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Net Extrusion of Larval Fish: Correction Factors for 0.333 mm *Versus* 0.505 mm Mesh Bongo Nets

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Abstract

Larval fish collected with a 61 cm diameter bongo frame fitted with 0.333 mm and 0.505 mm mesh plankton nets were analyzed to detect the effects of extrusion on the catches. Sampling extended from Cape Sable, Nova Scotia to Cape Hatteras, North Carolina during eight surveys from June 1984 to April 1985. Twenty-four taxa were analyzed for evidence of extrusion by comparing the standardized abundances between the two plankton nets. The mean estimated abundance under 10 m^2 of sea surface for all taxa combined was 54% higher in the 0.333 mm net. The difference in catches between nets occurred primarily in the 2 to 5 mm length range, indicating that the smaller larvae were extruded through the 0.505 mm mesh net. Analysis of individual taxa revealed significant differences in the catch ratios by millimeter length interval, depending upon the species and its morphology. Correction factors were calculated to convert the catches from the 0.505 mm net to the expected catch of the 0.333 mm net for the eight most abundant taxa.

Key words: Continental shelf, diurnal variations, larvae, plankton

Introduction

Abundance estimates of fish larvae using towed nets contain two main sources of uncertainty, escapement and extrusion (Tranter and Smith, 1968) while other factors such as patchiness of distribution are important. Escapement, or avoidance, involves complex reactions of fish larvae to the approach of the net, including sensory perception of the net and a variety of avoidance reactions. Numerous studies have found significant differences in day *versus* night catches, indicating that visual perception of the net by larvae affects catch rates (Bridger, 1956; Clutter and Anraku, 1968; Lenarz, 1973; Morse, 1989). Extrusion represents the loss of larvae through the net meshes by the combined effects of hydraulic pressure, morphology of the fish larvae and net mesh size and stability. Extrusion results in the underestimation of small larvae abundances while avoidance will underestimate larger, active larvae abundances. These two biases affect the results of larval fish studies because a significant, and often unknown, proportion of the population of larvae is not sampled (Lenarz, 1972; Colton *et al*., 1980; Lo, 1983; Houde and Lovdal, 1984). For a review of factors affecting larval fish catches see Tranter and Smith (1968).

This study compares catches from a 0.333 mm mesh net to a 0.505 mm mesh net fitted to a bongo net frame. We investigated seasonal changes in species composition and larval morphology to determine their effects on catches. Correction factors for extrusion are derived to account for differences in size-dependent catch rates between the two nets.

Materials and Methods

Larval fish were collected during eight surveys of the Northeast Continental Shelf ecosystem, as part of the Marine Resources Monitoring, Assessment and Prediction (MARMAP) (Sherman, 1986) field program. Stations were occupied from Cape Sable, Nova Scotia to Cape Hatteras, North Carolina from 17 June 1984 to 12 April 1985. A total of 866 stations was sampled and analyzed. A plot of the standard survey station locations and subareas is shown in Fig. 1. Four sampling unit areas of the Northeast Continental Shelf, i.e. Gulf of Maine (GOM), Georges Bank (GB), Southern New England (SNE), and the Middle Atlantic Bight (MAB), were used to partition the data set for analysis. For example, if a particular species did not occur in the GOM, then all stations occurring there were omitted from the analysis. Survey dates, stations occupied and unit areas sampled are shown in Table 1.

Sampling of larval fish was conducted with a 61 cm diameter bongo frame fitted with 0.333 mm and 0.505 mm mesh nets. The amount of water filtered by each net was measured by a flowmeter attached within the net mouth. The nets were lowered at 50 m per min, to within 5 m of the bottom or a maximum depth of 200 m, and retrieved at 20 m per min. Ship speed was maintained at approximately 1.5 knots to maintain a 45° tow wire angle. All catches were

