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Efficiency of the 1.0 m^2 Epibenthic Sled for Collecting Young-of-the-Year Striped Bass, White Perch, and Atlantic Tomcod in the Hudson River Estuary, 1978

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SUMMARY

During September and October 1978, Texas Instruments (TI) conducted a study to assess the efficiency of the 1.0 m^2 epibenthic sled used in the Fall Shoals Survey for collecting young-of-the-year striped bass, white perch, and Atlantic tomcod in the Hudson River estuary. Catch efficiency of the gear equipped with a 3000μ mesh net and towed at 1.5 m sec^{-1} at night was as follows:

- approximately 50% for young-of-the-year striped bass
- approximately 30% for young-of-the-year white perch
- low densities and consequently few non-zero catches of young-of-the-year tomcod precluded any estimate of catch efficiency.

INTRODUCTION

Escapement of organisms from towed nets (via avoidance or extrusion through the meshes) results in gear inefficiency and subsequent minimum estimates of species densities. Minimum estimates become a serious problem in the analysis of fisheries data when the catches are used to calculate estimates of absolute population size. Thus far, actual studies to estimate gear efficiency are still scarce (Kjelson and Colby 1977, TI 1978c), but fisheries scientists have recognized the obvious negative bias in the catches and have begun considering calculated densities as "minimal" estimates (e.g. Hatch 1978). Gear avoidance generally decreases as tow speed or net diameter increases; it is higher for larger organisms. In contrast, extrusion through meshes is higher at high speeds and for small organisms. Both types of sampling inefficiency are common in plankton sampling (Clutter and Anraku 1968, Vannucci 1968) and fisheries sampling (Kjelson and Colby 1977).

Empirical estimates of catch efficiency are difficult to obtain because of confounding by the extreme variability among catches related to the patchy distribution of the fish (Clutter and Anraku 1968). Additionally, variability of towed net catch efficiency may be size and/or species related as evident from several studies. Kjelson and Johnson (1978) reported the catch efficiency of a 6.1 m otter trawl to be 48% for juvenile pinfish and 32% for juvenile spot; the standard error ranged between 9 and 58% of the means. Kuipers (1975) reported efficiency of a 2 m beam trawl for plaice to decrease from 100% (plaice <7 cm length) to 15 to 30% (plaice >15 cm length). Loesch et al. (1976) reported that the catch efficiency of 4.9 m otter trawl was 25% for Atlantic croaker, 6% for spot, and 30 to 50% for brown shrimp. Loesch et al. hypothesized that these species were "probably more susceptible to capture than are most others because they are slow-moving demersal forms." In summary, estimates of catch efficiency are gear and species specific and are quite variable.

This report presents the results and conclusions of a study designed to estimate the catch (gear) efficiency of a 1.0 m^2 epibenthic sled towed at 1.5 m sec^{-1} at night for young-of-the-year striped bass, white perch, and Atlantic tomcod in the Hudson River estuary with respect to only the avoidance component of escapement. The size of the mesh, 3000 , and the size of the fish, generally 50 to 100 mm in total length, justify the assumption that extrusion through the mesh is negligible, thereby allowing sample densities to be related directly to avoidance without confounding with extrusion. This study had three objectives:

- to fit empirical data on catches of the three selected species to a model of catch efficiency,
- to estimate catch efficiency of the 1.0 m^2 epibenthic sled deployed under Standard Operating Procedures for the three selected species, and
- to recommend catch efficiency adjustment factors to be applied to standing crop estimates for the three selected species based on catches in the epibenthic sled.

The model developed for this study has intuitive appeal because of its simplicity and because it requires the estimation of only one parameter. It is well documented that catch by a gear increases as tow speed increases (Clutter and Anraku 1968). Our model assumes that catch increases with the tow speed of the sampling gear and can be described by a model of exponential approach to an asymptote. The model is described in the Methods Section.

Distributional patchiness of fish specified the sampling design. Differences in catch across several tow speeds provided an empirical estimate of catch efficiency where fish behavior (avoidance) is a random variable.

