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REPORT ON 1978-1979 STUDIES TO EVALUATE CATCH EFFICIENCY OF THE 1.0-m^2 EPIBENTHIC SLED

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FIGURES

SECTION I

SUMMARY

An asymptotic approach to 100% efficiency was hypothesized as the relationship between catch (i.e., density) and increasing speed of a towed net sampler. This study was designed to use a model of this relationship to empirically estimate the catch efficiency of a 1.0-m^2 epibenthic sled when deployed to sample young-of-the-year (YOY) white perch (*Morone americana*), striped bass (*Morone saxatilis*), and Atlantic tomcod (*Microgadus tomcod*) in the Hudson River estuary. During the months the study was conducted white perch were most abundant in the catch in October 1978, and November and December 1979. Striped bass were most abundant in September 1978. Few Atlantic tomcod were caught in either year. Consequently, the above species-month data sets could be used to investigate catch efficiency for white perch and striped bass only.

Contrary to expectations, mean density was not found to increase with increasing towing speed either for YOY white perch or for YOY striped bass. Scatter plots suggested a boat effect may have obscured this relationship. When data of December 1979 white perch densities were examined with a factorial analysis of variance, the Liberty Belle caught significantly fewer fish than the Sametta Too. Adjustment of the densities for this boat effect did not significantly change the fit to the hypothesized relationship; there was still no significant increase in density with increasing towing speed and an asymptotic model could not be fit to the data. An examination of the literature, however, suggested that the catch efficiency of the 1.0-m^2 epibenthic sled was extremely low (probably less than 10%) for YOY striped bass and white perch.

SECTION II

INTRODUCTION

The disparity between the number of fish encountered in the path of a towed net and the actual catch (i.e., density) by that gear is an expression of catch efficiency. A measure of catch efficiency can be used to adjust the catch to derive estimates of "true" or "absolute" fish abundance and population size. Texas Instruments (TI) has been involved in several catch efficiency studies as part of an on-going program of gear design and evaluation in the Hudson River estuary (TI 1977, 1978, 1979a, 1979b). In 1978, a preliminary study evaluated application of an exponential model to determine the catch efficiency of a 1.0-m^2 epibenthic sled for sampling young-of-the-year (YOY) striped bass (*Morone saxatilis*), white perch (*M. americana*), and Atlantic tomcod (*Microgadus tomcod*) (TI 1979b). Re-evaluation of the results of this 1978 study suggested the exponential model was inappropriate.

This report is intended to supersede the 1978 Catch Efficiency Study (TI 1979b). Several catch efficiency models are considered in addition to an exponential model, and the 1978 data are reanalyzed and combined with results from 1979. The primary objective was to empirically estimate the catch efficiency of the 1.0-m^2 epibenthic sled deployed by TI to sample YOY white perch, striped bass, and Atlantic tomcod in the Hudson River estuary. A secondary objective or corollary to this study was to identify factors affecting the catch efficiency of this gear.

Catch efficiency varies with gear characteristics and deployment techniques which elicit detection and avoidance behavior in fish. These factors have been identified and discussed in detail by Clutter and Anraku (1968) and will be only briefly summarized here.

Gear characteristics affecting visual detection by fish include the coloration and contrast of netting and the presence of reflective surfaces. Increased night catches versus day catches have been attributed to a reduction in detection distance and avoidance ability by fish in low light intensities (Clutter and Anraku 1968). Hydrodynamics, a function of net geometry and mesh filtration, can influence catch efficiency by creating pressure waves detectable by fish in advance of the net. For example, Smith (reported in Clutter and Anraku 1968) measured pressure waves 1.5 m in advance of a 1.0-m diameter net towed at 1.4 $m \cdot sec^{-1}$. The net diameter to length ratio, mesh size, bridle configuration, and towing speed were also identified as factors influencing catch efficiency by altering net hydrodynamics. Additionally, mesh size selectively affects fish retention or extrusion.

Barkley (1972) developed a geometric model which related catch efficiency to gear characteristics and detection and avoidance behavior by the fish. In this mechanistic model, probability of capture (catch efficiency) was considered a function of four parameters as follows:

$$PC = \left[1 - \frac{X_o}{R\sqrt{\frac{U^2}{U_e^2} - 1}} \right]^2 \qquad (1)$$

where

PC = probability of capture
X_o = detection distance
R = net radius
U = net speed
U_e = escape speed

For a particular net, species and size of fish, and environmental conditions, X_o, R, and U_e can be considered constants, and catch efficiency will increase as a function of towing speed to an asymptote at 100% efficiency (PC = 1) [Figure II-1(A)]. An increase in catch with increasing towing speed was observed by several investigators, including Aron and Collard (1969) and Clutter and Anraku (1968). A major limitation of the Barkley model is the difficulty of experimentally quantifying detection distance (X_o) and escape speed (U_e). When experimentally determined values for X_o and U_e are available, probability of capture (PC) may be calculated directly from equation 1 (with certain limitations as described in Appendix Figure 1). Barkley (1972) also provided a formula for calculating PC using the ratio of catches at two different towing speeds to approximate X_o and U_e, but he concluded that this method is only valid for escape speeds less than 30% of towing speeds.

The actual relationship between catch efficiency and towing speed could assume one of several theoretical forms (Figure II-1). An asymptotic approach to 100% efficiency is the basic premise common to most forms. The density at 100% efficiency (D_o in Figure II-1) represents the "true" population density. These curves describing the relationship between catch efficiency and towing speed can be classified into two categories based on characteristics of their shape. The curves A through D in Figure II-1 all rise continuously from, at or near, the origin in their approach to the asymptote, while curves E and F have a plateau at low efficiency and rise to the asymptote above the threshold towing speed (U_t). The former curves actually represent subsets of the latter in which the threshold speed is close to zero. The underlying purpose of the 1978 and 1979 studies with the 1.0-m^2 sled was to empirically determine the appropriate model and asymptote density by examining the change in density with increasing towing speed.