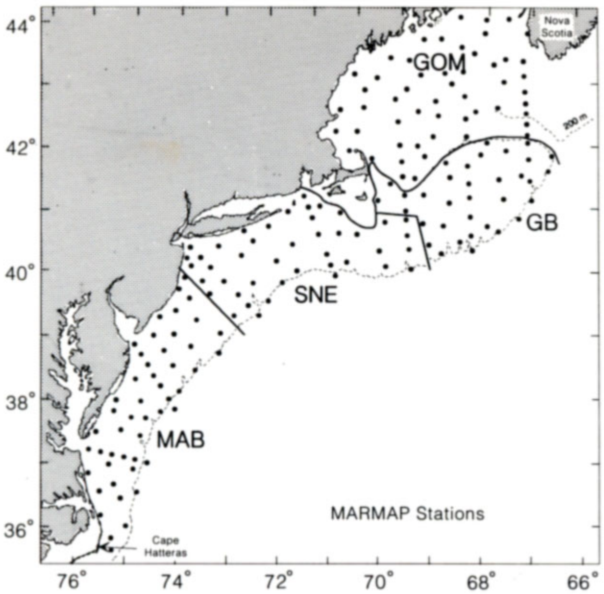

Fig. 1. Standard station locations and unit areas (GOM – Gulf of Maine, GB – Georges Bank, SNE – Southern New England and MAB – Middle Atlantic Bight) of the Northeast Continental Shelf.

standardized to the number of larvae under 10 m^2 of sea surface area (Smith and Richardson, 1977).

Net contents were preserved in 5% buffered formalin for analysis in the laboratory. A total of 50 larvae per taxon was measured when large catches required subsampling. Fish larvae were identified to the lowest taxon possible and measured to the nearest 0.1 mm standard length (SL). All larval lengths were rounded to the nearest millimeter before analysis. For descriptions of the bongo net and sampling procedures, see Posgay and Marak (1980), and Sibunka and Silverman (1984).

Analyses of the haul catches for the two nets include comparisons of the mean standardized abundance per 10 m^2 for all species and surveys combined, for individual surveys, and for individual species. In all cases, the mean catch and its variance were calculated using the assumptions of the Delta distribution, to account for zero tows, as described by Pennington (1983). The paired sample t-test was used to test for significant differences between means (Zar, 1984).

Correction factors were derived to convert the observed catches in the 0.505 mm mesh to the predicted catches of the 0.333 mm mesh. The ratios of the mean standardized abundances per 10 m^2 for each millimeter length interval between the two meshes were used to calculate a predictive model. Initial model fits, using the exponential and power curves, proved to be inappropriate because predicted ratios were underestimated at the 2–3 mm lengths and less than zero at lengths greater than 5 mm. The Laird-Gompertz curve of the form (Laird *et al.*, 1968):

$$P_r = A \exp(-B_1 (1 - \exp(B_2 * L)))$$

fit the data well without the problems mentioned above for the two parameter models. In the model, P_r = predicted ratio of the 0.333 mm net to the 0.505 mm net, A, B_1 and B_2 are constants and L is larval standard length in millimeters.

Results

All surveys

For all surveys combined, larval fish were captured at 690 stations by the 0.333 mm mesh net (80% occurrence) while the 0.505 mm mesh net contained larval fish at 714 stations (82% occurrence). The mean standardized abundances per 10 m^2 of all larvae was significantly different between the nets ($P<0.005$), according to the two-tailed paired sample t-test. The 0.333 mm net collected an average of 372.8 larvae per 10 m^2 while the 0.505 mm net collected 242.0 larvae, a difference of 54%.

Catches of all larvae grouped by length for each net are shown in Fig. 2. The greatest difference in

TABLE 1. List of surveys, sampling period and number of stations sampled by unit area and in total.

