International Commission for the Northwest Atlantic Fisheries

ANNUAL MEETING - JUNE 1975

Progress report on analysis of sampler and behavior-related variation in the catch of larval herring on ICNAF Larval Herring Surveys

by

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Introduction

In recent years considerable study has been made of the design and towing characteristics of plankton nets in an effort to improve their efficiency in capturing plankton, especially larval fishes. These studies have shown that net efficiency in respect to ichthyoplankton varies with net size (mouth area), filtering ratio (total mesh aperture area/mouth area), towing speed, and mesh size and also with length and species of larvae and time of day. The main causes of variation are escapement or extrusion of the smaller larvae through the meshes (Vannucci, 1968) and avoidance of the net by the larger larvae (Clutter and Anraku, 1968). In general, there is an increase in extrusion and a decrease in avoidance with increasing speed of tow and a decrease in avoidance during the night.

It is most important, therefore, that the sampling gear and method of tow be selected with a clear understanding of the research objectives and of the limitations the associated sampling variabilities impose. In this analysis we are attempting to evaluate on an _a posteriori_ basis the effectiveness of the sampling design employed to furnish the quantitative estimates of abundance necessary to meet the objectives of the ICNAF Larval Herring Surveys. These objectives were to delimit the major spawning grounds and to obtain relative estimates of spawning stock size and information of larval drift and dispersal (ICNAF 1971 and 1972). It was further agreed that, "The value of these surveys lies in the contribution they can make to estimation of adult stock size, to stock identification by following larval dispersion, and to understanding the factors influencing larval survival which will effect year-class size." (ICNAF 1973)

Field and Laboratory Methods

Ichthyoplankton samples collected on one cruise of the Delaware II (U.S.A.), one cruise of the Walther Herwig (Fed. Rep. of Germany) and four cruises of the Albatross IV (U.S.A.) were used in this analysis. A total of 676 stations were occupied on these six cruises. The dates, station

locations, and distribution of total herring larvae for each cruise are shown in Figure 1.

At each station a 3.5 knot (6.5 km/hour), double-oblique tow was made using paired 61 cm bongo samplers (Posgay and Marak, 1975) fitted with 0.505 mm (port) and 0.333 mm (starboard) nylon mesh nets. The sampler accessories (flowmeter, time-depth recorder, towing wire, and wire depressor) were rigged and of similar specifications as described by Posgay and Marak (1975).

On Delaware II Cruise 71-4 the maximum depth of tow was 200 m and the net was deployed at 50 m/min and retrieved at 20 m/min to 40 m depth. The upper 40 m of the water column was sampled in 20, 2 m interval steps of one-minute duration. On Albatross IV Cruise 71-7 the sampling procedure was similar except that the net was retrieved continuously at 10 m/min from 40 m to the surface. On all other cruises the maximum depth of tow was 100 m and the net was deployed at 50 m/min and retrieved at 10 m/min.

Fish eggs and larvae were sorted from the total 0.505 mm mesh samples and the larvae from each sample enumerated by species. For species numbering less than 100, all larvae were measured for standard length to the nearest 0.1 mm. The larvae were later combined into 1 mm and 3 mm size groups. In samples containing greater numbers of larvae, a subsample of at least 100 specimens was taken for length determinations and the total length frequency determined by multiplying the number at each length interval by the reciprocal of the aliquot fraction.

The flowmeter readings for each tow were converted to m^3 of water filtered. Those values for a given cruise were then plotted against the maximum tow depths and obvious discrepancies in volume values corrected on the basis of average tow depth-volume filtered values. Larval abundancies in terms of numbers per unit volume and numbers per unit surface area were then determined for each tow.

The length frequency and abundance data were further allocated into day, night, and twilight categories. Twilight was arbitrarily defined as the four-hour period, one hour before and after sunrise and sunset. The number of day, night, and twilight stations for each cruise are listed in Table 5.

Results

The length frequencies and mean lengths of larvae for total, day, night, and twilight stations for individual and total cruises are given in Tables 1, 2, 3, and 4. Histograms of the total length frequencies based on 3 mm length intervals for all stations and for the three time periods are shown in Figure 2.

The length frequency distributions and mean lengths varied between cruises, but for a given cruise the degree of variation in mean length for the three time periods was unexpectedly low. An analysis of variance on length for the three times showed the differences in mean length

to be significant for <u>Albatross IV</u> Cruise 74-2 (p=.05) and highly signi-
ficant (p=.001) for all other and total cruises. On the basis of previous
field observations and theoretical studies of net avoidance in relation
to time of day, we would expect to catch not only more, but appreciably
larger larvae with decreasing light intensity. Our data show that the
time period of maximum mean length of larval herring varied between
cruises. For total cruises, the mean length was greater during the day
(15.5 mm) than at night and twilight (15.1 mm). The marked downward
shift in modal length during twilight hours (Figure 2) reflects the high
proportion of larvae from <u>Anton Dohrn</u> samples during this time period
(54 percent of the total catch).

The average abundance of 3 mm length group and total larval
herring for the three time periods for individual and total cruises and
the night/day and twilight/day ratios of abundance for total cruises are
listed in Table 5. The average abundance values for the three time periods
for total cruises are plotted in Figure 3. There was appreciable variation
in the time period of maximum abundance between length groups and cruises.
This is as would be expected from the contagious distribution of larval
herring, which was more marked for individual length groups than for
total herring (Figure 1). In addition, the percentage of total stations in
which herring were found did not vary significantly between day (45%),
night (49%) and twilight (50%), indicating that if herring were present
at any location they were caught, but not necessarily in proportion to their
absolute numbers.

Of the 54 length group categories listed in Table 5, the abundance
of larvae was greatest in 55, 26, and 19 percent during the night, twilight,
and daytime periods, respectively. The total abundance was greatest at
night on three cruises (<u>Albatross IV</u>, Cruises 72-9, 73-9, and 74-2),
greatest at twilight on two cruises (<u>Delaware II</u> Cruise 71-4 and <u>Albatross IV</u>
Cruise 71-7), and approximately equal during night and twilight on one cruise
(<u>Anton Dohrn</u>). For all cruises combined, the abundance was greatest at
night for all length groups except 13-15 mm larvae (twilight). The ratio
of night/twilight/day abundances of total larvae for all cruises was
approximately 5/3/2.

