ABUNDANCE AND POTENTIAL YIELD OF THE ATLANTIC THREAD HERRING, *OPISTHONEMA OGLINUM*, AND ASPECTS OF ITS EARLY LIFE HISTORY IN THE EASTERN GULF OF MEXICO[1]

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ABSTRACT

Eggs and larvae of the Atlantic thread herring, *Opisthonema oglinum*, were collected in plankton surveys from 1971 to 1974 in the eastern Gulf of Mexico to determine spawning seasons, spawning areas, adult biomass, and potential yield to a fishery. Aspects of the early life history also were studied. Spawning occurred from February to September, but mostly from April through August, when surface temperatures were 22.5° to 30.3°C and surface salinities ranged from 32.4 to 36.8‰. Most spawning took place from the coastline out to the 30-m depth contour, and virtually all spawning occurred where depths were less than 50 m. The area of heaviest spawning was between latitudes 26°00′N and 28°00′N. The most reliable estimates of adult biomass were approximately 110,000 metric tons in 1971 and 370,000 metric tons in 1973. The most probable estimates of potential annual yield range from 60,300 to 120,600 metric tons. Based on the best larval mortality estimates, more than 99% mortality occurred from time of spawning until 19 days and 15.5 mm standard length in 1973, and approximately 98% mortality occurred for the same period in 1971.

The Atlantic thread herring, *Opisthonema oglinum* (Lesueur), is an underexploited clupeid fish that occurs widely in the western Atlantic from southern Brazil to the Gulf of Maine (Berry and Barrett 1963), but is mainly tropical and subtropical in its distribution (Hildebrand 1963). It is a coastal species that seldom occurs in depths greater than 90 m and is most abundant in depths less than 35 m (Klima 1971). In the Gulf of Mexico it is abundant and its fishery potential has been recognized for many years (Butler 1961; Reintjes and June 1961; Bullis and Carpenter 1968; Fuss et al. 1969; Houde 1973a). The total western Atlantic thread herring catch was 12,016 metric tons in 1974 (Food and Agriculture Organization 1975), of which 2,434 metric tons were landed by the United States. Some thread herring are landed as incidental catches by both Atlantic and Gulf of Mexico menhaden fleets (Klima 1971). Catch statistics are poor for thread herring in the Gulf of Mexico, but only 435 tons were reported in 1973 (Johnson 1974). However, 5,000 tons were landed from the eastern Gulf during a 4-mo period in 1967 when a preliminary attempt was made to establish a directed fishery. Based on school sightings and catch rates by commercial purse seiners, Bullis and Thompson (1967) roughly estimated that the total Gulf of Mexico thread herring stock might be 1×10^6 tons.

Eggs and larvae of thread herring have been described (Richards et al. 1974) and the species has been successfully reared from egg to juvenile under laboratory conditions (Richards and Palko 1969). There was no information on thread herring eggs or larvae from the eastern Gulf prior to my research. Kinnear and Fuss (1971) reported seasonal north-south migrations and distribution of thread herring in the eastern Gulf of Mexico, while Fuss et al. (1969) presented data on age, growth, maturity, and food habits of that stock. Fecundity of thread herring in the eastern Gulf was determined by Prest[3] and by Martinez (1972) for fish collected on the Florida Atlantic coast.

The objective of this research was to obtain a fishery-independent estimate of the abundance and potential yield to fisheries of thread herring in the eastern Gulf of Mexico based on annual surveys of eggs and larvae during 1971 to 1974. In addition, information was obtained on spawning seasons and areas, as well as on aspects of their early life history in the eastern Gulf.

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[3]Prest, K. W., Jr. 1971. Fundamentals of sexual maturation, spawning, and fecundity of thread herring (*Opisthonema oglinum*) in the eastern Gulf of Mexico. Unpubl. manuscr., Natl. Mar. Fish. Serv., NOAA, St. Petersburg Beach, Fla.

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METHODS

Adult biomass was determined from estimates of annual abundance of spawning products, a knowledge of the mean relative fecundity of thread herring, and an assumed sex ratio of 1:1 (Saville 1964; Ahlstrom 1968). Methods to determine thread herring egg and larval abundance, distribution, adult biomass, potential yield to a fishery, and mortality during egg and larval stages were analogous to methods reported in detail for round herring (Houde 1977a). Other details of survey design and planning also have been published (Rinkel 1974; Houde and Chitty 1976; Houde et al. 1976). Temperature and salinity data, as well as some egg and larvae data, from these surveys are stored in the National Oceanographic Data Center, Washington, D.C., under the MAFLA file.

The survey area was located on the broad continental shelf off western Florida in the eastern Gulf of Mexico, between lat. 24°45′N and 30°00′N (Figure 1). In 17 cruises (Table 1) from 1971 to 1974, plankton was collected with a 61-cm bongo net sampler fitted with 505- and 333-μm mesh nets. Most stations were over water depths from 10 to 200 m, except in 1974 when some stations as shallow as 5 m were added to the sampling plan. These shallow stations were added to determine if thread herring and scaled sardine, *Harengula jaguana*, spawning increased significantly nearshore where there had been no previous sampling. Thread herring eggs and larvae were identified using descriptions by Houde and Fore (1973) and by Richards et al. (1974).

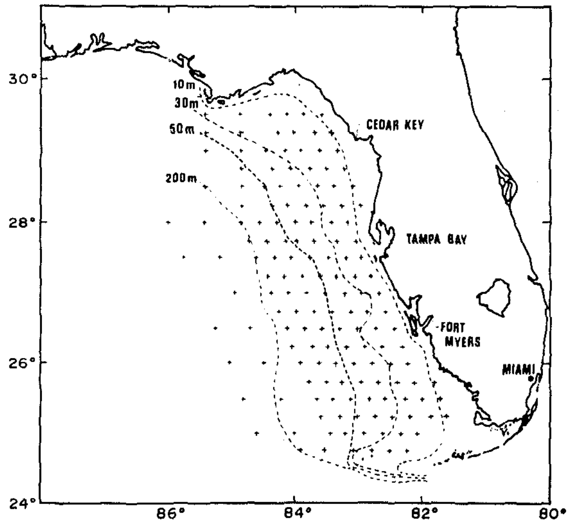


FIGURE 1.—Area encompassed by the 1971–74 eastern Gulf of Mexico ichthyoplankton surveys. Plus symbols (+) represent stations that were sampled during the survey. The 10-, 30-, 50-, and 200-m depth contours are indicated.

Egg and larval abundances at stations in the cruise area, over the time period represented by a cruise, and on an annual basis, were estimated using techniques similar to those outlined by Sette and Ahlstrom (1948), reviewed by Saville (1964), and most recently discussed by Smith and

TABLE 1.—Summarized data on cruises to the eastern Gulf of Mexico, 1971–74, to estimate abundance of thread herring eggs and larvae. GE = RV *Gerda*, 8C = RV *Dan Braman*, TI = *Tursiops*, 8B = RV *Bellows*, IS = RV *Columbus Iselin*, CL = RV *Calanus*.

Cruise	Dates	Number of stations	Positive stations for eggs[1]	Positive stations for larvae[2]	Mean egg abundance under 10 m²		Mean larvae abundance under 10 m²	
					All stations	Positive stations	All stations	Positive stations
GE7101[3]	1–8 Feb. 1971	20	0	0	0.00	—	0.00	—
8C7113								
TI7114	7–18 May 1971	123	13	47	28.42	276.82	27.67	52.63
GE7117	26 June–4 July 1971	27	4	13	0.85	14.39	17.48	51.87
8C7120								
TI7121	7–25 Aug. 1971	146	3	11	0.72	42.46	11.02	79.91
TI7131								
8B7132								
GE7127	7–16 Nov. 1971	66	0	0	0.00	—	0.00	—
8B7201								
GE7202	1–11 Feb. 1972	30	0	0	0.00	—	0.00	—
GE7208	1–10 May 1972	30	4	14	7.98	75.92	13.61	36.08
GE7210	12–18 June 1972	13	2	10	2.11	17.09	172.28	228.36
IS7205	9–17 Sept. 1972	34	0	4	0.00	—	1.04	13.78
IS7209	8–16 Nov. 1972	50	0	0	0.00	—	0.00	—
IS7303	19–27 Jan. 1973	51	0	0	0.00	—	0.00	—
IS7308	9–17 May 1973	49	4	21	60.53	999.46	34.73	101.19
IS7311	27 June–6 July 1973	51	12	19	28.28	137.98	68.74	229.37
IS7313	3–13 Aug. 1973	50	0	10	0.00	—	6.10	40.24
IS7320	6–14 Nov. 1973	51	0	0	0.00	—	0.00	—
CL7405	28 Feb–9 Mar. 1974	36	0	5	0.00	—	0.31	2.43
CL7412	1–9 May 1974	44	10	22	13.98	75.53	30.80	57.56

[1]Positive station is a station at which thread herring eggs were collected.
[2]Positive station is a station at which thread herring larvae were collected.
[3]An ICITA 1-m plankton net was used on this cruise. On all other cruises a 61-cm bongo net was used.

Richardson (in press). Variance estimates on cruise and on annual egg abundance estimates were calculated by methods used by Cushing (1957) and Taft (1960). Houde (1977a) has given detailed procedures, including estimating formulae, that were used to obtain abundance estimates of clupeid eggs and larvae in eastern Gulf of Mexico surveys.

Two methods were used to estimate adult biomass, based on two different procedures for determining annual spawning by thread herring. The first procedure is that given by Sette and Ahlstrom (1948). The estimate of annual spawning depends on integrating station and cruise estimates over area and time. The second procedure is based on a modification of Simpson's (1959) method in which annual spawning is estimated by plotting the daily spawning estimates for each cruise against the middate of the cruise and then determining the area under the resulting polygon by planimetry.