			Unit area				
Survey	Begin	End	Middle Atlantic Bight	Southern New England	Georges Bank	Gulf of Maine	Total
I	17 Jun 1984	24 Jun 1984	32	9	–	–	41
II	04 Jul 1984	18 Jul 1984	37	31	–	–	68
III	10 Jul 1984	30 Jul 1984	52	30	25	–	107
IV	25 Jul 1984	30 Aug 1984	21	39	36	12	108
V	17 Sep 1984	03 Nov 1984	38	37	35	47	157
VI	01 Nov 1984	05 Dec 1984	46	44	31	20	141
VII	08 Jan 1985	06 Feb 1985	41	43	33	8	125
VIII	27 Feb 1985	12 Apr 1985	30	33	28	28	119

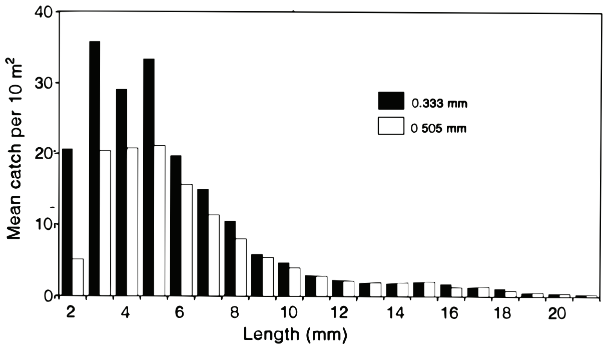

Fig. 2. Mean catch per 10 m^2 of all taxa for all surveys.

catches between the two nets occurred in the smallest length interval, between 2 and 5 mm. Above approximately 9 mm, little difference between the net catches was detected, indicating that extrusion was not occurring at these lengths. The length interval between 6 and 8 mm showed the 0.333 mm net catches were consistently higher than the 0.505 mm net and represented lengths where extrusion was occurring, but to a lesser extent than at shorter lengths.

Surveys

The results shown in Fig. 2 for all taxa represent the average catches for all surveys and taxa combined. Shifts in species composition between surveys were examined to detect possible seasonal trends or differences in extrusion rates. On seven of the eight surveys, the 0.333 mm net caught more larvae than the 0.505 mm net (Table 2). Of the seven surveys, the highest ratio of catches (survey II) was 3.15:1 during July and the lowest ratio (survey VIII, April) was 1.12:1. Only on survey VI (November) did the catch in 0.505 mm net slightly exceed the 0.333 mm net. Then the ratio was 0.89:1, though the mean catches were not significantly different ($P<0.05$). No consistent seasonal trend in catches by net was evident in the time series, though changes in species composition may have accounted for survey to survey differences in the overall catch ratios.

Taxa

Between-survey changes in the dominant taxa (defined as those taxa accounting for ≥10% of the catch within any survey) are shown in Table 3. For most taxa, the percent caught in the two nets differed little, though notable exceptions did occur. The percentages for hake (*Urophycis* spp.) for surveys II and IV, and searobins (*Prionotus* spp.) for survey V differed by a factor of 1.7 or more. Bluefish (*Pomatomus saltatrix*) in survey II, and Atlantic herring (*Clupea harengus*) in survey V differed by factors of 1.8 and 2.0, respectively. Both bluefish and Atlantic herring showed significantly higher ($P<0.05$) percentages caught in the 0.505 mm net.

The seasonal shifts in species composition of the dominant taxa were clearly evident (Table 3). *Ammodytes* spp., was the dominant taxon, accounting for 80–97% of the total catch, during the cold-water conditions of surveys VII and VIII. Table 2 shows that there was no significant difference ($P<0.05$) in the mean catch between the two nets for survey VIII, though survey VII catches were significantly different. The length composition of *Ammodytes* spp. larvae in the two surveys probably contributed to the differences between the two surveys. In survey VII, over 90% of the larvae were 8 mm or less, and in survey VIII, only 14% of the larvae were 8 mm or less in length. The warm-water months (surveys II–VI) were dominated by five to seven taxa, with the maximum percentage of any one taxon being ≤35%.

For all surveys combined, 24 taxa were captured in high enough numbers to analyze the differences in mean catch per 10 m^2 between the two nets (Table 4). Twenty taxa had higher mean catches in

TABLE 2. Mean and standard error of the standardized catch of larval fishes per 10 m^2 for the 0.333 mm and 0.505 mm mesh nets. N = total stations sampled, Pos. = stations containing larvae, ratio of mean standardized abundance, and P = probability of no difference in the mean catches.

