OYSTER MANAGEMENT WHITE PAPER - 2004[1]
Updates Through 2009[2]

Delaware Division of Fish and Wildlife

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Background

In June of 2001 the Delaware Legislature promulgated an amendment to Delaware Code, Title 7, Chapter 21 that affected how the state's oyster resources are managed. The major focus of the amended legislation dealt with changes in the long-standing requirements that oysters harvested from the state-owned natural oyster beds must be transplanted to privately leased beds in Delaware Bay. Historically oysters were transplanted from the natural beds to privately leased beds and then harvested for market. The new amended legislation now permits the "direct harvest" of oysters from the natural beds for commercial purposes. This modified approach to oyster harvesting was formulated in an effort to reduce the loss and risk associated with transplanting that had plagued the oyster industry during the past two decades. Continued problems associated with disease losses due to the oyster parasites MSX (*Haplosporidium nelsoni*) and DERMO (*Perkinsus marinus*) had essentially eliminated any interest in harvesting under the old transplant program, even though oyster stocks had recovered to levels that would support commercial harvesting. In an attempt to at least reestablish some harvesting that could benefit as many watermen as possible, the Division of Fish and Wildlife initiated modifications in the state's oyster resource management program that would allow for "direct harvesting" while still protecting the long term sustainability of the resource.

The Division had to rely on existing biological data sets to formulate a new oyster management strategy that would be compatible with a "direct market" fishery. One of these existing data sets was from a survey specifically designed to monitor annual oyster abundance on the state's natural oyster beds. The survey has been in existence since 1970. These surveys were always conducted during October in order to ensure that newly-set oyster spat had grown enough to be distinguishable and thus accurately counted. In addition, a fall survey provided insight into stock conditions that would be available for harvesting in the subsequent spring. Traditionally oysters were harvested from the natural beds during the spring months (April, May) for transplanting to the leased beds and then harvested for market from these same leased beds during the fall and early winter. Harvest effort in the spring fishery was controlled by the length of the season which generally ran from two to four weeks depending on the availability of oysters. Under the transplant program a one to one bushel return was virtually impossible to achieve due to losses associated with disease and the overall economic overhead costs associated with dredge harvesting. Fishing operations became cost-prohibitive once daily catches declined to a certain level, despite the fact that oysters still remained. In some cases fifty- percent harvest losses were not unusual. This created a situation that demanded that harvesters initially plant as many oysters as possible in the spring in order to have a chance for a profitable fall harvest.

This need for significant quantities of oysters for transplanting combined with the high levels of economic overhead inherent with this type fishery, created an economic induced buffer that helped ensure that the natural beds were not overharvested. Specifically, when daily harvest levels on the natural beds fell below two hundred bushels per day, it was not economically feasible to operate due to the risks associated with disease mortality losses inherent in the transplanting process. Consequently harvesting operations terminated at these reduced levels of harvest but there still remained adequate oyster densities on the natural beds to ensure eventual recovery of the resource in a reasonable amount of time (five to six years). During the last two decades, the natural oyster beds were closed during two different periods (1986 – 1990, 1996 – 2000) for the purpose of allowing the stocks to recover. Although the natural beds have not been able to continuously sustain commercial harvesting over an extended period of time, the beds have always been able to recover within five years after a closure. This suggests that remnant population densities, as a result of the economic buffer associated with transplanting, were adequate to support resource recovery.

