

DIEL MOVEMENTS OF LARVAL YELLOWTAIL FLOUNDER, *LIMANDA FERRUGINEA*, DETERMINED FROM DISCRETE DEPTH SAMPLING

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ABSTRACT

A 72-h study to investigate diel movements of yellowtail flounder larvae indicated that they exhibited pronounced vertical movements that were repetitious from day to day. Collections at 3-h intervals with 20-cm bongo nets revealed that larvae were near the surface at night, and mostly at a depth of 20 m during the day. Ascent and descent occurred largely at sunset and sunrise, respectively. Thermal gradients at 10 to 20 m and 30 to 40 m had no apparent influence on the vertical movements. Amplitude of the movements increased with the size of larvae. Recently hatched larvae remained near the shallow thermal gradient. Intermediate sized larvae migrated from middepths during the day to surface and near-surface at night. Large larvae moved throughout the water column. The incidence of feeding was low but a daily feeding pattern was evident. Most larvae with gut contents were collected from 1900 to 0100 h on the first day; from 1600 to 2200 h on the second day; and from 1600 to 0100 h on the third day. The near-absence of gut contents in larvae caught during morning daylight hours suggests that the onset of feeding is triggered by something other than, or in addition to, light. Wind driven circulation near the surface was thought to transport larvae at night, when they moved towards the surface. Subsurface circulation was sluggish and ineffective as a transporting mechanism.

Diel migrations by larval fishes play an important but largely unexplored role in dispersion during planktonic development. We became cognizant of the need to investigate this role after our initial ichthyoplankton survey, a series of cruises in the Middle Atlantic Bight to determine when and where coastal fishes spawn and to trace the dispersal of planktonic eggs and larvae (Clark et al. 1969). Despite a full schedule of field work, the survey was only partially successful. We learned where and when many fishes spawn and recognized seasonal shifts in spawning areas (see Smith 1973; Fahay 1974; Kendall and Reintjes 1975; Smith et al. 1975), but we were unsuccessful in tracking dispersion away from the spawning grounds.

After realizing the shortcomings of the survey, we began to speculate on the significance of diel migrations and how they might interact with circulation to affect dispersion, especially where the water column is thermally stratified and surface and subsurface currents differ in velocity. We theorized that a study of the diel movements of fish

larvae, when related to our survey data and to known circulation patterns, might provide us with better information on larval transport than we could obtain from continued surveys. In June 1972 we conducted a 72-h study of the diel movements of larval yellowtail flounder, *Limanda ferruginea* (Storer), an important species in the New England trawl fishery, and the most abundant flatfish larvae collected during our survey of the Middle Atlantic Bight. Our primary objectives were to determine whether the young flatfish undergo diel migrations, whether the migrations are repetitious in time and extent, and how they interact with circulation to affect dispersion.

Yellowtail flounder range from the Gulf of St. Lawrence to Chesapeake Bay. Their center of abundance lies between the western Gulf of Maine and southern New England (Bigelow and Schroeder 1953). They spawn from March to September in the Middle Atlantic Bight. Spawning progresses from south to north as the season advances. The peak of the season in the bight occurs in early May with heaviest spawning off New York and northern New Jersey. Based on the catch of larvae <4 mm, Smith et al. (1975) determined that most spawning takes place between 4° and 9°C.

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METHODS

We selected the general area for the 72-h study from results of the 1965-66 survey (Smith et al. 1975). The specific site, 98 km south of Montauk Point, N. Y., was selected by making trial plankton tows until we found the patch of larvae (Figure 1). To stay within the patch, we deployed a free-drifting parachute drogue similar to that described by Volkmann et al. (1956). The parachute was attached 18 m below the staff buoy on our drogue.

We sampled at 3-h intervals, from 1000 h on 15 June to 0700 h (EDT) on 18 June 1972. Temperature and salinity observations preceded each tow during the first 2 days. We continued to take temperatures at 3-h intervals on the third day but recorded salinity data at 6-h intervals. When we started sampling, the summer solstice was only 6 days hence and a day was divided into 15 h of daylight and 9 h of darkness. Sunrise and sunset were at about 0530 h and 2030 h, respectively. By sampling at 3-h intervals, we made five tows during daylight and three tows at night during each day.

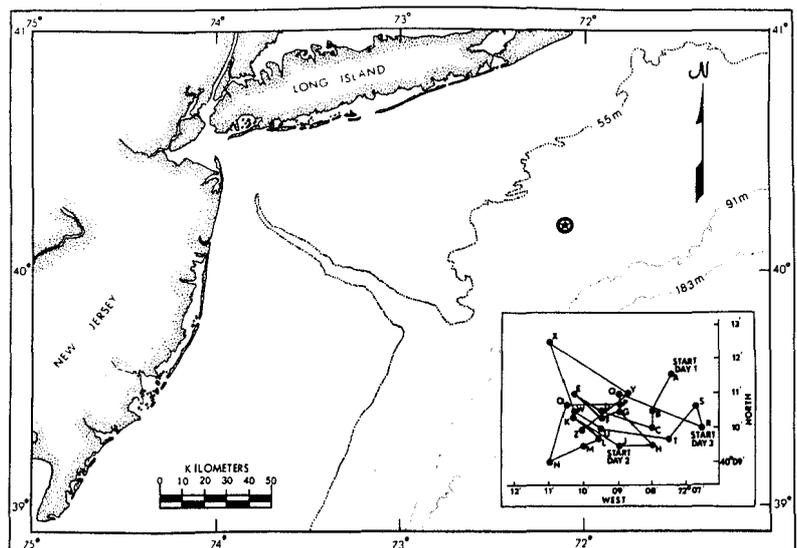
Plankton samples were taken with an array of four 20-cm bongos fitted with 0.505-mm mesh nets. Each tow lasted 15 min. Towing speed was 5 kn (3 m/s). We chose the 20-cm bongo over the larger 61-cm bongo to keep both plankton volumes and numbers of fish larvae at levels that would not exceed our laboratory capabilities. Catch comparison tests between the 20- and 61-cm nets re-

vealed no significant differences in the catch of larvae (Bjørke et al. 1974; Posgay et al.²).

