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Evaluation of Oyster Sampling Efficiency of Patent Tongs and an Oyster Dredge

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Abstract.—Sampling efficiency of two oyster fishing gears, patent tongs and an oyster dredge, were compared in reference to diver-harvested quadrats in Chesapeake Bay, which supports important harvests of eastern oyster *Crassostrea virginica*. Mean densities of spat (≤35 mm), small oysters (>35 mm to 75 mm), marketable oysters (>75 mm), and all oysters (three size-groups combined) estimated from patent tong samples were not significantly different from those derived from diver-harvested quadrat samples. In contrast, the densities estimated from dredge samples were low, only 2–32% of the diver estimates. Accordingly, patent tongs are recommended as the sampling gear for estimating eastern oyster stock abundance in the Maryland portion of Chesapeake Bay.

The eastern oyster *Crassostrea virginica* supports one of the most important commercial fisheries in the Maryland portion of Chesapeake Bay (Kennedy and Breisch 1981, 1983; McHugh 1984; Stagg 1985). Landings have declined 97% over the past century, from 15 million bushels in 1884 to 0.4 million bushels in 1990 (Bell and FitzGibbon 1978; Cabraal and Wheaton 1981; Kennedy 1989). To restore the eastern oyster fishery, a rational management policy is urgently needed. For this, an accurate assessment of oyster stock abundance is important (Gulland 1983; Rivest et al. 1990; Smith 1990), and an effective sampling gear is essential for the assessment.

Four types of commercial oyster fishing gear or harvest methods are used in the Maryland portion of Chesapeake Bay: hand tongs, patent (hydraulic) tongs, oyster dredge, and diver harvesting (Kennedy and Breisch 1981; Kennedy 1989). In 1878 Winslow (1884) first used the oyster dredge to assess eastern oyster stocks in Tangier and Pocomoke sounds in the bay. He stated that dredge samples severely underestimated oyster density, and thus the data were valuable only for comparative study of different oyster grounds. Grave (1907), based on the report of Winslow (1884), considered the oyster dredge to be an ineffective gear for examining oyster grounds. Yates (1913) used patent tongs and hand tongs to conduct oyster surveys in the Maryland portion of Chesapeake Bay from 1907 to 1912. However, since 1939 the Maryland Department of Natural Resources has used the oyster dredge to conduct its annual baywide survey. The reason for using the oyster dredge as the sampling gear for the survey is unknown, but the oyster dredge is easy and relatively inexpensive to use, and it allows more areas to be sampled (Newell and Barber 1990).

The oyster dredge also has been used for the annual spatfall monitoring program in the Virginia portion of Chesapeake Bay since 1947 (Andrews 1968; Haven et al. 1981; Whitcomb and Haven 1989); patent tongs were used to determine the areas and locations of public oyster grounds and to assess their productivity (Haven et al. 1981; Haven and Whitcomb 1983, 1986; Whitcomb and Haven 1987, 1989). The dredge was also used in assessing the eastern oyster stock in Delaware Bay in 1968 and 1969 (Maurer et al. 1971; Keck et al. 1973).

In addition to the negative opinions of the oyster dredge as a stock abundance tool that were expressed by Winslow (1884) and Grave (1907), Webster (1953) observed that the dredge did not collect everything in its path and that it yielded widely varying replicate samples. Furthermore, dredge sampling efficiency is affected by bottom characteristics, towing speed, and length of towline (Sanders 1966; Russell 1972; Allen and Cranfield 1976; Meyer et al. 1981; McLoughlin et al. 1991). When the 40-year time series of spat densities collected by the Maryland Department of Natural Resources was examined by autoregressive integrated moving average (ARIMA) models, white noise (random shock) was the main source of variability (Chai 1988). It was not known whether the white noise arose from natural, unpredictable, and