The total night/day abundance ratios were greater than one for
all length groups. The night/day ratio was appreciable greater for 4-6 mm
larvae than for the larger length categories. The total twilight/day
abundance ratios were greater than one for all length groups except 7-9 mm
and 28-30 mm larvae. For these length groups day catches were slightly
greater than twilight catches.

The total night/day abundance ratios for 1 mm length groups and
linear regression lines based on these values and on night/day ratio values
in the catch of Pacific sardine (<u>Sardinops caerulea</u>) larvae (Ahlstrom, 1954)
are plotted in Figure 4. The Pacific sardine data are based on 626, 1.5
knot (2.8 km/hour), double-oblique, one-meter net (1.0 or 0.7 mm mesh)
tows. The maximum sampling depth of these collections was approximately
100 m.

The statistics of a linear regression line fitted to the Pacific

sardine data show an increase in the night/day abundance ratio of 0.7 for
each mm increase in length, while a linear regression line based on the
Atlantic herring data indicates a decrease in the night/day abundance ratio
of 0.07 for each mm increase in length. A regression line fitted to the
night/day abundance ratio values for larval herring larger than 6 mm
showed no significant variation with length (Y=2.1734 + .03029X).

Discussion

In reference to previous observations, the two most obvious
discrepancies in the larval herring data are the relatively high night/
day abundance ratio (ca. 7/1) of yolk sac larvae (4-6 mm) and the fairly
consistent night/day ratios (ca. 2/1) of the larger larvae (7-30 mm). The
observation that larval herring larger than 6 mm showed no significant
variation in night/day abundance ratios with length suggests that all
larvae above 6 mm are capable of avoiding the 61 cm bongo net to some
degree and that this capability is dependent to a great extent on light
conditions (visibility).

An algebraic model of net avoidance which takes into account the
towing speed, net radius and the escape velocity, alarm or reaction distance,
and the initial offset of the larvae has been developed by Barkely (1964)
and further extended by Barkely (1972) and Murphy and Clutter (1972). As
Barkely (1972) has pointed out, probabilities of certain capture can only
be calculated for animals that react individually. Animals within a school
react to each others behavior and thus a school is more effective than the
sum of the individuals in detecting and responding appropriately to the
oncoming net. In an attempt to rationalize the consistancy of the day/
night abundance ratios, we determined theoretical minimum escape velocities
for one meter interval reaction distances using equation(2) of Barkley
(1972) in which:

$$u_e = \frac{U}{\sqrt{1 + \frac{x_o^2}{(R - r_o)^2}}}$$

Where: u_e = minimum escape velocity (cm/sec)
U = towing speed (cm/sec) = 180 cm/sec
x_o = reaction distance of larva (cm) = 100-1000 cm
r_o = initial offset of larva from net center (cm) = 0
R = net radius (cm) = 30.5 cm

In these calculations we have assumed that:

1. Larva selects the shortest possible escape path (i.e., normal
to direction of tow). It should be noted here that this ability to take
well-directed evasive action may be dependent on light conditions.

2. Larva is located along the axis of tow (initial offset from
dead center of net is zero).

3. Reaction distance is essentially constant for all size larvae
under a given set of light conditions (specific time of day). This is

probably a valid assumption, for in herring the visual cells are comprised of only cones in the larval stage and rods and associated retinomotor responses and schooling behavior do not develop until metamorphosis (Blaxter, 1965, 1966, and 1968; Blaxter and Jones, 1967; Rosenthal, 1968).

The calculated minimum escape velocities (u_e) are shown in Figure 5. For reaction distances less than 5 m, swimming speed is highly critical (37.6 cm/sec increase in swimming speed required for a decrease in reaction distance from 4 to 1 m). For reaction distances greater than 5 m, swimming speed is not as critical (3.6 cm/sec increase in swimming speed required for a decrease in reaction distance from 10 to 6 m).

Testing of avoidance theory requires some knowledge of escape velocities as a function of size. We are concerned here with darting or burst speeds sustainable over time periods of a few seconds and distances up to 100 cm or so. The literature on such quantified swimming ability for larval fishes is limited. Maximum swimming velocities of larval herring reported by Blaxter (1962) increased from 3 to 5 cm/sec in 8 mm larvae to 30 cm/sec in 20 mm larvae and fit well with the commonly used maximum swimming velocity of 10 body lengths/sec observed by Bainbridge (1960). For larval plaice (Pleuronectes platessa) having a mean length of 9.6 mm, Ryland (1963) obtained a mean darting speed of 10.0 cm/sec which corresponds to 10.4 body lengths/sec. Hunter (1972) observed maximum burst speeds of very short duration on anchovy (Engraulis mordax) as high as 28 body lengths/sec for 4.2 mm larvae and 25 lengths/sec for 12.1 mm larvae, but the typical average burst speeds were close to 15 lengths/sec. For larval lake whitefish (Coregonus clupeaformis) ranging in length from 15 to 28 mm, Hoagman (1974) observed maximum burst speeds of 4.4 and 8.2 body lengths/sec (mean, 7.6).

In Figure 5 we have plotted maximum swimming speeds of 5, 10, and 15 body lengths/sec for 1 mm length values to determine the minimum length at which escape is possible for reaction distances of 1 to 10 m. These minimum escape length values are listed in Table 6.

Under the conditions of tow employed in the ICNAF Larval Herring Surveys and within the range of maximum swimming speeds considered, none of the larvae within the size range sampled could escape at a reaction distance of 1 m. At a maximum swimming speed of 5 body lengths/sec and a reaction distance of 10 m, the minimum escape length is 11 mm. At maximum swimming speeds of 10 and 15 body lengths/sec, 7 mm larvae could avoid the 61 cm bongo net if their reaction distances were 8 and 5 m, respectively.