		0.333 mm			0.505 mm				
Survey	N	Pos.	Mean (10 m^2)	Standard error	Mean Pos.	Standard (10 m^2)	error	Ratio	P
I	41	38	93.87	22.66	39	69.34	19.75	1.35	<0.05
II	68	65	949.10	333.36	68	301.15	72.07	3.15	<0.02
III	107	102	377.46	71.10	103	232.24	44.74	1.63	<0.001
IV	108	90	246.59	59.62	90	156.86	31.21	1.57	<0.002
V	157	115	540.45	146.77	128	316.43	78.46	1.71	<0.01
VI	141	101	129.77	27.39	112	145.19	32.01	0.89	NS
VII	125	94	797.16	253.75	93	518.67	164.22	1.54	<0.002
VIII	119	85	215.77	57.51	88	193.10	49.31	1.12	NS

TABLE 3. Comparison of the dominant taxa (accounting for >10% of total catch) by survey between the 0.333 mm net (3) and 0.505 mm net (5). The values are the percent of the total catch of the taxa within each net for each survey.

	Survey															
	I		II		III		IV		V		VI		VII		VIII	
Taxa	3	5	3	5	3	5	3	5	3	5	3	5	3	5	3	5
Merluccius bilinearis	9.5	11.9	13.0	15.2	7.8	10.2	11.8	12.2	8.0	5.2	12.6	10.8				
Limanda ferruginea[a]	8.5	9.2														
Pomatomus saltatrix	5.3	7.1	13.4	24.8	9.1	8.5										
Hippoglossina oblonga	7.7	6.0	7.9	9.4	7.7	10.1	5.8	8.3								
Urophysis spp.			23.2	12.0	9.1		35.0	20.4	20.5	18.2	14.7	14.9				
Peprilus triacanthus	7.3	10.8	8.7	7.8	8.0											
Engraulidae			7.4	3.9	16.4	16.6										
Tautogolabrus adspersus[a]					9.9	6.3										
Ceratoscopelus maderensis							8.5	12.9								
Citharichthys arctifrons							4.8	7.4	8.4	10.5						
Micropogonias undulatus									13.5	12.3						
Prionotus spp.	6.6								20.2	11.7						
Clupea harengus									8.9	18.4						
Brevoortia tyrannus											14.7	20.1				
Scophthalmus aquosus											23.8	18.9				
Paralichthys dentatus											12.7	11.2				
Ammodytes spp.													97.2	96.7	80.7	84.4
Gadus morhua															10.1	8.5

[a] Included because of relative importance.

TABLE 4. Mean and standard error of the catch by taxon of larval fishes per 10 m^2 for the 0.333 mm and 0.505 mm mesh nets. N = total stations sampled, Pos. = number of stations with larvae, and P = probability 0.333 mm standardized abundance equals 0.505 mm.