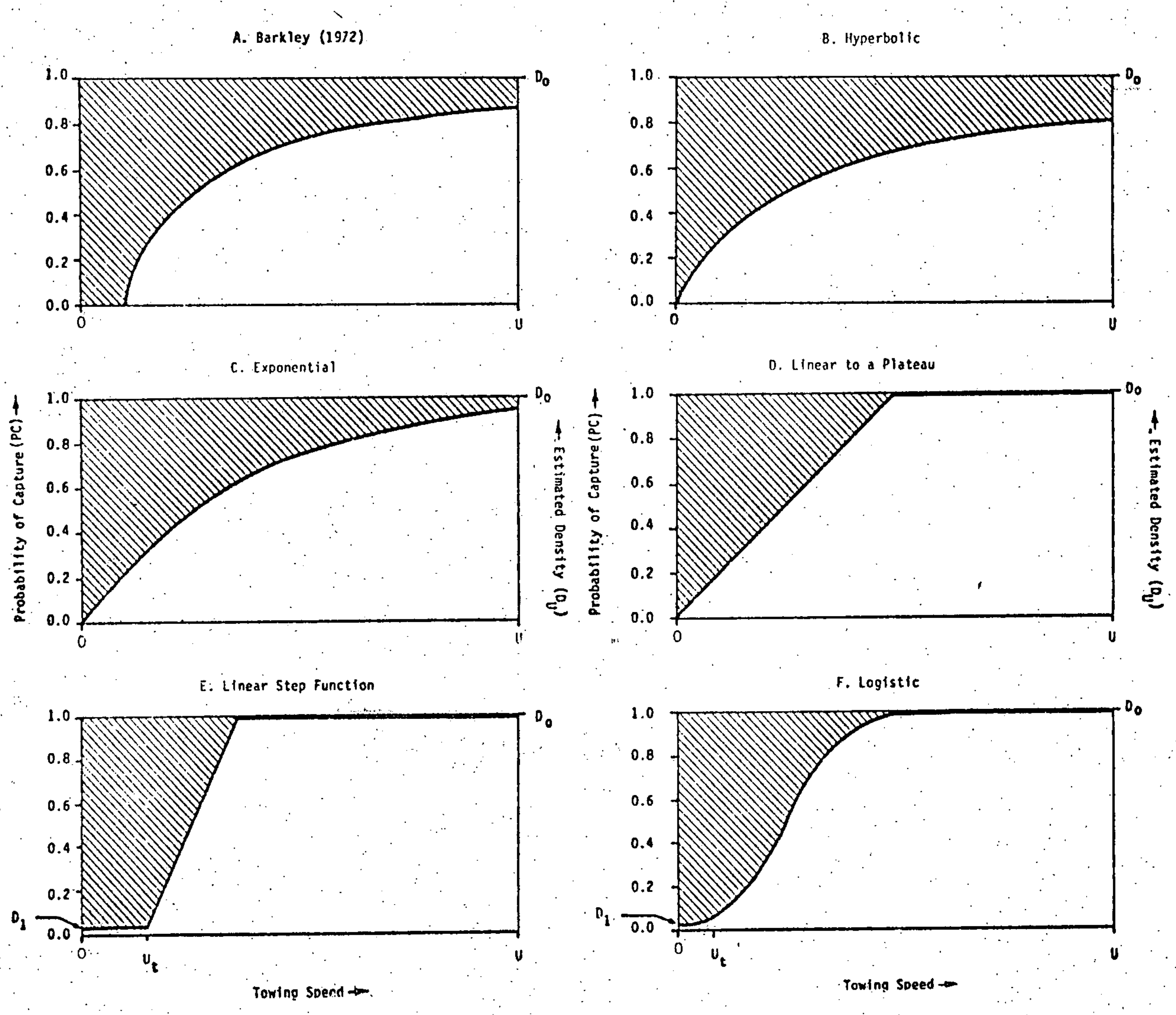

Figure II-1. Selected Hypothetical Models of Relationship between Catch Efficiency (probability of capture = PC) and Towing Speed (U) [all curves approach true density, D_o, (PC = 1.0) asymptotically; D_1 is a low plateau; U_t is a threshold speed; see text for explanation]

SECTION III

MATERIALS AND METHODS

A. FIELD AND LABORATORY

This study utilized the results of a catch efficiency study in 1979, and reanalyzed data from a similar study conducted in 1978. Both studies were designed to minimize or control sources of variation not directly attributable to the change in catch efficiency of the 1.0-m^2 epibenthic sled with increasing towing speed. To minimize temporal variation, sampling for YOY fishes was conducted at night and was limited to one week in each of two months in 1978 and 1979 (11 through 15 September and 9 through 13 October, 1978; 5 through 8 November and 3 through 6 December, 1979). In 1978, sampling was timed to concur with peak YOY striped bass abundance and in 1979 with peak YOY white perch abundance (TI 1979c).

Sampling within a week was limited to the same river region and bottom type. In September 1978 and November 1979, sampling was conducted in the Tappan Zee region (RM 24 through RM 33) in depths of 4 to 6 m of water over a smooth, muddy bottom. In October 1978 and December 1979, sampling was conducted in depths of 3 to 5 m of water in the Croton-Haverstraw region (RM 34 through RM 38) over similar bottom conditions. Consideration was given to preventing the overlap of towing paths within a region, because bottom disturbance from a previous tow could bias subsequent tows.

Paired samples (two boats towing in parallel approximately 10 to 15 m apart) were collected in an attempt to reduce variation in catch due to patchiness of fish distribution within a region. Pairing can reduce sampling variation by increasing the probability that the same patches or gaps in distribution are sampled by both experimental and standard tows. One boat always towed at 1.5 $m \cdot sec^{-1}$ (standard) and the other at 0.7, 1.1, 1.5, 1.9, or 2.3 $m \cdot sec^{-1}$ (experimental), except in 1978 when the 1.5 $m \cdot sec^{-1}$ experimental tows were not taken. The 1.5 $m \cdot sec^{-1}$ experimental tows were added in 1979 to allow examination of the variation in catch between boats which was independent of towing speed.

Towing durations were varied over experimental speeds to maintain an approximately constant sample volume and tow length. Table III-1 indicates the number of sample pairs collected, the variations in sample volumes, and the number of paired tows in which both experimental and standard tows collected at least one fish of the species considered. Field observations indicated a relatively constant tow length (approximately 450 m) was obtained.

Experimental towing speed and position relative to shore (proximal or distal) were randomly assigned to one of the two boats (Sametta Too or Liberty Belle), and the other boat was assigned the standard speed and other position. However, boat and engine capabilities (Appendix Table 1) limited assignment of the slowest towing speed (0.7 $m \cdot sec^{-1}$) to the Sametta Too, and the highest speed (2.3 $m \cdot sec^{-1}$) to the Liberty Belle. To examine possible variation in density estimates due to this nonrandom assignment of boats at extreme towing speeds, experimental speed was randomly assigned in a balanced, factorial design across the three intermediate speeds (1.1, 1.5, and 1.9 $m \cdot sec^{-1}$) for the collections made in December 1979.

The 1.0-m^2 epibenthic sled was equipped with a 3000 μm mesh net with an enlarged conical fyke attached to the cod end (TI 1979c). With this fine mesh net, mesh selectivity was not considered to vary during the studies and 100% retention of YOY fishes [>60 mm mean total length (TL)] was assumed. Laboratory processing of the YOY fishes followed standard operating procedures for the Fall Shoals Survey (TI 1979c).

Table III-1

Variation in Sample Volumes, Number of Paired Tows, and Number of Non-Zero Paired Tows for 1.0-m^2 Epibenthic Sled Study, 1978-1979

Year	Sampling Date	Experimental Towing Speed ($m \cdot sec^{-1}$)	Number of Sample Pairs	Variation in Tow Volume (m^3): Experimental $\bar{x}$*	Experimental S.E.†	Standard ($1.5 m \cdot sec^{-1}$) $\bar{x}$	Standard S.E.	Number of Non-Zero Pairs** Species‡: SB	WP	AT
1978	11 Sep - 15 Sep	0.7	23	386.4	13.1	405.4	6.3	5	2	2
		1.1	21	417.2	14.4	420.1	8.9	9	1	1
		1.9	20	416.1	4.8	429.5	5.8	11	1	0
		2.3	23	405.4	5.8	418.3	5.2	5	1	1
	Total		87					30	5	4
	09 Oct - 13 Oct	0.7	22	437.1	6.1	444.8	3.4	5	10	0
		1.1	22	444.3	6.2	438.1	4.3	5	13	0
		1.9	23	458.6	7.2	436.8	5.5	3	8	0
		2.3	22	450.6	6.8	421.7	3.9	4	8	0
	Total		89					17	39	0
1979	05 Nov - 08 Nov	0.7	17	416.9	9.4	416.0	6.0	1	12	6
		1.1	15	422.4	7.1	417.1	6.0	2	15	8
		1.5	13	411.0	3.7	411.5	4.7	2	11	6
		1.9	13	417.3	16.2	431.0	6.0	4	13	8
		2.3	17	423.4	7.7	420.0	5.1	5	15	10
	Total		75					14	66	38
	03 Dec - 06 Dec	0.7	19	421.8	9.4	454.1	7.2	4	18	3
		1.1	19	436.4	6.6	443.7	4.6	2	18	7
		1.5	18	431.0	5.4	435.5	4.8	2	17	5
		1.9	21	439.2	7.8	445.8	4.6	5	19	6
		2.3	18	436.4	11.5	419.0	6.0	0	15	1
	Total		95					13	87	22

*$\bar{x}$ = Mean

†S.E. = Standard Error

**A paired tow in which both the experimental and standard tows collected at least one fish of the species considered

‡SB = striped bass, WP = white perch, AT = Atlantic tomcod

Prior to sampling, it was necessary to determine the variation in filtration efficiency of the 1.0-m^2 epibenthic sled across the range of experimental speeds. An appreciable change (e.g., >10%) would require an adjustment to both the number of organisms caught and towing speed because 1) catch would vary directly with change in filtration efficiency (Tranter and Smith 1968) and 2) speed through the water was considered to be the towing speed. Filtration efficiency data were collected and analyzed in 1978 using linear regression (TI 1979b). These data were reanalyzed in this report using an analysis of variance (ANOVA) design. Filtration efficiency was determined as the ratio of water velocity through the net mouth to the velocity of the net through the water (measured with electronic flowmeters mounted in the net mouth and suspended 0.5 m to the outboard side of the net, respectively). Observations were taken simultaneously over a range of boat speeds from 1.2 to 2.4 $m \cdot sec^{-1}$ (as measured by the flowmeter suspended outside the net). Boat speed was used as the blocking factor and flowmeter location (inside or outside the 1.0-m^2 epibenthic sled) was the treatment factor. Both boat speed ($F = 157.21$, $p \leq 0.0001$) and flowmeter location ($F = 33.16$, $p \leq 0.0001$) were highly significant main effects (Appendix Table 2), but the interaction between these two factors was not significant ($F = 0.57$, $p \geq 0.7505$). Therefore, filtration efficiency was considered constant across the range of speeds used and was computed as 92.2% by taking the ratio of mean flowmeter readings ($m \cdot sec^{-1}$) inside and outside the 1.0-m^2 epibenthic sled. Since filtration efficiency was constant, adjustments to towing speed or density were unnecessary.

