue crab fishery in the Delaware Bay during winter, and the proximity of the study area to the Chesapeake Bay suggest that a similar pattern holds for the blue crab population in Delaware Bay.

Resource agencies reviewing potential impacts of the proposed Delaware River Main Channel Deepening Project have suggested that the project may impact over-wintering female blue crab populations if dredging is conducted in the winter season in lower Delaware Bay. During January 2001, Versar, Inc. conducted a stratified random swept area survey for the USACE to provide information on blue crab density, abundance and population characteristics for the lower Delaware Bay that could be used to assess the relative importance of the navigation channel as a habitat for hibernating crabs during winter (Vølstad and Kelley 2001). The 2001 study indicated that only a small fraction of crabs over-winter in the navigation channel, and that the dredging operation thus would have marginal effect on the winter crab dredge fishery and blue crab recruitment in the following year.

The primary purpose of this study was to verify that only a marginal fraction of the blue crab stock resides in the navigation channel during winter. The study was designed to: 1) determine the density distribution of over-wintering blue crabs with respect to the navigation channel, 2) assess the potential impacts of winter dredging on blue crab abundance by sex, and 3) provide an estimate of total blue crab standing stock in lower Delaware Bay for the winter 2001/2002 fishing season. The sampling intensity in the navigation channel was enhanced relative to the previous survey, taking into account more detailed and spatially referenced information about previous and planned dredging in the channel.

2.0 MATERIAL AND METHODS

2.1 STUDY AREA

This study was conducted in the lower Delaware Bay (including the lower portion of Section E of the Federal Navigation Channel) in an area extending from river mile 0 to the N 39º 20´ parallel, excluding tributaries and shallow waters (< 1.5 m (5 ft)). As for the 2001 study (Vølstad and Kelley 2001), the survey area was divided into six primary geographic strata: (1) Deep Waters, Lower Bay (Deep); (2) Lower New Jersey (NJL); (3) Lower Delaware (DEL); (4) Upper New Jersey (NJU), (5) Upper Delaware (DEU), and (6) the Navigation Channel (Channel) (Figure 1). These primary strata were designed to encompass major areas of habitat for the over-wintering blue crab stock, and to improve survey efficiency by accounting for differences in spatial distribution of crabs by size and sex. The navigation channel was further stratified into habitat categories (sub-strata) based on spatially referenced information about previous and planned dredging provide by the USACE (Jeffrey Gebert, pers. comm.; Table1):

1. Slated to be dredged for the 13.7 m (45 ft) project -- depths between 12.2 m (40 ft) and 14.3 m (47 ft), with no previous dredging;

2. Never dredged, and not scheduled to be dredged for the 13.7 m (45 ft) project -- depths greater than 14.3 m (47 ft)

3. Previously dredged -- depths less than 12.2 m (40 ft) subjected to maintenance dredging within the last 11 years; this category was divided into three sub-categories based on when they were dredged:
   3-1. Dredged from 1991 to 1995;
   3-2. Dredged in 1996;
   3-3. Dredged between 1999 to 2001.

The three sub-categories of the previously dredged area are of approximately equal size. In total, twenty-five previously dredged plots were defined for the Brandywine, Miah Maull, Cross Ledge, and Liston navigation ranges. These plots ranged in size from 19,700 m^2 to 278,061 m^2, and in several circumstances, overlapped for different years. The most recent year of dredging were assigned to overlapping plots that had been dredged in different years.

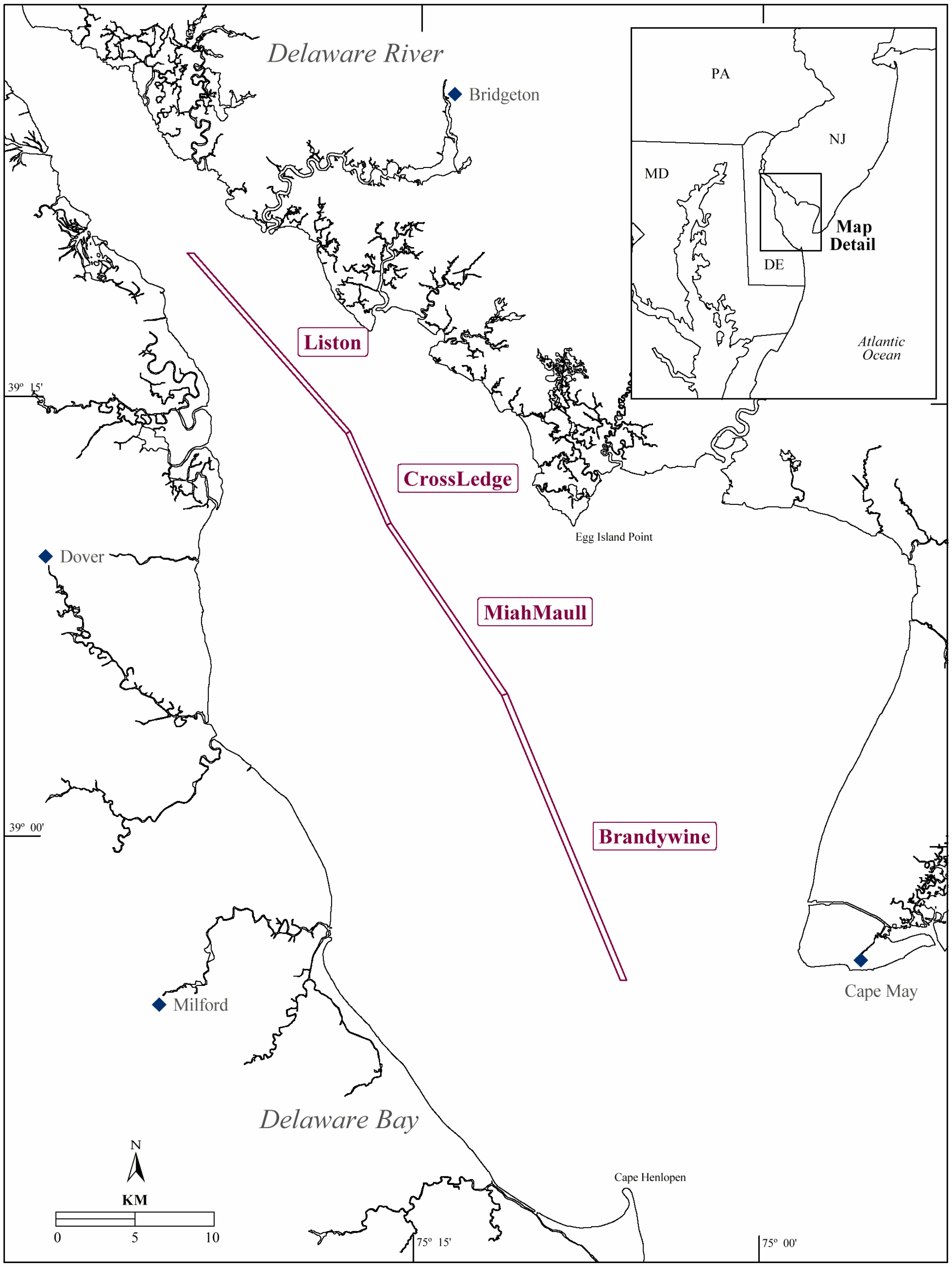

Figure 1. The Delaware Bay winter blue crab survey area, and the six primary geographic strata: (1) Deep Waters in the Lower Bay (Deep); (2) Lower New Jersey (NJL); (3) Lower Delaware (DEL); (4) Upper New Jersey (NJU), (5) Upper Delaware (DEU), and (6) the Navigational Channel (Channel).

Table 1. Geographic strata, sampling allocation, and strata areas			
Stratum	**Sub-stratum**	**Number of Stations**	**Area (m^2)**
Channel	Category 1	30	9,859,226
Channel	Category 2	30	6,517,865
Channel	Category 3-1	20	816,617
Channel	Category 3-2	20	595,023
Channel	Category 3-3	20	815,963
Lower Delaware (DEL)		15	367,944,000
Upper Delaware (DEU)		15	136,305,000
Lower Delaware Deep waters (DEEP)		15	261,570,000
Lower New Jersey (NJL)		15	480,234,000
Upper New Jersey (NJL)		15	123,993,000
All (Entire study area)		195	1,388,650,694

2.2 SURVEY DESIGN AND ANALYSIS

2.2.1 Stratified Random Swept Area Survey

A stratified random swept area survey was conducted to obtain separate estimates of density and abundance by sex for the navigation channel by dredging categories and, for reference, for the entire area of lower Delaware Bay with depths greater than 1.5 m (5 ft). A total of 195 stations were sampled, with 120 stations allocated to the navigation channel, and 15 stations to each of the other strata (Figure 2).