		0.333 mm			0.505 mm				
Taxon	N	Pos.	Mean (10 m^2)	Standard error	Pos.	Mean (10 m^2)	Standard error	Ratio	P
Brevoortia tyrannus	158	44	16.96	5.29	49	21.89	7.16	0.77	NS
Clupea harengus	98	36	48.03	20.78	46	45.22	17.55	1.06	NS
Engraulidae	248	104	38.63	9.73	86	18.69	4.41	2.07	<0.0025
Ceratoscopelus maderensis	201	49	20.92	6.72	59	17.02	4.74	1.23	NS
Urophysis spp.	448	232	74.04	13.75	219	33.98	5.14	2.18	<0.0005
Gadus morhua	104	40	14.12	4.86	38	12.70	4.13	1.11	NS
Pollachius virens	145	44	14.25	4.56	36	10.24	3.33	1.39	<0.03
Merluccius bilinearis	375	177	41.82	7.33	175	27.16	4.37	1.54	<0.01
Centropristis striata	128	29	2.53	0.74	36	3.44	0.97	0.74	NS
Pomatomus saltatrix	242	81	37.12	8.86	81	24.26	5.97	6.22	NS
Micropogonias undulatus	84	22	106.77	68.19	28	47.54	23.57	2.25	NS
Tautogolabrus adspersus	213	92	13.76	2.69	69	7.86	1.52	1.75	<0.01
Peprilus triacanthus	279	141	23.87	3.92	133	12.34	1.75	1.93	<0.0005
Prionotus spp.	150	92	25.37	6.21	73	16.32	4.06	1.55	NS
Ammodytes spp.	244	154	455.10	111.81	153	326.15	77.63	1.40	<0.001
Citharichthys arctifrons	375	181	30.46	4.89	146	19.32	3.23	1.58	<0.0005
Etropus microstomus	270	91	8.73	1.68	97	8.22	1.33	1.06	NS
Bothus spp.	178	46	3.16	0.65	60	3.87	0.61	0.82	NS
Hippoglossina oblonga	317	161	26.32	4.38	162	17.59	2.58	1.50	<0.005
Paralichthys dentatus	163	66	13.35	3.05	62	11.88	2.74	1.12	NS
Limanda ferruginea	255	86	5.25	0.71	85	4.36	0.55	1.20	NS
Scophthalmus aquosus	323	153	16.99	2.80	137	15.00	2.35	1.13	<0.03
Symphurus spp.	69	20	5.57	1.79	38	9.56	1.85	0.58	NS
Lophius americanus	242	77	2.73	0.33	69	2.12	0.27	1.29	NS

the 0.333 mm net, with 10 of these showing significant differences (P<0.05) using the two-tailed paired sample t-test. The four taxa with higher catches in the 0.505 mm net were not significantly different (P<0.05) to their 0.333 mm counterpart. It was clear from Table 4 that as the number of positive tows (those containing larvae) increased, the more likely it was of finding statistical differences between net catches. This is the result of the highly patchy nature of larval fish distributions and the effects of sample size on statistical tests (Smith and Richardson, 1977).

From Tables 3 and 4, it appeared that either net will adequately sample the larval fish community for dominant species composition, but the ordering of the species, as percent of the total catch, was not consistent between the two nets. In addition, for all but four of the taxa examined, the 0.333 mm net caught more larvae than the 0.505 mm net.

Length frequencies and correction factors

Of the 24 taxa in Table 4, eight were collected in sufficient numbers to analyze their length frequencies for differences in catch by net mesh. Figure 3 shows the mean catch per 10 m^2 by millimeter length interval for the two nets. The first six taxa in Fig. 3 were caught at a minimum length of 2 mm, while the last two taxa were caught in relatively small numbers at lengths between 3 and 4 mm, with none captured at 2 mm. The maximum lengths of larvae in Fig. 3 represent the longest length at which the species was caught by both nets. For lengths up to about 10 mm, the 0.333 mm net consistently caught more larvae than the 0.505 mm net, particularly at the shortest lengths caught. Ratios of the mean catch at 2 mm ranged from five to nine times higher in the 0.333 mm net, and decreased to about 1:1 at the 6–10 mm length interval. This disparity in catches was attributed to extrusion of small larvae through the meshes of the 0.505 mm net.