Readings obtained from digital flow meters were used to calculate the amount of water sampled by one side of each bongo. With the exception of the surface-sampling net, the bongos were attached to the towing wire to sample near depths where temperature changes were greatest. They sampled at 8 m, which was just above the shallower of the two temperature gradients; at 20 m, below the shallow gradient; and at 48 m, which was below the deep thermal gradient and about 17 to 20 m above bottom. We preserved the contents from only the metered side of each bongo. Bathymographs (BKG) were attached above two of the three subsurface nets to monitor sampling depth profiles. The sequence of attachment changed with each tow. Resultant BKG traces indicated that the average towing depth of each subsurface net was ± 2 m of the intended sampling depth. The bongos did not have opening-closing devices. We tried to minimize contamination during setting and retrieval by snapping the three subsurface nets onto the towing wire and lowering them into the water while the ship maintained just enough way to stay on course. Immediately after affixing the 8-m net, vessel speed was increased. The surface net was snapped in place and lowered into the water as the ship approached

²Posgay, J. A., R. R. Marak, and R. C. Hennemuth. 1968. Development and tests of new zooplankton samplers. Int. Comm. Northwest Atl. Fish., Res. Doc. 68/85, 7 p.

FIGURE 1.—Site of 72-h study of diel movements of yellowtail flounder larvae. Insert shows theoretical track of drogue and its position at 3-h sampling intervals.



towing speed. At the end of each tow the nets were retrieved as we slowed to a stop.

All yellowtail flounder larvae from each sample of <100 fish were counted and measured to the nearest 0.1 mm SL. If the count exceeded 100, a subsample of about 25% was randomly selected and measured. Then the number of larvae in each size increment was adjusted so that the sum corresponded with the total sample size. Despite our efforts to minimize sampling contamination while setting and retrieving the nets, subsurface nets sampled more water than the surface net. To compensate for contamination, we standardized the volume of water filtered by each net by using the mean amount of water filtered by the surface net (88.8 m³) as the standard. We then adjusted the catch of each net to correspond with the adjusted amount of water filtered. These changes accounted for average reductions in the catch of <1.0% in the surface net, 3.4% in the 8-m net, 4.4% in the 20-m net, and 13.4% in the 48-m net or a net reduction of 4.7% of the total catch.

We inspected digestive tracts of young flounders for indications of a feeding pattern, i.e., presence or absence of gut contents, that might be related to vertical movements. We were able to make these observations simply by using a microscope and incident lighting.

After grouping the adjusted larval catches into four size categories, ≤4.0, 4.1 to 8.0, 8.1 to 10.0, and >10.0 mm, we examined the data for homogeneity of sampling variance by comparing within station catches by depth. Daylight tows were considered replicates, as were night tows. Standard deviations were proportional to the means in the raw data, indicating that sampling variance was not homogeneous. The variance was stabilized by transforming the data to log₁₀(x + 1). We used the UCLA BMD computer program 02V, a multifactor ANOVA program (Dixon 1973), to test for differences in mean catches by day, depth, time (day vs. night), and size of larvae (Table 1). To meet a program prerequisite, we balanced the number of day and night tows used in the analysis by randomly selecting three of the five tows for each daytime period.

RESULTS

Light conditions and sea state varied during the 3-day study in response to changing weather. The sky was cloudy when we began sampling on 15 June. Seas were moderate, stirred by 2 days of

TABLE 1.—Analysis of variance of data collected during study of diel movements of yellowtail flounder larvae. Variables include days, time (day vs. night), capture depth, and length of larvae, grouped into size categories of ≤4.0, 4.1 to 8.0, 8.1 to 10.0, and >10.0 mm. Data were transformed to log₁₀(x + 1) and pertain to 3 day tows and 3 night tows taken during each day of the 3-day study.

Source of variation	df	S.S.	M.S.	F
1 (days)	2	0.21	0.11	0.93
2 (day-night)	1	23.83	23.83	208.40**
3 (depth)	3	16.81	5.60	48.99**
4 (size of larvae)	3	73.49	24.50	214.53**
1, 2	2	0.23	0.11	1.01
1, 3	6	1.79	0.30	2.61*
1, 4	6	1.45	0.24	2.11
2, 3	3	43.63	14.54	127.18**
2, 4	3	3.94	1.31	11.47**
3, 4	9	14.86	1.65	14.44**
1, 2, 3	6	2.20	0.37	3.21**
1, 2, 4	6	0.45	0.07	0.66
1, 3, 4	18	2.37	0.13	1.15
2, 3, 4	9	13.13	1.46	12.76**
1, 2, 3, 4	18	2.80	0.15	1.36
Within replicates	192	21.95	0.11	
Total	287	223.14		

*P < 0.05.

**P < 0.01.

brisk south to southwesterly winds of 15 to 20 kn (7-10 m/s). On the 16th the sky cleared but southerly winds persisted. The 17th was cloudy with intermittent periods of light rain until evening when dense fog set in. We completed field work in heavy rain on the morning of the 18th. There was little or no measurable wind during the last 24 h of sampling.

Water temperature in the Middle Atlantic Bight increases rapidly in the spring and the water column becomes thermally stratified during the summer (Norcross and Harrison 1967). At the time and site of our study, the surface temperature averaged 15.0°C, the bottom 5.7°C. A thermal gradient of about 5°C, the predecessor of the more strongly defined summer thermocline, occurred at depths between 10 and 20 m. A second, weaker gradient existed between 30 and 40 m. Salinity increased from 31.3‰ at the surface to 32.8‰ near the bottom. The most pronounced change in salinity occurred at about the same depths as the shallow thermal gradient (Figure 2).