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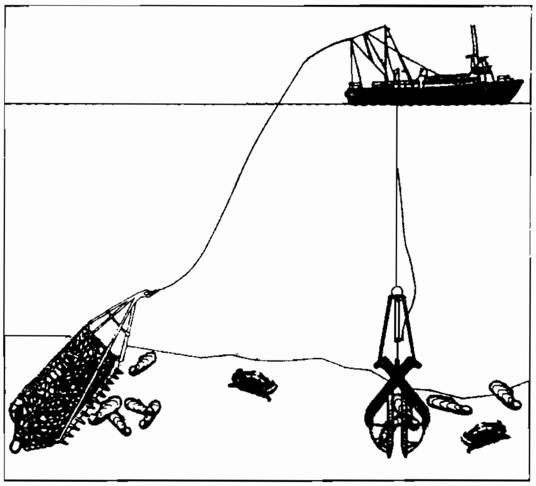

FIGURE 1.—Patent tongs and oyster dredge sampling methods used in this study.

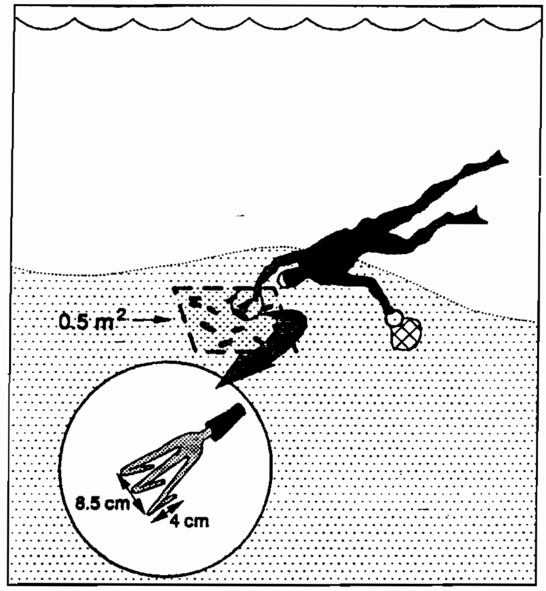

FIGURE 2.—Quadrat and rake used in the diver sampling method.

wide variations in spat settlement or from improper data collection.

Hand tongs are suitable only for shallow water (Grave 1907) and are too restrictive a sampling gear for stock assessment. Diver harvesting can accurately assess oyster stock abundance (Dugas 1977; Rodhouse 1976, 1979; Meyer et al. 1981). Diving has been commonly used in small-scale assessments of oyster stocks (recruitment, growth, and mortality: May 1971; Dugas 1977; Hoses and Ancelet 1987; Morales-Alamo and Mann 1990) and of habitats and resources (Soniat and Brody 1988; Berrigan 1990). However, it is too time-consuming to be cost-effective for a bay-wide survey.

Rodhouse (1976, 1979) found that the average sampling efficiency of an oyster dredge was 10% of that of a diver who harvested quadrats. A comparative study between dredge and diver sampling techniques was also conducted for clams (Meyer et al. 1981). We compared the sampling efficiencies of patent tongs and an oyster dredge, using diver-harvested quadrat samples as a reference. The objective was to select an appropriate gear for assessing the eastern oyster stock in the Maryland portion of Chesapeake Bay.

Methods

The gears used in this study—patent tongs, oyster dredge, and quadrat and rake used in diver sampling—are illustrated in Figures 1 and 2. The patent tongs were 1.2 m wide, had 1-cm tines spaced at 6-cm intervals, and were lined with a 12-mm wire mesh screen. They sampled an area of 1.41 m^2 to a depth of 10 cm into the substrate. The oyster dredge was 1 m wide with 1.5-cm tines spaced at 5.5-cm intervals, and it had a bag of 2.5-cm-mesh rope with 5-cm-diameter rings. It was towed for 131 m, the distance needed to half fill the dredge (effectively sampling 131 m^2). We used diver-harvested quadrats as reference samples as Rodhouse (1976, 1979) and Meyer et al. (1981) had done. All shell materials within a 0.5-m^2 quadrat and down to 10 cm deep was harvested by diver using a hand rake with 10-cm-long and 1-cm-wide tines spaced at 2.75-cm intervals.