The onset of “direct market fishing” in 2001, rather than the traditional “transplant fishery”, has required a complete change in the management approach needed to protect and sustain the state’s natural oyster beds. Under the “direct market” fishery, the existence of an economically induced buffer of oysters that had remained on the beds in the past was eliminated. With the “direct market” fishery, harvesters could potentially work the beds to extremely low daily catch levels and still continue to profit economically since there are no losses due to transplanting. The challenge to resource managers within the Division of Fish and Wildlife was to develop a management system that resulted in harvest patterns similar to those that had occurred on the natural beds during the past three decades while still permitting a “direct market” fishery to occur. The major objective in this management strategy was to insure that adequate remnant populations remain on the beds to enhance recovery within a reasonable amount of time. Four factors that strongly influence recovery in oyster stocks are related to population densities. First the actual pumping activity of the oysters helps keep sediments from depositing on the beds and potentially smothering the bed. Secondly, oysters discharge a pheromone that attracts larval oysters, presumably as a survival mechanism, to ensure that the larva set on suitable hard substrates, thus increasing the chance for survival. Thirdly, adequate brood stock are needed to produce the larvae that will eventually set on the beds and replace those oysters lost to natural and fishing mortality Finally, insuring that adequate densities of oysters remain on the beds to insure manipulation of habitat to improve oyster recruitment. For these reasons it is imperative that an adequate residual population be permitted to remain on each bed so that the complex interactions within the oyster community can continue to function as a viable entity.

Harvest Quota

Two analytical data sets were available for formulating a new oyster management strategy based on a harvest quota. The first set of biological survey data details the numbers of markets (> 3” shell height), smalls (< 3” and > 1” shell height) and spat (young of the year) on each bed at specific sampling locations on annual basis dating back to the early 1970’s. The second data set available details harvest information from each natural seedbed during the same time frame (Figure 1). Division staff collected these data while monitoring the “transplant fishery” spring harvest seasons.

Regression analysis was used to establish the relationship between catch and an index of markets and smalls from five (Ridge, Silver Bed, Drum, Lower Middle and Over the Bar) primary beds (Figure 2). From a statistical perspective it was determined that the limited data sets did not support individual bed management, therefore, the natural oyster beds should be managed as a unit stock comprised of all five beds. Furthermore, from law enforcement stand point it would require constant at sea enforcement to ensure that individual bed closures were enforced. Given the time constraints already imposed on the enforcement staff, it was unrealistic to expect this level of commitment, thus the unit stock approach was adopted.

Because the surveys were always conducted in the fall, and harvest data came from the subsequent spring of the following year, it was necessary to lag the harvest information by one year. For example, if the survey was conducted during the fall of 1988, the 1989 spring harvest data was used for the comparative analysis. The harvest was comprised of both Market and Small oysters, as no size limit was in place, during the “transplant” fishery years. For this reason, both categories were used to calculate the survey index used for the analysis (Figure

3). The individual bed averages were pooled and an overall average number of oysters per bushel by size category (Markets, Smalls) calculated for the unit stock. The survey index represents the sum of these two means for the unit stock.

The comparative analysis (regression) established a predictive relationship between the abundance of oysters in the survey and the harvest. Therefore, when the survey index went up or down the harvest responded in the same manner ninety percent (r^2 = .90) of the time (i.e. ninety percent of the variation in the harvest was explained by the survey index). It was verified through this analysis that harvest levels were a function of stock densities and thus provided a parameter to measure abundance of the oyster resource. Having established the relationship between the index and harvest it was then possible to use the 2000 index to project what the 2001 harvest could be given how the fishery historically operated. However, since the fishery would not be operating in its historic fashion additional safeguards were implemented to protect the resource and market. Namely, a 2.75-inch minimum size limit was established to: 1) delay mortality to improve overall yield and 2) prevent unscrupulous harvesters from flooding dealers with small unmarketable oysters. To determine what proportion of the population of oysters on these beds would meet the minimum size requirement of 2.75 inches and thus be available to harvesters, it was necessary to estimate the size composition of each bed.

In order to make this determination, a random subsample of 50 oysters from each survey tow was measured for shell height to the nearest millimeter. These data were used to develop a cumulative height distribution for each bed. From this analysis we were able to determine what percent of the population was greater or less than a specific size. For example, based on the October 2003 data, 94.75 percent of the oysters on the Ridge were greater than 2.75 inches in height. Estimates for each bed were then pooled and an overall average comprised of the means from all five beds was calculated for the management unit. The upper confidence interval on this mean was used as the point estimate for determining what percentage of the population was greater than 2.75 inches. This approach was selected in order to maximize the harvest quota while still insuring that adequate residual stock densities, comparable to those that remained during the historical transplant fishery, remained on the beds after the quota had been harvested.