Drift of the drogue was erratic and sluggish throughout the 72-h study. In 3 days it crossed its previous path 16 times, travelled a net distance of only 5.4 km in a southwesterly direction, and was never more than 7.2 km from the starting point. Net direction of drift was into the wind and the drogue travelled the greatest distance on the third day, when there was little or no wind. Because the drogue's direction of drift changed at approximately 6-h intervals, we concluded that tidal

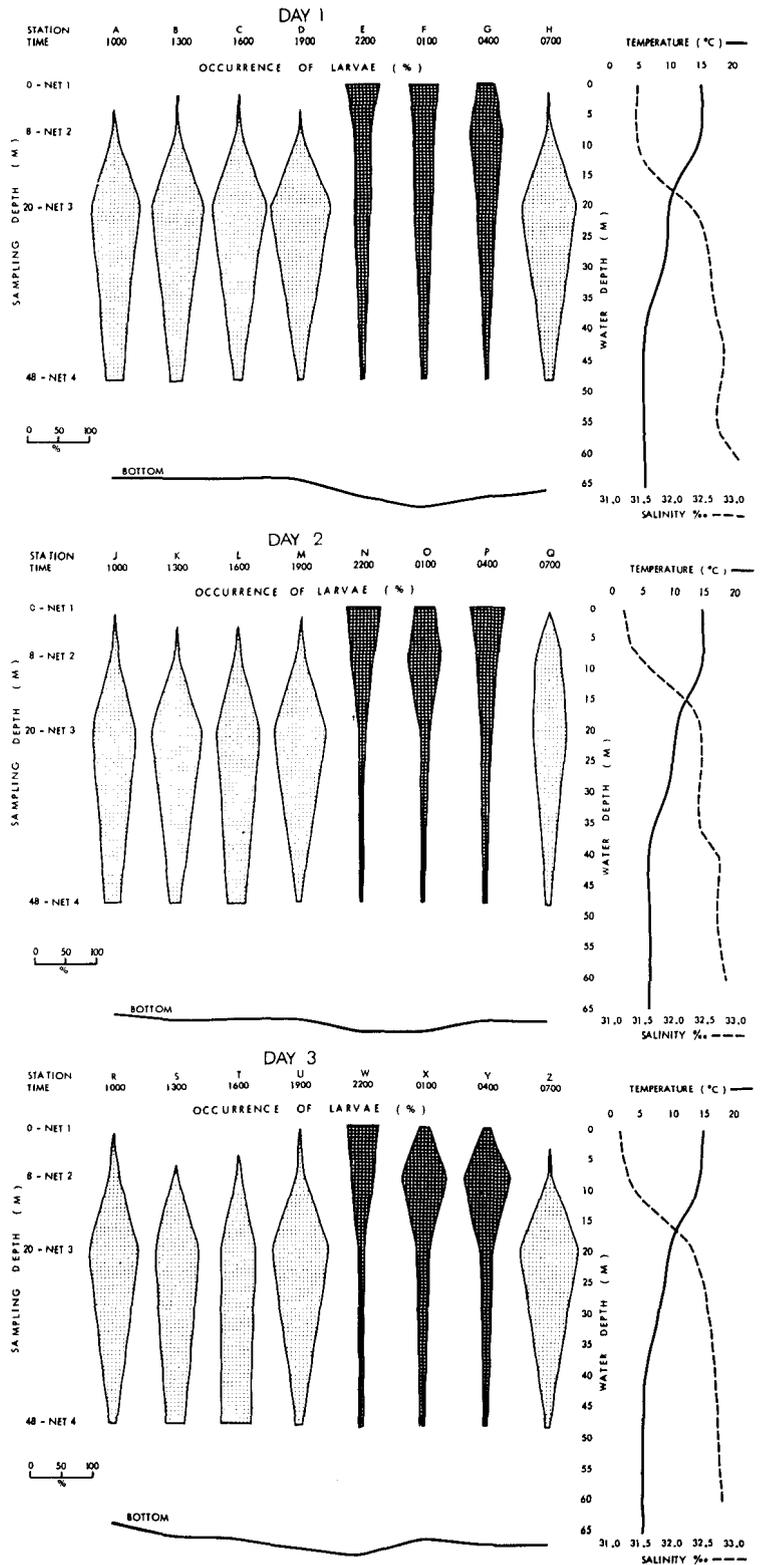


FIGURE 2.—Vertical distribution of yellow-tail flounder larvae at 3-h intervals, based on percent contribution of adjusted catches in each of four nets. Mean temperature and salinity profiles during each day of the 3-day study are shown at right.

circulation was largely responsible for its movements (see Figure 1 insert).

The analysis of variance indicated that we stayed within the same patch of larvae throughout the study. Daily mean differences in both the number and size of larvae were not significant. There was, however, a highly significant difference between means of day and night catches, and between catches at the four depths sampled. We attributed these differences to diel movements and the resultant shift in the distribution of most larvae toward the surface, where two nets fished, at night. The diel movements were repetitious in time and extent. There was no significant difference in means of catches within daylight and night tows, or in their depth distribution at a given time during each day (Table 1).

Larvae were most abundant in the 20-m net during daylight tows on the first day. None were caught by the surface net and the combined catch of the nets at 8 and 48 m contributed <15% of the daytime catch. The distribution of larvae changed significantly after dark. By 2200 h the catch in the surface net was greater than the combined catch of the other three nets and more than double that of any other net. When combined, the surface and 8-m catches accounted for nearly 77% of the 2200-h catch. At 0100 h larvae remained most abundant at the surface and, although the surface catch was less than at 2200 h, again the upper two nets accounted for >70% of the catch (Figure 2). At 0400 h, the last nighttime tow, most larvae were caught at 8 m (Table 2).

The vertical movements of larvae throughout the second day were similar to those on the first day. Most larvae were taken at 20 m on each of the five daylight tows. Except for a single specimen in the 1600-h tow, none were caught at the surface during daylight. By 2200 h the distribution again changed significantly. Like the first night, the surface catch was greater than the total catch of the other three nets. The combined catch at the surface and 8 m made up 88% of the 2200-h catch. Unlike the first night, larvae were less abundant at the surface than at 8 m at 0100 h but the upper two nets again contributed >80% of the catch (Figure 2). At 0400 h larvae reoccurred in greatest numbers at the surface. This increase in the surface catch at 0400 h did not occur on the previous day (Table 2).