The 120 stations in the channel were allocated to the three major dredging categories, and to the sub-categories of previously dredged habitat using stratified random sampling (Figure 3).

The swept area survey was conducted from the same commercial fishing vessel used for the 2001 study, using a commercial dredge (4.3 m wide) widely used in the Delaware winter blue crab fishery. The dredge was lined with a 12.7-mm nylon mesh to retain young-of-year crabs; it is assumed to have 'knife edged' selectivity for crabs with a carapace width (CW) of at least 15 mm (Sulkin and Miller, 1975). The dredge was hauled for 2 min along the bottom at a speed of 3 knots in the general survey area. At any station where the amount of debris in the dredge indicated gear saturation, a second parallel tow of 0.5 min duration was taken as replacement to eliminate bias. This procedure was introduced because 2 min hauls occasionally can result in gear saturation (Vølstad and Kelley 2001). In the navigation channel, 1 min hauls were conducted to ensure that swept area measures of abundance were obtained from the dredging

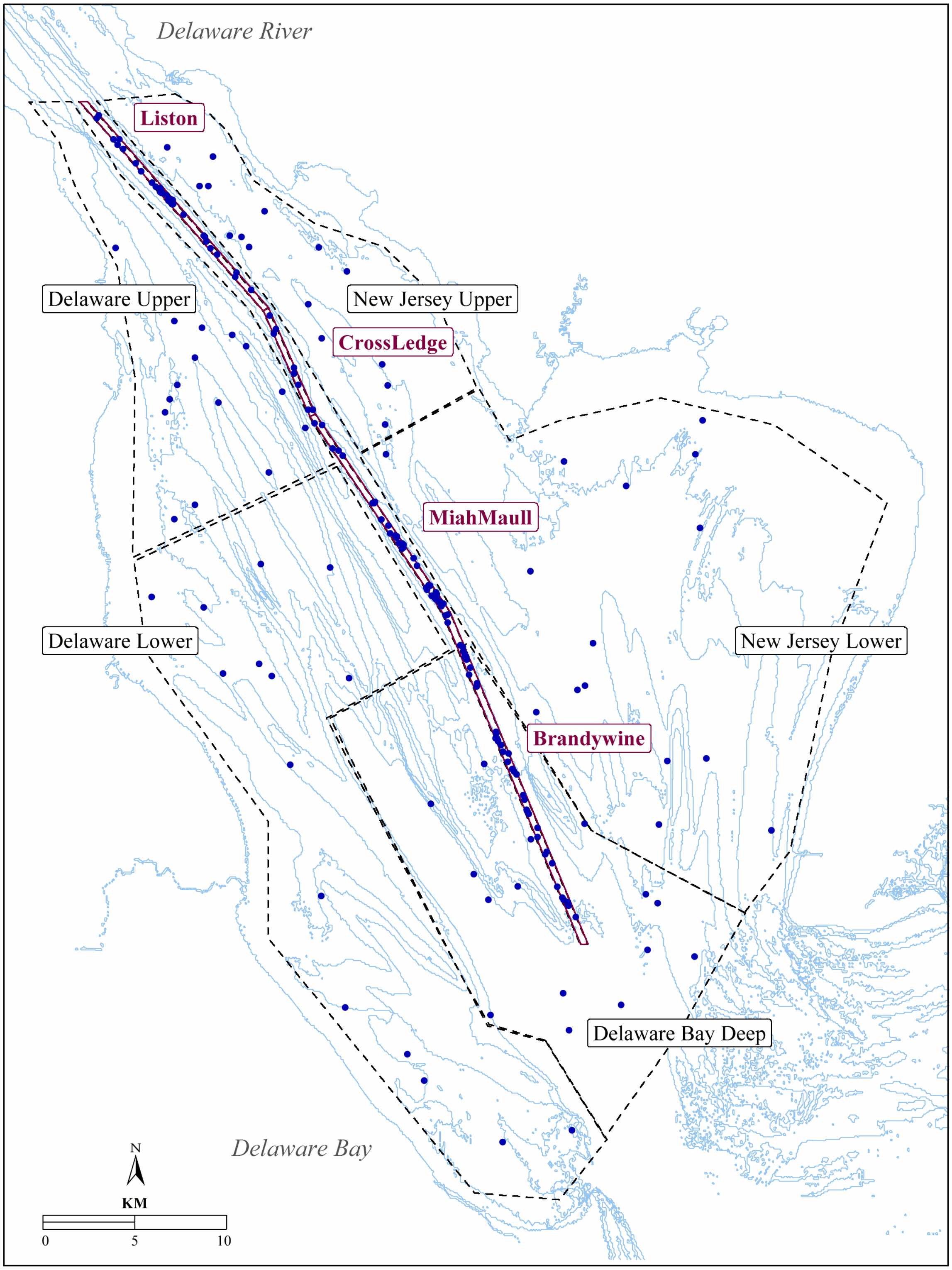

Figure 2. Distribution of sampling stations by stratum

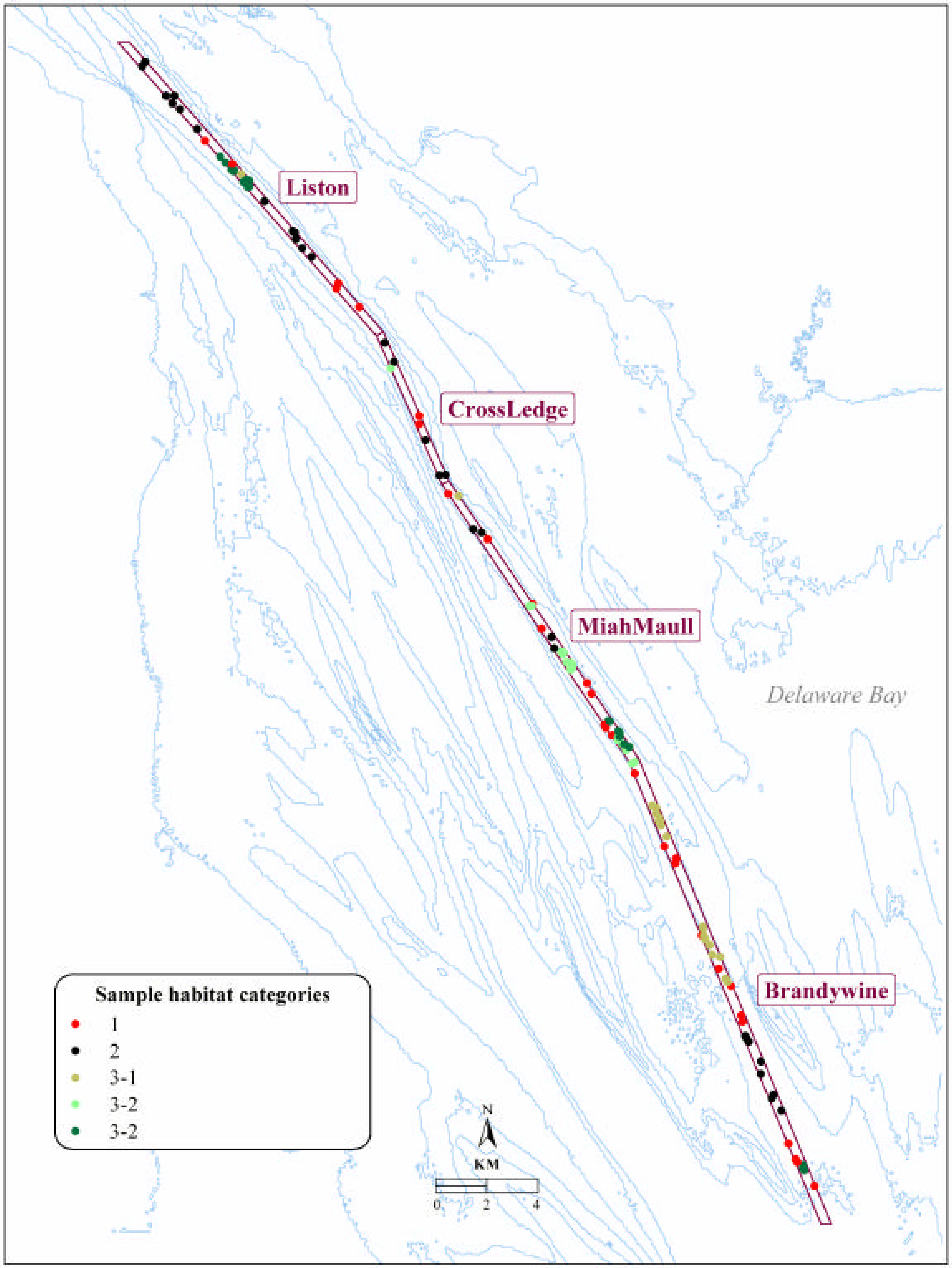

Figure 3. Distribution of sampling stations in the navigation channel by dredging category, as defined in section 2.1.