Considerable laboratory study has been made on the visual acuity of larval fishes, but these studies have been mainly concerned with their ability to find food. Woodhead (1966) has estimated the maximum sighting range of fishes under optimal conditions to be less than 15 m. Nichol (1963) concluded that in coastal waters (latitude 50°N) fish at 100 m depth could perceive objects from sunrise to sunset on the darkest winter day. Murphy and Clutter (1972) noted that the optical characteristis of sea water are such that objects become invisible through contrast attenuation rather than resolution attenuation. If this were so, large nets should be sighted at nearly the same distance as smaller nets resulting in a dramatic

increase catching efficiency with size of net. Their field data clearly show, however, that anchovy larvae reacted to the Isaacs-Kidd midwater trawl (IKMT) at considerably greater distances than to the 1-M net.

A reaction distance of 8 m during daylight hours appears to be reasonable and is similar to values determined by Barkely (1972) for anchovy larvae collected with a 10-foot IKMT ($u_e = 10$ BL, $x_O = 8.2$ m). The credibility of this reaction distance estimate is enchanced when we consider that the avoidance reaction is most likely initiated by a visual response to the whole bongo net array (including the wire depressor) rather than to the individual bongo samplers. Blaxter (1968) has suggested that because cones are the dominant mode of vision in larval fishes that they are better at receiving movement than patterns or images. The speed of tow, tow configuration, and dimensions of the sampling gear and associated hardware would tend to augment this form of perception.

Because minimum escape velocities of nets detectable at 6 m or more are a small fraction of the towing speed, the increase in swimming speed with length is not sufficient to appreciably increase daytime avoidance. Reaction distance is more critical than swimming speed and we have concluded that this accounts for the fairly constant night/day abundance ratios observed for herring larger than 6 mm.

One factor which could explain the relatively high night/day abundance ratios of 4-6 mm larvae would be a significant increase in the night-time catch of invertebrate fauna resulting in increased clogging of the net meshes and reduced escapement or extrusion of the smaller herring larvae. To check on this possibility, we determined total plankton displacement volumes for Albatross IV Cruise 73-9 samples. The night/day abundance ratio of 4-6 mm larvae collected on this cruise was 12.8 while the night/day ratio of displacement volumes was 1.3. Increase retention does not account for the markedly greater night-time catch of the smaller larvae.

The only other explanation we can think of for this anomaly is that the yolk-sac larvae are on or very near the bottom during the day and move up into the water column and above the maximum depth sampled by the bongo net (approximately 5 m off bottom) during the night. To date there have been no published field observations in which closing nets were spaced at small enough intervals to detect such small-scale movements. There is some evidence, however, from laboratory experiments and in-situ observations by divers that support this hypothesis. Blaxter (1973) monitored the movements of herring and plaice larvae of different ages from hatching to about 8 weeks old in a vertical tube at varying natural and artificial light intensities. The critical natural light intensity for movement to occur was equivalent to that of Civil Twilight (0.14 mc). For both herring and plaice, 0-day old larvae exhibited the least vertical movement and activity, but herring larvae from a fairly early stage undertook vertical migrations in response to day/night changes in light intensity.

Laboratory studies by Seliverstov (1974) showed that: (1) during

the first 12 hours herring larvae do not respond to light or else have weak negative phototaxis, (2) 48 hours after hatching most larvae were able to remain in midwater and possessed strong positive phototaxis, and (3) 8-day old larvae responded negatively to light by day but weakly positive to light by night. Blaxter and Ehrlich (1974) observed that yolk-sac herring larvae have a high initial sinking rate and as yolk is absorbed with an accompanying increase in water content, the sinking rate decreases and the larvae require progressively less energy to maintain position in the water column.

Dive teams from the N.M.F.S. Northeast Fisheries Center's Manned Undersea Research and Technology Investigation documented the presence of newly hatched herring larvae on the substrate on Jeffreys Ledge, Gulf of Maine, during the daylight hours in October 1974 (Cooper, et al., 1975). Relatively large numbers of yolk-sac larvae were observed amongst algal clumps in diver-collected substrate samples from depths of 35-40 m. It appears that newly hatched larvae are retained for several days among algal branches during which time the yolk sac is partially absorbed.

We still do not know if these yolk-sac larvae move off the bottom during the night. We hope to determine if this is so during the planned international Man-In-The-Sea Program scheduled for the fall of 1975 (Cooper, et al., 1975). During this operation we plan to study the micro-vertical distribution of larval herring in the lower 15 m of the water column incorporating taut-line, anchor-buoy stations in which closely spaced samplers will be serviced by divers at two or three-hour intervals over 48-hour or 72-hour periods. Two of these stations will be made, one at the time of hatching and another approximately one week later.

Future Studies

In addition to the field studies outlined above, we are planning to conduct detailed wire profile calibrations to determine if the towing wire could provide cues enabling animals to perform directed avoidance behavior (increasing reaction distance). We are currently trying to ascertain the degree of escapement or extrusion of the smaller larvae through the meshes by comparing the length frequencies of .505 mm and .333 mm mesh samples and comparing maximum scull width and body depth measurements to the mesh diagonal of the .505 mm and .333 mm nets. Preliminary results from these studies indicate that scull width is the critical dimension and that with the .505 mm mesh larvae are not fully retained below 9 mm and with the .333 mmm mesh larvae are not fully retained below 7.5 mm.

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Table 1. Length frequencies and mean lengths of larval herring, total stations.