The projected harvest for the next year was calculated using the predictive relationship between the abundance of oysters in the survey and the historical harvest (Figure 2). In order to account for the restraints in harvests associated with the minimum size requirement, it was necessary to multiply the projected harvest from the index calculation by the proportion estimate (percentage) of the oysters larger than 2.75 inches. The product of this calculation was the projected harvest quota (Table 1).

Table 1. An example of how the oyster quota was calculated using the 2003 survey information.

A. Maximum bound on average of overall percent oysters greater than 2.75 inches from five beds = 92.4%

B. Harvest estimate based on historical data as predicted by the survey.

C. 12,657 bushels (projected harvest) x .924 (maximum bound) = 11,965 bushels

<u>Harvest Control Rule</u>

In general, it is important for a marine fisheries management program to establish analytical population density thresholds to use as targets when assessing the overall condition of the resource being managed. These thresholds can be defined as a harvest control rule and management effort should ensure that stock densities do not fall below these benchmarks. After reviewing historical closure patterns instituted on the resource during the “transplant fishery” years (1977-2001), it appeared that it is appropriate to use the index of market oyster abundance to establish a harvest control policy. More specifically, the survey index of market oysters per bushel lower 95% confidence limit, average, and upper 95% confidence limits are set as flexible harvest control thresholds (Figure 4). The average number of market oysters (per bushel) corresponds to the low levels of relative abundance at which the oyster population is capable of recovering within a few years post closure. It is essential in the development of these control rules that spawning stock abundance be maintained for the long-term viability of the resource. A static control policy based on the average survey index of market oysters (per bushel) alone does not allow for changes in the age structure, recruitment patterns, or disease dynamics of the Delaware oyster stock, making it a more or less conservative policy at times. Therefore, the upper and lower confidence intervals provide managers the flexibility to protect the resource when it is most critical to conserve brood stock abundance, and have the ability to be more liberal with the regulations when it is less critical that the abundance of market-sized spawners be maintained. The environment and the resource is not static, therefore, it is necessary that the control rule be dynamic as well. It is now our goal to maintain market oyster densities throughout the unit stock (five beds) above the thresholds of 18.27, 22.98, or 27.69, as defined by this flexible harvest control rule. The present state of relatively low recruitment during the last eight years is of particular concern. Without recruits to replace those oysters harvested, the population will continue to decline for several years. Therefore, the lower confidence limit of 18.27 market oysters per bushel is recommended as the closure threshold to protect the resource in 2010.

Figures

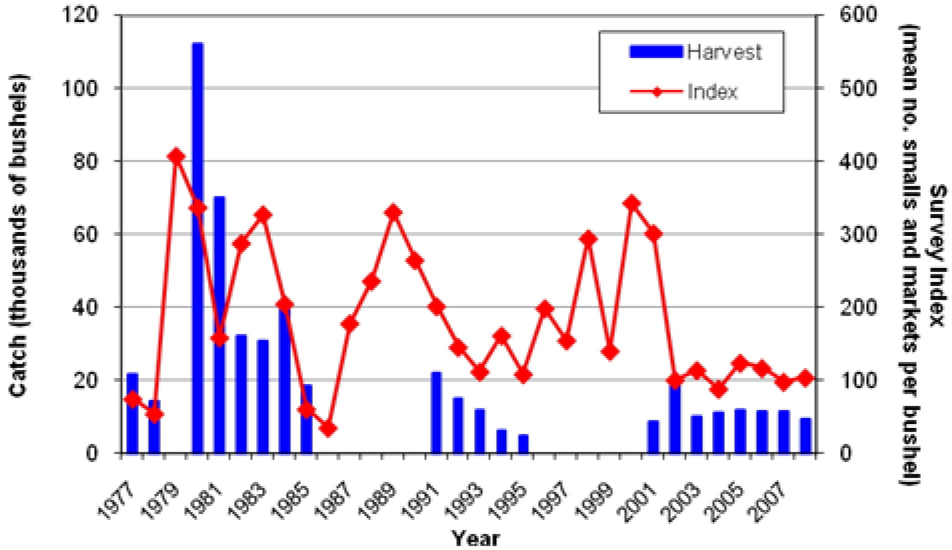

Figure 1. Delaware natural oyster beds harvest survey index, 1977-2008.