METHODS

Field and Laboratory

Samples of young-of-the-year fishes, collected at night from the Croton-Haverstraw and Tappan Zee regions of the Hudson River, were taken in paired tows of the 1.0 m^2 epibenthic sled equipped with a 3000μ mesh net (from two boats towing side by side approximately 10 to 15 m apart). Gear deployment and sample handling followed Standard Operating Procedures for the Fall Shoals Survey (TI 1978a) except that tow speeds of the boats were different. One boat always towed at 1.5 m sec^{-1} (standard) and the other at 0.7, 1.1, 1.9, or 2.3 m sec^{-1} (experimental). Tow durations were different over speeds so that each net was towed approximately 450 m.

Samples (paired tows) were taken from 11 through 15 September and 9 through 13 October (Table 1). Experimental tow speed and position relative to the shore were randomly assigned to one of the boats (the other boat was then assigned to the standard speed and other position), except for the highest and lowest speeds which were fixed by boat engine capabilities. Laboratory processing of young-of-the-year fishes followed TI's Standard Operating Procedures for the Fall Shoals Survey (TI 1978a).

Prior to taking samples to determine collection efficiency, it was necessary to determine whether filtration efficiency of the epibenthic sled changed over the range of experimental speeds. An appreciable change (>10%) would require an adjustment of tow speed in the analyses, as water speed through the gear mouth is the effective tow speed. Therefore, filtration efficiency was determined as the ratio of water velocity through the gear mouth to the velocity of the tow boat through water (Tranter 1968). Water velocity through the gear mouth was determined from an electronic flowmeter mounted in the gear mouth; boat speed was determined with an electronic flowmeter suspended in the water from the side of the boat. Observations were taken simultaneously over the range of speed from 1.2 to 2.4 m sec^{-1} and used to develop the following linear regression equations describing filtration:

Table 1

Number of Sample Pairs Collected at Experimental Tow Speeds and Number of Pairs Used in Analyses*

	Experimental Tow Speed	Number of Sample Pairs Taken	Number of Sample Pairs Used in Analyses		
			SB	WP	ATC
September	0.7 m sec^{-1}	23	15	7	7
	1.1 m sec^{-1}	20	14	9	8
	1.9 m sec^{-1}	20	17	7	8
	2.3 m sec^{-1}	23	14	5	7
	Total	86	60	28	30
October	0.7 m sec^{-1}	19	12	15	2
	1.1 m sec^{-1}	22	9	16	0
	1.9 m sec^{-1}	22	12	14	1
	2.3 m sec^{-1}	22	13	13	0
	Total	85	46	58	3

*A sample pair could be used in the analysis only if at least one of the pair was a non-zero catch

SB = striped bass
WP = white perch
ATC = Atlantic tomcod

$$\text{Est. Speed Out} = 0.0846 + 0.0019705\ X$$

and

$$\text{Est. Speed In} = 0.1294 + 0.0017552\ X$$

where

X = boat engine in revolutions min^{-1}

Est. Speed Out (or In) = estimated speed (relative to the water) in m sec^{-1} outside or inside the mouth of the epibenthic sled

Slopes on these regressions lines were significantly different ($t = 2.00$, $df = 36$), but estimated reduction in filtration efficiency was slight over the speed range 0.7 to 2.3 m sec^{-1}; estimated filtration efficiency was approximately 96.7% at 0.7 m sec^{-1}, approximately 91.4%, at 2.3 m sec^{-1}, and approximately 92.6% at 1.5 m sec^{-1} (the standard tow speed). These slight changes in filtration efficiency do not affect the analysis of catch efficiency.

Analyses

Catches of young-of-the-year striped bass, white perch, and Atlantic tomcod in paired tows were converted to densities (number • 1000 m^{-3}) to be directly comparable. Catch data of towed gear are not normally distributed (often they are a Poisson distribution) and there are at least two components of variation affecting their distribution, the number of schools within a region and the number of fish in a school. Pairing tows can reduce both components of variation by increasing the probabilty that a single school is exposed to both gear and ensuring that both gear are towed through an area containing a fixed number of schools. The variable to be analyzed, then, is a measure of the difference between the catches of the tows within a pair. A ratio provides the best measure of catch difference because it is free of variation due to regional density differences; e.g.