Potential Yield to a Fishery

Houde (1977a) used the estimator suggested by Alverson and Pereyra (1969) and Gulland (1971, 1972) to predict potential yield of round herring in the eastern Gulf. The same procedure was used for thread herring. The estimating formula is $C_{max} = XMB_0$ where X is assumed to equal 0.5, M is the natural mortality coefficient, and B_0 is the virgin biomass. My biomass estimates are estimates of B_0 since the thread herring stock is virtually unfished in the eastern Gulf. Because no estimate of M exists for thread herring, the potential annual yield was predicted using a range of probable values of the mortality coefficient.

Larval Abundance and Mortality

Mortality estimates were determined for larvae by length and by estimated ages. The exponential decrease in abundance of 1-mm length classes was used to calculate mortality coefficients to describe the decline in catches by length. Growth was assumed to be exponential during the larval phase. Based on this assumption and information on laboratory growth rates for thread herring larvae, ages of larvae in 1-mm length classes were estimated. Mortality coefficients were then estimated from the decline in abundance of larvae in relation to estimated age. Houde (1977a) gave estimating formulae and discussed the rationale for his procedures, which are similar to those used previously by Ahlstrom (1954) and Nakai and Hattori (1962).

RESULTS AND DISCUSSION

Occurrence of Eggs and Larvae

Thread herring eggs occurred in 8 of the 17 cruises from 1971 to 1974, and larvae occurred during 11 of the cruises (Table 1). Eggs were collected on cruises from May through August, although significant spawning may have occurred during April when no cruises were scheduled. Some larvae were collected as early as March and as late as September, but they were most abundant from May through August. No eggs or larvae were collected from September through January. Fuss et al. (1969) reported ripe or nearly ripe adult thread herring from the eastern Gulf in March through August. My data support their finding that thread herring spawning is confined to spring and summer in this area.

Most spawning takes place within 50 km of shore on the inner continental shelf in depths <30 m, and virtually all spawning occurs within 100 km of shore at depths <50 m (Figure 2). A single instance of egg occurrence beyond the 50-m depth contour was recorded (Figure 2). Spawning was most intense between lat. 26°00′N and 28°00′N, the area from just south of Fort Myers to Tampa Bay, Fla. This is the area where an attempt was made to establish a commercial fishery for thread herring in the 1960's (Fuss 1968; Fuss et al. 1969). Kinnear and Fuss (1971) found that thread herring that were concentrated near Fort Myers (lat. 26°00′N) in winter migrated north during warmer months. My egg distribution data suggest that a large part of the thread herring population remains within the Fort Myers–Tampa Bay area throughout the year.

Larval distribution was more widespread than that of eggs, presumably due to dispersal by water currents, but was generally similar to egg distribution (Figure 2). Most larvae were collected where water depths were <50 m and only six occurrences were recorded where depths were >50 m (Figures 2–6).

Thread herring eggs and larvae were relatively common in eastern Gulf ichthyoplankton. A total of 4,236 thread herring eggs were collected during the 17 cruises, 1.39% of the 304,507 total fish eggs

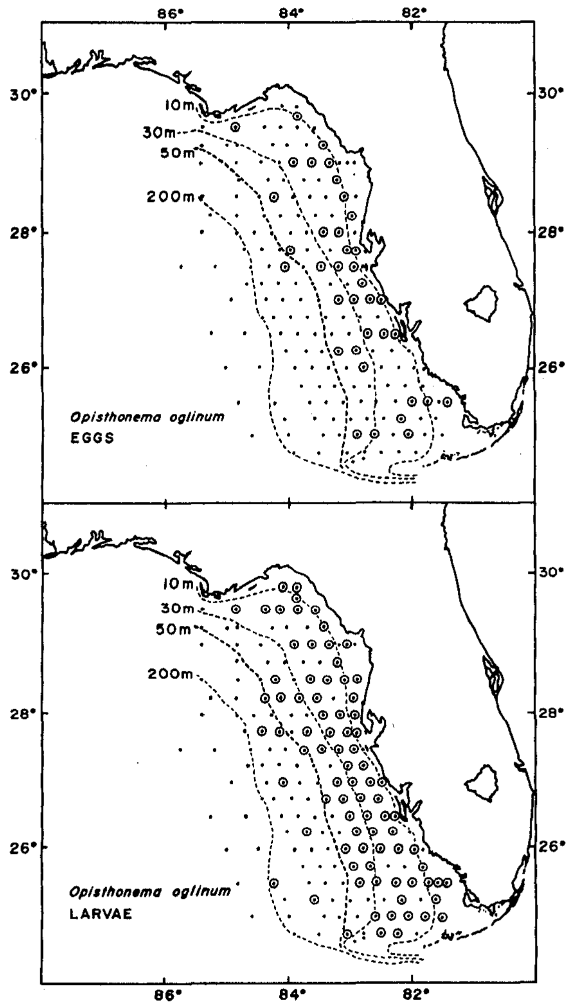


FIGURE 2.—Top. Stations in the survey area where eggs of thread herring were collected at least once during 1971–74. Stations where eggs did not occur are indicated by dots. Bottom. Stations in the survey area where larvae of thread herring were collected at least once during 1971–74. Stations where larvae did not occur are indicated by dots.

sorted from 867 samples. Number of thread herring larvae totalled 11,255, 7.87% of the 143,004 total larvae collected throughout the survey. Thread herring eggs constituted 13.20% of the total clupeid eggs collected, and thread herring larvae constituted 39.69% of the clupeid larvae.

Mean abundances of thread herring eggs under 10 m² of sea surface ranged from 0.00 to 60.53 for the 17 cruises (Table 1). At positive stations, cruise means ranged from 14.39 to 999.46 under 10 m². Most egg abundances at individual stations were <100 under 10 m² of sea surface, but abundances ranged from 101 to 1,000 under 10 m² on eight occasions and >1,000 under 10 m² on four occasions (Figures 3–6).

Thread herring larvae mean abundances for the 17 cruises ranged from 0.00 to 172.28 under 10 m² of sea surface (Table 1). At positive stations, mean cruise abundances ranged from 2.43 to 229.37 under 10 m². Larval abundances exceeded 1,000 under 10 m² on three occasions (Figures 3–6) and frequently were in the range of 101 to 1,000 under 10 m². Detailed summaries of station and cruise data for both larvae and eggs of thread herring were recently published (Houde et al. 1976).

Spawning intensity appeared to vary within the observed spawning area. The $\log_{10}$ mean egg abundance under 10 m² for positive stations from all cruises was 1.3837 at stations ≤30 m deep but was only 1.2750 at stations >30 m. The means did not differ significantly (t-test, $P>0.50$). But, the surface area encompassed by the ≤30-m depth zone was 76.03×10^9 m² as opposed to only 30.69×10^9 m² in the 30- to 50-m depth zone, beyond which virtually no spawning was observed (Figure 2). Most eggs were spawned where depth was <30 m.

There was no evidence that spawning intensity increased nearer to the coast than measured by our usual survey stations, based on cruise CL7412 (Figure 6, Table 1), when 12 nearshore stations were added to the usual stations. Thread herring eggs were collected at three of the nearshore stations and at seven of the regular, more offshore stations (Figure 6) on that cruise. The $\log_{10}$ mean catch under 10 m² was higher at the offshore stations, but due to the small number of stations it did not differ significantly ($P>0.10$) from the nearshore stations' mean:

Stations	*No. of stations with thread herring eggs*	*Log_{10} $\bar{x}$*	*Log_{10} $S_{\bar{x}}$*
Regular	7	1.5272	0.5064
Nearshore	3	0.5525	0.3101

$t_{calc} = 1.69 \qquad t_{0.05(2,\,8)} = 2.306$

Temperature and Salinity Relations

Thread herring eggs were collected where surface temperatures ranged from 22.5° to 30.3°C and surface salinities from 32.4 to 36.8‰. From May to September temperatures from surface to 15 m were nearly homothermous, but temperatures at the 30-m depth often differed from the surface by