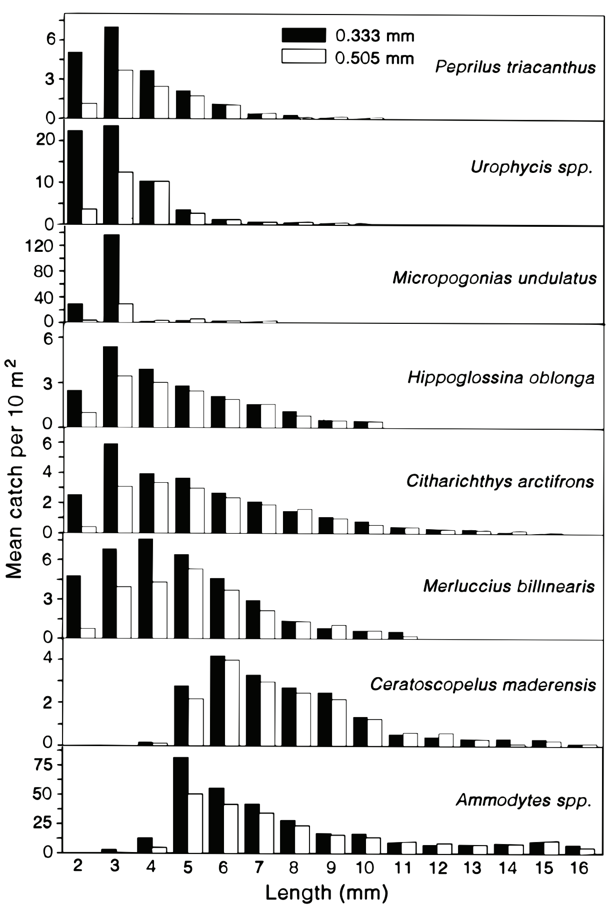

Fig. 3. Mean catch per 10 m^2 by length for eight taxa collected in 0.333 mm and 0.505 mm mesh nets.

Ratios of the catches for the two nets (0.333 mm/0.505 mm net) and fitted non-linear predictive curves are shown in Fig. 4. The maximum length in Fig. 4 was the length at which the ratio stabilized at a ratio of about 1:1. The first three taxa, (*Peprilus triacanthus*, *Urophycis* spp. and *Micropogonias undulatus*), revealed that extrusion occurred at lengths between 2 and 6 mm, with the ratio increasing from about five to nine at 2 mm. The fourth species (*Hippoglossina oblonga*), was captured at 2 mm (see Fig. 3), but at only one station and, therefore, this length was omitted from the analysis. Both *Citharichthys arctifrons* and *Merluccius bilinearis* were captured at the minimum length of 2 mm and the maximum length subject to extrusion increased to 7 and 8 mm, respectively. The minimum length of the last two taxa, *Ceratoscopelus maderensis* and *Ammodytes* spp., again occurred to 3 mm and extrusion was evident to lengths of 9 to 10 mm. The parameters of the equations for predicting the catches of the 0.333 mm net from 0.505 mm net catches are given in Table 5.

The illustrations of larvae shown in Fig. 4 help explain the differences in catch ratios by length and the differences between taxa in the maximum length extruded. The general shape of the larvae varied from robust for *P. triacanthus* to slender for *Ammodytes* spp. The gradual change in the larval shape was coincidental with both, an increase in the ratio of the catches of 2 mm fish and an increase in the minimum length captured from 2 to 3 mm. In addition, the maximum length of larvae captured by both nets increased from 6 mm for robust forms to 10 mm for the slender forms.

Discussion

The quantitative capture of larval fish from natural populations using towed nets involves three main sources of uncertainty: avoidance, extrusion and patchiness. Optimization of these factors involves trade-offs in capture efficiency and biologists often compromise high efficiency for a balance between extrusion and avoidance. Higher towing speed may reduce avoidance but faster tows increase extrusion through higher hydraulic pressures inside the net. Increasing speed also tends to damage larvae and make identification more difficult. Previous accounts show inconsistencies regarding the effects of tow speed and its influence on avoidance and escapement of plankton (Clutter and Anraku, 1968). Smaller net mesh size will reduce extrusion but increase the potential for net

TABLE 5. Nonlinear regression coefficients, standard error of the regression (SER), and coefficient of determination (r^2) for the relationship of larval length (L mm) and the ratio (R) of the standardized mean catch per 10 m^2 of the 0.333 mm to the 0.505 mm nets. The equation is $P_r = A \exp(-B_1 (1 - \exp(B_2 * L)))$ and the numbers in parentheses are the standard errors of the coefficients.