the ratio of 1 to 3 is comparable to the ratio of 10 to 30 although their absolute differences are not comparable. Ratios (r_{ijm}) of catches from paired tows were calculated as:

$$r_{ijm} = \frac{(d_{ijm} + 1)}{(d_{ism} + 1)} \qquad (1)$$

Natural logarithmic mean monthly ratios ($\bar{r}_{jm}$) (geometric means) were calculated as:

$$\bar{r}_{jm} = \sum_{i=1}^{n} \ell n \left[\frac{(d_{ijm} + 1)}{(d_{ism} + 1)}\right] \Big/ n \qquad (2)$$

where

d_{ijm} = density estimate of experimental speed in tow pair i in month m

d_{ism} = density estimate of the standard speed in tow in month m

n = number of paired tows at experimetal speed j for the month m

The value, one, was added to each density to circumvent the problem of division by zero (Southwood 1966). One was the appropriate value to add as it is the smallest unit of animal that can exist, and its addition to both the numerator and the denominator affects the variance of the ratio less than a smaller number. This allowed use of all pairs in which at least one sample had a non-zero catch. Pairs in which both catches were zero were excluded from efficiency analyses as these provided no estimate of how gear efficiency changed with speed. Had the intent of the study been to estimate densities, then inclusion of zero estimates would have been required. But in catch efficiency analysis zero versus zero does not mean no change; it means no information can be derived concerning change.

The accuracy and precision of the above ratio calculations will be affected by the population density with better estimates occurring at higher population densities (Sokal and Rohlf 1969). Therefore, the population densities from September and October will allow qualitative assessment of which month's ratios yield more accurate efficiency estimates. Natural logarithmic mean monthly densities ($\bar{a}_m$) (geometric means) from the standard speed (1.5 m sec^{-1}) were calculated (zeros included) as:

$$\bar{a}_m = \sum_{i=1}^{n} \ln (d_{ism} + 1)/n \qquad (3)$$

Catch efficiency of the epibenthic sled was estimated with non-linear regression by fitting catch ratios (r_{ijm}) to the asymptotic model:

$$\hat{D}_j = D_o - D_o e^{kj} \qquad (4)$$

where

$\hat{D}_j$ = density estimated at speed j

D_o = true population density (unknown)

e = natural logarithm base

k = rate constant

j = tow speed

This is a model of exponential approach to an asymptote (Figure 1) in which D_o is the true density of the population or the density estimate when the gear is 100% efficient. The quantity, $D_o e^{kj}$, is the density of fish not caught (gear inefficiency) at speed j, and the quantity decreases exponentially (the stippled area in Figure 1) as speed increases; this is an assumption inherent to the model. In substituting the catch ratio (r_{ijm}) for $\hat{D}_j$, D_o becomes R_o (or D_o/D_s), the ratio of the true population density to the estimate of the population density obtained from the epibenthic sled towed at 1.5 m sec^{-1}. Equation (4) can be rearranged as:

$$\hat{D}_j = D_o (1 - e^{kj})$$

and

$$\hat{D}_j/D_o = 1 - e^{kj}$$

where D_j/D_o is the proportion of the true population density caught in the epibenthic sled towed at speed j. Non-linear regression was used to estimate k, the rate constant by which gear efficiency increases with speed (j) in Equation 4. The convergence criterion and algorithm of the non-linear regression program are described in Barr et al. (1976).