Three oyster bars were used for the experiments: Holland Point bar near Herring Bay, Walter White bar in Prospect Bay, and Hog Island bar near the mouth of the Patuxent River (Figure 3). An oyster bar is defined as the area of shell where pelagic oyster larvae settle, survive, and grow (Meritt 1977; Haven and Whitcomb 1986; Whitcomb and Haven 1987; Seliger and Boggs 1988). The three oyster bars were selected from Meritt's (1977) maps of Maryland oyster bars, which were revised from those developed by Yates (1913). The bottom substrates were hard clay at the Holland Point bar, mud and shell at the Walter White bar, and hard clay and shell at the Hog Island bar.

Hydroacoustics were used first at each bar to determine the location of the area containing shell. Twenty samples were then randomly taken by each of the three sampling methods. Diver-harvested samples were taken on the first day and patent tong samples on the next day. Dredge samples were taken last to minimize the chance of sampling on previously disturbed bottoms.

The live oysters were counted and measured in each sample. They were classified by size as spat (≤35 mm), small oysters (>35 mm to 75 mm), and marketable oysters (>75 mm). Because the area sampled by each method differed, the oyster density estimated by each method was standardized as the number of oysters per square meter (number/m^2).

Eastern oysters are gregariously distributed because of the contagious setting of spat, which tend to clump together in patches (Hidu 1969; Hidu and Haskin 1971; Powell et al. 1987). Their spatial distribution is affected by patch size and the distance between patches. Therefore, the ratio of sample variance to mean density (s^2/mean) was used as an index of dispersion (Elliott 1977; Pielou 1977). A ratio less than 1.0 indicates a homogeneous distribution; a ratio greater than 1.0 implies a heterogeneous distribution (patchiness). Because the number of oyster samples collected was small (20 per gear per bar) and they came from gregariously distributed populations, the data were transformed ($\log_e[x + 1]$) for analyses of variance (ANOVA) (Elliott 1977).

A 3×3, two-way ANOVA was used to determine the main effects of two factors (sampling method and oyster bar) and their interaction on oyster density estimates. We conducted 2 × 3, two-way ANOVAs for pairs of sampling methods on the three oyster bars. These analyses detected the sources of interactions observed in the 3 × 3 ANOVA. One-way ANOVAs were used to determine the effects of the three sampling methods on density estimates for each oyster bar. We used Student–Newman–Keuls (SNK) multiple comparisons (Sokal and Rohlf 1981) to determine the differences in density estimates between pairs of sampling methods on each oyster bar. These comparisons detected the sources of differences observed in the one-way ANOVAs.

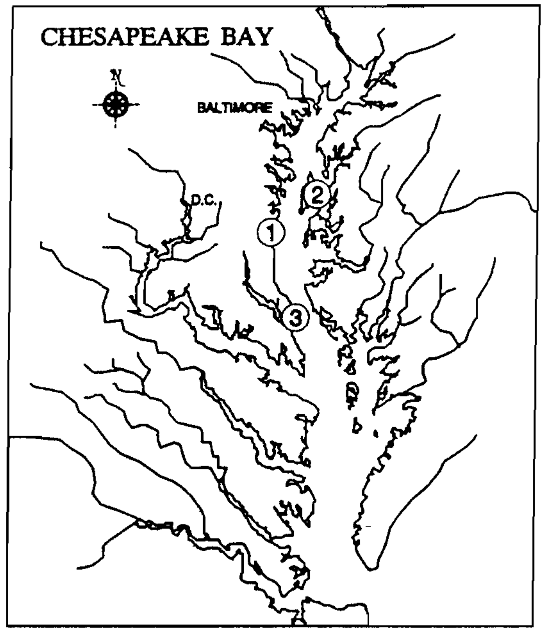

FIGURE 3.—Locations of expermiental bars—Holland Point (1), Walter White (2), and Hog Island (3)—in the Maryland portion of Chesapeake Bay. D.C. is District of Columbia.