categories to which the station was assigned. The towing distance (in meters) for all hauls was measured by GPS, and depth was recorded from acoustic readings. The area swept for each haul was estimated as the towing distance multiplied by the width of the dredge (4.3 m). For all catches, the number of blue crabs was recorded, and information on carapace width (CW) to the nearest mm, sex, and overall condition was collected for each specimen. Live crabs and dead crabs were tallied separately by sex to provide information on winter mortality. The data collection forms used are provided in Appendix B. The catch-per-unit-effort (CPUE) for each haul was standardized to number of crabs per 1000 m2 area swept. Presence of blue mussels, oyster shells, sulfur sponge, and other by-catch information was recorded for all hauls. Detailed station information including catch and by-catch is in the Appendices.

2.2.2 Testing for Differences in Density among Dredging Categories in the Navigation Channel

We conducted analysis of variance, using a generalized linear model (GLM), to test for significant differences in the density of blue crabs between the five distinct dredging categories in the channel. The data from the channel were analyzed using the model

$$y_{ij} = m + a_i + e_{ij} \qquad (1)$$

where y is the log of (CPUE+1) for each tow, m is the overall mean, a is the dredging category effect, and e is the error term. The errors are assumed to be independently and identically distributed in a normal distribution (Box et al. 1978).

2.2.3 Removal Experiments

Removal experiments were conducted to estimate the catch efficiency of the dredge. CPUE must be adjusted for the catchability coefficient of the sampling gear to estimate absolute density and abundance from the survey data (Gunderson 1993). The catchability coefficient (i.e., the fraction of crabs present in the path of the dredge that is captured) was estimated from removal experiments (Seber 1973; Ricker, 1975; Hilborn and Walters 1992). In each experiment, a closed population was sampled repeatedly over a relatively short time. For each catch, all crabs were sorted by sex, counted and measured (CW) to the nearest mm. Information about the habitat type was obtained by visual inspection of the sediment remains in the dredge, and from by-catch data at each experimental site. The possible effect of body size on the catchability coefficient was evaluated by comparing mean carapace width and size frequency distributions between removals. If large crabs have a higher probability of capture than small crabs, for example, the mean CW of crabs in the first removals would, on average, be larger than the mean CW for the final removals.

Ten removal experiments were conducted at a random subset of survey stations with positive catches, following the same procedures as for the 2000/2001 winter survey. In each experiment, an area of 100 m by 4.3 m was swept 10 times by the dredge. We assume that no emigration, immigration, or natural mortality occurred during the experiment (Otis et al. 1978; Schnute 1983; Hirst 1994). Migration is likely to be minimal during the short period of an experiment (< 1 hour) because blue crabs are largely inactive during winter.

2.2.3.1 Estimating Catching Efficiency of the Sampling Gear

The estimate of the catchability coefficient for each experiment was based on the slope of a linear regression of CPUE on cumulative catch (Leslie and Davis 1939):

$$y_i = q[P_0 - K_{i-1}] = qP_0 - qK_{i-1} \qquad (2)$$

where y_i is the catch from the ith removal, and K_{i-1} is cumulative catch taken before each removal. P0 is the initial population in the area before the depletion experiment. The catchability coefficient q is simply the slope of the linear regression estimated from (2).

Because the dredge was significantly less effective in habitats with oyster-shells, we estimated separate mean coefficients for sites with and without oyster shells. For each of the two habitats, the catchabilities from each removal experiment were weighted by the abundance in the experimental area using the method described in Vølstad et al. (2000). An estimator the catchability coefficient to use for calibrating CPUE in the dredge survey is

$$\bar{q} = \sum \frac{c_i q_i}{C} \qquad (3)$$

where c_i is the total number of crabs caught in the ith experiment; q_i is the corresponding estimated gear efficiency; and C is total number of crabs caught in the n experiments. The standard error of (3) is estimated using the jackknife method (Efron and Gong 1983; Vølstad et al. 2000).

2.2.3.2 Testing if Catch Efficiency Depends on the Size of Crabs

We follow Hirsch et al. (1982) and use the Kendall test for trend in the mean carapace width (CW) of crabs over the n removals across experiments (10 removals in this analyses). Testing the null hypothesis that CW is independent of the sequence of removals is a proxy for testing if catch efficiency is independent of the CW of crabs. If large crabs have a higher probability of being caught, for example, then a negative trend in CW would be expected as the depletions progress. Because of the significant difference in the size of crabs between sites with oyster shells and other sites, we conducted separate tests for each habitat. We pooled the crabs across experiments by depletion number. For a given habitat class, let x_j and x_k be the estimated mean CW of the pooled crabs caught in removal numbers j and k respectively. The Kendall test statistic S is defined as

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k)$$

where

$$\operatorname{sgn}(q) = \begin{cases} 1 & if \quad q > 0 \\ 0 & if \quad q = 0 \\ -1 & if \quad q < 0 \end{cases}$$

Under H_0 the mean and variance of S is

$$E[S] = 0$$

$$Var[S] = n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)/18$$

where t is the number of x's involved in a given tie, and $\sum_t$ denotes the summation of all ties. A negative value of S represents a negative trend in CW over the ten removals analyzed (pooled across experiments). Kendall's S has an approximate normal distribution for n = 10 (Hirsch et al. 1982), and therefore the test for trends is based on the standard normal test statistic Z, computed as

$$Z = \begin{cases} \dfrac{S-1}{(Var[S])^{1/2}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \dfrac{S+1}{(Var[S])^{1/2}} & if \quad S < 0 \end{cases} \tag{4}$$

In a two-sided test for trend, H_0 is rejected if $|Z| > z_{a/2}$, with a being the significance level of the test. In this study, we use a 5% significance level for all tests, and thus $z_{a/2}$=1.96.

2.2.4 Estimating Absolute Density and Abundance

Density and abundance was estimated by sex, size class, and for all crabs across size and sex. We separated the CPUE data into three size stages based on their carapace width: < 60 mm CW, 60-119 mm, and 120 mm and greater (Helser 2000, Sharov et al. 2001). The small stage represents the young-of-year (age 0) crabs hatched during the preceding summer. We assume that crabs with CW greater or equal to 60 mm are one year and older (age 1+). The large stage corresponds to fully recruited crabs. By October, the medium stage has typically merged with the distribution of older crabs resulting in a bi-modal CW distribution that represents age 0 and age 1+ crabs (Helser 2000). We also provide separate estimates for females and males.

Let x_{ij} denote the number of crabs caught per area swept (m^2) at station i in stratum j, and let $\overline{q}_{ij}$ denote the (habitat specific) catch efficiency of the dredge estimated from equation (3). An estimator for the absolute number of crabs per m^2 at station i in stratum j is then

$$y_{ij} = \frac{x_{ij}}{q_{ij}} \tag{5}$$

and the mean density of crabs across stations in stratum j is estimated by

$$\overline{y}_j = \frac{1}{n_j}\sum_{i=1}^{n_j} y_{ij} \tag{6}$$

with variance

$$\operatorname{var}(\overline{y}_j) = \frac{\sum_{i=1}^{n_j}(y_{ij} - \overline{y}_j)^2}{n_j(n_j - 1)} \tag{7}$$

where n_j is the number of stations in stratum j. The stratified mean density for the entire survey area (A) is estimated by

$$\overline{y}_{st} = \sum_{j=1}^{L} W_j \overline{y}_j \tag{8}$$

with variance

$$\operatorname{var}(\overline{y}_{st}) = \sum_{j=1}^{L} W_j^2 \operatorname{var}(\overline{y}_j) \tag{9}$$

where L is the number of strata, and W_j is the proportion of the total survey area in stratum j (e.g., Cochran 1977, Thompson 1992). Density of crabs in the channel for areas never dredged (Categories 1 and 2 combined), and for the combined areas previously dredged (Category 3) and the standard errors (SE) were also estimated using equations 5 to 9. The standard error for a mean or total is defined as the square root of its variance. The relative standard error (RSE) for a mean (or total) is the SE divided by the mean (or total). The SE and RSE are measures of precision.