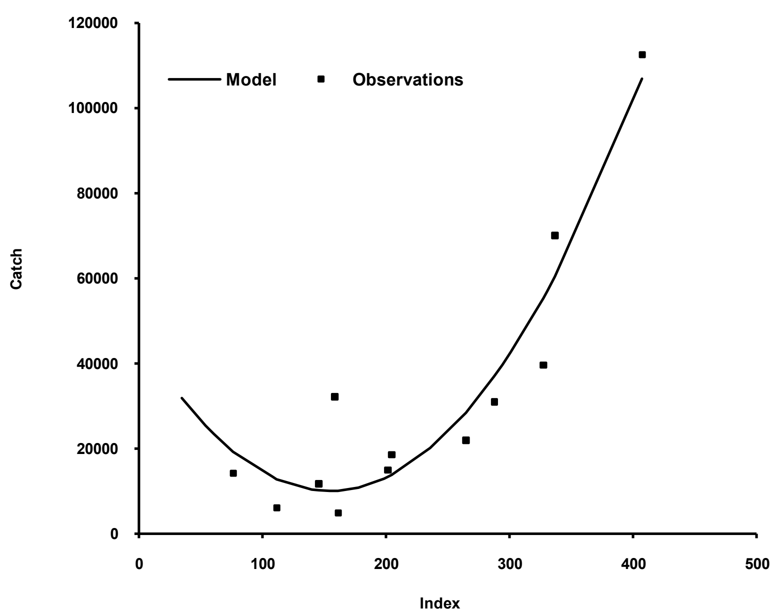

Figure 2. Regression relationship (quadratic) between natural oyster bed catch and survey index, lagged one year.

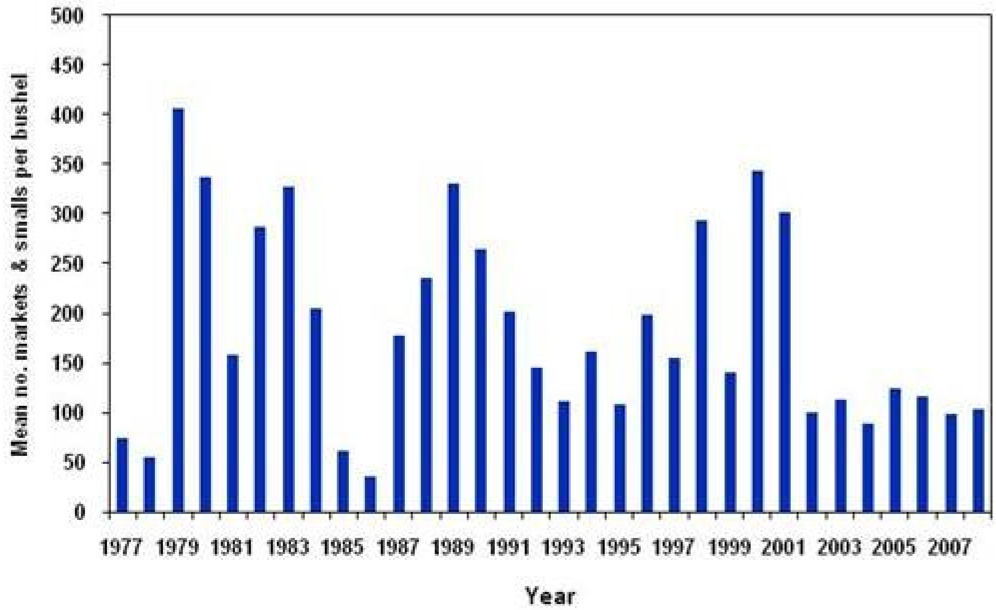

Figure 3. Natural oyster bed survey index comprised of markets and smalls from five beds (pooled average).