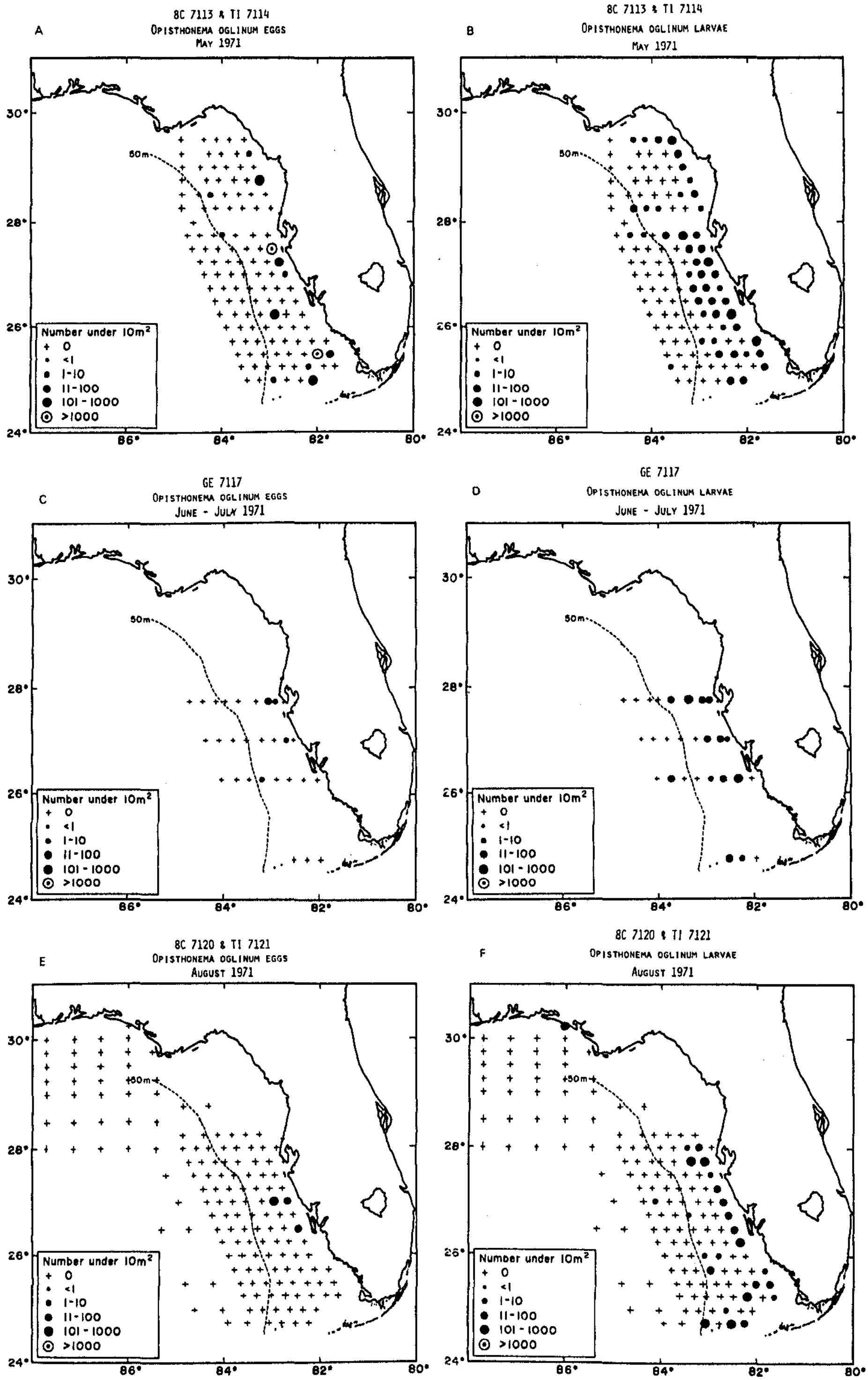
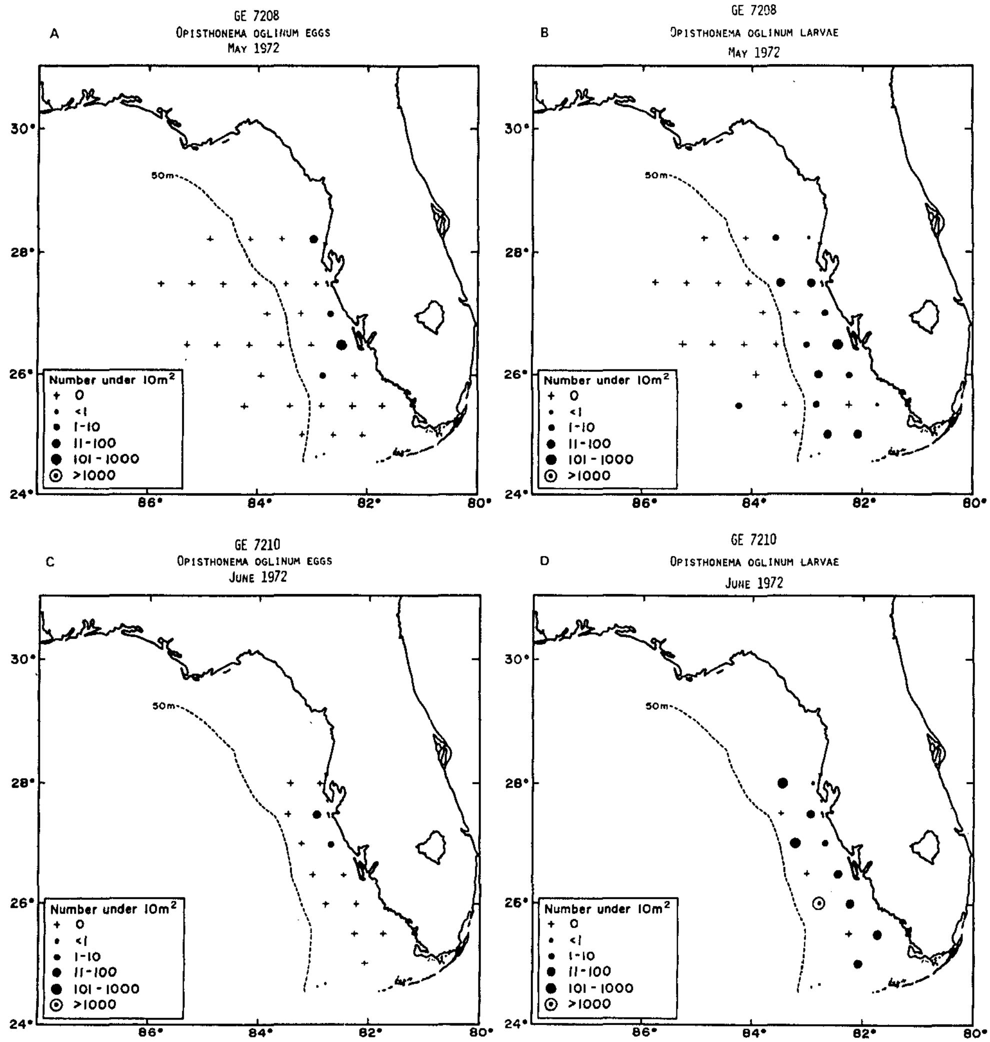


FIGURE 3.—Distribution and abundance of thread herring eggs and larvae. Catches are standardized to numbers under 10 m² of sea surface A, B. Cruise 8C7113–TI7114, May 1971. C, D. Cruise GE7117, June–July 1971. E, F. Cruise 8C7120–TI7121, August 1971.



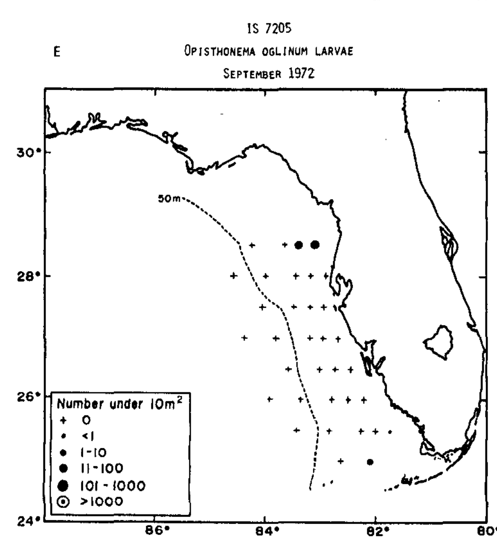
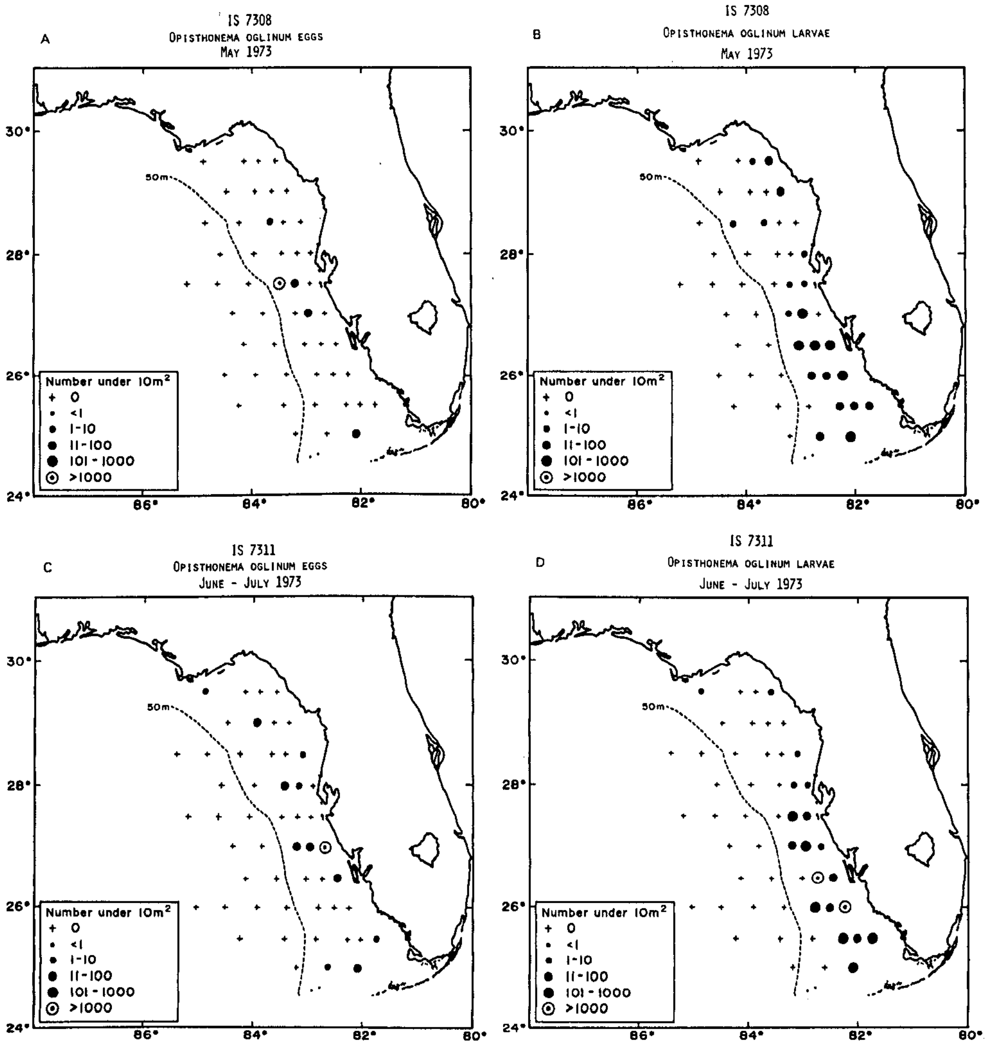


FIGURE 4.—Distribution and abundance of thread herring eggs and larvae. Catches are standardized to numbers under 10 m² of sea surface. A, B. Cruise GE7208, May 1972. C, D. Cruise GE7210, June 1972. E. Cruise IS7205, September 1972. No eggs were collected on this cruise.