The absolute abundance (total number of crabs) in a stratum j is estimated by extrapolating the stratum mean density to the stratum area (A_j),

$$t_j = A_j \times \overline{y}_j \tag{10}$$

and the variance of (10) is estimated by

$$\operatorname{var}(t_j) = A_j^2 \operatorname{var}(\overline{y}_j) \tag{11}$$

The absolute abundance (t) across L strata ($j = 1,...,L$) is estimated by

$$t = \sum_{j=1}^{L} t_j \tag{12}$$

with variance estimated by

$$\operatorname{var}(t) = \sum_{j=1}^{L} \operatorname{var}(t_j) \tag{13}$$

These equations are used to estimate total abundance in the survey area, as well as for the channel (across sub-strata).

2.2.5 Testing for Differences Between Two Population Quantities

Comparisons of statistical differences between two population quantities (for example mean density in the channel versus the entire survey area) were conducted using the standard method recommended by Schenker and Gentleman (2001). We used this test because it is more robust than the commonly used method of examining the overlap between the two associated confidence intervals. Assume that $\hat{Q}_1$ and $\hat{Q}_2$ are two independent estimates of abundance (or density) of blue crabs, and that the associated standard errors (*SE*) are estimated by $\hat{SE}_1$ and $\hat{SE}_2$. The estimated quantities $\hat{Q}_1$ and $\hat{Q}_2$ could, for example, represent estimated density of blue crab for two geographic areas (e.g,. inside the navigation channel versus the general population in the study area), or estimates of the total abundance in the study area from two independent studies. We estimated the 95% confidence interval for $\hat{Q}_1 - \hat{Q}_2$ by

$$(\hat{Q}_1 - \hat{Q}_2) \pm 1.96 \left[\hat{S}E_1^2 + \hat{S}E_2^2 \right]^{1/2} \tag{14}$$

and tested (at 5% nominal level) the null hypothesis that $\hat{Q}_1 - \hat{Q}_2 = 0$ by examining whether the 95% confidence interval contains 0. The null hypothesis that two estimates are equal was rejected if and only if the interval did not contain 0 (Scenker and Gentleman 2001).

3.0 RESULTS

3.1 CATCH EFFICIENCY OF THE DREDGE

The estimated catchability coefficient for the commercial crab dredge with nylon liner from individual depletion experiments varied from 0.07 to 0.37 (Table 2), with an overall weighted mean (eq. 3.) across sites of 0.22 (SE = 0.06). The weighted mean catch efficiency of the dredge at sites with no oyster shells was 0.33 (SE=0.02), as compared to 0.11 (SE = 0.06) for sites with oyster shells. The 95% CI of difference in catch efficiency was 0.09 to 0.34 (eq. 14) and does not contain zero. Following Scenker and Gentleman (2001) we therefore conclude that the catch efficiency in oyster habitat on average was significantly lower than for sites without oyster shells. The declining trend in mean carapace width (CW) by depletion indicates that larger crabs have a slightly higher probability of being caught than smaller crabs (Figures 4 and 5). The Kendal seasonal test for trend (Hirsch et al. 1982) showed significant negative trends in the CW for either habitat class. For sites without oyster shells, the test statistics (eq. 4) were S=-33 and $|Z| = 2.86$, and for sites with oyster shells S=-27 and $|Z| = 2.33$, and thus the null hypothesis was rejected.

Table 2. Number of crabs per coverage (sweep of the bottom area) in each of the ten removal experiments; C is the total number of crabs caught in each experiment, $\hat{q}_i$ is the estimated gear efficiency based on model 2.1, and R^2 is the coefficient of determination for the regressions. The jackknife estimate of weighted average $\hat{q}$ for all experiments is 0.22 (SE. = 0.06). The jackknife estimates of weighted average $\hat{q}$ inside and outside oyster beds were 0.11 (SE=0.05) and 0.33 (SE=0.02) respectively.

Coverage	**Removal experiment number (i)**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	38	46	36	35	7	31	13	11	9	10
2	46	34	24	21	52	56	14	4	9	9
3	29	41	29	33	40	65	15	11	6	7
4	17	35	18	7	53	42	4	1	2	11
5	22	21	4	8	83	33	6	0	1	4
6	4	5	1	5	57	36	5	2	0	1
7	4	4	3	3	57	35	2	0	3	0
8	1	2	1	2	24	26	1	1	3	0
9	0	1	3	1	46	11	0	3	0	0
10	2	1	1	0	11	11	0	0	0	3
C	163	190	120	115	430	346	60	33	33	45
$\hat{q}_i$	0.36	0.29	0.35	0.35	0.07	0.16	0.32	0.35	0.37	0.29
R^2	0.96	0.83	0.85	0.79	0.26	0.87	0.89	0.52	0.83	0.72
Habitat	Sandy -mud	Mud	Mud	Muddy-sand	Oyster-shell	Oyster-shell	Sandy-mud	Sandy-mud	Sand	Sand

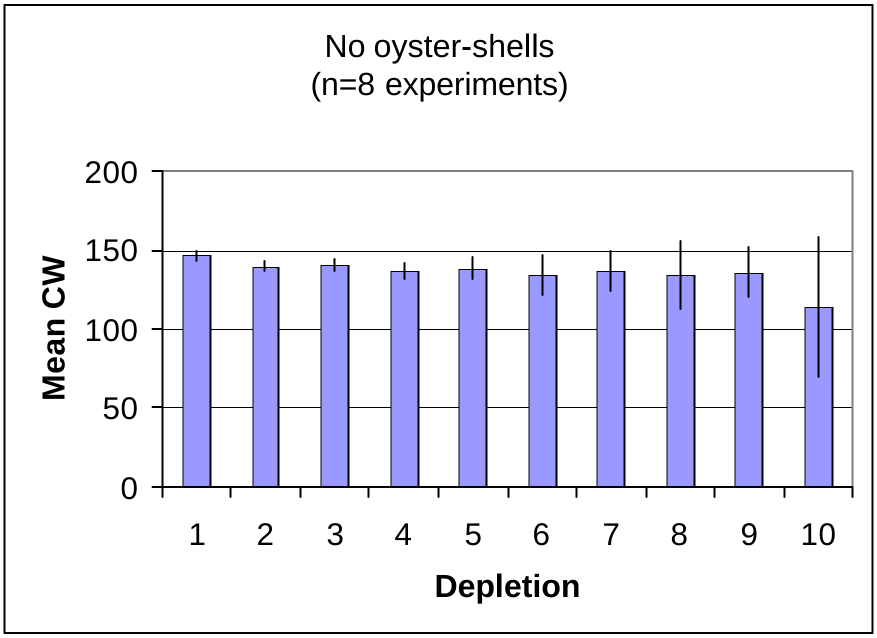

Figure 4. Mean carapace width (CW) in mm versus depletion number for habitat without oyster-shells. The error bars show 95% confidence intervals for the mean CW.

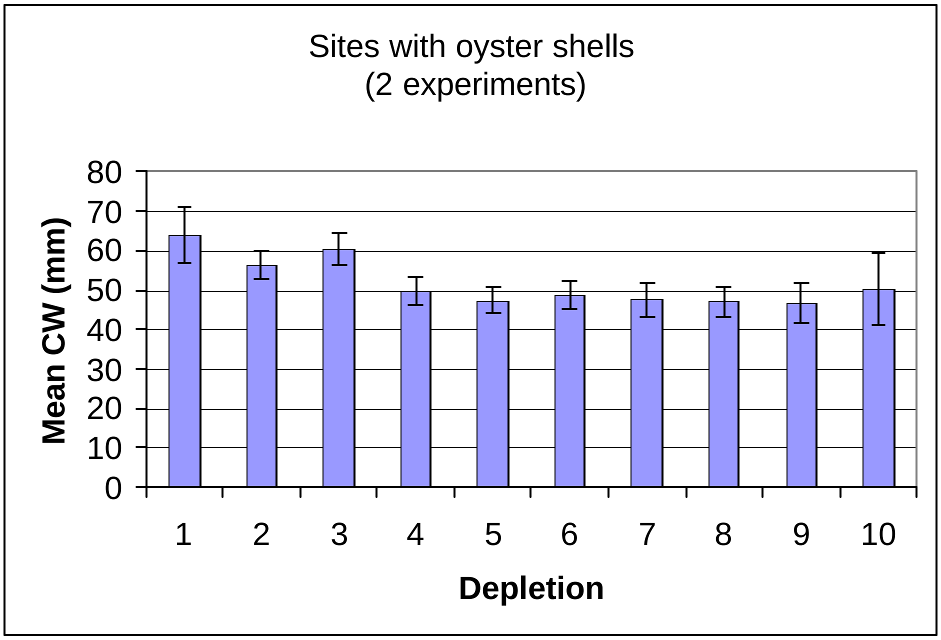

Figure 5. Mean carapace width (CW) in mm versus depletion number for habitat with oyster-shells. The error bars show 95% confidence intervals for the mean CW.