B. DATA ANALYSES

Data analyses followed the flow diagram in Figure III-1. Catches of YOY striped bass, white perch, and Atlantic tomcod were converted to densities (number$\cdot$1000 m^{-3}) to be directly comparable, and analyzed separately by month. To examine the empirical relationship between towing speed and density, two measures of density were used. A

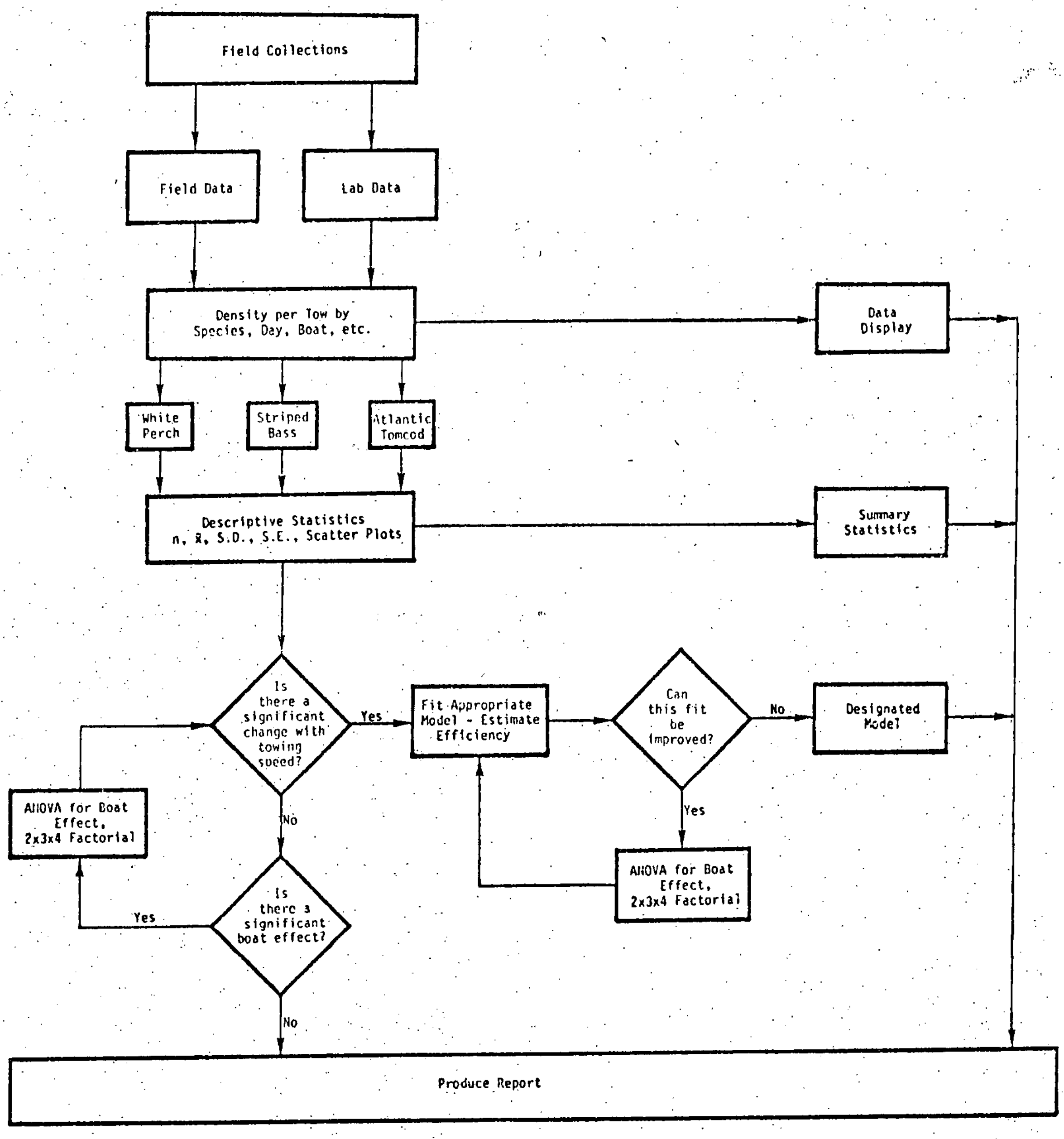

Figure III-1. Diagrammatic Representation of Analytical Procedures Used to Fit a Catch Efficiency Model direct measure, the density at each of the experimental speeds, was calculated using all catch data (i.e., both zero and non-zero catches). A second measure, the ratio of densities between experimental and standard tows (relative density), utilized the effectiveness of paired tows in reducing variation due to regional density differences. For example, a ratio of 1:3 for one pair of samples is comparable to a ratio of 10:30 for another, although an order of magnitude difference in their absolute densities exists. When relative densities were used in these analyses they were derived from non-zero paired catches only.

Descriptive statistics [Figure III-1: means ($\bar{x}$), standard deviations (S.D.), standard errors (S.E.)] and scatter plots were used to identify the empirical relationship between density and towing speed for each species-month combination. If this relationship had resembled an approach to an upper asymptote, the next step in this analysis would have been to fit each of the hypothesized models (Figure II-1) to the data to determine the most appropriate model (best fit to the data). A 2x3x4 factorial analysis of variance (Helwig and Council 1979) was performed on December 1979 white perch data to identify significant interactions and separate the effects of days in the week and boats from towing speeds. The main effects were the two boats (Liberty Belle and Sametta Too), three intermediate towing speeds (1.1, 1.5, and 1.9 $m \cdot sec^{-1}$), and four sampling days. The catch parameter used in this ANOVA was white perch density in experimental tows, transformed by $\log_{10}(x)$ to eliminate variance heterogeneity.

SECTION IV

RESULTS AND DISCUSSION

The basic pattern depicted by mean density of YOY striped bass, white perch, and Atlantic tomcod in 1978-79 was one of no consistent change in catch by the 1.0-m^2 epibenthic sled with increasing towing speed (Tables IV-1 through IV-3). This pattern was observed for all species and months in 1978 and 1979, and for both density at experimental speed and relative density. Examination of the standard error of the mean density (Tables IV-1 through IV-3) or twice the standard error (as an approximate 95% confidence interval) indicated mean density at the highest experimental towing speed (2.3 $m \cdot sec^{-1}$) appeared slightly lower than the density at slower speeds. Densities were extremely low for Atlantic tomcod in all months, for striped bass in all months but September 1978, and for white perch in September 1978; subsequent inferences will be made exclusive of these species-month data sets. Densities at 0.7 and 2.3 $m \cdot sec^{-1}$ for striped bass in September 1978 (Figure IV-1) had less scatter about the mean and lower means than for the intermediate towing speeds (1.1 and 1.9 $m \cdot sec^{-1}$). In December 1979 (Figure IV-2), a similar pattern for white perch was apparent, although not as distinct as for striped bass. Relative density for white perch in December 1979 (Figure IV-3) had reduced scatter of points about all means, but several large values appeared at intermediate speeds. These outliers, the relatively wide scatter observed at intermediate speeds, and the low densities at 2.3 $m \cdot sec^{-1}$ suggested that a boat effect may have obscured the relationship between density and towing speed.