Results of tows on the last day were much like those on the first 2 days. Larvae were most abundant at 20 m on all five daylight tows. Only one

larva was taken at the surface, that at 1900 h. By 2000 h the distribution of larvae shifted towards the surface. The young flounder repeated their behavior of the previous day by descending at 0100 h. Most were at 8 m and, for the first time, the 20-m net caught more larvae than the surface net on a night tow. Despite the somewhat deeper distribution, the combined catch of the surface and 8-m nets contributed nearly 80% of the 0100-h catch (Figure 2). The distribution of larvae at 0400 h was much like that at 0100 h. It differed from the other two 0400-h tows in that the contribution of the surface net was greatly reduced, and that of the 8-m net greatly increased (Table 2).

The amplitude of diel movements increased with size of larvae but, within each of the four size groups, the movements were similar each day (Figure 3). The vertical movements of larvae ≤ 4.0 mm were relatively insignificant compared with those of larger larvae. During daylight hours the recently hatched larvae were at an average depth of about 24 m, at night 20 m, a difference of only 4 m. Larvae 4.1 to 8.0 mm long were more active. They moved vertically from an average depth of 24 m during the day to about 9 m at night. The trend continued with larvae 8.1 to 10.0 mm long. During the day were at an average depth of 29 m. At night they ascended to an average depth of 5 m. Larvae >10.0 mm exhibited the most pronounced vertical movements. During the day they were at an average depth of 41 m, at night 7 m.

By not having a net near bottom, we failed to sample the entire depth range of larvae. However, it appears that our nets encompassed the depth distribution for nearly all larvae <10.0 mm. Only 5% of those <10.0 mm were caught in the 48-m net and we assume that their numbers continued to decline below that depth. On the other hand, the daytime distribution of larvae >10.0 mm may have been deeper than our results indicate. Almost half (46%) of the daytime catch of larvae >10.0 mm was caught in the deep net. None were caught at depths <20 m, and most (77%) of the large larvae caught at 20 m during the day were collected at 0700 h, probably during their morning descent.

The incidence (percent) of larvae with visible gut contents was as high as 40% at one station but only 6% of the larvae caught during the 3-day study contained visible gut contents. The overall incidence was low, but our results indicate that most feeding occurred at about the same time on all 3 days. We found the highest incidence from

TABLE 2.—Adjusted catch of yellowtail flounder larvae by size group, depth, and time. Results are presented by day, beginning with the initial daylight tow, although we began sampling at 1000 h (Station A) and finished at 0700 h (Station Z).

Stn.	Hour of tow	Net depth (m)	Day 1						Day 2								
			Size group (mm)				Total		Size group (mm)				Total				
			<4	4-8	8-10	>10	No.	%	No./m ³	Stn.	<4	4-8	8-10	>10	No.	%	No./m ³
Day tows:																	
H	0700	Surf	0	0	0	0	0	0	0	Q	0	0	0	0	0	0	0
		8	0	21	1	0	22	5	0.2		0	125	76	0	201	42	2.3
		20	26	350	15	0	391	84	4.4		0	153	95	15	263	54	3.0
		48	1	38	7	4	50	11	0.6		0	14	2	3	19	4	0.2
		Total	27	409	23	4	463	100		0	292	173	18	483	100		
A	1000	Surf	0	0	0	0	0	0	0	J	0	0	0	0	0	0	0
		8	2	6	0	0	8	1	0.1		0	48	12	0	60	11	0.7
		20	84	447	8	0	539	76	6.1		25	315	22	1	363	67	4.1
		48	0	85	68	12	165	23	1.9		2	87	26	7	122	22	1.4
		Total	86	538	76	12	712	100		27	450	60	8	545	100		
B	1300	Surf	0	0	0	0	0	0	0	K	0	0	0	0	0	0	0
		8	0	12	1	0	13	3	0.1		0	15	8	0	23	4	0.3
		20	25	411	16	0	452	82	5.1		15	325	74	4	418	82	4.7
		48	6	51	20	7	84	15	0.9		5	49	11	5	70	14	0.8
		Total	31	474	37	7	549	100		20	389	93	9	511	100		
C	1600	Surf	0	0	0	0	0	0	0	L	0	1	0	0	1	<1	<0.1
		8	0	12	2	0	14	4	0.2		1	16	4	0	21	6	0.2
		20	15	285	24	1	325	85	3.7		29	173	31	3	236	67	2.7
		48	0	33	6	3	42	11	0.5		13	68	11	4	96	27	1.1
		Total	15	330	32	4	381	100		43	258	46	7	354	100		
D	1900	Surf	0	0	0	0	0	0	0	M	0	0	0	0	0	0	0
		8	0	13	0	0	13	1	0.1		1	62	19	0	82	13	0.9
		20	22	864	18	0	904	96	10.2		24	444	60	2	530	83	6.0
		48	0	14	9	6	29	3	0.3		0	14	6	8	28	4	0.3
		Total	22	891	27	6	946	100		25	520	85	10	640	100		
All day tows:																	
		Surf	0	0	0	0	0	0	0		0	1	0	0	1	<1	<0.1
		8	2	84	4	0	70	2	0.2		2	266	119	0	387	15	0.9
		20	172	2,357	81	1	2,611	86	5.9		93	1,410	282	25	1,810	72	4.1
		48	7	221	110	32	370	12	0.8		20	232	56	27	335	13	0.8
		Total	181	2,642	195	33	3,051	100		115	1,909	457	52	2,533	100		
Night tows:																	
E	2200	Surf	10	922	342	30	1,304	54	14.7	N	4	795	215	24	1,038	53	11.7
		8	13	421	93	18	545	23	6.1		29	504	111	36	680	35	7.7
		20	61	411	53	15	540	22	6.1		16	169	17	3	205	11	2.3
		48	1	21	2	0	24	1	0.3		1	23	2	1	27	1	0.3
		Total	85	1,775	490	63	2,413	100		50	1,491	345	64	1,950	100		
F	0100	Surf	4	329	126	20	479	43	5.4	O	0	374	146	24	544	30	6.1
		8	10	268	29	2	309	27	3.5		0	886	62	18	966	54	10.9
		20	49	230	11	1	291	26	3.3		29	216	10	5	260	15	2.9
		48	3	34	3	0	40	4	0.5		1	22	0	0	23	1	0.3
		Total	66	861	169	23	1,119	100		30	1,498	218	47	1,793	100		
G	0400	Surf	4	274	33	4	315	25	3.5	P	5	551	126	0	682	47	7.7
		8	11	505	59	7	582	47	6.6		12	338	102	18	470	33	5.3
		20	46	244	7	5	302	25	3.4		12	227	0	0	239	17	2.7
		48	7	27	0	0	34	3	0.4		5	35	2	2	44	3	0.5
		Total	68	1,050	99	16	1,233	100		34	1,151	230	20	1,435	100		
All night tows:																	
		Surf	18	1,525	501	54	2,098	44	7.9		9	1,720	487	48	2,264	44	8.5
		8	34	1,194	181	27	1,436	30	5.4		41	1,728	275	72	2,116	41	7.9
		20	156	885	71	21	1,133	24	4.3		57	612	27	8	704	13	2.6
		48	11	82	5	0	98	2	0.4		7	80	4	3	94	2	0.4
		Total	219	3,686	758	102	4,765	100		114	4,140	793	131	5,178	100		
All tows:																	
		Surf	18	1,525	501	54	2,098	27	3.0		9	1,721	487	48	2,265	29	3.2
		8	36	1,258	185	27	1,506	19	2.1		43	1,994	394	72	2,503	32	3.5
		20	328	3,242	152	22	3,744	48	5.3		150	2,022	309	33	2,514	33	3.5
		48	18	303	115	32	468	6	0.7		27	312	60	30	429	6	0.6
		Total	400	6,328	953	135	7,816	100		229	6,049	1,250	183	7,711	100		