3.2 ESTIMATES OF DENSITY, ABUNDANCE, AND SIZE COMPOSITION

3.2.1 Absolute Density

Absolute density was estimated by adjusting the catch per 1000 m^2 for gear-efficiency, using equations 5 to 9. The catch efficiency was $\overline{q} = 0.11$ for sites with oyster shells, and $\overline{q} = 0.33$ elsewhere. The estimated absolute densities of live crabs by sex and size classes are in Tables 3 and 4. The absolute density of live crabs across size and sex for the entire survey area was estimated at 21.87 crabs per 1000 m^2 (SE = 4.82) as compared to 3.60 crabs per 1000 m^2 for the navigation channel overall (SE = 1.26) (Table 3). The fraction of dead crabs (males and females) for all size classes combined was insignificant for the general survey area, as well as for the channel.

The navigation channel had significantly lower density of crabs than the general survey area; the 95% CI for the difference in density was 8.05 - 27.77 crabs per 1000 m^2, and thus the null hypothesis of equal density was rejected. The overall density of crabs in previously dredged sections of the channel (category 3) was 0.96 crabs per 1000 m^2 (SE= 0.49), as compared to 3.96 crabs per 1000 m^2 (SE = 1.44) for areas that have never been dredged (categories 1 and 2 combined); the difference in density between the two was not significant. The density in areas slated to be dredged (category 1) was 4.02 crabs per 1000 m2 (SE=2.01). ANOVA (model 1.1) for the randomized block experiment did not reveal a significant difference in density between the five dredging categories in the channel (DF = 4; F = 1.37, $p > 0.24$) at the 5% significance level. Detailed catch and habitat information for all stations are in Appendices B and C.

Females constitute the larges fraction of the blue crabs that over-winter in the lower Delaware Bay (Figure 6). The percentage of females in the navigation channel is similar, but slightly lower than for the general population in the lower Delaware Bay.

The blue crabs in the navigation channel had the same size composition as crabs in the lower New Jersey stratum (NJL), and only slightly differed from the composition of the overall stock (Figure 7). Only the fully recruited component of the stock ($CW \geq 120$ mm) over-winter in the deep section of the Delaware Bay. The size composition of crabs by stratum suggests that young-of-year crabs ($CW < 60$ mm) primarily inhabit the upper Delaware Bay during winter. Detailed size distributions of crabs by stratum are in Figures 8 – 13.

Table 3. Estimated absolute density (mean number of crabs per 1000 m^2) for all size classes combined for Females, Males and combined. The relative standard error (SE) is a measure of precision; *n* is number of sampling stations.

Stratum	Sub_stratum	*n*	Stratum Area (m^2)	Absolute density (# Crabs per 1000 m2)			SE		
				All (F+M)	F	M	All	F	M
Channel	Category 1	30	9,859,226	4.02	3.81	0.21	2.01	2.01	0.21
Channel	Category 2	30	6,517,865	3.86	2.23	1.63	1.94	1.22	1.11
Channel	Category 3-1	20	816,617	0.71	0.71	0.00	0.49	0.49	0.00
Channel	Category 3-2	20	595,023	0.00	0.00	0.00	0.00	0.00	0.00
Channel	Category 3-3	20	815,963	1.91	0.76	1.15	1.23	0.53	1.15
DEL		15	367,944,000	37.76	33.02	4.03	13.55	11.91	2.26
DEU		15	136,305,000	29.56	16.33	13.23	8.00	4.67	4.14
Deep		15	261,570,000	3.50	3.50	0.00	1.94	1.94	0.00
NJL		15	480,234,000	13.62	11.81	1.81	8.54	7.62	0.97
NJU		15	123,993,000	39.71	21.55	18.15	10.44	6.76	4.91
All		195	1,388,650,694	21.87	17.06	4.62	4.82	4.20	0.91
Channel Summary									
Never dredged		60	16,377,091	3.96	3.18	0.78	1.44	1.30	0.46
Dredged		60	2,227,603	0.96	0.54	0.42	0.49	0.26	0.42
All Channel		120	18,604,694	3.60	2.86	0.73	1.26	1.15	0.41

Table 4. Estimated absolute density (mean number of crabs per 1000 m^2 swept) for three major size (CW) categories: (1) < 60 mm; (2) 60-119 mm; (3) 120 mm +. The mean catchability coefficient for the sampling dredge is assumed to be constant at 0.11 for oyster habitats, and 0.33 elsewhere. The standard error (SE) is a measure of precision; *n* is the number of sampling stations.

Stratum	Sub_stratum	*n*	Stratum Area (m^2)	Absolute density by CW			SE		
				< 60 mm	60 - 119 mm	120 mm +	< 60 mm	60 - 119 mm	120 mm +
Channel	Category 1	30	9,859,226	0.24	0.21	3.57	0.24	0.21	2.01
Channel	Category 2	30	6,517,865	0.26	1.92	1.68	0.26	1.35	1.13
Channel	Category 3-1	20	816,617	0.00	0.40	0.31	0.00	0.40	0.31
Channel	Category 3-2	20	595,023	0.00	0.00	0.00	0.00	0.00	0.00
Channel	Category 3-3	20	815,963	0.38	0.77	0.76	0.38	0.77	0.53
DEL		15	367,944,000	0.44	4.24	32.36	0.44	3.16	12.34
DEU		15	136,305,000	3.63	17.95	7.98	1.26	6.09	2.86
Deep		15	261,570,000	0.00	0.00	3.50	0.00	0.00	1.94
NJL		15	480,234,000	0.93	2.76	9.94	0.72	1.86	8.05
NJU		15	123,993,000	21.65	9.65	8.40	8.04	3.00	4.05
All		195	1,388,650,694	2.73	4.71	14.24	0.78	1.24	4.33
Channel Summary									
Never dredged		60	16,377,091	0.25	0.89	2.82	0.18	0.55	1.29
Dredged		60	2,227,603	0.14	0.43	0.39	0.14	0.32	0.22
All Channel		120	18,604,694	0.23	0.84	2.53	0.16	0.49	1.14

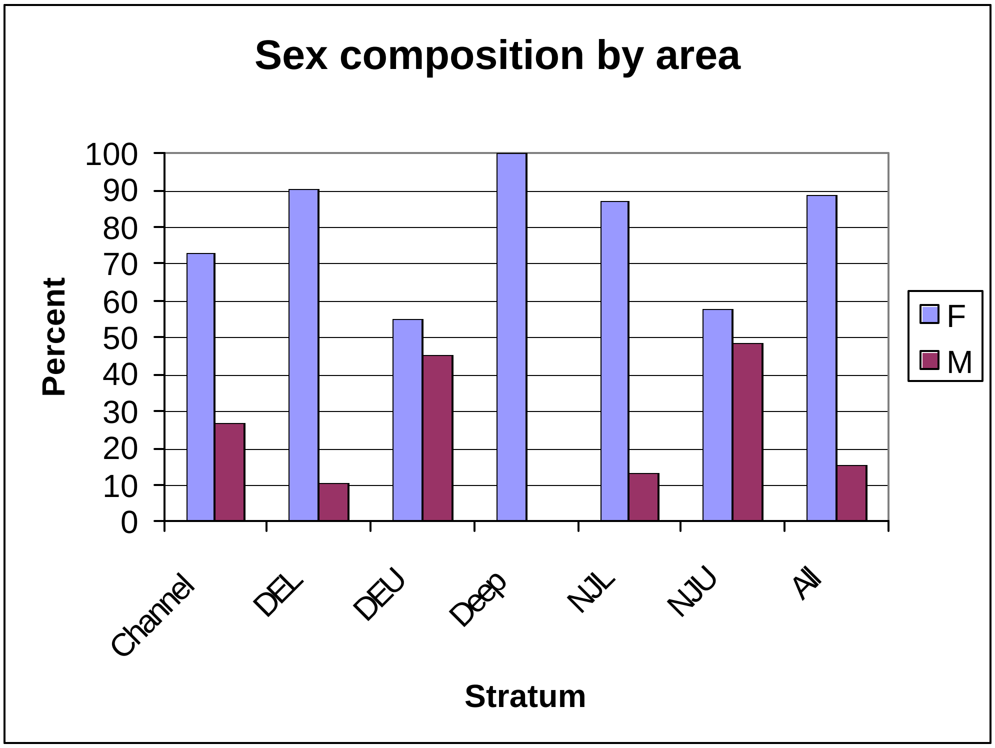

Figure 6. Sex composition of crabs (all size groups) in each stratum and for all strata combined