This boat effect on the collection of white perch was examined in a 2x3x4 factorial ANOVA which was incorporated in the sampling design for December 1979. A strong boat effect was present ($F = 6.24$, $p=0.020$; Appendix Table 3); the Sametta Too caught significantly more fish than

Table IV-1

Mean Densities for Young-of-the-Year Striped Bass Caught by 1.0-m^2 Epibenthic Sled, 1978-1979

Year	Sampling Date	Experimental Towing Speed ($m \cdot sec^{-1}$)	Experimental Tows n*	Experimental Tows $\bar{x}$†	Experimental Tows S.E.**	Standard Tows ($1.5 m \cdot sec^{-1}$) n	Standard Tows $\bar{x}$†	Standard Tows S.E.	Relative Density*** ($Experimental \cdot Standard^{-1}$) n	Relative Density $\bar{x}$‡	Relative Density S.E.
1978	11 Sep - 15 Sep	0.7	23	2.01	0.84	23	7.57	2.47	5	0.64	0.13
		1.1	21	10.67	3.96	21	8.04	2.02	9	1.67	0.54
		1.9	20	12.44	3.51	20	14.45	4.37	11	1.62	0.65
		2.3	23	2.82	1.83	23	11.94	3.15	5	0.38	0.21
	09 Oct - 13 Oct	0.7	22	1.12	0.44	22	1.92	0.62	5	1.48	0.41
		1.1	22	1.41	0.62	22	1.44	0.66	5	0.71	0.20
		1.9	23	0.77	0.26	23	1.70	0.58	3	0.85	0.53
		2.3	22	2.20	0.65	22	1.86	0.88	4	0.87	0.38
1979	05 Nov - 08 Nov	0.7	17	1.01	0.37	17	1.13	0.36	1	1.10	--
		1.1	15	2.28	0.91	15	2.20	0.63	2	1.12	0.18
		1.5	13	0.74	0.42	13	2.07	0.67	2	1.47	0.51
		1.9	13	1.63	0.62	13	3.05	0.84	4	0.59	0.09
		2.3	17	1.88	0.54	17	1.52	0.49	5	0.96	0.19
	03 Dec - 06 Dec	0.7	19	2.83	0.97	19	0.59	0.28	4	2.85	1.64
		1.1	19	1.51	0.59	19	1.60	0.78	2	3.15	0.17
		1.5	18	1.68	1.31	18	1.15	0.65	2	5.52	5.33
		1.9	21	1.95	0.77	21	1.28	0.37	5	1.52	0.54
		2.3	18	0.12	0.12	18	1.24	0.53	0	--	--

*n = Number of paired tows

†$\bar{x}$ = Mean density (number individuals$\cdot 1000 m^{-3}$)

**S.E. = Standard error of mean density

‡$\bar{x}$ = Mean relative density (ratio of experimental to standard density)

***Calculated from non-zero paired tows in which both the experimental and standard tows collected at least one fish of the species considered

Table IV-2

Mean Densities for Young-of-the-Year White Perch Caught by 1.0-m^2 Epibenthic Sled, 1978-1979

Year	Sampling Date	Experimental Towing Speed ($m \cdot sec^{-1}$)	Experimental Tows			Standard Tows ($1.5 m \cdot sec^{-1}$)			Relative Density*** ($Experimental \cdot Standard^{-1}$)		
			n*	$\bar{x}^{\dagger}$	S.E.**	n	$\bar{x}^{\dagger}$	S.E.	n	$\bar{x}^{\ddagger}$	S.E.
1978	11 Sep - 15 Sep	0.7	23	0.84	0.30	23	0.20	0.14	2	0.97	0.09
		1.1	21	0.85	0.33	21	0.61	0.30	1	0.88	--
		1.9	20	0.50	0.30	20	0.72	0.31	1	0.95	--
		2.3	23	0.24	0.24	23	0.82	0.35	1	1.20	--
	09 Oct - 13 Oct	0.7	22	3.67	1.62	22	5.58	1.24	10	0.96	0.21
		1.1	22	4.59	0.98	22	4.64	1.49	13	1.58	0.35
		1.9	22	6.36	1.75	23	2.61	0.84	8	1.52	0.33
		2.3	23	7.05	1.73	22	2.62	1.01	8	2.90	0.87
1979	05 Nov - 08 Nov	0.7	17	10.90	3.05	17	10.17	2.55	12	2.33	1.08
		1.1	15	17.97	4.82	15	19.07	3.60	15	0.95	0.16
		1.5	13	14.67	3.67	13	15.89	2.89	11	1.28	0.28
		1.9	13	18.09	5.19	13	25.02	6.37	13	0.73	0.13
		2.3	17	15.54	3.32	17	18.43	4.48	15	1.28	0.23
	03 Dec - 06 Dec	0.7	19	27.66	5.93	19	21.25	4.11	18	1.41	0.24
		1.1	19	33.88	7.33	19	31.76	4.82	18	1.87	0.79
		1.5	18	25.20	4.04	18	18.78	4.48	17	2.77	1.06
		1.9	21	22.50	7.33	21	28.07	6.06	19	0.94	0.22
		2.3	18	13.08	2.60	18	19.00	3.02	15	0.99	0.33

*n = Number of paired tows

$^{\dagger}\bar{x}$ = Mean density (number individuals$\cdot 1000 m^{-3}$)

**S.E. = Standard error of mean density

$^{\ddagger}\bar{x}$ = Mean relative density (ratio of experimental to standard density)

***Calculated from non-zero paired tows in which both the experimental and standard tows collected at least one fish of the species considered

Table IV-3

Mean Densities for Young-of-the-Year Atlantic Tomcod Caught by 1.0-m^2 Epibenthic Sled, 1978-1979

			Experimental Tows			Standard Tows (1.5m·sec^{-1})			Relative Density*** Experimental·Standard^{-1}		
Year	Sampling Date	Experimental Towing Speed (m·sec^{-1})	n*	$\bar{x}$†	S.E.**	n	$\bar{x}$†	S.E.	n	$\bar{x}$‡	S.E.
1978	11 Sep - 15 Sep	0.7	23	0.48	0.22	23	0.68	0.29	2	0.78	0.25
		1.1	21	1.42	0.75	21	0.67	0.36	1	6.08	--
		1.9	20	1.00	0.68	20	1.29	0.61	0	--	--
		2.3	23	0.24	0.24	23	1.06	0.38	1	2.40	--
	09 Oct - 13 Oct	0.7	22	0.00	0.00	22	0.20	0.14	0	--	--
		1.1	22	0.00	0.00	22	0.00	0.00	0	--	--
		1.9	23	0.00	0.00	23	0.10	0.10	0	--	--
		2.3	22	0.00	0.00	22	0.00	0.00	0	--	--
1979	05 Nov - 08 Nov	0.7	17	4.35	0.90	17	2.77	0.94	6	1.46	0.33
		1.1	15	3.54	1.12	15	5.31	1.25	8	0.85	0.15
		1.5	13	2.40	0.94	13	4.51	0.99	6	1.26	0.31
		1.9	13	4.05	1.00	13	3.56	0.89	8	0.93	0.17
		2.3	17	3.28	0.82	17	3.49	1.01	10	1.30	0.29
	03 Dec - 06 Dec	0.7	19	1.35	0.50	19	1.56	0.53	3	1.81	0.79
		1.1	19	2.09	0.44	19	1.92	0.47	7	0.85	0.11
		1.5	18	1.02	0.34	18	1.93	0.43	5	0.87	0.10
		1.9	21	1.63	0.36	21	1.17	0.42	6	1.19	0.31
		2.3	18	0.29	0.20	18	0.66	0.26	1	1.11	--

*n = Number of paired tows

†$\bar{x}$ = Mean density (number individuals·1000^{-3})

**S.E. = Standard error of mean density

‡$\bar{x}$ = Mean relative density (ratio of experimental to standard density)

***Calculated from non-zero paired tows in which both the experimental and standard tows collected at least one fish of the species considered