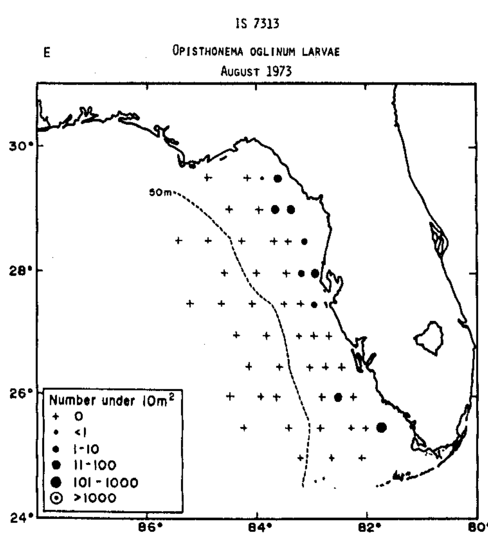


FIGURE 5.—Distribution and abundance of thread herring eggs and larvae. Catches are standardized to numbers under 10 m² of sea surface. A, B. Cruise IS7308, May 1973. C, D. Cruise IS7311, June–July 1973. E. Cruise IS7313, August 1973. No eggs were collected on this cruise.

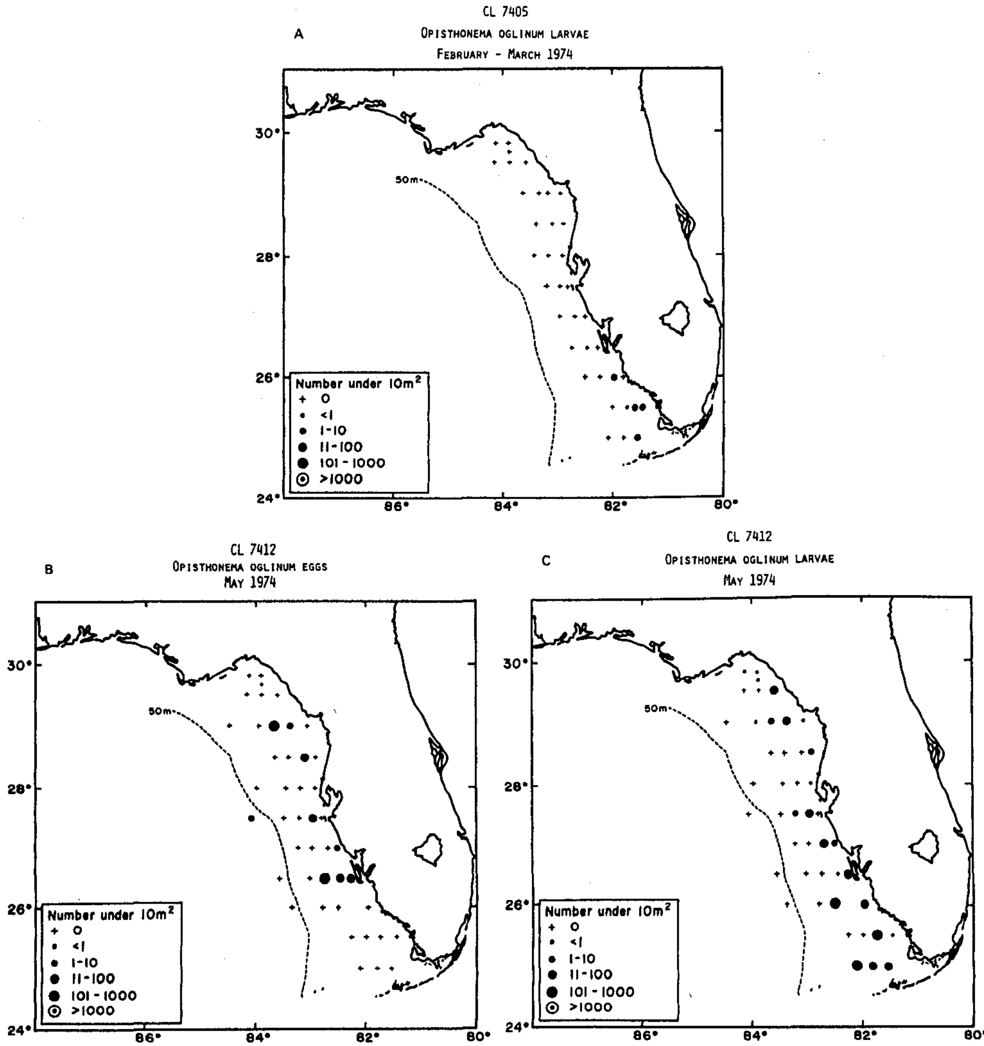


FIGURE 6.—Distribution and abundance of thread herring eggs and larvae. Catches are standardized to numbers under 10 m² of sea surface. A. Cruise CL7405, February–March 1974. No eggs were collected on this cruise. B, C. Cruise CL7412, May 1974.

2° to 3°C, with a maximum difference of 5°C observed. At the 50-m depth, temperatures differed from the surface by as much as 9°C, but usually by 3° to 5°C. Because most spawning takes place at depths less than 30 m, it is unlikely that spawning and surface temperatures differed by more than 2°C. Salinity did not differ by more than 1‰ from surface to the 50-m depth, except in 1973, when surface salinities over wide areas during summer were depressed (Anonymous 1975)[4] due to Mississippi River runoff some months earlier. In 1973 salinity differences as great as 4‰ between surface and 50 m were observed in areas where some thread herring spawning occurred. Small larvae (≤5.0 mm standard length [SL]), <5 days old, were collected where surface temperatures were 18.5° to 30.9°C and salinities were 27.3 to 36.9‰. The ranges were greater for larvae than for eggs.

Based on combined 1971–74 data, most thread herring eggs and ≤5.0-mm larvae were collected at surface temperatures from 25.1° to 30.0°C (Figure 7). All stations with eggs and more than 98% of the stations with ≤5.0-mm larvae had surface temperatures above 22°C. More than 74% of the

[4]Anonymous. 1975. Compilation and summation of historical and existing physical oceanographic data from the eastern Gulf of Mexico. State Univ. Syst. Fla., Inst. Oceanogr., St. Petersburg, Fla. Final Rep. to U.S. Bur. Land Manage., Contract No. 08550-CT4-16, 97 p., 10 app.

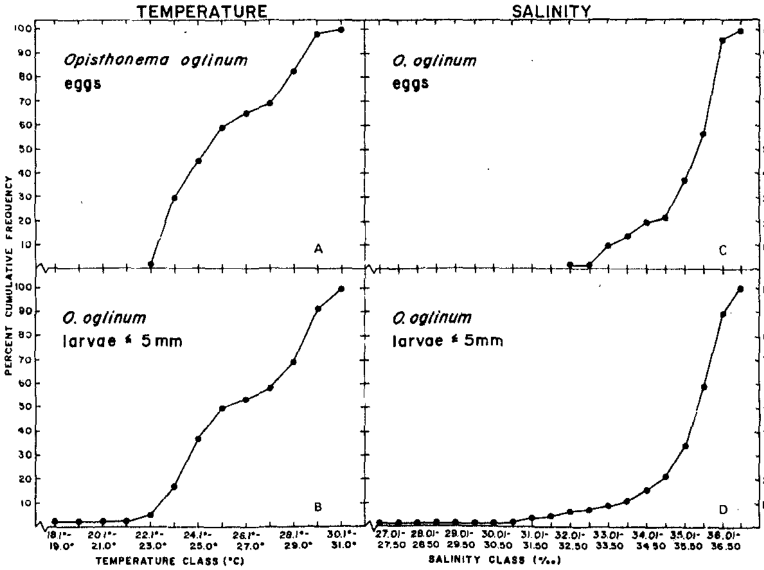


FIGURE 7.—Percent cumulative frequency distribution of 1971–74 stations where thread herring eggs occurred in relation to surface temperatures (A) and to surface salinities (C), and ≤5.0-mm SL larvae occurred in relation to surface temperatures (B) and surface salinities (D).

stations with eggs and 68% with ≤5.0-mm larvae occurred where salinity ranged from 35.0 to 36.5‰. Spawning rarely occurred at surface salinities <33‰.

Egg and Larval Abundance in Relation to Zooplankton

There was no clear relationship between abundance of thread herring eggs or larvae and zooplankton volume at stations for 12 cruises in 1972–74. Houde and Chitty (1976) determined that mean zooplankton volume from the 333-μm mesh bongo net was 153.4 cm^3/1,000 m^3 in that period. Egg abundances showed no relationship to zooplankton volumes; larvae did appear to be most abundant at stations where zooplankton volumes exceeded 153.4 cm^3/1,000 m^3. But, zero catches or low catches of larvae also were common where zooplankton volumes were high. The lack of significant correlation between larval abundance and zooplankton volume was not surprising because the 333-μm mesh does not sample zooplankton of the size eaten by small thread herring larvae.

Relative Fecundity

The mean relative fecundity of thread herring females is 594.0 ova/g ($S_{\bar{x}}$ = 29.4 ova/g), calculated from Martinez's (1972) weight and fecundity data that he obtained from nine females of 53.8 to 109.4 g. There was no apparent relationship between relative fecundity and either length or weight of the nine thread herring used in this analysis. The mean relative fecundity value was used in all subsequent biomass estimate calculations. Because mean relative fecundity with its 0.95 confidence limits is $\bar{x}$ = 594 ± 68, the maximum biomass estimating error attributable to the relative fecundity estimate is about ±11%.

Time Until Hatching

Thread herring eggs apparently hatch in <24 h at temperatures of 25° to 30°C, where most spawning takes place in the eastern Gulf. The evidence is indirect because no living thread herring eggs were available for incubation experiments. Eggs did not occur in more than one stage of development from any single sample during these surveys. Newly fertilized eggs were collected only at night, mostly from 2200 to 0200; and full-term embryos were found only during the afternoon from 1400 to 1800. I assigned a mean estimated hatching time for eggs as 0.84 days (20 h) from the evidence that was available. Thread herring eggs were rarely caught at stations sampled between the hours of 1600 and 2100, presumably because they had already hatched. Thus, abundance of thread herring eggs spawned during each cruise was underestimated. Annual spawning estimates, as well as variances, were corrected for egg stage duration (equations 4, 5; Houde 1977a) and corrected estimates were subsequently used to calculate biomasses.

