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Dredge efficiency on natural oyster grounds in Delaware Bay and its application in monitoring the Eastern oyster (*Crassostrea virginica*) stock in Delaware, USA

Frank Marenghi[a,1], Kathryn Ashton-Alcox[b], Richard Wong[c], Bellamy Reynolds[a], Gulnihal Ozbay[a,*]

[a] Delaware State University, 1200 North DuPont Highway, Dover, DE 19901, USA
[b] Haskin Shellfish Research Laboratory, Rutgers University, 6959 Miller Avenue, Port Norris, NJ 08349, USA
[c] Delaware Division of Fish and Wildlife, 3002 Bayside Dr., Dover, DE 19901, USA

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ABSTRACT

The annual Natural Oyster Ground Survey is the primary tool used in the management of the oyster fishery in the Delaware portion of Delaware Bay, USA. This survey monitors relative abundance, annual mortality, and recruitment of oysters from commercially important beds and tracks relative changes in the overall stock. Studies have shown that the commercial dredge gear used for this and similar surveys does not collect live oysters, boxes, and cultch with equal efficiency. We compared catch rates of live oysters, boxes, and cultch using this gear to adjacent diver-collected samples. Dredge efficiency varied by bed with the lowest efficiency on the bed with the least fishing pressure, possibly due to a higher degree of reef consolidation. Dredge efficiencies between size classes (20–65 mm, 65–75 mm, >75 mm) were highly variable, although the dredge may be biased towards the capture of live oysters and larger (>65 mm) individuals. Oyster abundance (not including spat) estimated from annual surveys and corrected for dredge efficiency on the commercially important Delaware oyster beds increased from approximately 240 million to 491 million individuals between 2007 and 2008. A comparison of three estimation techniques (bed-specific efficiencies, mean efficiencies, and bootstrapping) is discussed in the broader context of estimating population abundance, size structure, recruitment, and mortality, when corrected and uncorrected for dredge efficiency.

1. Introduction

Eastern oyster, *Crassostrea virginica* Gmelin, 1791, beds in Delaware Bay historically supported large oyster fisheries. Industry and managers adopted practices to maintain the population for the continuation of the fishery from as early as 1873 (Fegley et al., 2003). Annual landings for Delaware Bay were consistently between 1 and 2 million bushels until the middle of the 20th century when oyster mortalities caused by *Haplosporidium nelsoni* (MSX) and *Perkinsus marinus* (Dermo) were first documented (Ford and Haskin 1987; Ford, 1996). Declines in landings are also attributed to fluctuations in imported seed and market demand, particularly in the years of the Great Depression (Ford, 1997; Fegley et al., 2003). The effect of fishing cannot be quantified because the stock was not regularly monitored after a 1910 survey (Moore, 1911) and removals from the natural beds could not be distinguished from planted stock (Ford, 1997). Nevertheless, these landings may have been unsustainable due to declining oyster abundance even in the absence of disease epizootics (Moore, 1911; Fegley et al., 2003). Like New Jersey, Delaware traditionally had a transplant fishery in which small oysters experiencing slower growth and lower mortality on up-bay public seed beds were transplanted onto private leases down-bay in higher salinity waters, increasing their growth rate and market quality prior to harvest later in the year or in future years (Powell et al., 1997; Ford et al., 1999; Greco, 2009). Legislation enacted in 2001 established a quota-based fishery in which oysters were sold directly from the natural seed beds (Cole et al., 2009).

The annual Natural Oyster Ground Survey is the primary tool used in the management of the oyster fishery in Delaware. Since

* Corresponding author.
E-mail address: gozbay@desu.edu (G. Ozbay).
[1] Current address: Maryland Department of Natural Resources, 580 Taylor, Ave B-2, Annapolis, MD 21401, USA.

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1974, the Delaware Department of Natural Resources and Environmental Control (DNREC) has collected relative abundance, mortality, and recruitment data from the major oyster beds in the Delaware portion of Delaware Bay to track relative changes in the stock (Greco, 2009). The annual oyster harvest quota in Delaware is based on the relationship between harvest and relative abundance from the annual survey in prior years (Cole et al., 2009).

Commercial oyster dredges or smaller dredges have been used in surveys in both Delaware and Chesapeake bays for many decades (Cole, 1988; Fegley et al., 2003; Mann et al., 2004; Tarnowski, 2005; Volstad et al., 2008; Greco, 2009). Inefficiency and bias in dredge sampling have been noted for at least two decades (Chai et al., 1992; Powell et al., 2002; Mann et al., 2004). The dredge with its iron tooth bar is designed to ideally pull the topmost oysters off a reef, leaving behind the associated reef material. In areas of highly consolidated reef or with rock, a dredge may 'bounce' somewhat, while in softer, less consolidated areas, the teeth are likely to dig in and pick up more objects in its path. In Virginia, a dredge survey has been supplemented with quantitative sampling with patent tongs since 1993 (Mann et al., 2004). The New Jersey survey was improved in 2000 by using dredge calibration in conjunction with measured swept areas and tow volumes (Powell et al., 2002, 2007). Powell et al. (2002, 2007) determined that oysters were captured with greater efficiency than boxes (dead oysters with articulated valves) while boxes were picked up with greater efficiency than cultch (oyster shell only). Larger oysters and boxes are often collected with greater efficiency than smaller oysters and boxes, although the tendency of oysters to attach to each other makes this evaluation difficult (Powell et al., 2002, 2007). The dredge may simply not pick up some oysters while others may pass through the mesh. If not accounted for by dredge calibration, these biases may have large ramifications in estimating numbers of oysters and boxes based on dredge samples. For example, if dredge efficiency for live oysters varies significantly from that for boxes, annual mortality will be under- or overestimated with potentially large management implications. If the dredge is biased with regard to oyster shell length, this will alter the perceived size class distribution, e.g., the estimation of the number of market-sized animals.