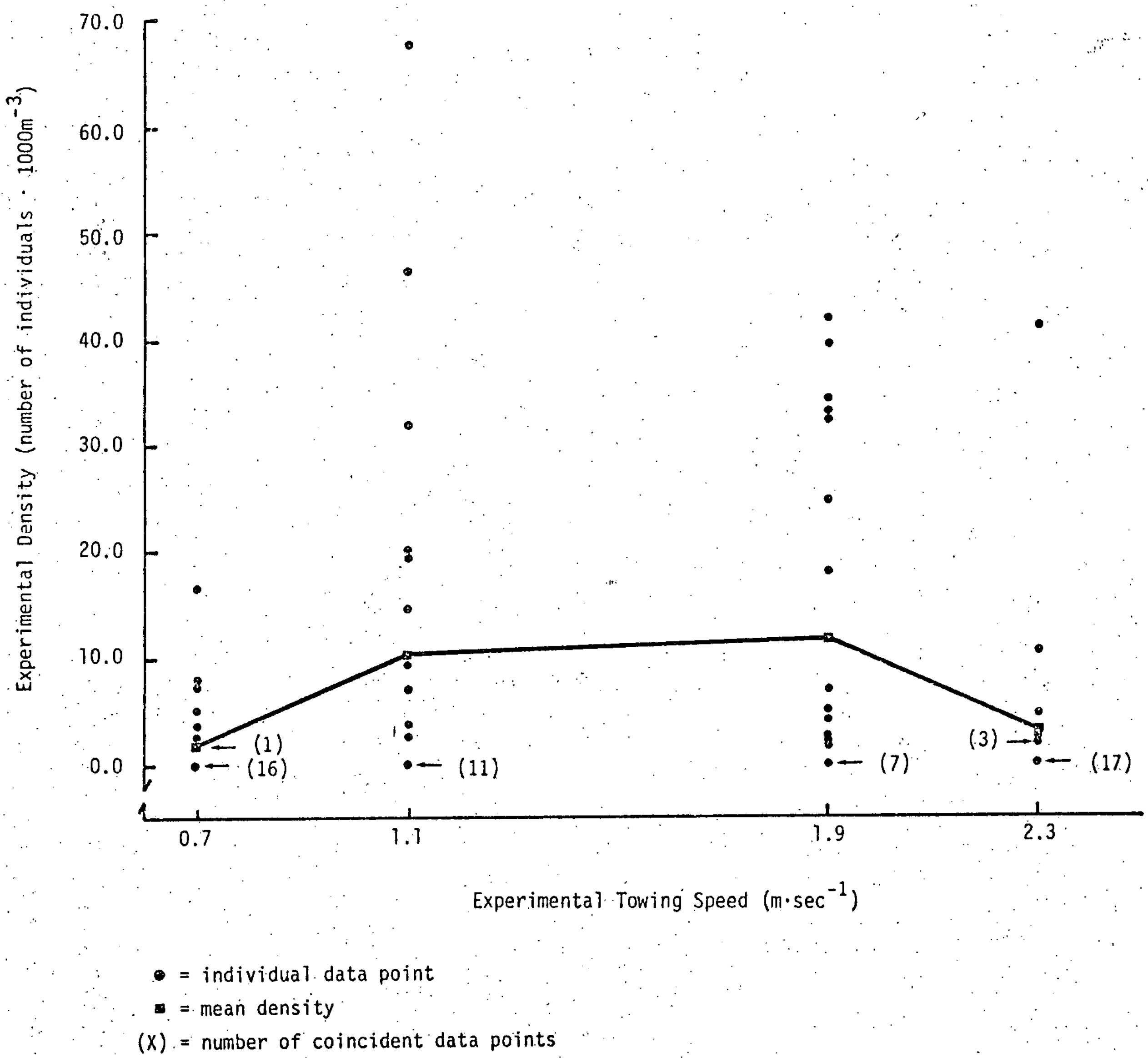

Figure IV-1. Relationship between Young-of-the-Year Striped Bass Density and Experimental Towing Speeds for September, 1978

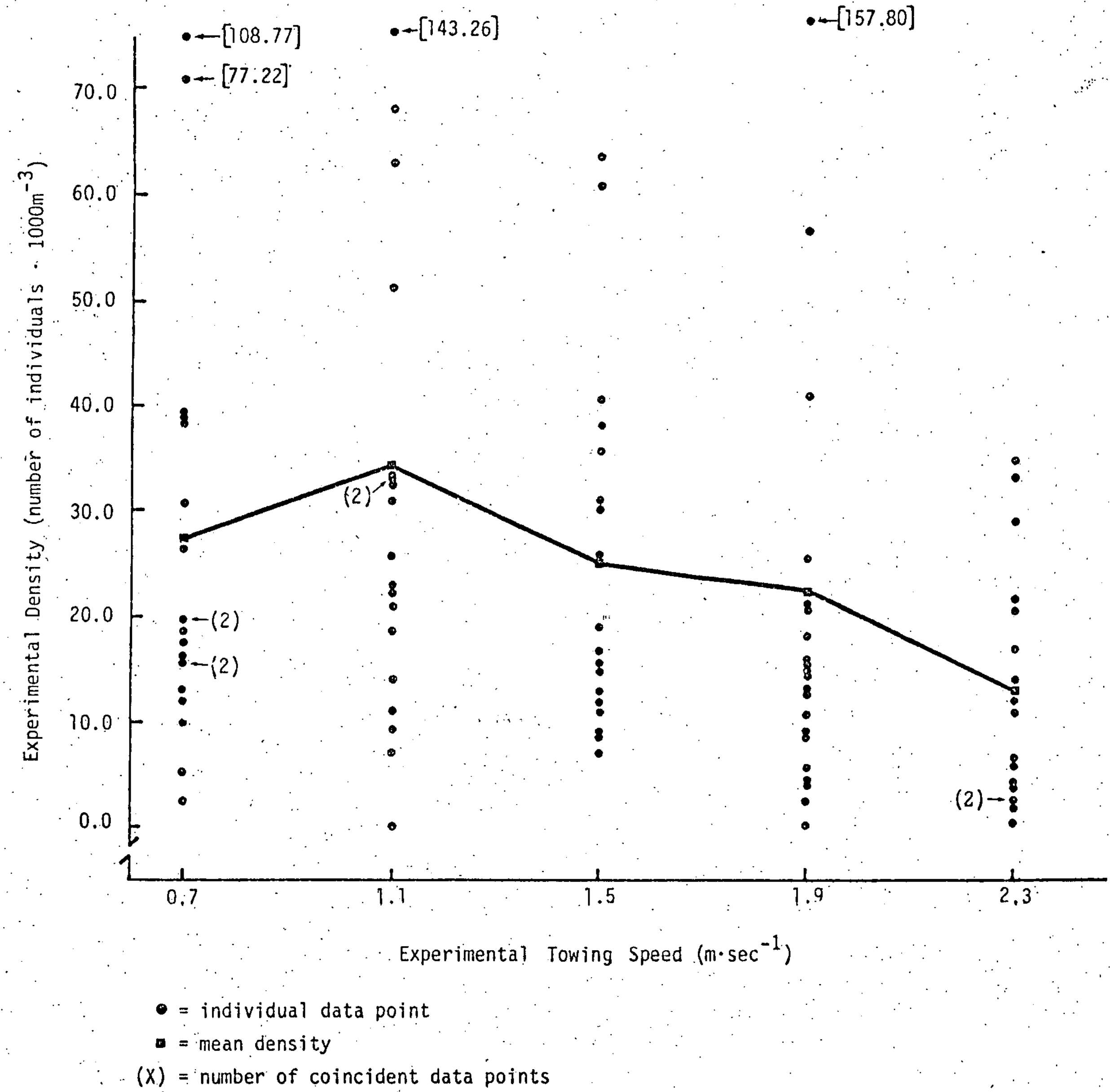

Figure IV-2. Relationship between Young-of-the-Year White Perch Density and Experimental Towing Speeds for December, 1979