1900 to 0100 h on the first day; from 1600 to 2200 h on the second day; and from 1600 to 0100 h on the third day. The evening ascent toward the surface occurred during the time of peak feeding, but the incidence of feeding remained highest in larvae caught at 20 m before, during, and after the evening ascent (Figure 4). We concluded that essential prey organisms occur throughout the water col-

umn and that diel movements and feeding are not directly related.

DISCUSSION

When Sette (1943) studied the early life history of Atlantic mackerel, *Scomber scombrus*, in the Middle Atlantic Bight in 1929, he made four tows,

TABLE 2.—Continued.

Stn.	Hour of tow	Net depth (m)	Day 3							3-day total							
			Size group (mm)				Total			Size group (mm)				Total			No./m ³ (avg.)
			<4	4-8	8-10	>10	No.	%	No./m ³	<4	4-8	8-10	>10	No.	%		
Day tows:																	
Z	0700	Surf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		8	1	13	5	0	19	3	0.2	1	159	82	0	242	15	0.9	
		20	11	271	218	71	571	93	6.4	37	774	328	86	1,225	79	4.6	
		48	0	17	2	3	22	4	0.2	1	69	11	10	91	6	0.3	
		Total	12	301	225	74	612	100		39	1,002	421	96	1,558	100		
R	1000	Surf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		8	0	17	32	0	49	13	0.6	2	71	44	0	117	7	0.4	
		20	6	151	123	15	295	79	3.3	115	913	153	16	1,197	74	4.5	
		48	0	21	5	2	28	8	0.3	2	193	99	21	315	19	1.2	
		Total	6	189	160	17	372	100		119	1,177	296	37	1,629	100		
S	1300	Surf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		8	0	0	2	0	2	1	<0.1	0	27	11	0	38	3	0.1	
		20	47	150	9	0	206	71	2.3	87	886	99	4	1,076	80	4.0	
		48	3	42	24	12	81	28	0.9	14	142	55	24	235	17	0.9	
		Total	50	192	35	12	289	100		101	1,055	165	28	1,349	100		
T	1600	Surf	0	0	0	0	0	0	0	0	1	0	0	1	<1	<0.1	
		8	1	5	0	0	6	3	0.1	2	33	6	0	41	4	0.2	
		20	25	106	3	0	134	53	1.5	69	564	58	4	695	71	2.6	
		48	1	66	35	10	112	44	1.3	14	167	52	17	250	25	0.9	
		Total	27	177	38	10	252	100		85	765	116	21	987	100		
U	1900	Surf	0	1	0	0	1	<1	<0.1	0	1	0	0	1	<1	<0.1	
		8	0	30	7	0	37	6	0.4	1	105	26	0	132	6	0.5	
		20	14	467	46	0	527	89	5.9	60	1,775	124	2	1,961	90	7.4	
		48	0	11	6	10	27	5	0.3	0	39	21	24	84	4	0.3	
		Total	14	509	59	10	592	100		61	1,920	171	26	2,178	100		
All day tows:																	
		Surf	0	1	0	0	1	<1	<0.1	0	2	0	0	2	<1	<0.1	
		8	2	65	46	0	113	5	0.3	6	395	169	0	570	7	0.4	
		20	103	1,145	399	86	1,733	82	3.9	368	4,912	762	112	6,154	80	4.6	
		48	4	157	72	37	270	13	0.6	31	610	238	96	975	13	0.7	
		Total	109	1,368	517	123	2,117	100		405	5,919	1,169	208	7,701	100		
Night tows:																	
W	2200	Surf	4	574	235	28	841	53	9.5	18	2,291	792	82	3,183	54	11.9	
		8	8	374	206	28	616	39	6.9	50	1,299	410	82	1,841	31	6.9	
		20	12	68	6	0	86	6	1.0	89	648	76	18	831	14	3.1	
		48	0	23	3	2	28	2	0.3	2	67	7	3	79	1	0.3	
		Total	24	1,039	450	58	1,571	100		159	4,305	1,285	185	5,934	100		
X	0100	Surf	5	197	43	0	245	10	2.8	9	900	315	44	1,268	23	4.8	
		8	0	1,488	274	16	1,778	70	20.0	10	2,642	365	36	3,053	56	11.5	
		20	32	412	3	0	447	17	5.0	110	858	24	6	998	18	3.7	
		48	7	57	0	1	65	3	0.7	11	113	3	1	128	3	0.5	
		Total	44	2,154	320	17	2,535	100		140	4,513	707	87	5,447	100		
Y	0400	Surf	0	55	36	4	95	6	1.1	9	880	195	8	1,092	26	4.1	
		8	4	851	209	31	1,095	71	12.3	27	1,694	370	56	2,147	51	8.1	
		20	24	257	10	0	291	19	3.3	82	728	17	5	832	20	3.1	
		48	11	38	3	1	53	4	0.6	23	100	5	3	131	3	0.5	
		Total	39	1,201	258	36	1,534	100		141	3,402	587	72	4,202	100		
All night tows:																	
		Surf	9	826	314	32	1,181	21	4.4	36	4,071	1,302	134	5,543	36	6.9	
		8	12	2,713	689	75	3,489	62	13.1	87	5,635	1,145	174	7,041	45	8.8	
		20	68	737	19	0	824	14	3.1	281	2,234	117	29	2,661	17	3.3	
		48	18	118	6	4	146	3	0.5	36	280	15	7	338	2	0.4	
		Total	107	4,394	1,028	111	5,640	100		440	12,220	2,579	344	15,583	100		
All tows:																	
		Surf	9	827	314	32	1,182	15	1.7	36	4,073	1,302	134	5,545	24	2.6	
		8	14	2,778	735	75	3,602	46	5.1	93	6,030	1,314	174	7,811	33	3.6	
		20	171	1,882	418	86	2,557	33	3.6	649	7,146	879	141	8,815	38	4.1	
		48	22	275	78	41	416	6	0.6	67	890	253	103	1,313	5	0.6	
		Total	216	5,762	1,545	234	7,757	100		845	18,139	3,748	552	23,284	100		