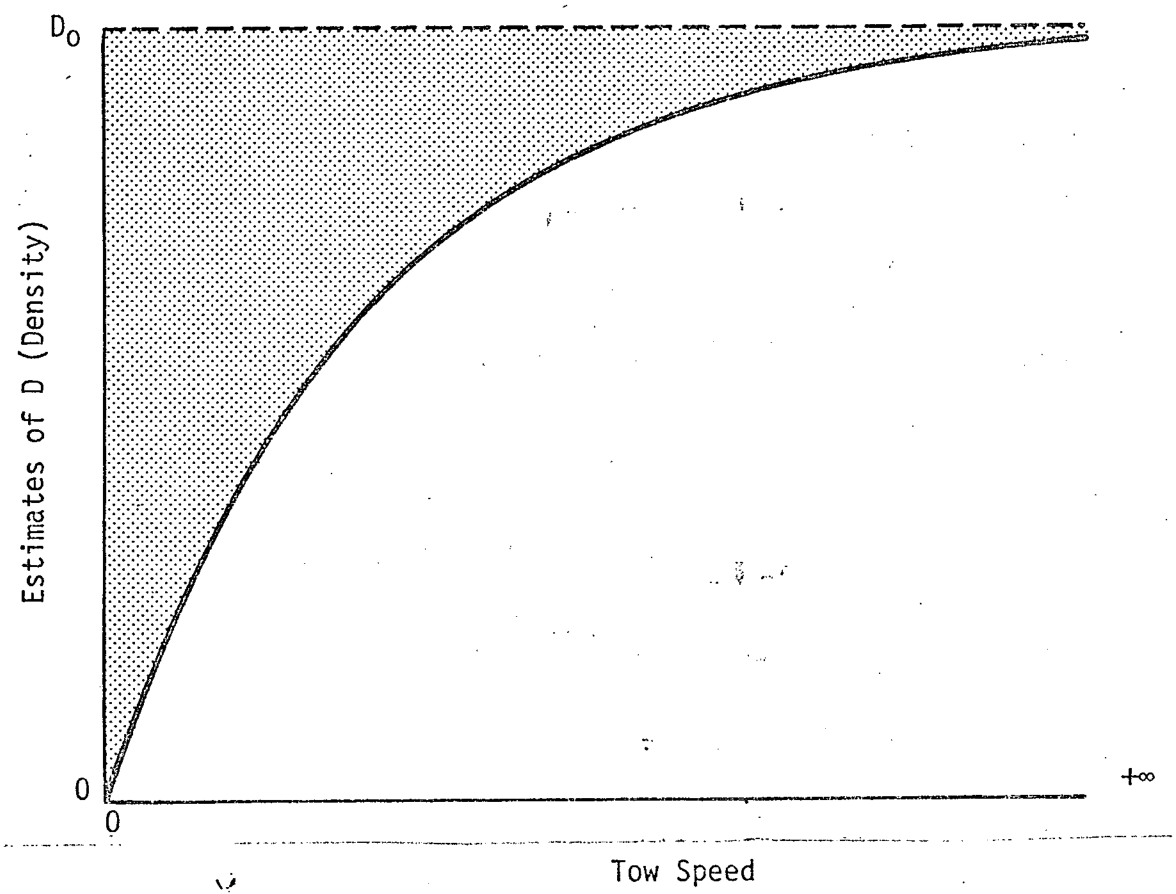

Figure 1. Graph of Asymptotic Model of Catch Efficiency ($D = D_o - D_o e^{kj}$ for k = 0.5) for 1.0 m^2 Epibenthic Sled. Density Estimates Approach True Population Density (D_o) as Tow Speed Increases.

RESULTS AND DISCUSSION

Only paired tows in which at least one non-zero catch occurred were used in analyses to estimate gear efficiency. Experimental to standard ratios ($\bar{r}_{jm}$'s) for the experimental tow speed 2.3 m sec^{-1} in September were the lowest observed for all three species (Table 2) and were significantly ($\alpha = 0.05$) lower than zero, indicating a significant deviation from the theory of gear avoidance. Therefore, catch data from the highest speed (2.3 m sec^{-1}) taken in September were discarded from analyses of gear efficiency of catch.

For striped bass, non-linear regression analysis of experimental to standard ratios (r_{ijm}), resulted in estimates of catch efficiency in September of 7.8% (k = -0.054) and 61.4% in October (k = -0.635). Density estimates were significantly higher in September, (t = 5.58) than in October (Table 3) as is past years (TI 1977, 1978a, 1978b). September data, therefore, may provide more accurate catch ratios than October data. October estimates comprised catch ratios from four tow speeds, while only tow speeds of 0.7, 1.1 and 1.9 m sec^{-1} were available for September. Therefore, October ratios may estimate the asymptote more accurately. Experimental to standard ratios were pooled across the two months; the resulting estimate of catch efficiency from non-linear regression was 45.8% (k = -0.408 with and asymptotic standard error of 0.78).

For white perch, ratios of experimental to standard tow speed catch densities from September did not follow the theory underlying our model of gear avoidance; i.e. catch at speed 1.9 m sec^{-1} was less than at the standard speed, perhaps due to low densities (Table 3) and/or small sample sizes (Table 1) in September; therefore, no estimate of catch efficiency could be made from the study results. Young-of-the-year white perch densities are usually lower in the Croton-Haverstraw and Tappan Zee regions during September than in October (TI 1977, 1978a, 1978b). Ratios of experimental to standard tow speed catches from October increased linearly and the criterion for convergence in non-linear regression was not met;