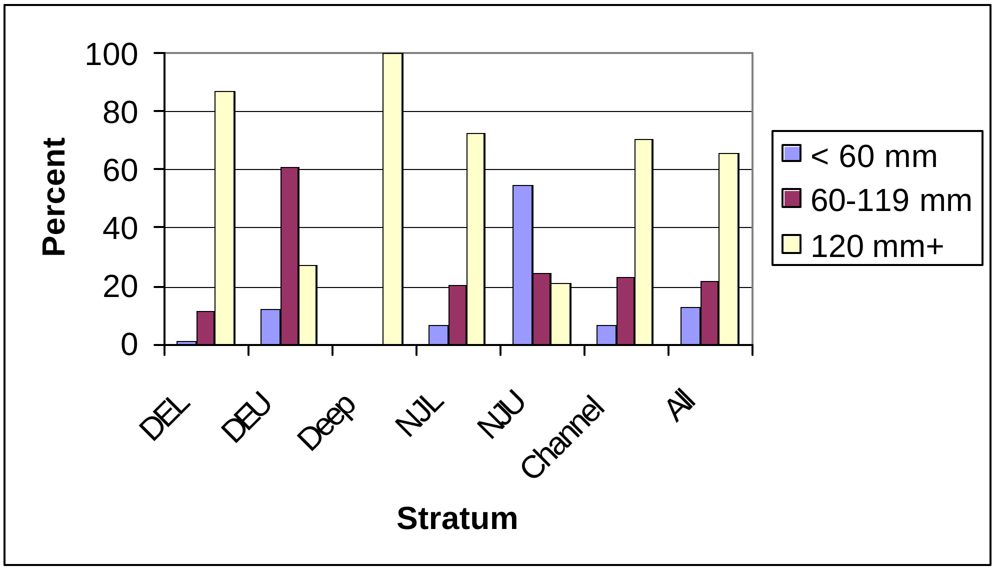

Figure 7. Percentage of the stock in each of three major carapace width size categories: < 60 mm, 60-119 mm, and 120 mm and greater by stratum.

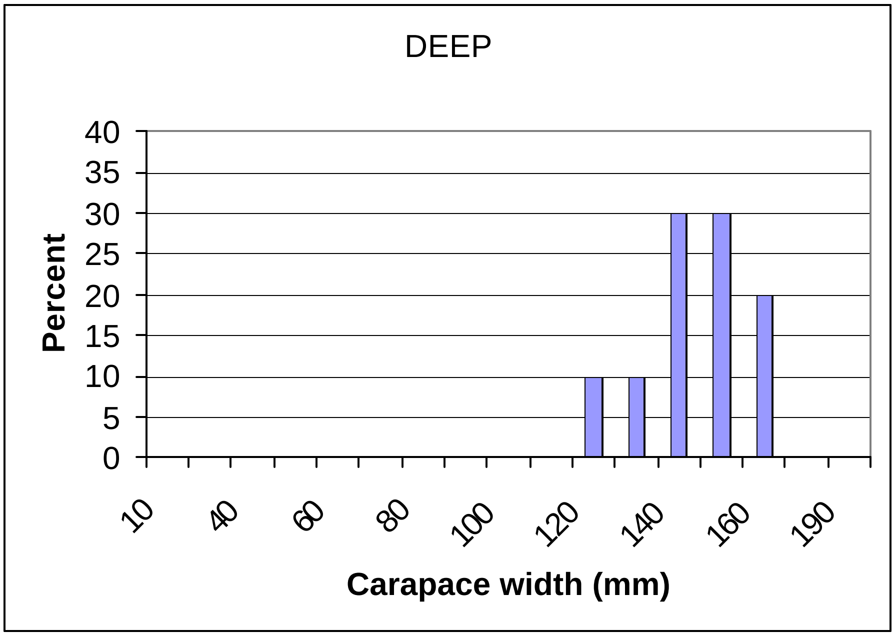

Figure 8. Size distribution of live crabs (Carapace width) in the deep water stratum in lower Delaware Bay.

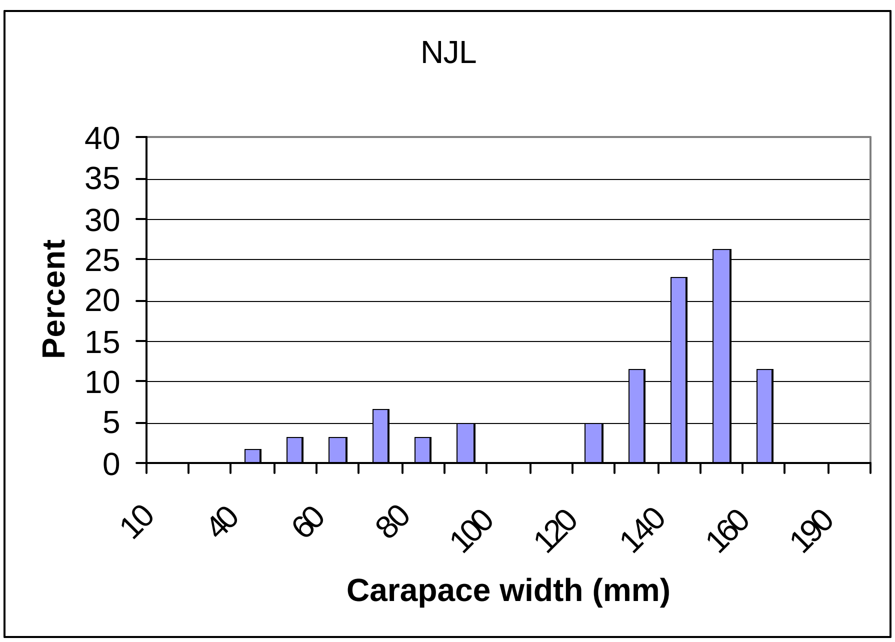

Figure 9. Size distribution of live crabs (Carapace width) in the lower New Jersey stratum

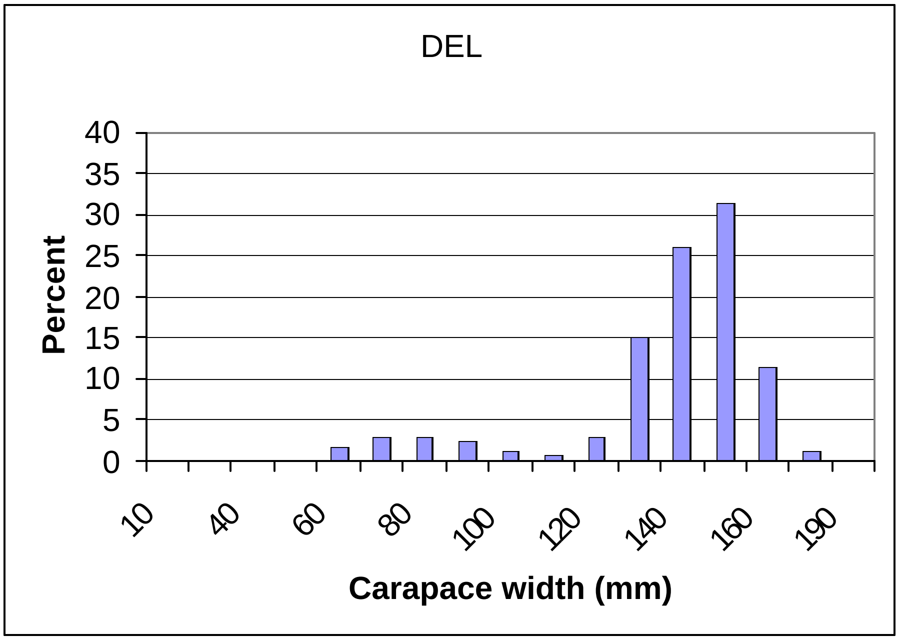

Figure 10. Size distribution of live crabs (Carapace width) in the lower Delaware stratum