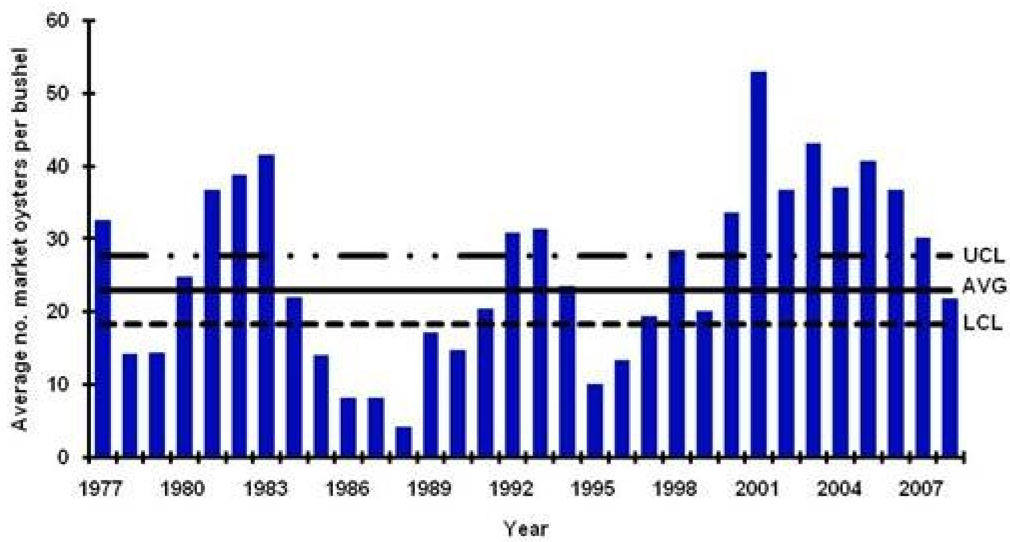

Figure 4. The pooled average survey index (bars) from five oyster beds and the flexible harvest control rule with lower 95% confidence limit (LCL), average (AVG), and upper 95% confidence limits (UCL) at 18.27, 22.98, 27.69 market oysters per bushel, respectively.

Addendum I

Modifications to quota calculations, December 2006[3]

For the 2007 quota, a three parameter nonlinear model replaced the curvilinear model previously used to predict upcoming quotas. The nonlinear model was used to fit the observed harvest from 1978 to 1995 to corresponding survey index values from October of the previous calendar year (Figure A1).

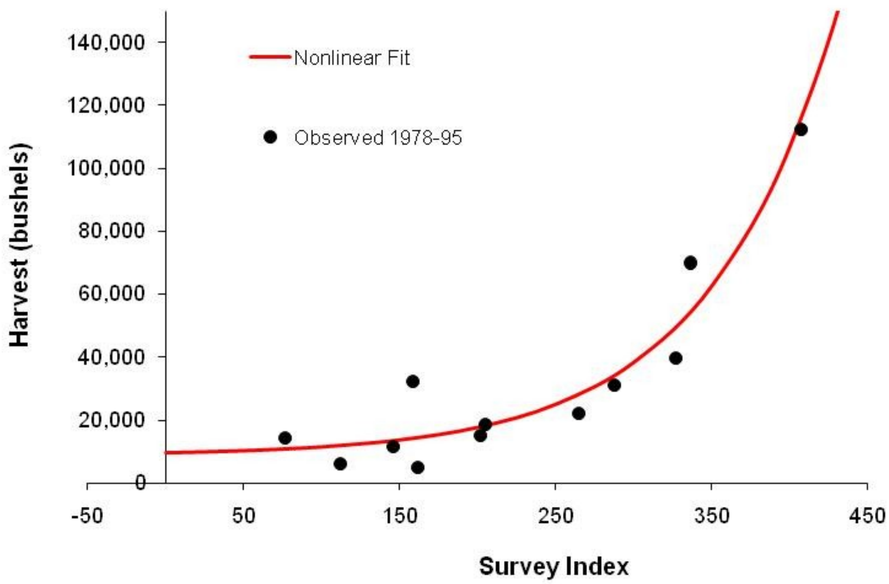

Figure A1. Correlation between survey and observed harvest.