morning, noon, evening, and midnight, off Fire Island to investigate the vertical distribution of eggs and larvae. Royce et al. (1959) included a cursory presentation of data on yellowtail flounder larvae from Sette's series of discrete depth tows. Although Sette's nets were towed slower (1 kn vs. 5 kn) and the flounder larvae were smaller ($\bar{x} = 3.9$ mm vs. $\bar{x} = 6.7$ mm) than ours, the results of the two studies are similar in several aspects. For

example, Royce et al. (1959) reported larvae at the surface at night, but not during daylight; the night catch was double the daytime catch; and the catch dropped off sharply in their deep net at night. Their larvae were most concentrated at a depth of 10 m on all four tows. Although this appears to differ from our results, we have shown that larvae <4 mm do not participate in the diel migrations but remain within a limited depth stratum. Thus

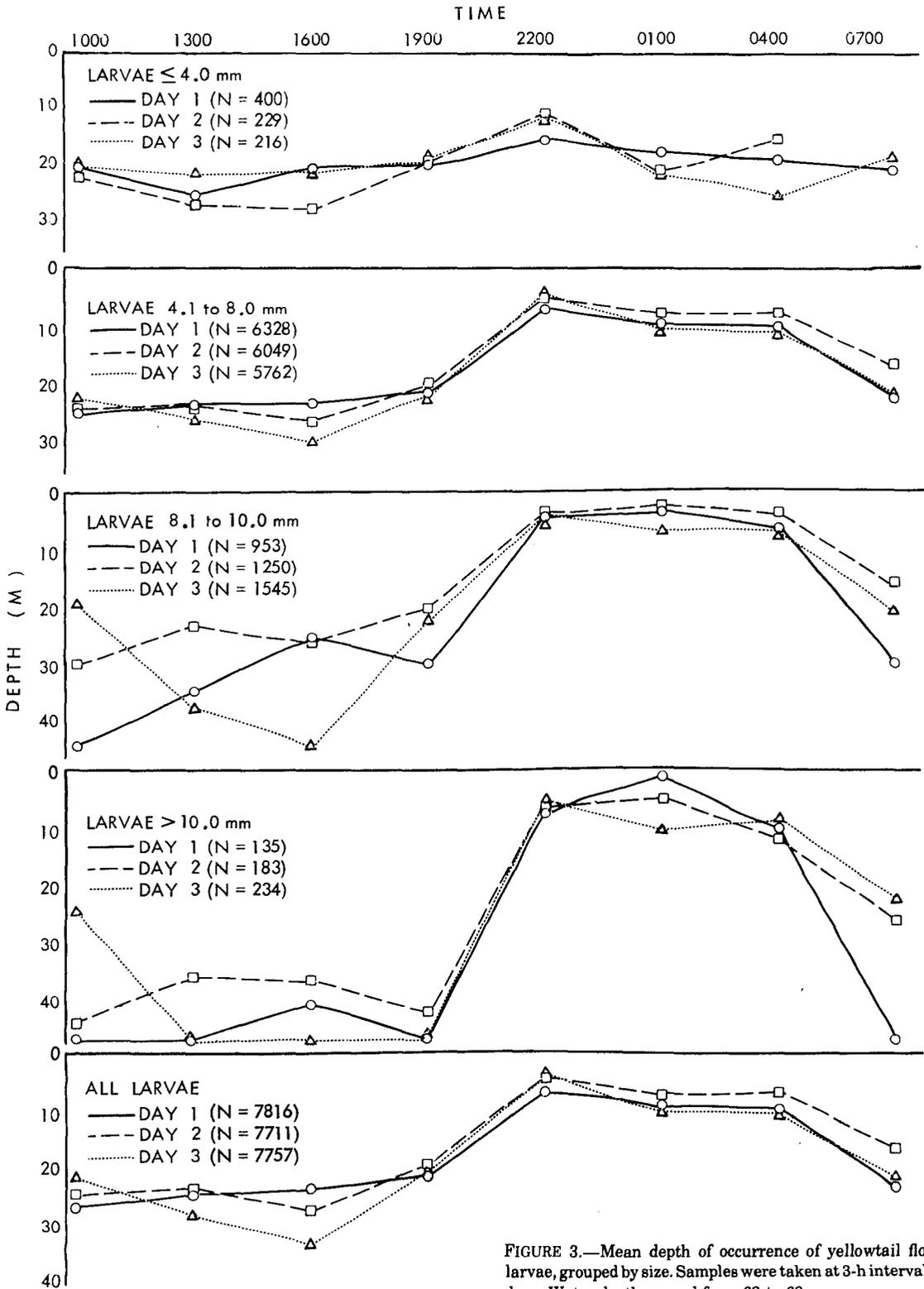


FIGURE 3.—Mean depth of occurrence of yellowtail flounder larvae, grouped by size. Samples were taken at 3-h intervals for 3 days. Water depth ranged from 63 to 68 m.