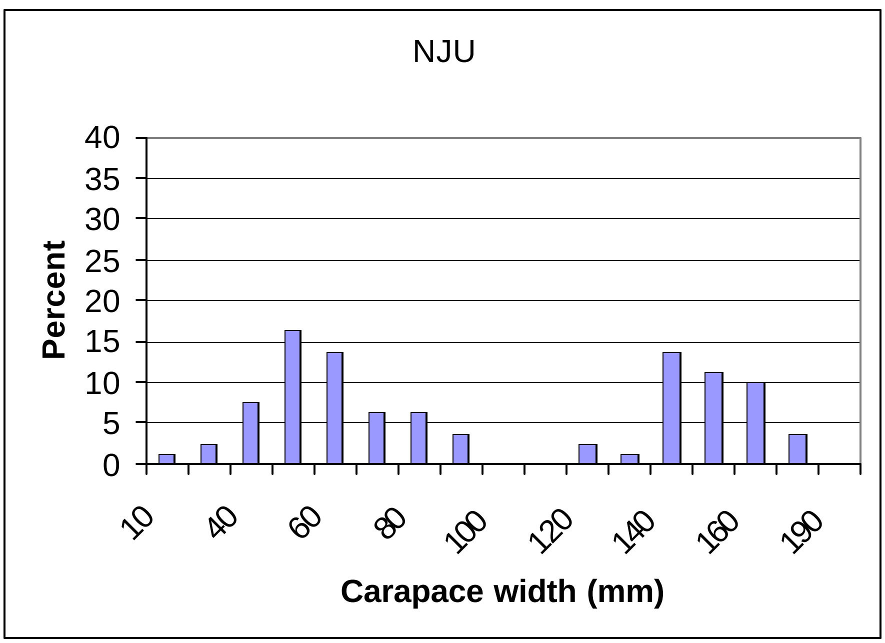

Figure 11. Size distribution of live crabs (Carapace width) in the upper New Jersey stratum

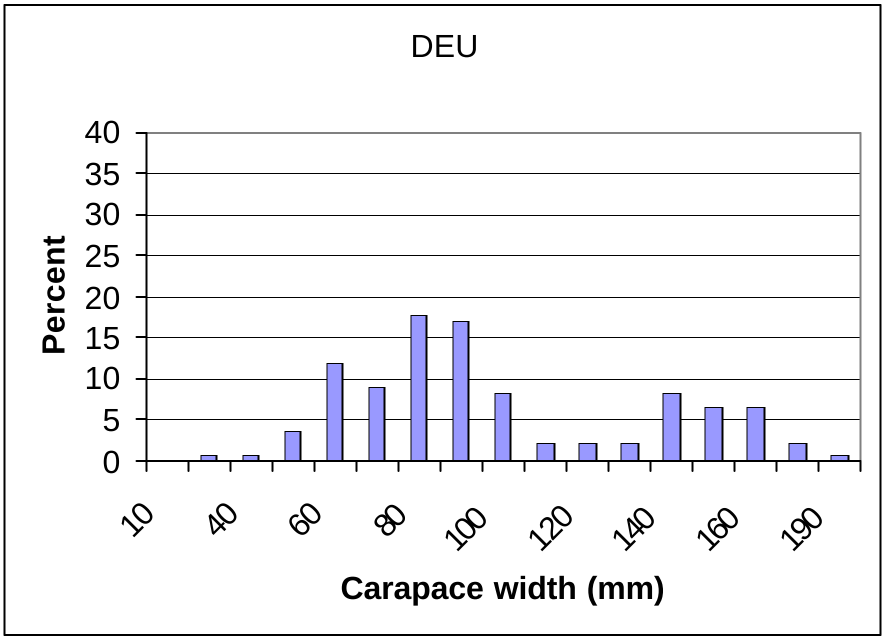

Figure 12. Size distribution of live crabs (Carapace width) in the upper Delaware stratum

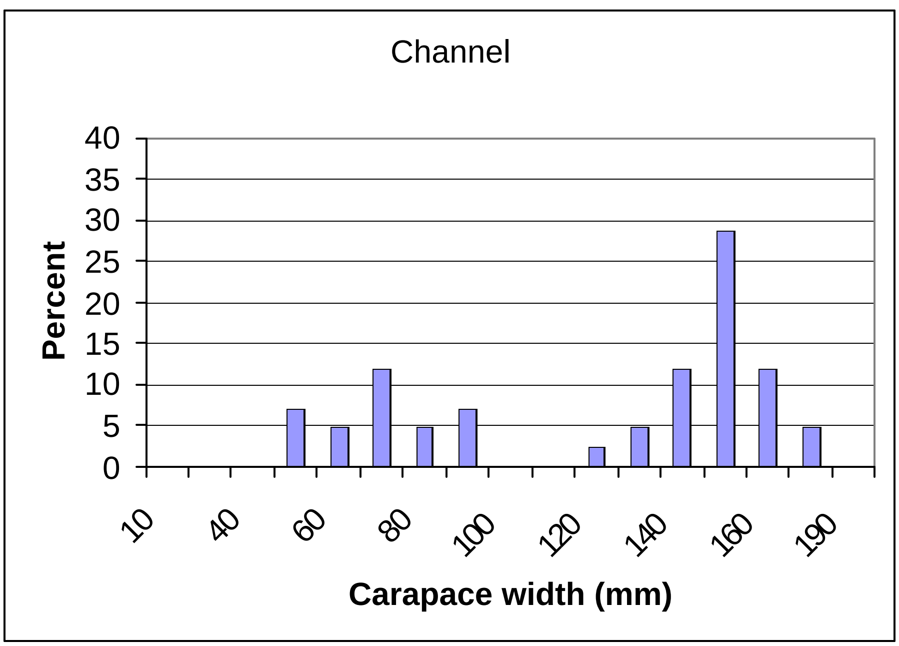

Figure 13. Size distribution of all live crabs (Carapace width) in the navigation channel

3.2.2 Absolute Abundance

Estimates of absolute abundance (eqs. 10 to 13) for all crabs, and by sex and the three major size classes are in Tables 5 and 6. The absolute abundance of live crabs across size and sex classes was estimated at 30.37 million crabs (RSE = 0.22) for the entire lower Delaware Bay, and 66,977 crabs (RSE = 0.36) for the entire channel (0.22% of the total standing stock; Tables 5 and 6). The estimated absolute abundance for the part of the channel slated to be dredged (category 1) was 39,635 crabs (RSE = 0.5), which constitutes 0.13 % of the standing stock in the entire survey area. The abundance of live females was 23.68 million (RSE = 0.25) for the entire survey area, as compared to 53,209 (RSE = 0.41) for the channel (0.22% of the female stock). An estimated 78% of the population across strata was females, as compared to 79% for the channel. The absolute abundance of fully recruited crabs (CW $\geq$120 mm) in the study area was 19.77 million crabs (RSE = 0.30), as compared to 47,021 (RSE = 0.45) for the navigation channel, and 35,191 (RSE=0.56) for the part of the channel slated to be dredged (Table 6).

In Delaware, the total reported landings from December 2001 through January 2002 was 10,330 bushels of females, and 1104 bushels of males (Desmond Kahn, DENREC, pers. comm.). In New Jersey, 98 bushels of males and 2,908 bushels of females were reported for the same period (Paul Scarlett, NJ Division of Fish and Wildlife, pers. comm.). Assuming 100 males (commercial category #1) and 150 females (commercial category #3) per bushel respectively[1], we estimated that the total landing from December 15, 2001, through January 31, 2002, corresponds to approximately 1.4 million crabs. This is less than 50% of the landings reported for the same period during the previous year. Assuming no errors in reported landings, and zero natural mortality from December 2001 to January 2002, the 95% interval estimate for the number of fully recruited crabs in the study area at the beginning of December is 9.5 million to 32.8 million crabs. The estimated abundance of fully recruited crabs was significantly lower than for the previous year's 95% interval estimate of 39.4 million to 88.0 million crabs (Kelley and Vølstad 2001). The reported landings for the entire fishing season, from December 15, 2001, through March 31, 2002, was 1,736 bushels of males (#1) and 18,872 bushels of females, corresponding to 3 million crabs, which is 75% of the reported landings in the winter dredge fishery for the previous year.