Cruise Egg Abundance

The estimated abundance of thread herring eggs in the area represented by each cruise is given in Table 2. For cruises in which eggs occurred, abundances ranged from 0.86 to 91.66 × 10^{10} eggs. The Table 2 estimates, which represent abundance of eggs present on a day during a cruise, were corrected for egg stage duration and then expanded to represent the number of days encompassed by the cruise period (Sette and Ahlstrom 1948; Houde 1977a).

TABLE 2.—Abundance estimates of thread herring eggs for each cruise. Estimates were obtained using Equations (2) and (3) (Houde 1977a) and are not corrected for duration of the egg stage.

Cruise	Area represented by the cruise ($m^2 \times 10^9$)	Positive area[1] ($m^2 \times 10^9$)	Cruise egg abundance (eggs × 10^{10})
GE7101	25.79	0.00	0.00
8C7113 and TI7114	120.48	55.81	34.25
G7117	101.10	48.73	0.86
8C7120 and TI7121	189.43	26.26	1.37
GE7127, 8B7132 and TI7131	72.99	0.00	0.00
8B7201 and GE7202	148.85	0.00	0.00
GE7208	124.88	65.98	11.93
GE7210	48.43	38.93	1.02
IS7205	104.59	11.16	0.00
IS7209	149.80	0.00	0.00
IS7303	149.80	0.00	0.00
IS7308	151.42	54.09	91.66
IS7311	156.50	53.21	44.26
IS7313	153.18	21.75	0.00
IS7320	153.89	0.00	0.00
CL7405	52.00	6.70	0.00
CL7412	91.33	47.89	12.77

[1]Positive area is defined as the area representing stations where either eggs or larvae of thread herring were collected.

Adjusting Cruise Egg Abundance Estimates

Because the entire potential spawning area was not sampled on cruises GE7117, 8C7120–TI7121, GE7208, and GE7210 (Figures 3, 4), an area adjustment factor was applied to correct the egg abundance estimates in Table 2. The area adjustment factor was equal to the fraction of the potential spawning area that was sampled on a given cruise. For cruise GE7117 it was 0.404; for 8C7120–TI7121, 0.746; for GE7208, 0.746; and for GE7210, 0.753. The abundance estimate for each of those cruises (Table 2) was corrected by dividing it by its area adjustment factor. Corrected abundance estimates are: GE7117—2.12 × 10^{10}; 8C7120–TI7121—1.83 × 10^{10}; GE7208—15.98 × 10^{10} GE7210—1.36 × 10^{10}.

Annual Spawning and Biomass Estimates

Method I

Estimates of total annual spawning by thread herring in the eastern Gulf ranged from 140.528 × 10^{11} eggs in 1972 to 1,105.932 × 10^{11} eggs in 1973 (Table 3). Estimated adult biomasses were 110,024 metric tons in 1971, 47,316 metric tons in 1972, and 372,367 metric tons in 1973 (Table 3). The 1972 estimate is unreliable because a cruise that was scheduled during the peak of the spawning season was terminated before completion, due to a hurricane. The actual biomass in 1972 probably is much higher than the estimate. Consider-

TABLE 3.—Annual spawning and biomass estimates for thread herring from the eastern Gulf of Mexico during 1971, 1972, and 1973 spawning seasons. Estimates are based on the Sette and Ahlstrom (1948) technique. The 1972 estimate is unreliable because a hurricane curtailed survey cruise GE7210 during the peak of the spawning season. Details of the estimating procedure are given in Houde (1977a).

Year	Cruise	Daily spawning estimate (eggs × 10^{11})	Days represented by cruise	Eggs spawned during cruise period (× 10^{11})	Variance estimates on spawned eggs (× 10^{24})	Adult biomass (metric tons)
1971	GE7101	0.000	51.5	0.000	—	
	8C7113 TI7114	4.111	74.5	306.283	20.429	
	GE7117	0.255	44.5	11.365	8.549	
	8C7120 TI7121	0.220	41.5	9.124	1.556	
Annual total				326.772	30.534	110,024
1972	8B7201 GE7202	0.000	50.0	0.000	—	
	GE7208	1.919	65.0	124.706	47.060	
	GE7210	0.163	97.0	15.822	25.507	
Annual total				140.528	72.567	47,316
1973	IS7303	0.000	46.5	0.000	—	
	IS7308	11.004	79.5	874.802	49.839	
	IS7311	5.313	43.5	231.130	20.284	
	IS7313	0.000	42.5	0.000	—	
Annual total				1,105.932	70.123	372,367

ing only 1971 and 1973 estimates of egg abundance and their respective variances, the 0.95 confidence intervals on thread herring biomass during those years ranged from 72,814 to 428,758 metric tons.

The area adjustments that corrected egg abundance estimates for four 1971 and 1972 cruises had a relatively minor effect on biomass estimates in those years. Corrected estimates, presented in Table 3, exceeded uncorrected estimates by 3,060 metric tons in 1971 and by 11,946 metric tons in 1972.

Method II

An estimate of annual spawning also was obtained by a modification of Simpson's (1959) method (Houde 1977a). Biomasses of adult thread herring were then estimated (Table 4); they were 108,139 metric tons in 1971, 45,048 metric tons in 1972, and 325,803 metric tons in 1973.

Most Probable Biomass

If the 1972 estimates are not considered, the most likely adult thread herring biomass in the eastern Gulf during 1971–73 was between 100,000 and 400,000 metric tons. Yearly fluctuations in thread herring biomass may be significant in the eastern Gulf of Mexico but the size of such fluctuations could not be determined. Severe red tides, which are common in the area, and hurricanes are just two phenomena occurring during summer months that might affect annual recruitment, causing significant year-class fluctuations. But, during the years of this study it seems unlikely that the stock of adult thread herring exceeded 430,000 metric tons and it probably was less than that amount. These estimates represent only a part of the Gulf of Mexico thread herring population. Large sotcks exist in the northern and western Gulf that are not included in the estimates. Also, juvenile thread herring biomass is not included and it may constitute a significant part of the population that could be harvested by a fishery.

TABLE 4.—Annual spawning and biomass estimates for thread herring from the eastern Gulf of Mexico during 1971, 1972, and 1973. Estimates are based on the method described by Simpson (1959). The 1972 estimate is unreliable because a hurricane curtailed survey cruise GE7210 during the peak of the spawning season.

Year	Cruise	Daily spawning estimate (eggs × 10^{11})	Annual spawning estimate (eggs × 10^{11})	Adult biomass (metric tons)
1971	GE7101	0.000		
	8C7113			
	TI7114	4.111		
	GE7117	0.255		
	8C7120			
	TI7121	0.220		
			321.172	108,139
1972	8B7201			
	GE7202	0.000		
	GE7208	1.919		
	GE7210	0.163		
			133.793	45,048
1973	IS7303	0.000		
	IS7308	11.004		
	IS7311	5.313		
	IS7313	0.000		
			967.636	325,803

Concentration of Biomass

If thread herring adults were evenly distributed from the coastline to the 50-m depth contour in 1971 and 1973, an area of 106.7 × 10^5 ha, the concentration of biomass would be in the range of 6.8 to 40.2 kg/ha, based on adult biomass estimates and the 0.95 confidence interval on those estimates. The estimated thread herring biomass concentration is less than that for round herring (Houde 1977a) which ranged from 14.1 to 102.3 kg/ha. Round herring occur in a smaller area of the eastern Gulf than thread herring; the round herring being mostly confined to the 30- to 200-m depth zone which is 76.5 × 10^5 ha. Thread herring, although less concentrated, are highly visible because of surface schooling behavior and also are presumably more accessible to a potential fishery because they are found nearer to the coast in shallower water.

Potential Yield to a Fishery

Estimates of annual potential yield of adult thread herring from the eastern Gulf range from 27,506 to 186,184 metric tons (Table 5). Estimates were obtained from $C_{max} = XMB_0$ where M, the natural mortality coefficient, was assigned three

TABLE 5.—Range of potential yield estimates for eastern Gulf of Mexico thread herring, based on biomass estimates in 1971 and 1973 by the Sette and Ahlstrom (1948) method. Yields are predicted at three possible values of M, the natural mortality coefficient. Biomass estimates were obtained from values in Table 3.

Year	Biomass estimate (metric tons)	Estimated potential annual yields (metric tons) for given values of M		
		M=0.5	M=0.75	M=1.0
1971	110,024	27,506	41,259	55,012
1973	372,367	93,092	139,638	186,184
Mean of 1971 and 1973	241,196	60,299	90,448	120,598

values (0.5, 0.75, and 1.00) within the probable range for thread herring. Based on the mean of 1971 and 1973 biomass estimates, potential yield ranged from 60,300 to 120,600 metric tons. It is likely that the sustainable yield of adult stock was in that range during 1971–73. Assuming thread herring are evenly distributed within the 106.7 × 10^5 ha spawning area, then probable harvestable yields of adult thread herring range from 5.6 to 11.3 kg/ha. Yield could be supplemented by some additional catch of juveniles.

The eastern Gulf thread herring stock apparently is not as large as the menhaden stock in the north-central Gulf. But, a potential harvest, based on 1971–73 biomass levels, of about 100,000 metric tons substantiates the belief that thread herring are a significant resource in the eastern Gulf that could provide raw material for the fishmeal industry. Because large fluctuations in thread herring year-class strength may occur, yield in some years could be considerably higher than that predicted based on 1971–73 abundance. The potential for thread herring harvest is higher in the eastern Gulf of Mexico than that estimated along the Atlantic coast by Pristas and Cheek (1973).

Larval Abundance

Larval abundance varied seasonally with peak abundance in spring and summer months (Table 6). Abundance estimates for cruises in which thread herring larvae were collected ranged from 0.16 to 107.57 × 10^{10} larvae in the survey area. Thread herring larvae were collected in small numbers on three cruises in which no eggs were taken (Table 1). Cruises IS7205 and IS7313 were made in late summer when eggs, if present, must have been rare. Larvae collected in early March, during cruise CL7405, occurred only in the southernmost part of the survey area (Figure 6). They occurred at five stations on that cruise but abundances were only 0.6 to 4.4 under 10 m^2. The presence of larvae indicated that some spawning began as early as February and that it continued as late as September.