Results

Eastern oyster densities estimated by the three sampling methods on the three oyster bars, as well

TABLE 1.—Densities (means ± SDs, number/m^2) of eastern oysters estimated by gear types, and variance (s^2) and s^2/mean ratios of total oyster densities for each of three oyster bars sampled.

Sampling method	Oyster density, by size-group					
	Spat	Small	Marketable	Total	s^2	s^2/mean
			Holland Point			
Diver	0.00 ± 0.00	0.60 ± 0.94	1.10 ± 2.00	1.80 ± 2.67	7.12	3.95
Patent tongs	0.00 ± 0.00	0.85 ± 1.12	1.17 ± 1.40	1.99 ± 2.15	4.62	2.32
Dredge	0.00 ± 0.00	0.19 ± 0.13	0.28 ± 0.16	0.46 ± 0.27	0.07	0.15
			Walter White			
Diver	0.20 ± 0.62	6.00 ± 5.39	11.20 ± 10.61	17.80 ± 12.94	167.44	9.40
Patent tongs	0.96 ± 2.39	5.85 ± 4.43	9.22 ± 6.13	16.06 ± 8.94	79.92	4.98
Dredge	0.01 ± 0.01	0.34 ± 0.25	0.40 ± 0.22	0.89 ± 0.49	0.24	0.27
			Hog Island			
Diver	14.60 ± 14.57	16.05 ± 24.33	1.00 ± 2.47	33.00 ± 39.30	1544.49	46.80
Patent tongs	10.21 ± 9.30	22.48 ± 25.51	1.14 ± 1.23	35.04 ± 31.88	1016.33	29.00
Dredge	0.25 ± 0.14	0.25 ± 0.20	0.03 ± 0.04	0.53 ± 0.24	0.06	0.11

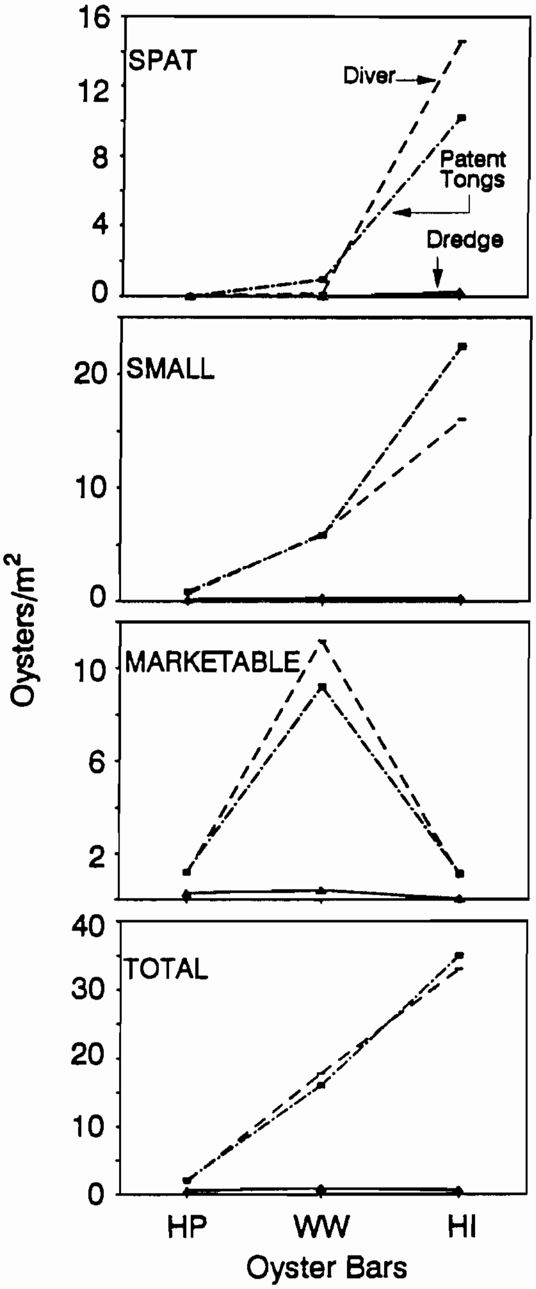

FIGURE 4.—Comparisons of mean eastern oyster densities at three oyster bars (HP, Holland Point bar; WW, Walter White bar; HI, Hog Island bar) for spat, small oysters, marketable oysters, and total oysters estimated by diver, patent tong, and dredge sampling methods. Lines are used for visual reference only.