The advantage of this model is the better fit between low index values and low harvest observations.

The nonlinear equation is described as:

$$y = y_{intercept} + \alpha e^{\beta x}$$

with estimated parameters: $y_{intercept}$, α, β
where y = harvest $_{t+1}$ and x = survey index $_t$.

The following parameter estimates provided the best fit to the data ($P < 0.0001$):

$y_{intercept}$	8605.1
α	810.3
β	0.012

[3] Wong, R. Delaware Division of Fish and Wildlife

Addendum II

2007 Swept Area Abundance Estimation, February 2009[4]

Methods:

In October 2007, a gear efficiency study was conducted to compare the oyster catch rates from dredge gear used in the Delaware Oyster Dredge Survey to adjacent diver-observed measurements.

Twenty-seven dredge tows were taken across four natural oyster beds (Ridge, Lower-Middle, Over-the-Bar, Silver). Two locations within each bed (3 locations at the Ridge) were identified for study areas. Three replicate dredge tows were conducted at each location producing 27 total dredge tows. Each dredge path was measured by GPS. The total volume of bottom material collected by the dredge was recorded for each tow. A one bushel sub-sample was taken from each tow sample and measured for live and dead market, juvenile, and spat abundances, and cultch volume.

At each tow site, 12 replicate 0.25 m^2 quadrats were sampled by divers along an undisturbed transect immediately adjacent to the dredge path. All bottom material was collected in dive bags at each quadrat.

Given the known dredge width (52.5 cm) and tow path distance, the area of dredged bottom was calculated for each tow. Oyster counts within a tow sub-sample were expanded by the ratio of (total tow volume/sub-sample volume). Oyster abundance was standardized per 1 m^2. Diver observed counts of oysters were similarly standardized per 1 m^2. The dredge efficiency was expressed as the regression of diver-observed oysters*m^{-2} to dredge-captured oysters*m^{-2} across 27 tow sites. Separate efficiencies were investigated for each size class of oysters.

The gear efficiency regression(s) were used to adjust the oyster abundance*m^{-2} observed in the Delaware Oyster Dredge Survey. The efficiency-adjusted, average abundance*m^{-2} observed in the survey was multiplied by the total Delaware oyster bed area to estimate the absolute oyster abundance in Delaware waters. The area of natural oyster beds in Delaware waters was ascertained from a 2005 hydroacoustic – core sampling study conducted by the Division of Soil and Water (Wilson 2005) (Table B1). Since the survey occurs in October, the abundance calculation is essentially an end-of-the-year estimate of absolute abundance.

Exploitation rate was calculated as:

$$\mu_t = \frac{harvest_t}{(harvest_t + absolute\ abundance_t)} ,$$

except in the terminal year 2009, where

$$\mu_t = \frac{harvest_t}{(absolute\ abundance_{t-1})} .$$

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[4] Wong, R. Delaware Division of Fish and Wildlife

Black Buoy abundance was excluded in the μ calculations since it was an unexploited bed area with unknown oyster density (not sampled by the survey) (*pers. com. R. Cole*).

Table B1. Natural oyster bed area in Delaware waters.

Bed	Acres	Square Meters
Black Buoy	110.45	446,975
Over The Bar	287.58	1,163,795
Lower Middle	259.50	1,050,159
Red Buoy	176.74	715,241
Silver Bed	320.49	1,296,977
Pleasanton's Rock	60.88	246,373
Ridge	377.45	1,527,486
Drum Bed	41.18	166,650
Woodland Beach	96.79	391,695
Persimmon Tree	12.50	50,586
Grand Total	1,744	7,055,937

Results/Discussion:

The dredge captured 11.3% of market sized (≥2.75”) oysters relative to diver observations (across equally weighted tows). The relationship between diver observations and dredge catch is described by the regression,

$$y = 6.5739x + 5.1746,$$

where *y*=diver counts, *x*=dredge counts (Figure B1).