TABLE 6.—Abundance estimates of thread herring larvae for each cruise. Estimates include larvae in all size classes and were obtained using Equations (2) and (3) (Houde 1977a).

Cruise	Area represented by the cruise ($m^2 \times 10^9$)	Positive area[1] ($m^2 \times 10^9$)	Cruise larvae abundance[2] (larvae × 10^{10})
GE7101	25.79	0.00	0.00
8C7113 and TI7114	120.48	55.81	33.34
GE7117	101.10	48.73	17.67
8C7120 and TI7121	189.43	26.26	20.87
GE7127, TI7131, and 8B7132	72.99	0.00	0.00
8B7201 and GE7202	148.85	0.00	0.00
GE7208	124.88	65.98	20.36
GE7210	48.43	38.93	83.43
IS7205	104.59	11.16	1.09
IS7209	149.80	0.00	0.00
IS7303	149.80	0.00	0.00
IS7308	151.42	54.09	52.58
IS7311	156.50	53.21	107.57
IS7313	153.18	21.75	9.34
IS7320	153.89	0.00	0.00
CL7405	52.00	6.70	0.16
CL7412	91.33	47.89	28.13

[1]Positive area is defined as the area representing stations where either eggs or larvae of thread herring were collected.
[2]Values are not adjusted for cruises that did not encompass the entire area, nor have estimates been corrected to account for gear avoidance by larvae at stations sampled in daylight.

The seasonal nature of thread herring larvae abundance can be observed in plotted length-frequency distributions for each cruise in which larvae were collected (Figure 8). Larvae were represented in length classes up to 23.0 mm SL, but specimens longer than 15.0 mm were uncommon. The smallest length classes (1.1–3.0 mm) represent larvae in poor condition or that were distorted from net capture and preservation, because recently hatched thread herring larvae are 3.8 to 4.0 mm SL (Richards et al. 1974).

Fewer larvae were collected at stations sampled during the day than at night, indicating that gear avoidance was relatively great during daylight, particularly by larger larvae. The ratio of night catches to day catches increased rapidly when summed catches under 10 m^2 over all cruises were plotted for each 1-mm length class (Figure 9). No larvae longer than 17.0 mm were collected during daylight. An exponential function $R = 0.3470e^{0.2492X}$ was fitted to the plotted data for larvae up to 17.0 mm (Figure 9), where R is the ratio of night-caught to day-caught larvae and X is standard length. It provided the correction factor R (Houde 1977a), by which daytime catches were adjusted to obtain abundance estimates of larvae by 1-mm length classes in each station area on a cruise. The correction for undersampling during daylight probably did not completely account for gear avoidance by larvae (Smith and Richardson in press), but it helped to provide a better estimate of larval abundance for subsequent estimation of survival rates. The observed increase in ratio of night- to day-caught thread herring larvae throughout the larval period seems typical of clupeid larvae (Ahlstrom 1954, 1959; Lenarz 1973; Matsuura in press). But, observations on round

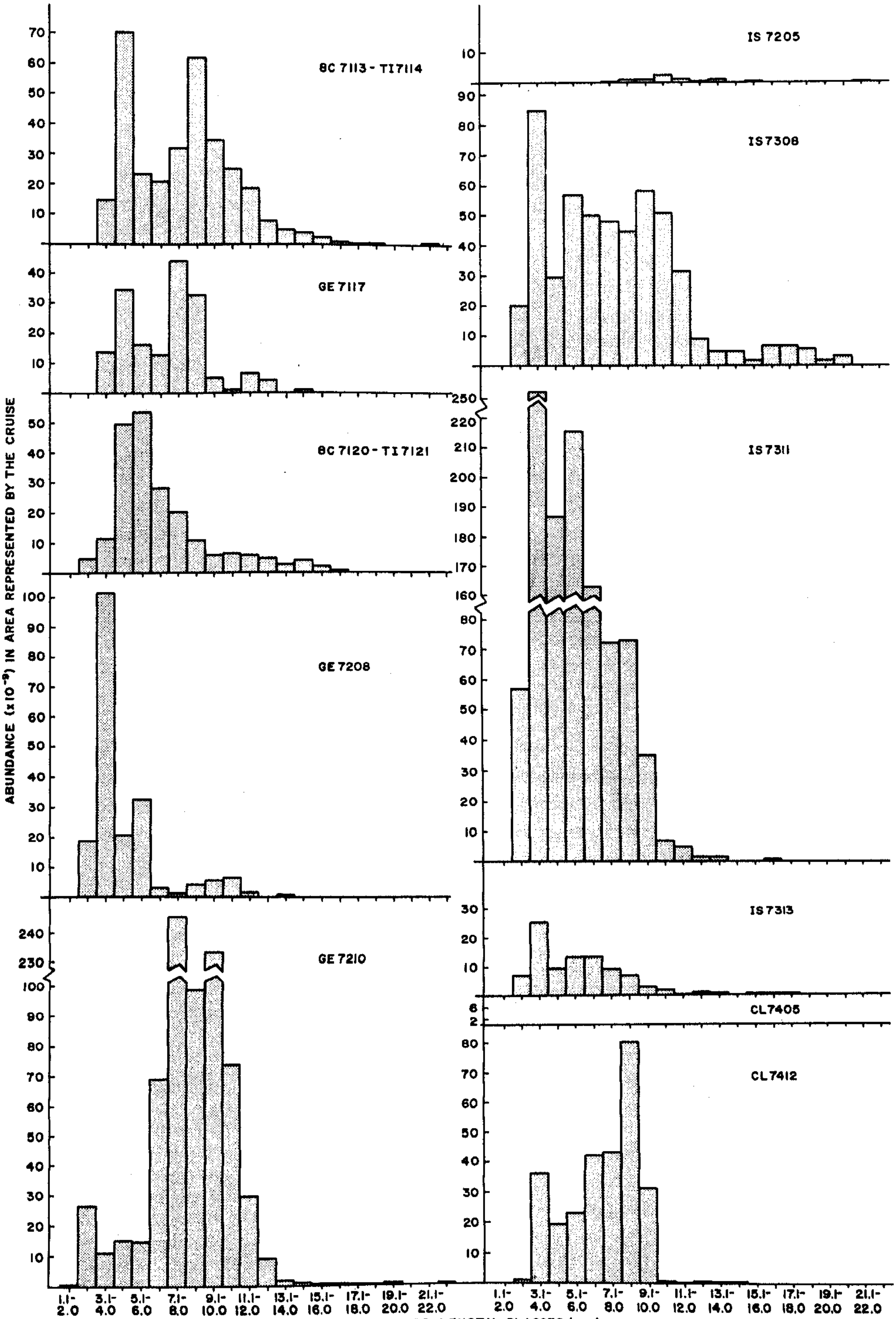


FIGURE 8.—Length-frequency distributions of thread herring larvae for 1971–74 cruises to the eastern Gulf of Mexico. Frequencies are expressed as estimated abundance of larvae in each length class within the area represented by the cruise. No adjustments for abundance have been made for cruises that did not cover the entire area where thread herring larvae might occur.

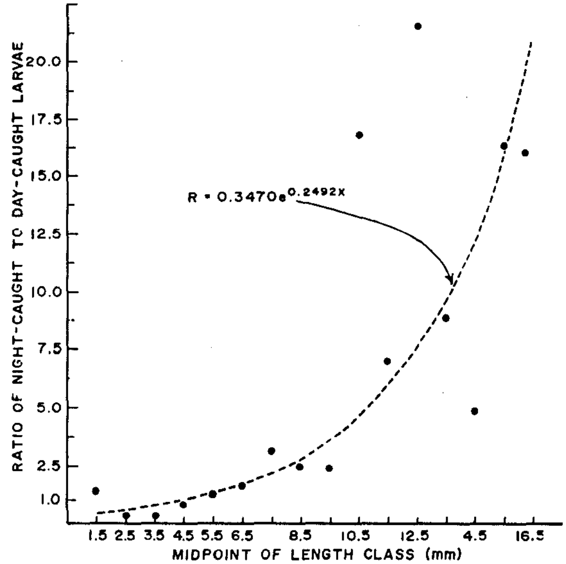


FIGURE 9.—Night to day ratios of sums of catches, standardized to numbers under 10 m^2 of sea surface, for thread herring larvae collected in 1971–74 in the eastern Gulf of Mexico. The ratios were calculated for larvae within each 1-mm length class from 1.1 to 17.0 mm SL. A fitted exponential regression describes the relationship. Larval abundance estimates for each length class at stations occupied during daylight were corrected by the appropriate ratio factor for each length class to account for daytime avoidance.

herring larvae (Houde 1977a) showed relative increases in night catches until larvae were 13.0 mm; then the ratio declined to unity for larger larvae. In scaled sardine larvae (Houde 1977b), the ratio increased throughout the larval size range, but the relative increase in night catches was slight compared to thread herring.

Annual estimates of larval abundance by 1-mm length classes were calculated for 1971 and 1973 (Figure 10), after the data had been corrected for daytime avoidance. Abundance of larvae was slightly higher in 1973 than in 1971. The abundance of 3.0- to 7.0-mm larvae accounted for the difference between the two years (Figure 10). Larvae longer than 17.0 mm were more abundant in 1973 than in 1971.