TABLE 2.—F-values of 3×3, two-way analyses of variance to determine the main effects of three sampling methods (diver, patent tongs, dredge) and three oyster bars (Holland Point, Walter White, Hog Island), and their interaction, on the $\log_e(x + 1)$-transformed densities estimated for three size-groups of eastern oyster. All F-values were significant ($P < 0.01$).

Factor	Oyster size-group: Spat	Small	Marketable	Total oysters
Sampling method	19.08	31.52	33.11	56.49
Oyster bar	85.16	27.42	58.72	41.44
Interaction	15.42	6.25	9.02	8.76

as variances and variance/mean ratios, are shown in Table 1; mean densities also are plotted in Figure 4. Compared to diver-harvested quadrat samples, mean densities estimated from oyster dredge samples were extremely low: 2–5% of diver values for spat, 2–32% for small oysters, 3–25% for marketable oysters, and 2–26% for total oysters. The s^2/mean ratios associated with diver and patent tong data were greater than 1.0 for all the oyster bars, indicating a gregarious distribution (Greig-Smith 1964; Elliott 1977; Pielou 1977). The patchiness increased as oyster density increased. In contrast to the diver harvest and patent tong estimates, s^2/mean ratios associated with the oyster dredge were less than 1.0, indicating that the dredge could not detect patchy distributions on the three oyster bars.

In 3×3, two-way ANOVA, F-values for the main effects of sampling method and oyster bar were highly significant, as were the values for interactions (though they were much smaller than those of the main effects) (Table 2). This implied that the density estimates for each and all size-groups differed significantly among sampling methods and also among oyster bars. Also, sampling methods and oyster bars added slightly to each others' variances (Snedecor and Cochran 1980).

In the 2×3, two-way ANOVA of diver versus patent tongs, the main effect of oyster bar was highly significant, but neither the main effect of sampling method nor the interaction of methods and bars was significant (Table 3). This implied that when diver and patent tongs were used, the oyster density estimates for the three size-groups were significantly different among the three oyster bars, but not significantly different between sampling methods. It also implied that sampling method and oyster bar had independent effects on density estimates. In contrast, when dredge estimates were compared with either diver or patent tong

TABLE 3.—F-values of 2×3, two-way analyses of variance to determine the main effects of pairs of sampling gears and three oyster bars (Holland Point, Walter White, Hog Island), and their interaction, on the $\log_e(x + 1)$-transformed densities estimated for three size-groups of eastern oyster. Asterisks denote significance at $P < 0.01$**.

Factor	Oyster size-group			Total oysters
	Spat	Small	Marketable	
Diver and patent tongs				
Sampling method	0.01	0.78	1.76	0.14
Oyster bar	82.07**	28.16**	63.03**	43.10**
Interaction	0.88	0.30	0.09	0.11
Diver and dredge				
Sampling method	37.90**	58.34**	36.93**	130.14**
Oyster bar	52.59**	14.07**	22.96**	27.87**
Interaction	34.57**	11.73**	13.91**	20.97**
Patent tongs and dredge				
Sampling method	38.74**	65.63**	124.87**	127.96**
Oyster bar	39.25**	13.70**	46.16**	20.87**
Interaction	24.20**	11.94**	28.27**	15.46**

estimates, both main effects and the interaction between them were highly significant. The data plots (Figure 4) and the 2×3, two-way ANOVAs suggested that poor sampling performance of the oyster dredge was the source of the interaction observed in the 3×3, two-way ANOVAs.

The one-way ANOVAs indicated that density estimates usually differed significantly among sampling methods on oyster bars (Table 4). Exceptions (spat on the Walter White bar; small and marketable oysters on the Holland Point bar) were associated with size-group densities that were too small to estimate accurately (Table 1).