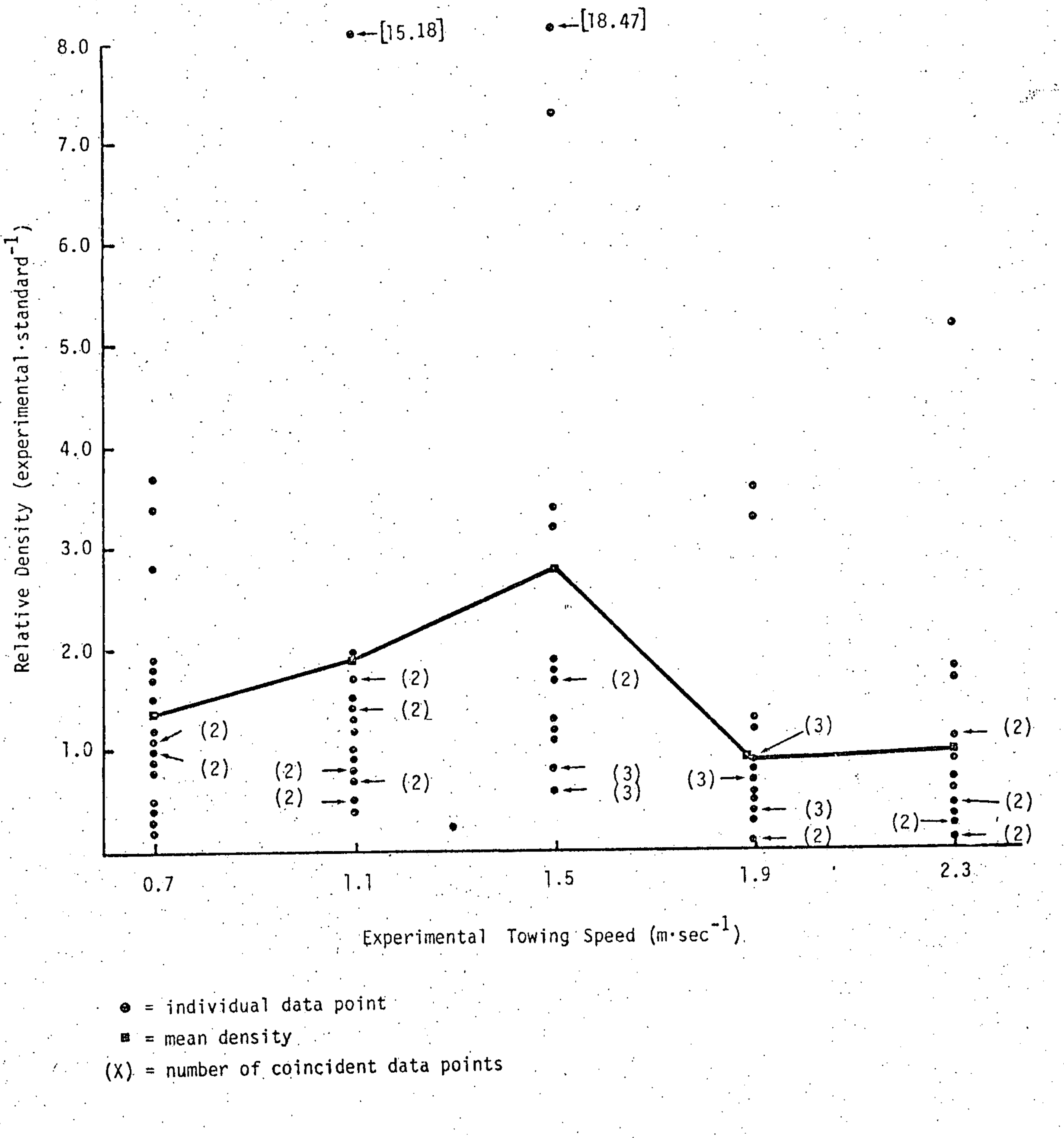

Figure IV-3. Relationship between Relative Density (ratio of experimental to standard density) of Young-of-the-Year White Perch and Experimental Towing Speeds for December, 1979 the Liberty Belle (Duncan's Multiple Comparison Test, $p<0.05$). Boat speed, as a main effect, was also significant ($F = 3.51$, $p = 0.046$) with density significantly lower at 1.9 $m \cdot sec^{-1}$ than at 1.1 $m \cdot sec^{-1}$ (Duncan's Multiple Comparison Test, $p<0.05$). Day, as a main effect, and the two and three factor interactions were not significant. The Sametta Too mean density was highest at 1.1 $m \cdot sec^{-1}$ (Figure IV-4). Liberty Belle mean densities were highest at 1.1 and 1.5 $m \cdot sec^{-1}$ and lowest at 1.9 and 2.3 $m \cdot sec^{-1}$. The mean densities of YOY white perch captured by the two boats were similar only at the standard towing speed of 1.5 $m \cdot sec^{-1}$.

The significantly lower densities of YOY white perch captured by the Liberty Belle may be related to engine characteristics which permit this boat to tow at the fastest but not the slowest towing speed. The Liberty Belle has a larger propeller than the Sametta Too (Appendix Table 1), and this characteristic may create turbulence which the fish can detect and avoid in advance of the net. Detection of this turbulence was probably enhanced by the shallow depths (3 to 6 m) sampled in the study.

The significant boat effect offered an explanation for the patterns observed in the scatter diagrams (Figures IV-1 through IV-3). Low density estimates by the Liberty Belle and high densities by the Sametta Too increased the scatter about mean density at the three intermediate towing speeds (1.1, 1.5, and 1.9 $m \cdot sec^{-1}$). At 0.7 and 2.3 $m \cdot sec^{-1}$, scatter was relatively low because only one boat was assigned each speed. The low density at 2.3 $m \cdot sec^{-1}$ probably occurred because sampling at that speed was limited to the Liberty Belle.

This boat effect would also differentially affect the variance of relative density estimates. If the experimental density in the numerator was derived from a Liberty Belle sample, the value of the ratio would be decreased. Similarly, the ratio would be increased if

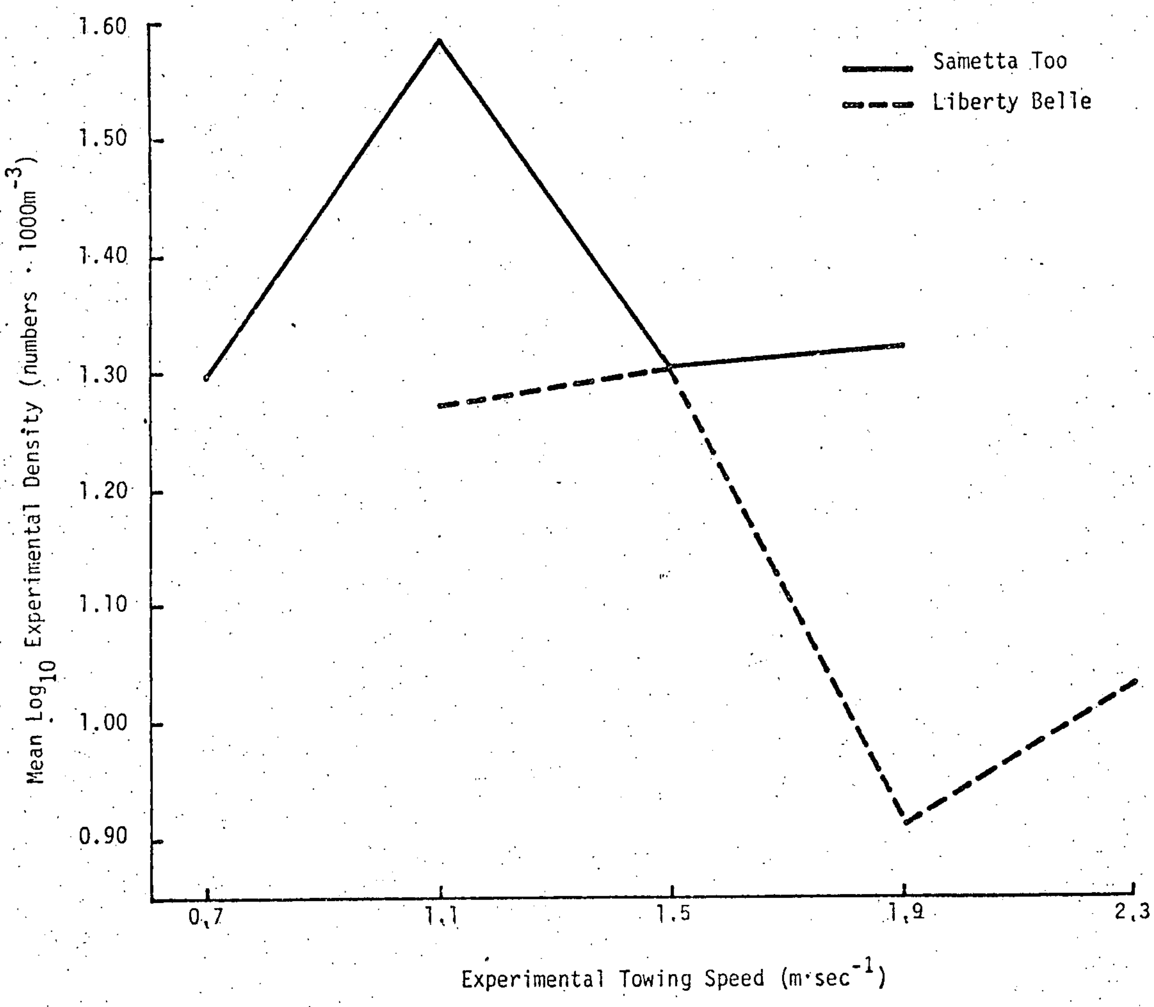

Figure IV-4. Mean Log_{10} Density of Young-of-the-Year White Perch Caught by Sametta Too and Liberty Belle in Experimental Tows in December, 1979 the Sametta Too density was the numerator. The outlying high values appeared (Figure IV-3) when relative density was calculated with Sametta Too density as the numerator.

Since a strong boat effect existed and the December 1979 white perch data did not resemble any of the hypothesized models (Figure II-1), density estimates from one boat were adjusted with respect to the other to eliminate this boat effect. The adjustment factor was derived from the difference between mean $\log_{10}$ density of the two boats. Adjustment did not significantly alter the relationship (Figure IV-5); there was no increase in density with increasing towing speed. Therefore, regardless of the parameter and adjustment used, a plateau in density occurred between towing speeds of 0.7 and 2.3 $m \cdot sec^{-1}$.