Length mm	Del. II 71-4	Alb. IV 71-7	Anton Dohrn	Alb. IV 72-9	Alb. IV 73-9	Alb. IV 74-2	Total	
4	–	–	3	10	9	–	22	
5	–	–	21	12	113	1	147	402
6	–	1	32	20	179	1	233	
7	2	–	84	9	103	–	198	
8	4	2	471	7	113	–	597	1751
9	1	8	811	13	123	–	956	
10	3	19	1152	33	102	2	1311	
11	9	16	284	118	86	–	513	2524
12	16	34	336	158	156	–	700	
13	6	58	635	109	211	1	1020	
14	10	65	725	77	256	–	1133	3232
15	10	64	491	78	435	1	1079	
16	6	143	260	123	697	5	1234	
17	5	255	183	134	609	13	1199	3639
18	–	281	176	130	612	7	1206	
19	–	253	145	117	516	11	1042	
20	–	173	157	96	716	17	1159	2967
21	–	124	48	87	486	21	766	
22	–	66	33	67	319	29	514	
23	–	39	29	52	153	14	287	960
24	–	27	6	21	68	37	159	
25	1	7	6	18	10	29	71	
26	–	2	1	15	14	25	57	167
27	–	4	5	5	11	14	39	
28	–	2	–	5	12	16	35	
29	–	1	–	2	9	16	28	81
30	–	3	–	1	2	12	18	
31	–	1	1	2	–	1	5	
32	–	–	–	2	–	2	4	15
33	–	–	–	–	2	4	6	
Total	73	1648	6095	1521	6122	279	15738	
Mean	13.0	18.0	12.4	16.2	16.6	23.6	15.2	

Table 2. Length frequencies and mean lengths of larval herring, day stations.

Length mm	Del. II 71-4	Alb. IV 71-7	Anton Dohrn	Alb. IV 72-9	Alb. IV 73-9	Alb. IV 74-2	Total	
4	-	-	-	-	2	-	2	
5	-	-	6	-	2	-	8	30
6	-	1	11	3	5	-	20	
7	-	-	29	4	6	-	39	
8	-	2	96	2	8	-	108	280
9	1	8	115	2	7	-	133	
10	-	17	107	1	24	1	150	
11	4	11	40	8	22	-	85	369
12	-	21	48	6	59	-	134	
13	-	10	72	18	63	-	163	
14	4	4	97	12	55	-	172	579
15	6	10	88	12	128	-	244	
16	5	16	53	22	148	-	244	
17	5	22	26	44	186	3	286	783
18	-	33	22	50	148	-	253	
19	-	34	14	50	96	4	198	
20	-	16	22	25	78	3	144	428
21		15	3	21	46	1	86	
22	-	12	-	10	25	2	49	
23	-	4	-	13	33	1	51	146
24	-	5	-	7	24	10	46	
25	-	2	-	3	2	11	18	
26	-	-	-	3	7	7	17	37
27	-	-	-	1	-	1	2	
28	-	-	-	2	2	4	8	
29	-	-	-	1	-	6	7	18
30	-	-	-	-	-	3	3	
31	-	-	-	-	-	1	1	
32	-	-	-	2	-	1	3	6
33	-	-	-	-	-	2	2	
Total	25	243	849	322	1176	61	2676	
Mean	14.6	16.5	12.1	17.8	16.7	24.8	15.5	

Table 3. Length frequencies and mean lengths of larval herring, night stations.

Length mm	Del. II 71-4	Alb. IV 71-7	Anton Dohrn	Alb. IV 72-9	Alb. IV 73-9	Alb. IV 74-2	Total	
4	-	-	3	10	5	-	18	
5	-	-	12	12	108	1	133	357
6	-	-	13	17	175	1	206	
7	2	-	48	4	95	-	149	
8	4	-	369	3	99	-	475	1400
9	-	-	661	8	107	-	776	
10	1	3	936	29	68	1	1038	
11	-	4	187	27	53	-	341	1848
12	1	6	246	131	85	-	469	
13	1	41	353	83	115	1	594	
14	-	54	345	48	138	-	585	1705
15	1	48	202	49	225	1	526	
16	-	108	120	74	473	4	779	
17	-	174	90	66	370	9	710	2269
18	-	190	107	58	419	6	780	
19	-	167	95	50	398	4	714	
20	-	124	102	57	628	12	923	2258
21	-	77	44	51	434	15	621	
22	-	39	31	47	293	22	432	
23	-	25	29	32	117	10	213	742
24	-	17	6	12	42	20	97	
25	-	5	6	12	7	10	40	
26	-	2	1	12	8	15	38	113
27	-	4	4	4	11	12	35	
28	-	1	-	2	10	9	22	
29	-	1	-	1	9	7	18	53
30	-	2	-	1	2	8	13	
31	-	1	-	2	-	-	3	
32	-	-	-	-	-	1	1	8
33	-	-	-	-	2	2	4	
Total	10	1093	4010	972	4497	171	10753	
Mean	9.6	18.1	12.0	15.7	16.7	23.1	15.1	

Table 4. Length frequencies and mean lengths of larval herring, twilight stations.

Length mm	Del. II 71-4	Alb. IV 71-7	Anton Dohrn	Alb. IV 72-9	Alb. IV 73-9	Alb. IV 74-2	Total	
4	-	-	-	-	2	-	2	
5	-	-	2	-	4	-	6	21
6	-	-	13	-	-	-	13	
7	-	-	31	1	2	-	34	
8	-	-	17	2	6	-	25	107
9	-	-	35	3	10	-	48	
10	2	-	95	3	10	-	110	
11	5	1	59	12	11	-	88	299
12	15	7	46	21	12	-	101	
13	5	7	207	8	33	-	260	
14	6	7	276	17	64	-	370	927
15	3	5	199	17	73	-	297	
16	1	19	87	27	77	1	212	
17	-	57	63	24	53	1	198	577
18	-	58	40	22	46	1	167	
19	-	52	31	17	23	3	126	
20	-	33	31	14	11	2	91	277
21	-	32	1	15	7	5	60	
22	-	15	1	10	2	5	33	
23	-	10	-	7	4	3	24	73
24	-	5	-	2	2	7	16	
25	1	-	-	3	-	8	12	
26	-	-	-	-	-	3	3	17
27	-	-	1	-	-	1	2	
28	-	1	-	1	-	3	5	
29	-	-	-	-	-	3	3	10
30	-	1	-	-	-	1	2	
31	-	-	1	-	-	-	1	
32	-	-	-	-	-	-	-	1
33	-	-	-	-	-	-	-	
Total	38	310	1236	226	452	47	2309	
Mean	12.9	18.5	13.7	16.6	15.3	23.5	15.1	

TABLE 5. Average abundance (No./1000m³) of larval herring by day, night, and twilight for individual and total cruises and total night/day and twilight/day abundance ratios.