Table 2

Natural Logarithmic Means ($\bar{r}_{jm}$) and Variances (S^2) of Experimental to Standard Tow Speed Catch Ratios in 1.0m² Epibenthic Sled (Eq. 2) for Young-of-the-Year Striped Bass, White Perch, and Atlantic Tomcod

	Experimental Tow Speed	Striped Bass			White Perch			Atlantic Tomcod		
		(n)	$\bar{r}_{jm}$	(S^2)	(n)	$\bar{r}_{jm}$	(S^2)	(n)	$\bar{r}_{jm}$	(S^2)
September	0.7m sec^{-1}	(15)	-1.121	(2.709)	(7)	+0.953	(0.495)	(7)	-0.241	(1.336)
	1.1m sec^{-1}	(14)	-0.276	(1.352)	(9)	+0.267	(1.956)	(8)	+0.380	(2.594)
	1.9m sec^{-1}	(17)	-0.276	(2.834)	(7)	-0.343	(1.945)	(8)	-0.370	(3.704)
	2.3m sec^{-1}	(14)	-1.764	(1.816)	(5)	-1.146	(0.614)	(7)	-1.187	(0.770)
October	0.7m sec^{-1}	(12)	-0.529	(1.110)	(15)	-0.803	(0.999)			
	1.1m sec^{-1}	(9)	+0.150	(1.787)	(16)	+0.299	(0.618)			
	1.9m sec^{-1}	(12)	-0.405	(1.685)	(14)	+1.046	(1.120)			
	2.3m sec^{-1}	(13)	+0.580	(1.739)	(13)	+1.173	(1.346)			

(n) = sample size

Table 3

Monthly Mean Densities (Arithmetic) and 95% Confidence Intervals of Young-of-the-Year Striped Bass, White Perch, and Atlantic Tomcod from Standard Speed Tows with 1.0m^2 Epibenthic Sled

	September		October	
	Mean	(n)	Mean	(n)
Striped Bass	3.87	(86)	0.80	(85)
95% CI	2.60 - 5.59		0.49 - 1.17	
White Perch	0.30	(86)	1.80	(85)
95% CI	0.15 - 0.46		1.21 - 2.55	
Atlantic Tomcod	0.44	(86)	0.04	(85)
95% CI	0.25 - 0.66		0.00 - 0.09	

(n) = sample size

hence the asymptote could not be accurately estimated. Since the asymptote cannot be less than the density estimated by the 2.3 m sec^{-1} speed, the catch efficiency of the epibenthic sled cannot be greater than the reciprocal of the ratio of experimental to standard catch for the tow speed 2.3 m sec^{-1}. Converting the geometric mean from Table 3 to the linear scale and taking its reciprocal results in a maximum estimate of catch efficiency of 31% for young-of-the-year white perch.

For young-of-the-year Atlantic tomcod, ratios of experimental to standard tow speed catch densities from September did not follow the theory underlying our model of gear avoidance. Catch at tow speed of 1.9 m sec^{-1} was less than at the standard speed, perhaps due to low densities (Table 3) and/or small sample sizes (Table 1). Densities (Table 3) and sample sizes (Table 1) were even lower in October. Therefore no estimate of catch efficiency for Atlantic tomcod could be made from the study results.

CONCLUSIONS AND RECOMMENDATIONS

For striped bass, the catch efficiency of the 1.0 m^2 epibenthic sled was best estimated from non-linear regression of pooled catch ratios from September and October; catch efficiency was about 50%. Standing crop estimates of young-of-the-year striped bass* based on catches in the epibenthic sled should be doubled to adjust for gear efficiency before being used to obtain estimates of absolute abundance by a density-volume method.

For white perch, the catch efficiency of the epibenthic sled (estimated from October data) probably was not greater than 31%. Although non-linear regression could not be used to estimate the true population density, it was at least as high as the density estimated by the fastest tow speed. Standing crop estimates of white perch young-of-the-year* should be multiplied by a minimum value of 3.23 to adjust for gear efficiency before being used to obtain estimates of absolute abundance.

For young-of-the-year Atlantic tomcod, the catch efficiency of the epibenthic sled could not be estimated because differences in catches across tow speeds were not detected due to low densities and, consequently, few non-zero catches.

*Estimates of standing crops not adjusted for this catch efficiency factor appeared in several previous reports, including TI (1975, 1977, 1978a, 1978b), McFadden (1977), McFadden and Lawler (1977) and McFadden et al. (1978).

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