Abundance of larvae decreased exponentially in both years as lengths increased (Figure 10). Exponential functions were fitted to data in the 4.1- to 19.0-mm length classes in 1971 and to the 5.1- to 20.0-mm length classes in 1973 (Figure 10), giving estimates of the instantaneous decline in abundance of thread herring larvae per millimeter increase in length. The instantaneous coefficients estimate larval mortality rates if gear avoidance

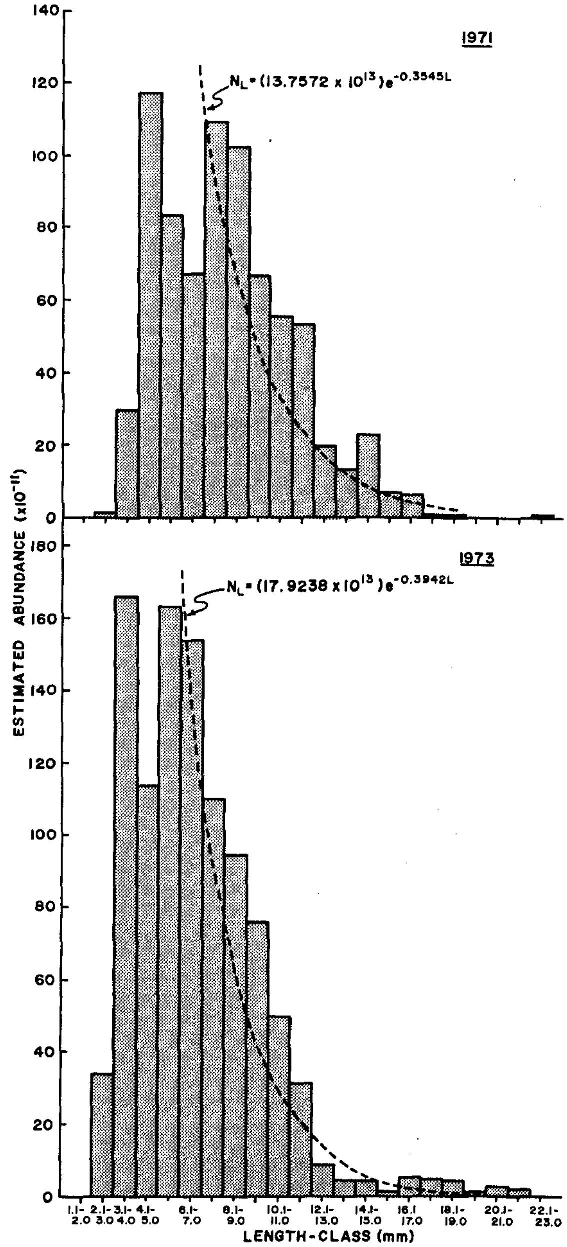


FIGURE 10.—Length–frequency distribution of annual larval abundance estimates for thread herring larvae collected in the eastern Gulf of Mexico, 1971 and 1973. Frequencies in each 1-mm length class are expressed as estimated annual abundance and have been corrected for daytime avoidance. Fitted exponential functions provide estimates of the instantaneous coefficient of decline in abundance by length.

is not too great over the length ranges in the analysis. Coefficients were $Z = 0.3545$ in 1971 and $Z = 0.3942$ in 1973. The corresponding percentage losses per millimeter increase in length are 29.9% in 1971 and 32.6% in 1973. Confidence limits on Z at the 0.95 probability level were $Z \pm 0.0816$ in 1971 and $Z \pm 0.1385$ in 1973. The mortality coefficients did not differ significantly between years (t-test; $P>0.50$).

Mortality coefficients for round herring larvae per millimeter increase in length were $Z = 0.2269$ in 1971–72 and $Z = 0.3647$ in 1972–73 in the eastern Gulf of Mexico (Houde 1977a). Larval mortality of scaled sardines in 1973 was $Z = 0.3829$ (Houde 1977b), which is nearly identical to that for thread herring. Lenarz (1973) reported ranges of instantaneous coefficients for abundance at length data to be 0.15 to 0.33 for Pacific sardine, *Sardinops caeruleus*, and from 0.32 to 0.46 for northern anchovy, *Engraulis mordax*, larvae. The Pacific sardine coefficients were lower than those for thread herring, but the anchovy coefficients were similar to thread herring coefficients. Matsuura (in press) obtained a high instantaneous coefficient of $Z = 0.4962$ for Brazilian sardine, *Sardinella brasiliensis*, which is higher than any values observed for Gulf of Mexico clupeid larvae.

To obtain estimates of larval mortality relative to age rather than length, an exponential growth model was used to estimate age at length for thread herring larvae, given various mean daily growth increments during the larval stage. Mean daily growth increments of eastern Gulf clupeid larvae probably range from 0.3 to 1.0 mm based on laboratory rearing experiments for some species (Richards and Palko 1969; Saksena and Houde 1972; Saksena et al. 1972; Houde 1973b; Houde and Swanson 1975). At temperatures above 26°C, healthy larvae grew, on average, more than 0.5 mm/day. Duration of the egg stage for thread herring is about 0.84 days. The duration of nonfully vulnerable length classes also was estimated before mean age of each fully vulnerable 1-mm length class was calculated. Nonfully vulnerable length classes were 1.1 to 4.0 mm in 1971 and 1.1 to 5.0 mm in 1973. The duration of these stages in thread herring probably is from 1.0 to 3.0 days and 4.0 to 6.0 days, respectively, based on evidence from laboratory rearing of similar clupeid larvae (Houde et al. 1974; Houde and Swanson 1975). Eastern Gulf clupeid larvae quickly attain 4.0 mm length during the first day after hatching, but show no further growth in length until the fourth day after hatching. No direct observations of stage duration for thread herring larvae 5.0 mm or less in length were available from laboratory experiments but their growth pattern during this stage probably does not differ from that of other clupeids. Stage durations of nonfully vulnerable length classes were assigned based on observations of the other species. Methods and details of the mortality estimating procedure were given by Houde (1977a).

Two examples of duration-corrected abundance data assuming exponential growth of fully vulnerable larval length classes up to 19.0 mm in 1971 and 20.0 mm in 1973 are given in Table 7. In these examples, the mean daily growth increment was assumed to be 0.8 mm. Sets of such abundance

TABLE 7.—Two examples of data from 1971 and 1973 used to obtain stage duration, mean age, and duration-corrected abundance of thread herring eggs and larvae. Duration-corrected abundances were subsequently regressed on mean ages to obtain mortality rates (Table 8). Abundance estimates in the second column of the Table were previously corrected for daytime avoidance. In these examples, the mean daily growth increment ($\bar{b}$) was set at 0.80 mm. The nonfully vulnerable size classes were 1.1 to 4.0 mm in 1971 and 1.1 to 5.0 mm in 1973. Calculating procedures were given in Houde (1977a), Equations (12) to (16). Regressions for these data are presented in Figure 18.

Stage	Abundance (no. × 10^{11})	Duration (days)	Mean age (days)	Duration-corrected abundance (no. × 10^{11})	Stage	Abundance (no. × 10^{11})	Duration (days)	Mean age (days)	Duration-corrected abundance (no. × 10^{11})
		1971					1973		
Eggs	274.49	0.84	0.42	326.77	Eggs	921.24	0.84	0.42	1,105.93
1.1– 4.0 mm	31.65	1.00	1.34	31.65	1.1– 5.0 mm	313.69	4.00	2.84	78.42
4.1– 5.0	117.33	2.49	3.01	47.14	5.1– 6.0	163.32	2.04	5.79	80.13
5.1– 6.0	83.72	2.04	5.52	41.08	6.1– 7.0	154.18	1.73	7.88	89.33
6.1– 7.0	66.38	1.73	7.62	38.46	7.1– 8.0	109.80	1.50	9.68	73.35
7.1– 8.0	108.92	1.50	9.41	72.77	8.1– 9.0	94.93	1.32	11.25	71.84
8.1– 9.0	102.14	1.32	10.98	77.30	9.1–10.0	75.86	1.18	12.64	64.14
9.1–10.0	66.52	1.18	12.38	56.24	10.1–11.0	49.55	1.07	13.90	46.28
10.1–11.0	55.47	1.07	13.63	51.81	11.1–12.0	31.82	0.98	15.04	32.55
11.1–12.0	53.74	0.98	14.77	54.96	12.1–13.0	8.88	0.90	16.08	9.87
12.1–13.0	19.29	0.90	15.82	21.44	13.1–14.0	4.53	0.83	17.05	5.44
13.1–14.0	12.68	0.83	16.79	15.21	14.1–15.0	4.24	0.78	17.94	5.46
14.1–15.0	22.51	0.78	17.68	29.01	15.1–16.0	1.56	0.73	18.78	2.15
15.1–16.0	7.16	0.73	18.52	9.86	16.1–17.0	5.59	0.68	19.57	8.20
16.1–17.0	6.38	0.68	19.30	9.35	17.1–18.0	5.24	0.64	20.30	8.15
17.1–18.0	0.17	0.64	20.04	0.26	18.1–19.0	4.60	0.61	21.00	7.55
18.1–19.0	0.31	0.61	20.74	0.51	19.1–20.0	1.44	0.58	21.66	2.49

estimates, assigning other mean daily growth increments and other durations for nonfully vulnerable larvae, were generated. Duration-corrected abundances (Table 7) were then regressed on estimated mean ages, the resulting regression coefficients from the fitted exponential functions being estimates of the instantaneous mortality coefficients (Z) for age in days.

Examples of probable thread herring larval mortality estimates in 1971 and 1973 for a range of possible mean daily growth increments and for two probable stage durations of nonfully vulnerable larvae are given in Table 8. The ranges of probable larval mortality rates were similar in the two years. The probable instantaneous mortality coefficients ranged from 0.1371 to 0.2575 in 1971, corresponding to daily mortality rates of 12.8 to 22.7%. In 1973 the estimates of instantaneous mortality coefficients ranged from 0.1691 to 0.3050, which correspond to daily rates of 15.6 to 26.3%. The effect of varying the assumed duration of nonfully vulnerable stages had a relatively minor effect on mortality rate estimation compared with varying growth rates (Table 8).

The y-axis intercepts (N_0) of the exponential regressions used to obtain mortality estimates (Table 8) also estimate annual spawning by thread herring. The range of estimates in Table 8 encompasses the estimate obtained for 1971 and 1973 by the Sette and Ahlstrom (1948) or Simpson (1959) techniques (Tables 3, 4). At a mean daily growth increment of 0.8 mm, a probable value based on laboratory growth data, the annual spawning estimates from the y-axis intercepts (Table 8) are similar to those obtained by the other methods (Tables 3, 4).