This plateau may be at either extremely high efficiency [near D_0 in Figure II-1(A and F)] or at extremely low efficiency [D_1 in Figures II-1 (E and F)]. Literature values for a comparable gear and deployment technique suggest it was a low plateau. For example, Kuipers (1975) used a 2-m beam trawl towed at 0.5 $m \cdot sec^{-1}$ and observed a catch efficiency of approximately 20% for juvenile plaice (<u>Pleuronectes platessa</u>, 140 to 200 mm). Murphy and Clutter (1972) towed a 1.0-m net at 0.76 $m \cdot sec^{-1}$ and found the catch efficiency was only 7% for Hawaiian anchovy (<u>Stolephorus purpureus</u>) larvae. Loesh et al. (1976) deployed a 4.9-m trawl (1.5-m sweep) at 1.1 $m \cdot sec^{-1}$ and captured spot (<u>Leiostomus xanthurus</u>) with only a 4 to 9% catch efficiency. Applying his model to the anchovy catch of Murphy and Clutter (1972), Barkley (1972) calculated catch efficiencies ranging from 35% for 4.5-mm fish to 0.02% for 11.5-mm fish. Barkley (1972) also applied his model to catch data of California smoothtongue (<u>Bathylagus stilbius</u>) taken with a 6-m Isaacs-Kidd mid-water trawl (Aron and Collard 1969). This relatively large trawl had a catch efficiency of 7.3% for 72-mm fish when towed at speeds less than 1.6 $m \cdot sec^{-1}$ and 33% when towed at speeds greater than 1.6 $m \cdot sec^{-1}$.

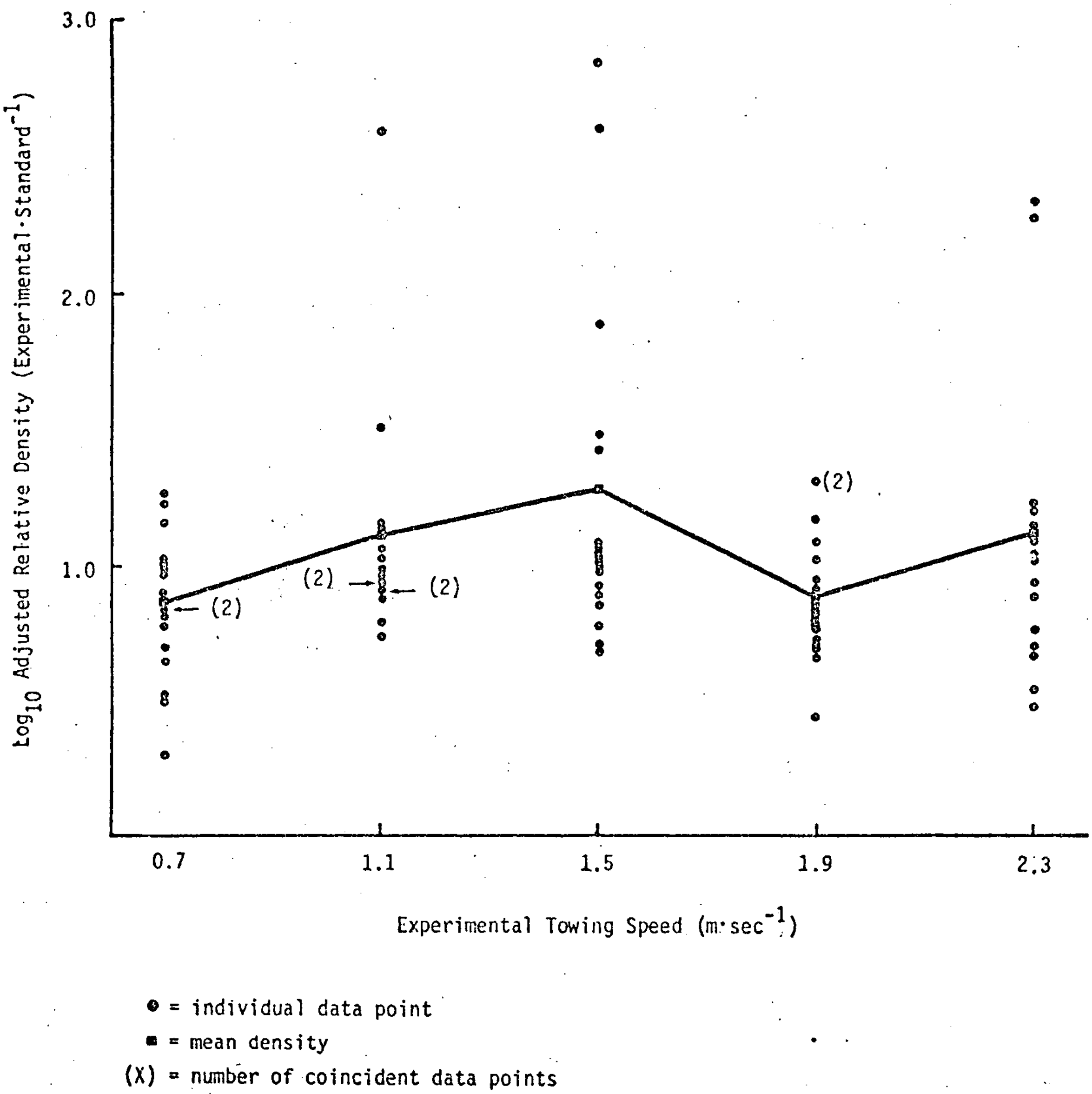

Figure IV-5. Relationship between Log_{10} Adjusted Relative Density (ratio of experimental to standard density) of Young-of-the-Year White Perch and Experimental Towing Speed for December, 1979 (m·sec^{-1}) (density of Liberty Belle samples adjusted to density of Sametta Too samples by adding 0.239384 to $\log_{10}$ Liberty Belle density)

To further investigate the low plateau hypothesis, Barkley's model was applied to white perch densities in this study by making the following assumptions: 1) YOY white perch with a mean body length of 70 mm TL (TI 1979) had an escape speed of 10 body lengths per second (0.7 $m \cdot sec^{-1}$) (Bainbridge 1960), 2) the minimum detection distance was 1.5 m (Smith in Clutter and Anraku 1968), and 3) the 1.0-m^2 epibenthic sled fished similarly to a circular 1.0-m diameter net. The conservative nature of this model was apparent since the catch efficiency of the 1.0-m^2 epibenthic sled was essentially undefined and close to zero at towing speeds less than 2.3 $m \cdot sec^{-1}$ (Appendix Figure 1) and was approximately 0.2% at 2.3 $m \cdot sec^{-1}$. Since the Barkley model assumed optimum avoidance behavior, catch efficiencies determined by this model were quite low and probably represent minimum values. Nevertheless, both applications of the Barkley model and the work of other researchers cited herein suggest catch efficiency of the 1.0-m^2 epibenthic sled for YOY white perch and striped bass is at a low plateau [D_1 in Figure II-1(E and F)] and probably less than 10%.

An implication of the Barkley model and the work of Laval (1974), Murphy and Clutter (1972), and others (summarized in Clutter and Anraku 1968), was that a relatively small increase in net diameter would increase catch efficiency more significantly than a relatively large increase in towing speed. It may not be mechanically possible to tow at speeds fast enough to observe an increase in catch efficiency with a small (1.0-m^2) net and large fish ($\geq$70 mm TL). Mechanical limitations of the gear and/or boat would cause the relationship between density and towing speed to reach a plateau at some density less than the true population density (D_o). This gear efficiency plateau was consistently observed for large trawls by Ionas (1967). We therefore conclude that a theoretical model of the relationship between density and towing speed does not appear to be the best method for the evaluation of catch efficiency for the 1.0-m^2 epibenthic sled, since it does not distinguish between a gear efficiency plateau and a plateau at the true population density.