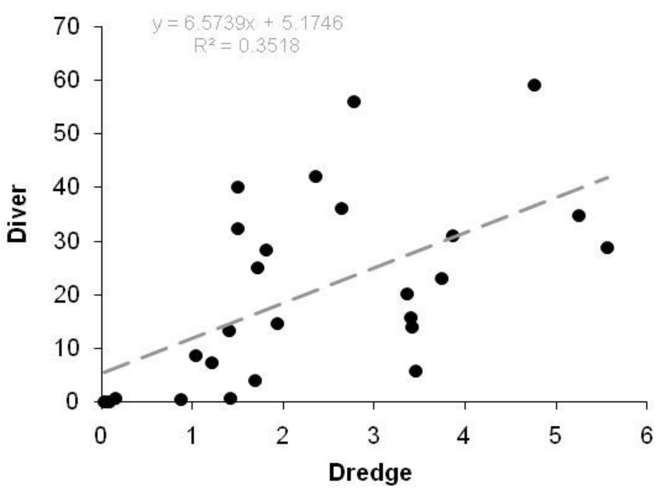

Figure B1. Diver observed catch (per m^2) versus dredge tow catch (per m^2) of market sized oysters (≥2.75”) across 27 sampling sites.

Using the gear efficiency regression and a known bed area of 6.6 million m^2 (Black Buoy excluded), the dredge survey results indicate roughly 119 and 94 million market-sized oysters in 2007 and 2008 (Table B2). Exploitation rates were 2.64% and 3.14% in 2007 and 2008. These exploitation rates are upper estimates since the survey occurs near the end of the year (after natural mortality has occurred). The 2009 μ does not account for losses due to natural mortality, nor recruitment into legal sizes through growth, so potential bias of the estimate is uncertain. Nonetheless, exploitation rates are high relative to New Jersey estimates (<2% annually since 1981) and appear to be increasing.

Table B2. Delaware Oyster Dredge Survey results and estimates of market-size (≥2.75") absolute abundance and exploitation rates. Exploitation rates were calculated as μ_t = harvest $_t$/(harvest $_t$ + absolute abundance $_t$), except in 2009 (μ_t = harvest $_t$/abundance $_{t-1}$). Since abundance is estimated near the end of the year, exploitation rates in 2007 and 2008 should be considered upper estimates of exploitation. The 2009 exploitation rate should be considered a lower prediction of μ.

	2007	2008	2009
Area (m^2) sampled by oyster dredge survey	5,177	6,195	
Number of legal sized oysters*m^{-2} observed in dredge survey	1.952	1.377	
Efficiency-adjusted number of legal sized oysters*m^{-2}	18.0	14.2	
Absolute abundance of legal sized oysters	119,018,729	94,028,035	
Harvest quota in bushels	11,872	11,218	11,405
Harvest quota in numbers	3,229,184	3,051,296	3,102,160
Exploitation rate	2.64%	3.14%	3.30%

Addendum III

Meta-data:

In 2002, the *Ringgold Bros*. research vessel was replaced by the new research vessel, *First State*. No comparison tows were taken.

In 2005, new oyster bed footprints were determined from hydroacoustic/core sample analyses conducted by the Delaware Coastal Program and summarized in a seabed classification survey report (Wilson 2005). As a result of this study, Ridge bed survey stations were moved to new locations within the bed in 2005.

Beginning in 2008, heavily mudded dredge survey samples were raised and dunked in the water alongside the vessel prior to sorting. Pre-washing results in loss of an unknown amount of captured materials. This affects the measurement of the total volume of dredge material recorded by staff. The total volume measurement is important in the calculation of the absolute abundance of oysters in the swept area analysis since sub-sample measurements are expanded by the total volume in the tow.