Cruise	Time Period	No. Sta.'s	Length (mm)									
			4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	Total
Del. II 71-4	Day	54	0	0.02	0.08	0.21	0.21	0	0	0	0	0.51
	Night	46	0	0.14	0.04	0.04	0	0	0	0	0	0.22
	Twi.	22	0	0	1.23	0.78	0.06	0	0	0.06	0	2.12
Alb. IV 71-7	Day	45	0.03	0.38	1.86	0.90	2.70	2.46	0.80	0.07	0	9.22
	Night	80	0	0	0.28	3.08	10.16	7.92	1.74	0.24	0.09	23.51
	Twi.	23	0	0	0.78	1.84	12.92	11.29	2.88	0	0.20	29.89
Anton Dohrn	Day	31	0.84	11.87	9.65	12.87	5.00	1.93	0	0	0	42.01
	Night	62	0.67	25.96	32.98	21.64	7.64	5.82	1.60	0.27	0	96.58
	Twi.	21	1.17	6.50	15.66	53.42	14.89	4.93	0.08	0.08	0	96.81
Alb. IV 72-9	Day	34	0.17	0.46	0.84	2.38	6.53	5.40	1.69	0.40	0.17	18.14
	Night	73	0.96	0.38	6.40	4.40	4.91	3.93	2.27	0.69	0.11	24.12
	Twi.	18	0	0.62	3.72	4.34	7.56	4.77	1.97	0.32	0.11	23.37
Alb. IV 73-9	Day	29	0.55	1.27	6.41	15.08	20.42	13.43	5.01	0.55	0.12	71.84
	Night	66	7.04	7.40	5.07	11.71	31.04	35.90	11.09	0.63	0.52	110.44
	Twi.	16	0.71	2.10	3.83	19.76	20.45	4.76	0.93	0	0	52.51
Alb. IV 74-2	Day	15	0	0	0.18	0	0.53	1.40	2.29	3.34	2.29	10.71
	Night	30	0.14	0	0.06	0.14	1.26	2.06	3.39	2.46	1.60	11.38
	Twi.	11	0	0	0	0	0.43	1.45	2.17	2.03	0.72	6.81
Total Cruises	Day	208	0.22	2.08	2.73	4.30	5.81	3.17	1.08	0.28	0.14	19.83
	Night	357	1.56	6.18	8.16	7.49	10.00	10.00	3.27	0.51	0.24	47.41
	Twi.	111	0.32	1.61	4.51	13.99	8.71	4.19	1.11	0.29	0.12	34.84
	N/D Ratio		7.09	2.97	2.99	1.74	1.72	3.15	3.03	1.82	1.71	2.39
	T/D Ratio		1.45	0.77	1.65	3.25	1.50	1.32	1.03	1.04	0.86	1.76

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TABLE 6. Minimum escape length (mm) for various swimming speeds (BL/sec) and reaction distances (m).