SECTION V

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APPENDIX

APPENDIX

The Barkley (1972) model is as follows:

$$PC = \left[1 - \frac{X_o}{R\sqrt{\frac{U^2}{U_e^2} - 1}} \right]^2$$

where

PC = probability of capture (catch efficiency)
X_o = detection distance
R = net radius
U = net speed
U_e = escape speed

Examination of this model indicates three general restrictions apply:

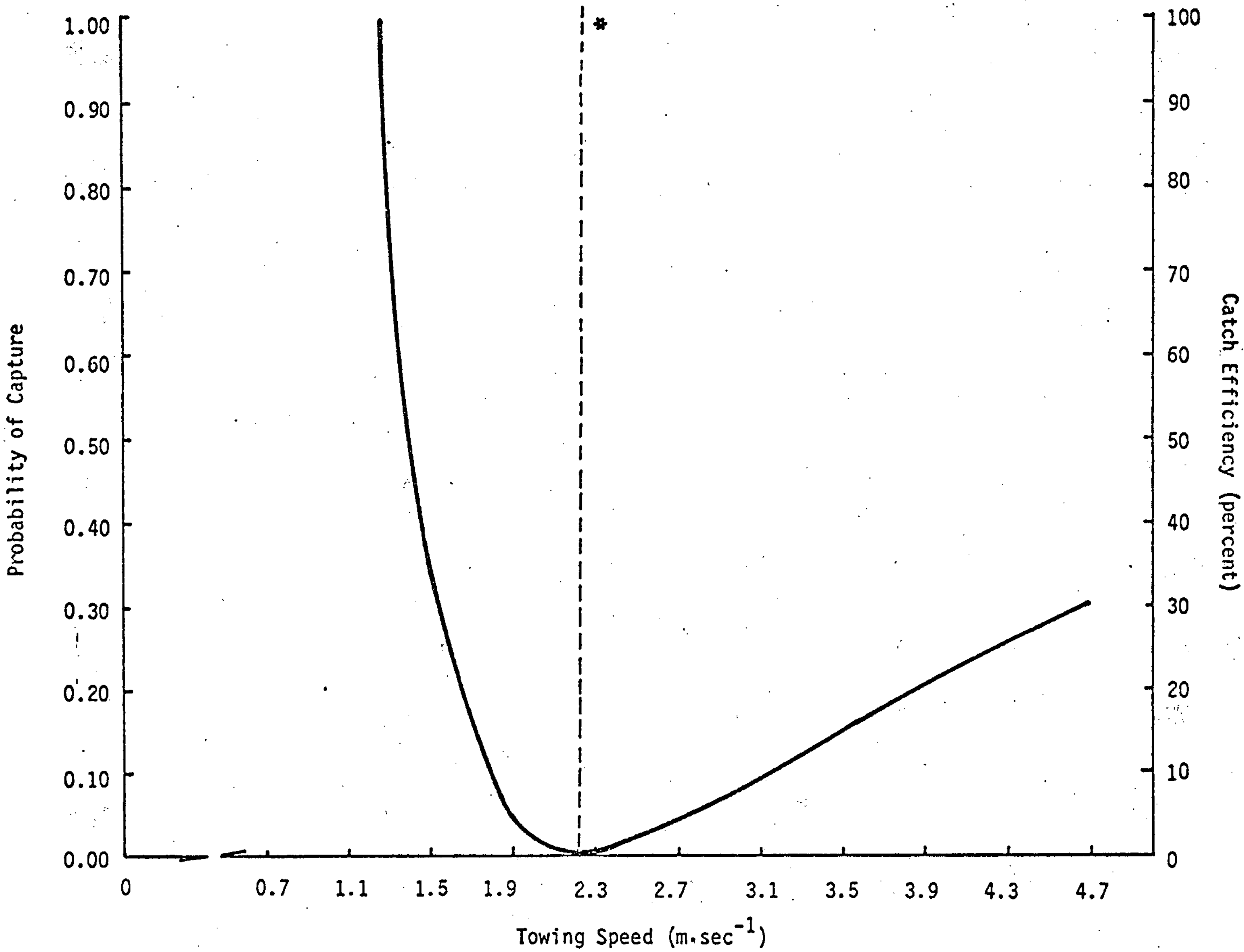
Restriction 1: U_e must be greater than zero, otherwise a division by zero would be attempted.

Restriction 2: U must be greater than U_e (i.e., greater than 0.7 $m \cdot sec^{-1}$ in this study), otherwise a square root of a zero or negative number would be attempted.

Restriction 3: The term $\left[\frac{X_o}{R\sqrt{\frac{U^2}{U_e^2} - 1}} \right]$ must be equal to or less than one.

When this term equals one, PC = 0. In this study, this occurred at a towing speed of 2.2 $m \cdot sec^{-1}$ (Appendix Figure 1). When this term is less than one, PC increases with increasing towing speed as indicated in Figure II-1(A) and the right-hand portion of Appendix Figure 1. When this term is greater than one, PC increases with decreasing towing speed and exceeds 100% efficiency (left-hand portion of Appendix Figure 1). This biological impossibility occurred at towing speeds below 1.26 $m \cdot sec^{-1}$ in this study.

Therefore, the catch efficiency for Barkley's model under the conditions of the present study was operationally defined as 0% (PC=0) at towing speeds ≤ 2.2 $m \cdot sec^{-1}$. Barkley's model was used to estimate catch efficiency only at towing speeds greater than 2.2 $m \cdot sec^{-1}$ (e.g. at 2.3 $m \cdot sec^{-1}$).



*Dashed vertical line at 2.2 m · sec^{-1} towing speed is the effective lower bound for the Barkley model (PC=0)

Appendix Figure 1. Probability of Capture (PC) or Catch Efficiency (percent) Determined from Barkley's (1972) Model as a Function of Towing Speed (U), with Constant Values for Net Radius (R=0.5 m), Detection Distance (X_o=1.5 m), and Escape Speed (U_e=0.7 m·sec^{-1})

Appendix Table 1

Characteristics of Two Boats Used in 1978-1979 Epibenthic Sled Catch Efficiency Study

Boat Characteristics	Sametta Too	Liberty Belle
Hull Construction	wood	solid fiberglass
Dimensions		
LOA (overall length)	11.9 m	11.9 m
Beam	3.7 m	3.6 m
Draft	1.1 m	1.1 m
Engine		
Type	Perkins 6-354	GM 6-71
Fuel	Diesel	Diesel
Reduction Gear Ratio	2.1/1.0	2.5/1.0
Propeller		
Number of Blades	3	4
Diameter	53 cm	71 cm
Pitch	46 cm	69 cm
Approximate RPM For Each Towing Speed		
0.7 $m \cdot sec^{-1}$	1000	-
1.1 $m \cdot sec^{-1}$	1350	520
1.5 $m \cdot sec^{-1}$	1790	720
1.9 $m \cdot sec^{-1}$	2200	920
2.3 $m \cdot sec^{-1}$	-	1120

Appendix Table 2

Two-Way Analysis of Variance (ANOVA) on Electric Flowmeter Readings ($m \cdot sec^{-1}$) Taken Simultaneously Inside (In) and Alongside (Out) Epibenthic Sled at Seven Selected Towing Speeds ($m \cdot sec^{-1}$) [treatment = flowmeter location, blocking factor = seven towing speeds, and three observations per cell (except at fastest speed where there were two observations per cell)] and Duncan's Multiple Comparison Test

Source	df	SS	MS	F	p
Model	13	53858.33	4142.95	75.37*	0.0001
Boat Speed	6	51847.92		157.21*	0.0001
Flowmeter Location (In or Out)	1	1822.50		33.16*	0.0001
Boat Speed X Flowmeter Location	6	187.92		0.57	0.7505
Error	26	1429.16	54.97		
Total	39	55287.15			

*significant at $p \leq 0.0001$

df = degrees of freedom

SS = sum of squares

MS = mean square

F = calculated F-ratio

p = probability of obtaining a larger F-ratio

Duncan's Multiple Comparison Test*

Factor	Comparison across Levels of Each Factor						
Boat Speed ($m \cdot sec^{-1}$)	1.1	1.3	1.5	1.7	1.9	2.1	2.3
Flowmeter Readings		Inside			Outside		

*For factors with a significant F-ratio, using the error mean square and associated degrees of freedom as the testing term [factor levels among which no significant (α=0.05) difference exists are underlined]

Appendix Table 3

2X3X4 Analysis of Variance (ANOVA) on Log_{10} Experimental Density of Young-of-the-Year White Perch Caught by Epibenthic Sled in December, 1979 (main factors were towing speed, date in week, and boat) and Duncan's Multiple Comparison Test

Source	df	SS	MS	F	p
Model	23	3.99	0.17	1.57	0.139
Towing Speed	2	0.77		3.51	0.046*
Boat	1	0.69		6.24	0.020*
Date	3	0.75		2.28	0.106
Towing Speed X Boat	2	0.37		1.67	0.210
Towing Speed X Date	6	0.58		0.87	0.531
Boat X Date	3	0.49		1.49	0.243
Towing Speed X Boat X Date	6	0.34		0.51	0.795
Error	24	2.65	0.11		
Total	47	6.64			

*significant at $0.01 \le p \le 0.05$

df = degrees of freedom

SS = sum of squares

MS = mean square

F = calculated F-ratio

p = probability of obtaining a larger F-ratio

Duncan's Multiple Comparison Test*

Factor	Comparison across Levels of Each Factor
Towing Speed ($m \cdot sec^{-1}$)	1.1 1.5 1.9
Boat	Sametta Too Liberty Belle

*For factors with a significant F-ratio, using the error mean square and associated degrees of freedom as the testing term [factor levels among which no significant (α=0.05) difference exists are underlined]

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