[1] Jeff Tinsman, State of Delaware Department of Natural Resources & Environmental Control, Division of Fish & Wildlife, pers. comm., 2001.

Table 5. Estimated absolute abundance for all size classes combined for Females (F), Males (M) and combined (F+M). The relative standard error (RSE= $SE/\bar{x}$) is a measure of precision; *n* is the number of sampling stations.

Stratum	Sub_stratum	*n*	Strata Area (m^2)	Absolute abundance			RSE		
				All (F+M)	F	M	All (F+M)	F	M
Channel	Category 1	30	9,859,226	39,635	37,524	2,111	0.50	0.53	1.00
Channel	Category 2	30	6,517,865	25,176	14,551	10,625	0.50	0.55	0.68
Channel	Category 3-1	20	816,617	579	579	0	0.69	0.69	0.00
Channel	Category 3-2	20	595,023	0	0	0	0.00	0.00	0.00
Channel	Category 3-3	20	815,963	1562	624	938	0.64	0.69	1.00
DEL		15	367,944,000	13,892,231	12,148,212	1,482,145	0.36	0.36	0.56
DEU		15	136,305,000	4,029,654	2,225,802	1,803,852	0.27	0.29	0.31
Deep		15	261,570,000	916,310	916,310	0	0.55	0.55	0.00
NJL		15	480,234,000	6,541,599	5,673,775	867,824	0.63	0.65	0.54
NJU		15	123,993,000	4,923,407	2,672,528	2,250,879	0.26	0.31	0.27
All		195	1,388,650,694	30,370,153	23,689,904	6,418,375	0.22	0.25	0.20
Channel Summary									
Never dredged		60	16,377,091	64,853	52,079	12,774	0.36	0.41	0.59
Dredged		60	2,227,603	2,138	1,203	936	0.51	0.48	1.00
All Channel		120	18,604,694	66,977	53,209	13,581	0.35	0.40	0.56

Table 6 Estimated absolute abundance for three major size (CW) categories: (1) < 60 mm; (2) 60-119 mm; (3) 120 mm +. The mean catchability coefficient for the sampling dredge is assumed to be 011 for oyster habitats, and 0.33 elsewhere. The relative standard error (RSE= $SE/\bar{x}$) is a measure of precision.

Stratum	Sub_stratum	*n*	Stratum Area (m^2)	Absolute abundance by size class			RSE		
				< 60 mm	60-119 mm	120 mm+	< 60 mm	60-119 mm	120 mm+
Channel	Category 1	30	9,859,226	2,333	2,111	35,191	1.00	1.00	0.56
Channel	Category 2	30	6,517,865	1,690	12,542	10,944	1.00	0.70	0.67
Channel	Category 3-1	20	816,617	0	325	254	0.00	1.00	0.00
Channel	Category 3-2	20	595,023	0	0	0	0.00	0.00	0.00
Channel	Category 3-3	20	815,963	313	626	624	1.00	1.00	0.69
DEL		15	367,944,000	163,524	1,559,079	11,907,754	1.00	0.75	0.38
DEU		15	136,305,000	495,203	2,446,502	1,087,949	0.35	0.34	0.36
Deep		15	261,570,000	0	0	916,310	0.00	0.00	0.00
NJL		15	480,234,000	444,250	1,325,142	4,772,207	0.77	0.67	0.81
NJU		15	123,993,000	2,684,958	1,196,983	1,041,466	0.37	0.31	0.48
All		195	1,388,650,694	3,792,272	6,543,310	19,772,698	0.28	0.26	0.30
Channel Summary									
Never dredged		60	16,377,091	4,094	14,585	46,147	0.71	0.62	0.46
Dredged		60	2,227,603	312	955	873	0.99	0.74	0.57
All Channel		120	18,604,694	4,279	15,540	47,021	0.68	0.58	0.45

4.0 DISCUSSION AND CONCLUSION

The swept area abundance estimate of fully recruited crabs (CW $\geq$120 mm) in the Delaware Bay for the winter 2002 (14.77 million crabs, RSE = 0.30) was within the range of abundance estimates for 1979-1999 (6 to 65 million) based on the modified DeLury method, and did not significantly differ from the 1979 – 1999 DeLury average of 25 million (RSE = 0.37) reported in Helser (2000). A direct comparison of abundance estimates from the two methods can only be made when the DeLury stock assessment is updated. Our study provides a snapshot of the winter population in the lower Delaware Bay, and does not cover the entire distribution area of the blue crab. The dominance of age 1+ females in the dredge samples can be attributed to the spatial coverage of the survey, and is consistent with the sex composition of the commercial landings from the winter dredge fishery in Delaware Bay. Mature female crabs favordeeper waters in the lower bay. A significant number of age 0 crabs and adult males (age 1+) are likely to over-winter in the upper Delaware Bay and its tributaries, and were not sampled effectively in this study. This portion of the stock is unlikely to be affected by the deepening project, and therefore was not a target for this study. The lower population size of fully recruited crabs can explain the reduction in landings as compared to the 2001/2002 winter fishery.

The conversion of landings from number of bushels to number of blue crabs may not be accurate because the State of Delaware Department of Natural Resources has not sampled the landings from the winter dredge fishery to date (Desmond Kahn, DENREC, pers. comm.). We chose to use the same conversion factors as we applied last year for ease of comparison across years.

The estimated absolute abundance, obtained after statistically adjusting for the catch efficiency of the dredge, suggests that only a small fraction (0.13 %) of the blue crab population in the lower Delaware Bay resides in the limited area of the channel slated to be dredged during winter. The navigation channel had a significantly lower average density of blue crab than the overall lower Delaware Bay. Thus, the planned navigation channel deepening project during winter is likely to have marginal impact on the blue crab stock.

The swept area estimates of overall density (number of crabs per 1000 m^2) in the Delaware Bay, and for the navigation channel was significantly lower in 2002 than the 2001 estimates for all size classes combined, and for fully recruited crabs (CW $\geq$ 120 mm). The overall density estimate is in the lower range when compared to densities for the Chesapeake Bay in the 1990s (Sharov et al. 2001). The mean absolute density in the entire Chesapeake Bay declined from a high of 35-38 crabs per 1000 m^2 in 1990-1991 to 8.3 crabs per 1000 m^2 in 1999 (Sharov et al. 2001). In the lower Chesapeake Bay, which has similar sex and size composition as the lower Delaware Bay, the mean absolute density of crabs during winter ranged from 11.8 to 44.8 crabs per 1000 m^2 between 1994 and 1999 (A. Sharov, pers. comm.). The lower Chesapeake Bay has high salinity (25-35 ppt) and relatively deep waters, and like Delaware Bay is almost exclusively inhabited by mature females during winter (Sharov et al. 2001); females made up 88% to 96% of the age 1+ population in lower Chesapeake Bay from 1994 to 1999.

The overall estimated mean catch efficiency of the vessel and commercial dredge this year (22%) was identical to the 2001 estimate for the same vessel and gear, and is reasonable when compared to estimated efficiencies for the vessels and gear used in the Chesapeake Bay winter dredge survey (Vølstad et al. 2000, Sharov et al. 2002). The average catch efficiency for the four vessels participating in the Chesapeake Bay survey between 1990 and 1999 ranged from 0.13 to 0.29. The sampling gear used in the Delaware Bay survey consists of two 2.15 m wide dredges that are hinged together. The wider dredge may be more stable than the 1.87 m modified Virginia oyster dredge used in the Chesapeake Bay, and thus could have increased catch efficiency. The lower catch efficiency at stations with oyster-shells is reasonable because the dredge cannot penetrate the bottom as well as for softer habitats. In this case, the application of habitat-specific catch efficiencies for the dredge is likely to produce more accurate estimate of overall abundance. The slightly higher catch efficiency for larger crabs suggest a small negative bias in the estimated abundance of smaller crabs. However, the estimated differences in density and abundance between the channel and the lower Delaware Bay in general is likely to hold because the two populations compared had a similar size structure.

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