The SNK multiple comparisons indicated that there were no significant differences in density estimates between the diver samples and the patent tong samples for all three oyster size-groups (Table 5). However, mean dredge estimates differed significantly from both diver and tong estimates for spat on the Hog Island bar, for small oysters on the Walter White and Hog Island bars, for marketable oysters on the Walter White bar, and for total oysters on the Walter White and Hog Island bars. Comparison of Tables 1, 4, and 5 indicated that the differences in density estimates among sampling methods revealed by one-way ANOVAs were due to low values of the dredge estimates.

Discussion and Conclusions

We assume that the diver collected all eastern oysters in quadrats with negligible sampling error (Rodhouse 1976, 1979; Meyer et al. 1981). Mean densities estimated for spat, small oysters, marketable oysters, and total oysters from patent tong samples were not significantly different from those estimated from diver samples, but dredge estimates often were significantly smaller. The dredge estimates were so low—only 2–32% of diver estimates—that they could not distinguish differences in oyster abundance among the bars. Maurer et al. (1971) and Rodhouse (1976) estimated oyster densities from dredge samples that had been calibrated by diver samples. Such calibration may be invalid, because we found that density estimates from dredge samples were not proportional to estimates from diver samples (Figure 4).

During the course of a tow, shell gradually fills the dredge, decreasing the space for trapping more oysters and reducing the water flow that carries oysters into the dredge (Allen and Cranfield 1976). This asymptotic decrease in effectiveness is a characteristic of dredge sampling, and it means that any tow longer than a few meters will yield underestimates of oyster density. Our tows were 131 m long.

All the variance/mean ratios for dredge samples were less than 1.0, suggesting that the oyster dredge obliterated any information on patchy distribution

TABLE 4.—F-values of one-way analyses of variance to determine the effects of three sampling methods (diver, patent tongs, dredge) on the $\log_e(x + 1)$-transformed densities of eastern oyster size-groups estimated on three oyster bars. Asterisks denote significance at $P < 0.05$* or $P < 0.01$**.

Oyster bar	Oyster size-group			Total oysters
	Spat	Small	Marketable	
Holland Point		2.38	2.55	3.43*
Walter White	2.62	19.94**	23.70**	66.01**
Hog Island	21.53**	14.71**	5.53**	21.24**

TABLE 5.—Results of Student–Newman–Keuls multiple-comparison tests of $\log_e(x + 1)$-transformed densities of eastern oyster size-groups estimated by three sampling methods on three oyster bars. Within each bar and size-group, entries with a letter in common indicate no significant difference ($P \geq 0.05$) in density between sampling methods.

Oyster bar	Sampling method	Oyster size-group			
		Spat	Small	Marketable	Total oysters
Holland Point	Diver		AB	AB	AB
	Patent tongs		B	B	B
	Dredge		A	A	A
Walter White	Diver	AB	A	A	A
	Patent tongs	B	A	A	A
	Dredge	A	B	B	B
Hog Island	Diver	A	A	AB	A
	Patent tongs	A	A	B	A
	Dredge	B	B	A	B

of oysters. Apparently, the dredge acts as an integrating gear that smooths the nonrandom distribution of oysters (Skellam 1952; Saila and Gaucher 1966). Therefore, dredge sample estimates cannot show the patchiness that is characteristic of oyster distribution.

The patchy distribution of oysters causes positive autocorrelation among spatial density distributions. The variance among density estimates increases as the unit size sampled increases (Cochran 1977). This means that estimates are more accurate when the sample area is smaller (Beall 1940; Finney 1946; Taylor 1953; Elliott 1977). Because the area sampled by patent tongs is only about 1.4 m^2, and the area sampled by a dredge is markedly greater, patent tongs are better suited for sampling a gregarious population.

Patent tongs are a better sampling gear than the oyster dredge for estimating the density of spat, small oysters, marketable oysters, and total oysters. They provide more accurate information on stock size and the characteristics of the oyster population. Therefore, patent tongs are recommended as the sampling gear for eastern oyster stock assessment in the Maryland portion of Chesapeake Bay.

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