Taxon	A	B_1	B_2	SER	r^2
Peprilus triacanthus	273.18	5.69	0.64	0.17	0.99
	(425.61)	(1.47)	(0.18)		
Urophycis spp.	395.45	6.55	0.51	0.44	0.99
	(139.02)	(0.29)	(0.10)		
Micropogonias undulatus	61.02	12.84	0.08	1.32	0.93
	(157.99)	(74.52)	(0.63)		
Hippoglossina oblonga	26.53	3.23	0.66	0.06	0.99
	(21.05)	(0.75)	(0.15)		
Citharichthys arctifrons	4 211.50	8.44	0.71	0.27	0.99
	(10 594.09)	(2.40)	(0.18)		
Merluccius bilinearis	105.13	4.87	0.47	0.63	0.91
	(254.81)	(2.00)	(0.33)		
Ceratoscopelus maderensis	108.58	4.68	0.56	0.11	0.96
	(211.31)	(1.94)	(0.15)		
Ammodytes spp.	4 403.91	8.48	0.48	0.20	0.99
	(6 857.96)	(1.48)	(0.07)		

clogging, which decreases filtration efficiency. Lower filtration efficiency produces an increased acceleration front ahead of the net which will increase avoidance response of larvae (Tranter and Smith, 1968). The design of a plankton net influences its filtration accuracy; its form dictates the volume of water and the evenness of pressure distribution. Intercalibration of net mesh sizes and larval fish catches, as presented here, offers an opportunity to reduce the conflicts between avoidance and extrusion by describing the magnitude of extrusion losses.

In a recent paper, Somerton and Kobayashi (1989) investigated the combined effects of extrusion and avoidance on the catches of nehu (*Encrasicholina purpurea*). They advocated the simultaneous solution of avoidance and extrusion probabilities for a complete and unbiased correction of net catches. This was accomplished by developing a method for estimating entry and retention probabilities, applied to correct the length frequency distribution of larvae. Clearly, this is desirable, but given the trade-offs in capture efficiencies between extrusion and avoidance, our two-net study concentrated on only extrusion. We have assumed, as did Somerton and Kobayashi (1989), that avoidance was constant between the two nets. While the finer mesh net may have a larger pressure gradient in front of it, the use of the bongo nets for comparison of catches standardizes within-tow variables that would affect catches from repeated tows with different net meshes. The variables held constant include tow time, tow depth, tow direction, and the effects of patchiness on the precision of the estimates of mean catches. In addition, the deployment of two mesh sizes on the bongo frame minimized the variability that occurs when separate tows are made for each net. Factors such as tow depth, tow time, and net speed, as well as the effects of small scale patchiness, are difficult to control when separate tows are made and compared. The bongo frame offers an ideal sampling gear for net mesh comparisons, contrary to the statements by Colton *et al*. (1980). They indicated that a comparison of catches from 0.333 and 0.505 mm mesh nets, at least for Atlantic herring larvae, using survey data was not appropriate because samples are taken from a wide area, over a "considerable" time period and because larvae are from contagious and varying age structured populations. We feel these factors are, in fact, needed to determine average rates of extrusion under actual field conditions. In any case, no difference in catches of Atlantic herring larvae were found in this study or by Colton *et al*. (1980), regardless of sampling methods or mesh size (0.333 mm *versus* 0.505 mm).

The extent to which extrusion of larval fish is a serious problem depends upon the intended use of the catch data. If lengths not subject to extrusion are analyzed, then the problem is overcome. Ecological studies of larval fish communities, e.g. dominant species and species composition, will be subject to some bias from extrusion, but may not be serious. However, studies of the distribution and