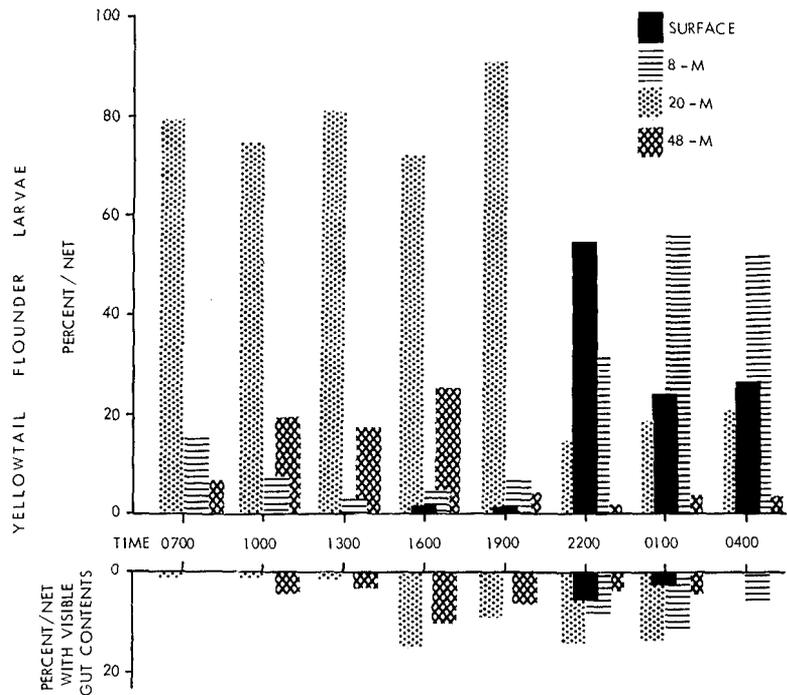


FIGURE 4.—Percent of yellowtail flounder larvae by depth and time (upper graph); and percent of larvae with visible gut contents by depth and time (lower graph). Figure represents averaged results from 3-day study.

the small larvae exhibited similar behavior in both studies. Although their larvae were concentrated at shallower depths than ours, in both cases the temperature was about 10°C where larvae <4 mm were most abundant. See Sette (1943) for temperature profile pertaining to data presented by Royce et al. (1959).

A *t*-test on our adjusted catch data from the 15 daylight tows and 9 night tows indicated that the catch at night was significantly greater than the daytime catch. Some of this difference might result from avoidance during daylight but, based on our fast towing speed, which would curtail avoidance, and results of gear performance tests by Bjørke et al. (1974) and Posgay et al. (see footnote 2), which showed the 20-cm bongo to be an effective sampler, we concluded that the greater catch at night was largely attributable to a change in the vertical distribution of larvae and our sampling depths. Comparisons of day:night catch ratios of daily catches and catches at 20 m support our conclusion. Whereas the day:night catch ratios of the adjusted catch (larvae per cubic meter) were 1:1.56, 1:2.04, and 1:2.66 on days 1 through 3, respectively, the reverse was true at 20 m, where the ratios were 2.30:1, 2.57:1, and 2.10:1. Night catches were greater than day catches because most larvae migrated towards the surface at night, where two nets fished. The resultant con-

centration of larvae in a confined depth stratum, and the "extra" net fishing within the stratum where larvae were concentrated, accounted for the significantly greater catch with less sampling effort at night. After descending during the early morning hours, larvae were largely subjected to capture at 20 m, where the daytime catch was more than twice as great as the catch at night. If avoidance were the principal factor in the day:night differences, we would expect larger catches at all depths at night.

Both Bridger (1958) and Wood (1971) found that the daytime distribution of herring, *Clupea harengus*, larvae depended on light conditions. Their larvae were nearer the surface on cloudy days than on sunny days. Although weather conditions changed from partly cloudy to sunny, followed by fog and rain, and sea conditions changed from moderate to calm as winds diminished, yellowtail flounder larvae showed little variation in their diel movements during our 3-day study. We caught only two larvae at the surface during daylight hours. On all 3 days larvae began to ascend after 1900 h and were at the surface in greatest numbers at 2200 h. During the early morning hours of darkness their numbers decreased at the surface but the young fish did not disappear from the surface until sometime between 0400 and 0700 h. Judging from our results and those of Royce et

al. (1959), we presume both the daily ascent and descent occurred near sunset and sunrise, respectively.

Ahlstrom (1959) studied the vertical movements of larvae of several fishes off the coast of California. He found no evidence that larvae moved through the thermocline. His collections showed that they migrated vertically but the movements were usually restricted to the upper mixed layer. In contrast, neither the salinity gradient at 10 to 20 m nor the temperature gradients beginning at 10 and 30 m had a noticeable effect on the vertical movements of yellowtail flounder larvae in our study. Our collections indicate that the small flounder that migrated between middepths and the surface routinely tolerated salinity differences of 1.5‰ and temperature changes of 5°C, and those that moved throughout the water column withstood changes of about 10°C. Such rapid changes in temperature seem deleterious but our survey collections indicated that larvae of most flatfishes spawned in the Middle Atlantic Bight are physiologically adapted to wide ranges in temperature. For example, in 1966, when yellowtail flounder spawned mostly at bottom temperatures between 4° and 9°C, we caught their larvae where the surface temperature was 5°C in April and 23°C in August (Smith et al. 1975).