| | Reaction Distance | | | | | | | | | |
	1	2	3	4	.5	6	7	8	9	10
5 BL	–	––	––	27.5	22.0	18.0	16.0	14.0	12.0	11.0
10 BL	–	27.0	18.0	13.5	11.0	9.0	8.0	7.0	6.0	5.5
15 BL	–	18.0	12.0	9.0	7.5	6.0	5.0	4.5	4.0	3.5
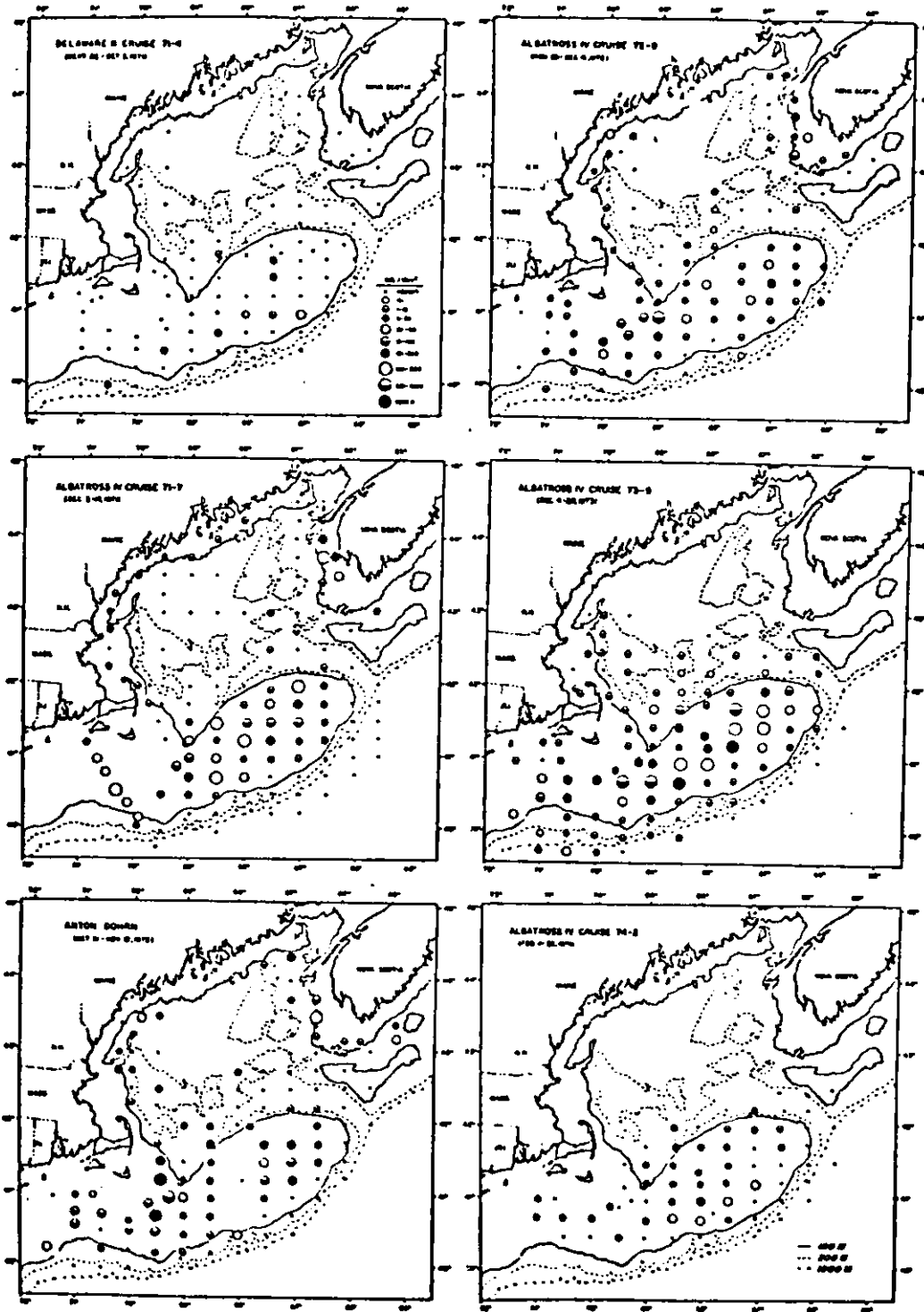
Figure 1. Dates, Station Locations, and Distribution of Total Herring,