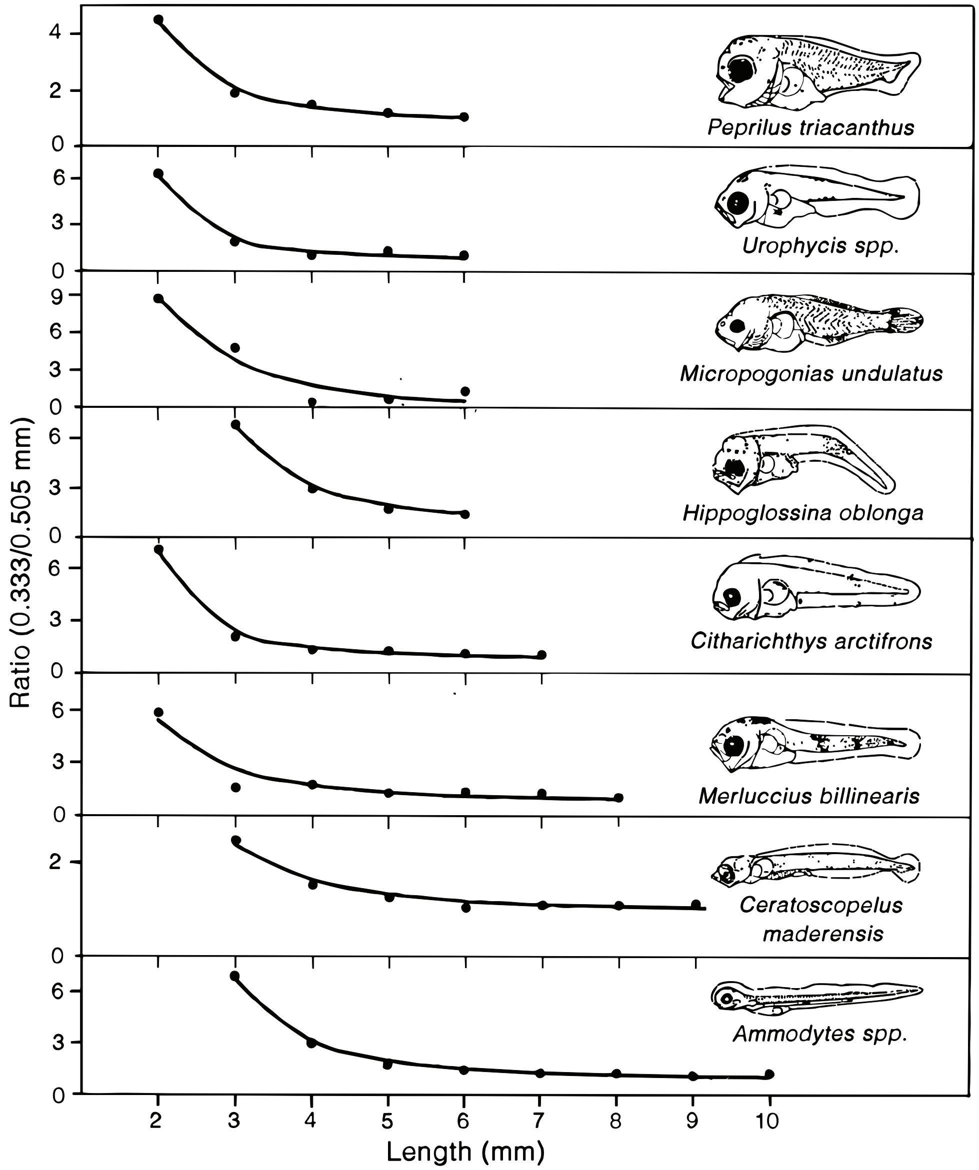

Fig. 4. Observed points and predictive curves derived from differences in standardized mean catch per 10 m^2 between the 0.333 mm and the 0.505 mm mesh nets. (Illustrations from Fahay, 1983).

abundance of newly hatched larvae or the calculation of mortality rates from length frequencies will incorporate serious bias if extrusion losses are overlooked. Thus, the selection of sampling gear, including mesh size, is predicated on the types of analyses intended for the catch data.

Future investigations should examine the relationship between extrusion and body dimensions of fish larvae. Body types of most continental shelf larval fish are long and laterally compressed, with a single rudimentary dorsal fin (Aleev, 1969). Additional morphometric features such as spines, bulbous heads, or stocky bodies will inhibit extrusion. Studies of the relationships of larval morphology and extrusion, e.g. skull width, mesh size and extrusion rate Colton *et al.* (1980), should be pursued to offer field biologists the appropriate background information to optimize field sampling programs.

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