The amplitude of the vertical migrations by yellowtail flounder larvae increased in proportion to their size. Similar behavior was reported for larval haddock, *Melanogrammus aeglefinus* (Miller et al. 1963), and larval *Clupea harengus* (Seliverstov 1974). Recently hatched yellowtail flounder remained most abundant beneath the shallow thermal gradient, whereas late-stage larvae exhibited extensive vertical migrations that included most or all of the water column. Larvae >10 mm probably spend some time on the bottom. Bigelow and Schroeder (1953) reported that young yellowtail flounder descend to the bottom when 14 mm long. Royce et al. (1959) concluded that they seek bottom when 12 to 19 mm long. Judging from this information and the advanced stage of development of some larvae we caught near the surface after dark, we concluded that the change from a pelagic to a demersal life is not abrupt. Larvae making the transition to a demersal life continue to migrate towards the surface at night. This nocturnal behavior might reflect a gradual dietary change from planktonic to benthic organisms. Although we are unsure of how long they continue the vertical migrations, the 20.7-mm SL specimen

collected during our survey (see Smith et al. 1975) might represent the maximum size at which they ascend toward the surface.

In his review of the "critical period" concept, May (1974) pointed out that field studies of larval feeding have produced highly variable results. He cited several investigations that found the feeding incidence of clupeoid larvae very low, others that found it very high, and discussed theories that have been advanced to explain this variability. They include rapid digestion; nutrition from dissolved organics; low food requirements; daily feeding patterns; defecation upon capture and preservation; escapement by healthy, feeding larvae; and food availability. Our data on yellowtail flounder larvae support at least two of these theories, namely, a daily feeding pattern and rapid digestion. Both the highest and lowest incidence of feeding occurred at predictable times on all 3 days and, with the exception of five specimens, the guts of all larvae appeared to be empty within hours after the period of maximum feeding.

Several studies report that fish larvae feed most actively at high light intensities, but others differ. For example, Kjelson et al. (1975) found the digestive tract of young Atlantic menhaden, *Brevoortia tyrannus*; pinfish, *Lagodon rhomboides*; and spot, *Leiostomus xanthurus*, fullest at midday. Rudakova (1971) estimated that an average of 25% of the Atlantic herring, *Clupea harengus harengus*, larvae that he caught fed during the day, only 3.2% at night. Feeding studies by Blaxter (1965), Schumann (1965), and Braum (1967) support the above studies. On the other hand, Marak (1974) reported that young redfish, *Sebastes marinus*, fed during day or night and Blaxter (1969) found that larval sole, *Solea solea*, feed at night. Shelbourne (1953) reported that all postlarval plaice, *Pleuronectes platessa*, that he collected between 1400 and 2000 h had food in their guts. The percent of feeding larvae declined to between 70 and 80% in his samples collected from 2000 to 0200 h, then dropped sharply until daylight when it again increased to 100% for a short time.

Our results resemble Shelbourne's (1953), except that we caught fewer feeding larvae and we did not find an indication of feeding at sunrise. The near absence of feeding larvae during daylight morning hours suggests that something other than, or in addition to, light triggers feeding by yellowtail flounder larvae. It appeared to us that feeding intensity increased during afternoon and evening hours. Larvae that had food in their guts

at 2200 and 0100 h might have fed after dark or they might have stopped feeding after sunset. Further study is needed to determine whether yellowtail flounder larvae feed at night.

After analyzing 10 yr of drifter releases, Bumpus (1973) reported that surface currents in the Middle Atlantic Bight occasionally reach speeds of 15 mi/day (27 km/day), but they are usually less than 10 mi/day (18 km/day). He estimated bottom drift at 0.5 ± 0.2 mi/day (0.9 ± 0.4 km/day) and speculated that circulation near bottom was so random and sluggish that it was unrealistic to derive drift rates of bottom water from his data, except from nearshore releases, which stranded within a reasonable time frame. Howe (1962) concluded that coastal circulation between Cape Cod and New York was largely attributable to short-term wind effects and that waters inside the 90-m isobath were comparatively stagnant during the first half of the year. The sluggish performance of our drogue supports Howe's results and indicates that the velocity of middepth drift at the time and location of our study was similar to Bumpus' description of bottom circulation.

Returns from drift bottle releases indicate that surface water generally moves westward off Long Island then southward along the Middle Atlantic States (Bumpus and Lauzier 1965). However, both Norcross and Stanley (1967) and Bumpus (1969) found evidence of surface current reversals in the Middle Atlantic Bight during the summer, and Doebler (1966) showed that the direction of surface water transport off Delaware responded rapidly to changes in wind direction. On the basis of these reports, we assume that the brisk south to southwest wind during the first 48 h of our study propelled surface water towards southern New England. Although yellowtail flounder larvae were not at the surface during the day, 44% of our night catches were taken at the surface during the first two nights. During this time wind probably influenced their horizontal displacement. By passing the 15 h of daylight at subsurface depths, it appears from the net drift of our drogue that the larvae were transported in the opposite direction to that at night.

Assuming that our drogue's erratic and sluggish drift is representative of middepth circulation off Long Island in the spring, when spawning by yellowtail flounder peaks, and that effects of spring and summer winds on circulation are usually limited to a few days at a time, we conclude that wind driven currents in the study area do not play a

major role in dispersing the larvae. Our conclusion is supported by Royce et al. (1959). Similarities in patterns of distribution between eggs and larvae led them to conclude that larvae were demersal before much horizontal drift occurred. It seems worth noting here that the smallest larvae, those least able to swim with directed movements, did not ascend to the surface at night. They remained below the shallow thermal gradient, where they were unaffected by wind-driven circulation.

Whether or not our interpretation of the effects of currents on the distribution of yellowtail flounder larvae is correct, it is clear to us that researchers must investigate the diel movements of larvae they are studying before hypothesizing on how circulation affects the distribution and survival of young fishes. It is common practice to overlook or ignore larval behavior and relate the transport of larvae from both day and night collections by obliquely towed nets to surface circulation. In many cases, this oversight produces an exaggerated estimate of the distance larvae are transported and, perhaps, an erroneous estimate of the direction of transport.

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