Albatross IV, Delaware II, and Walther Herwig Cruises.
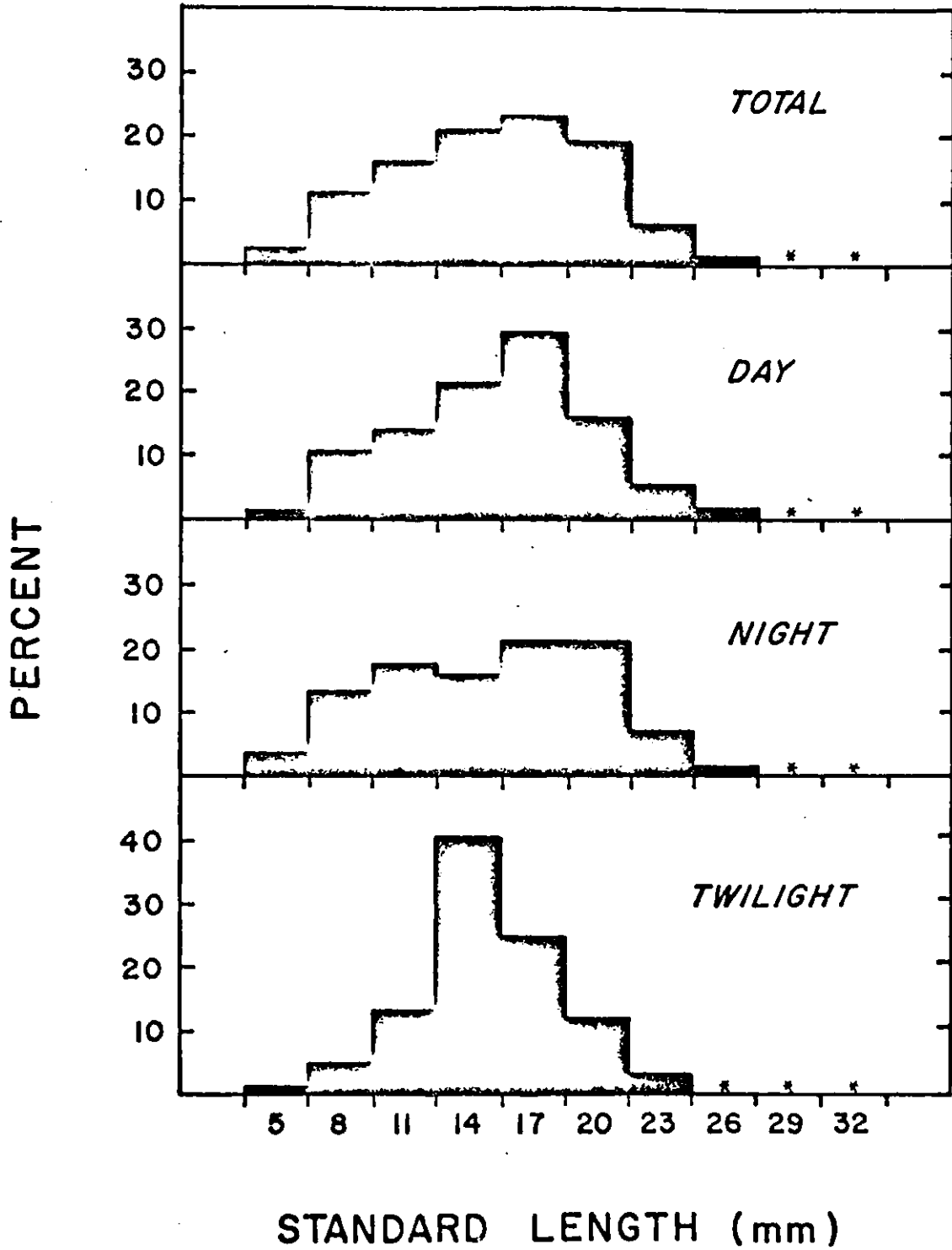
Figure 2. Length Frequency of Larval Herring for Total, Day, Night
and Twilight Stations (* = less than one). Data are
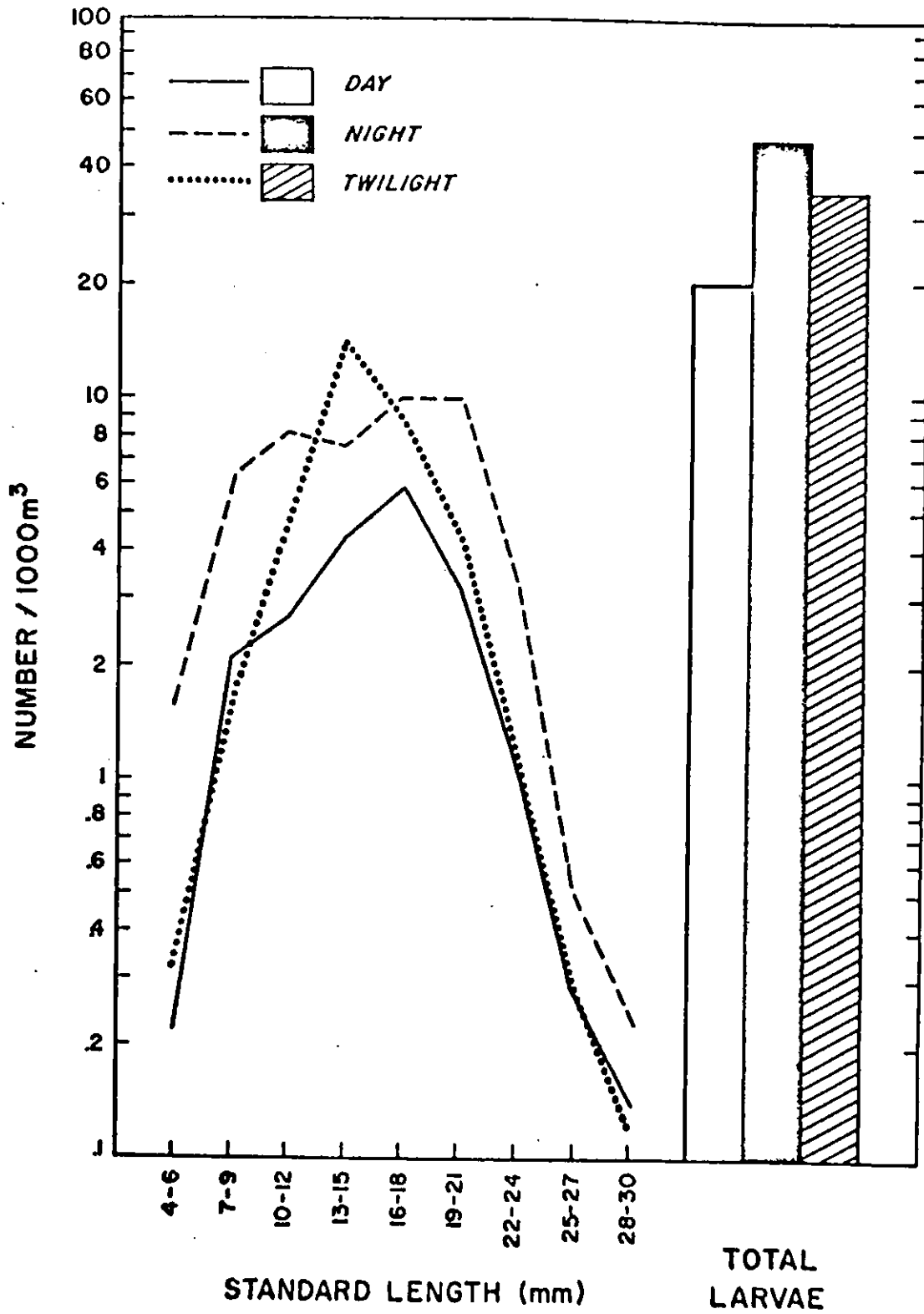combined in 3 mm size groups.