Our study determines survey-employed commercial dredge efficiencies on four commercially important oyster beds for various material types (live oyster, box, cultch), and size classes (20–65 mm, 65–75 mm, >75 mm) in 2007 in Delaware (Dredge Calibration). We then convert efficiencies into catchability coefficients to expand survey dredge catches to absolute oyster abundances. These abundances and harvest monitoring results can be used by DNREC to determine annual exploitation rates, providing information used when setting quotas. Differences between efficiency-corrected and uncorrected estimates of abundance, annual mortality, and recruitment as well as the implications of three estimation techniques (bed-specific efficiencies, mean efficiencies, and bootstrapping) are discussed.

2. Methods

2.1. Dredge calibration

We conducted a gear efficiency study in October 2007 to compare the oyster catch rates from DNREC survey dredge gear to adjacent diver-collected samples. The survey vessel is 19 m in length and uses a stern-towed, commercial dredge (1.33 m width with 24 teeth measuring 9.5 cm long, spaced 6.4 cm apart). The dredge bag is constructed with 6.0 cm rings with a 5.4 cm inside diameter spaced 6.4 cm apart. There was no diving plane. This is the same design as is used throughout the Delaware Bay for both commercial oystering and survey sampling in New Jersey. Samples were collected and processed using methods developed for the New Jersey oyster beds (Powell et al., 2002, 2007). Twenty-seven dredge tows (paired with diver transects described below) were taken across the four most important natural oyster beds in Delaware: Ridge, Lower Middle, Over-the-Bar, and Silver (Fig. 1, Table 1). Three study sites were located on Ridge and two study sites were situated on each of the other beds. Study sites were intentionally located in the middle portions of each bed, away from the bed peripheries, and in close proximity to the DNREC annual survey stations. Three replicate tows were taken at each location. Each tow lasted approximately 45 s. This relatively short tow time is necessary so the dredge does not overfill and begin to push material along the bottom (Powell et al., 2002; Mann, 2010). For each tow, total bottom time and positions were recorded using the Global Positioning System (GPS) onboard the survey vessel. Tow distance was calculated from GPS positions recorded every 5 s over a 45 s tow. The total volume of bottom material collected by the dredge was recorded and a one-bushel (35 L) subsample was taken from each tow.

At each site, a leaded line was deployed immediately adjacent (within ~5 m) and parallel to the dredge path (Powell et al., 2002). Twelve replicate 0.25 m^2 quadrats were sampled by divers along the undisturbed transect. Divers took all loosely consolidated reef material on the bottom within the quadrat and placed it in the dive bag. In the event that large quantities of shell were present, the diver took enough of the upper portion of the shell base to fill the dive bag (Powell et al., 2002). There are two assumptions inherent in this method: (1) the dredge is less than 100% efficient but the diver can collect everything within the quadrats and (2) the dredge tow and the diver transect are close enough to independently sample two very similar portions of the oyster bed.

All dredge and dive bag samples were stored in a refrigerated walk-in cooler at approximately 10 °C prior to sorting. Each sample (bushels and dive bags) was sorted into categories: live oysters, boxes, spat (oyster <20 mm), and cultch. The volume of each material was recorded and the total shell length (longest dimension) of all oysters and boxes was measured. Counts of live oysters and boxes were divided into three size classes for analysis: smalls, 20–65 mm in length; sub-markets, 65–75 mm (Kraeuter et al., 2007); and markets, >75 mm. All sizes of cultch were sorted together.

The area of the bottom swept by the gear was determined by multiplying distance towed (m) × dredge width (m). Counts of oysters and boxes per sample bushel and cultch volume per sample bushel were standardized per square meter swept. The volumes of material collected from the diver transects were also standardized per square meter sampled and oyster, box and cultch density (m^{-2}) were calculated in a similar fashion.

Dredge efficiency (e) was calculated as the ratio of oyster density in the dredge sample (m^{-2}) to oyster density in the dive sample (m^{-2}) for oysters and boxes; the dredge efficiency for cultch was

Table 1
Oyster bed names, their area (m^2), and sampling intensity for the 2007 and 2008 Delaware Natural Oyster Grounds surveys.

Bed name	Area (m^2)	Number of Survey Tows
Ridge	1,527,540	15
Silver	1,297,023	10
Over-the-Bar	1,163,836	6
Lower Middle	1,050,197	6
Red Buoy	715,267	3
Woodland Beach	391,709	6
Pleasanton's Rock	246,381	3
Drum	166,655	3
Persimmon Tree	50,588	2
Total	6,609,196	54