Figure 3. Average Abundance (total cruises) of 3 mm Length Group
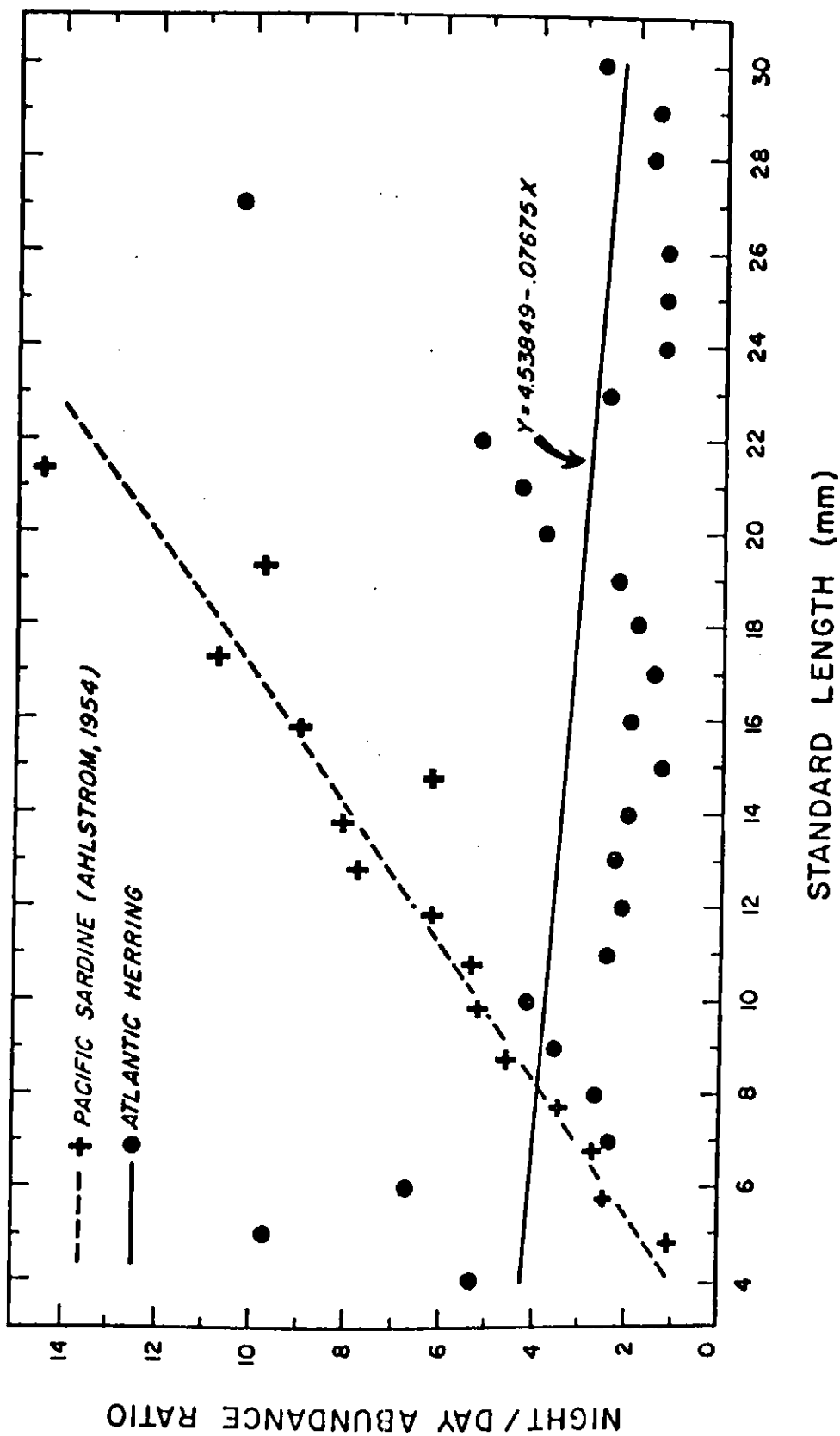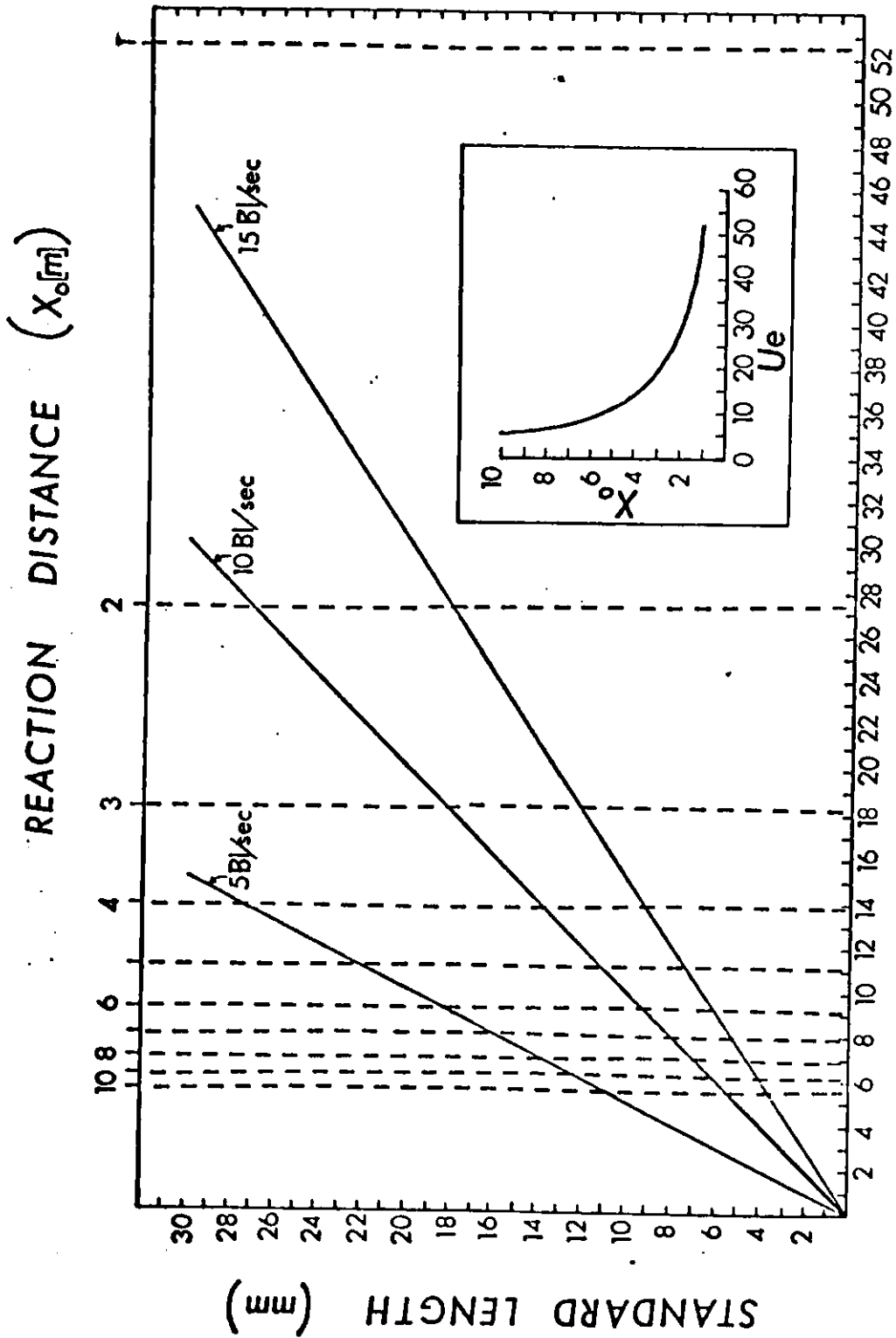and Total Herring Larvae by Day, Night, and Twilight.

Figure 4. Relationship Between Average Night/Day Abundance Ratio and Standard Length. The Lines are Least Square Regressions.

Figure 5. Regressions of Reaction Distance (Xo) on Minimum Escape Velocity (Ue) and of Larval
Length on Maximum Swimming Speed for Velocity Values of 5, 10, and 15 Body Lengths
(BL)/Sec. Values for Ue for One Meter Intervals of Xo Are Indicated By Vertical Dashed Lines.