I believe that the best estimates of larval mortality were generated from abundance and age data in Table 7. These data indicated that daily mortality of thread herring larvae was approximately 20% in both 1971 and 1973. Instantaneous mortality coefficients for conditions in Table 7 were $Z = 0.2124$ in 1971 and $Z = 0.2564$ in 1973, which correspond to daily mortality rates of 19.1 and 22.6% (Table 8). Regressions from which those instantaneous mortality coefficients were derived are given in Figure 11. Confidence intervals on Z at the 0.95 probability level ranged from 0.0990 to 0.3258 in 1971 and from 0.1993 to 0.3224 in 1973. The instantaneous coefficients were not tested to determine if they differed significantly between 1971 and 1973 because variances of the estimates were not homogeneous ($S_b^2 = 0.0028$ in 1971, $S_b^2 = 0.0007$ in 1973), but the overlapping confidence intervals indicated that they did not differ significantly.

Regressions of duration-corrected abundance on estimated mean age (Figure 11) suggested that

TABLE 8.—Summary of mortality estimates for thread herring larvae from the eastern Gulf of Mexico, 1971 and 1973. Estimates were obtained from the exponential regression of egg and larvae abundances on mean age. Instantaneous growth and mortality coefficients were calculated for various possible combinations of mean daily growth increment and duration of the nonfully vulnerable larval stages. Egg stage duration was assumed to be 0.84 days. Nonfully vulnerable larval stages were 1.1 to 4.0 mm SL in 1971 and 1.1 to 5.0 mm SL in 1973. Explanation of the estimating method is given in Equations (12) to (16) of Houde (1977a).

Year	Mean daily growth increment, $\bar{b}$ (mm)	Instantaneous growth coefficient, g	Nonfully vulnerable larvae duration (days)	Instantaneous mortality coefficient, Z	Y-axis intercept, N_0 (no. × 10^{11})	Daily mortality rate, $1 - \exp(-Z)$
1971	0.5	0.0498	1.0	0.1403	219.43	0.1309
	0.6	0.0598	1.0	0.1650	258.43	0.1521
	0.7	0.0698	1.0	0.1890	297.83	0.1722
	0.8	0.0797	1.0	0.2124	337.80	0.1913
	0.9	0.0897	1.0	0.2352	378.36	0.2096
	1.0	0.0997	1.0	0.2575	419.59	0.2270
	0.5	0.0498	3.0	0.1371	266.31	0.1281
	0.6	0.0598	3.0	0.1601	321.57	0.1479
	0.7	0.0698	3.0	0.1820	378.83	0.1664
	0.8	0.0797	3.0	0.2030	437.93	0.1837
	0.9	0.0897	3.0	0.2230	498.64	0.1999
	1.0	0.0997	3.0	0.2421	560.70	0.2150
1973	0.5	0.0498	4.0	0.1733	466.83	0.1591
	0.6	0.0598	4.0	0.2024	588.96	0.1832
	0.7	0.0698	4.0	0.2301	722.16	0.2056
	0.8	0.0797	4.0	0.2564	865.78	0.2262
	0.9	0.0897	4.0	0.2814	1,019.02	0.2453
	1.0	0.0997	4.0	0.3050	1,180.73	0.2629
	0.5	0.0498	6.0	0.1691	590.12	0.1556
	0.6	0.0598	6.0	0.1961	761.18	0.1780
	0.7	0.0698	6.0	0.2211	948.51	0.1983
	0.8	0.0797	6.0	0.2442	1,149.53	0.2167
	0.9	0.0897	6.0	0.2656	1,361.12	0.2333
	1.0	0.0997	6.0	0.2853	1,580.16	0.2482

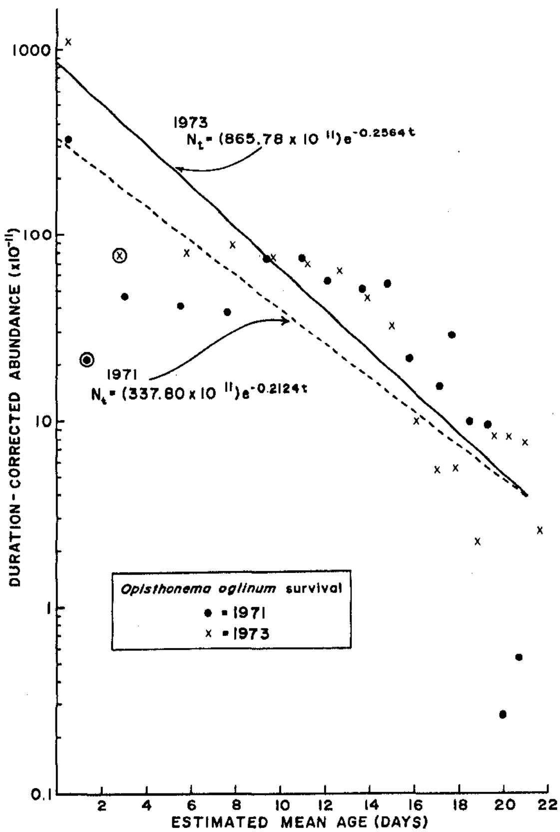


FIGURE 11.—Estimated abundance of egg and larval stages of thread herring in the eastern Gulf of Mexico in 1971 and 1973. Abundance is expressed as a function of estimated age. Fitted exponential functions give estimates of the instantaneous rates of decline in abundance for eggs and larvae up to 21 days of age. The two symbols enclosed in circles represent nonfully vulnerable length classes and were not included in the regression of instantaneous decline.

abundance of young larvae was underestimated in each year. If this is true, then mortality estimates (Table 8) are too low. Also, if growth was not exponential, but linear, then abundance of larvae in older age-classes was overestimated and mortality rates of thread herring larvae would be greater than estimates from the regression coefficients (Table 8).

Houde (1977a) estimated instantaneous mortality coefficients from abundance at age data for round herring larvae to be $Z = 0.1317$ in 1971–72 and $Z = 0.1286$ in 1972–73. These estimates are lower than the most probable rates for thread herring laryae. The estimated mortality coefficient ($Z = 0.2835$) for scaled sardine larvae in 1973 was similar to those for thread herring (Houde 1977b). The thread herring instantaneous mortality coefficients for abundance at age data were similar to those for Pacific sardine ($Z = 0.16$–0.17) (Ahlstrom 1954), jack mackerel ($Z = 0.23$) (Farris 1961), and Japanese mackerel ($Z = 0.3295$) (Watanabe 1970), but higher than those reported for Japanese sardine ($Z = 0.1279$) (Nakai and Hattori 1961) or plaice ($Z = 0.0209$ to 0.0685) (Bannister et al. 1974).

Estimated numbers and percentage survival of thread herring at hatching, 5.5 mm SL, and 15.5 mm SL were calculated given three possible instantaneous growth rates, corresponding to mean daily growth increments of 0.6, 0.8, and 1.0 mm (Table 9). The estimating procedure used parameters from the exponential functions describing decline in numbers by age (Table 8) and the age-at-length data assuming exponential growth (examples in Table 7). The estimated number of spawned eggs, from Table 3, varied by more than a factor of three between 1971 and 1973, yet the estimated number of survivors when larvae begin to transform to juveniles (15.5 mm SL) (Richards et al. 1974) was not much different between years (Table 9). Percentage survival from spawned egg to that stage did vary between 1971 and 1973; an estimated mortality of >99% occurred in 1973, but mortality was approximately

TABLE 9.—Estimated numbers and percentages of survivors of thread herring at hatching, 5.5 mm SL, and 15.5 mm SL in 1971 and 1973. Estimates are made at three possible growth rates (see Table 8). Duration of the nonfully vulnerable larval stages was set at 1.0 days for 1.1 to 4.0 mm larvae in 1971 and at 4.0 days for 1.1 to 5.0 mm larvae in 1973. The number of spawned eggs in each year was based on the estimates in Table 3. Predicted numbers at hatching, 5.5 mm, and 15.5 mm are calculated from exponential functions based on Table 8 data.

Year	Instantaneous growth coefficient, g	Number of spawned eggs ($\times 10^{11}$)	Instantaneous mortality coefficient, Z	Number hatching ($\times 10^{11}$)	Percent mortality[1] to hatching	Number of 5.5-mm larvae ($\times 10^{11}$)	Percent mortality to 5.5 mm	Number of 15.5-mm larvae ($\times 10^{11}$)	Percent mortality to 15.5 mm
1971	0.0598	326.77	0.1650	224.98	31.2	84.85	74.0	4.86	98.5
	0.0797	326.77	0.2124	282.60	13.5	104.59	68.0	6.61	98.0
	0.0997	326.77	0.2575	337.98	—	122.22	62.6	8.42	97.4
1973	0.0598	1,105.93	0.2024	496.88	55.1	171.35	84.5	5.14	99.5
	0.0797	1,105.93	0.2564	698.02	36.9	196.19	82.3	7.02	99.4
	0.0997	1,105.93	0.3050	913.87	17.4	213.98	80.7	9.00	99.2

[1]Hatching assumed to occur at 0.84 days.

98% in 1971. Estimated percentage mortalities from spawning to hatching (Table 9) were lower for thread herring than those estimated previously for round herring (35 to 90%) from the eastern Gulf (Houde 1977a). They also were lower than those (>85%) estimated for scaled sardines (Houde 1977a) in 1973. The 5.5 mm SL stage represents postyolk-sac thread herring larvae that had succeeded in starting to feed; percentage mortality to that stage was estimated to range from 62.6 to 84.5% (Table 9).

The 15.5-mm stage would be attained at 18.5 to 19.0 days if the instantaneous growth coefficient was 0.0797 (equals 0.80-mm mean daily growth increment) (Table 7). At that growth rate 20 larvae/1,000 spawned eggs would have survived to 15.5 mm SL in 1971, but only 6 larvae/1,000 eggs would have survived to 15.5 mm in 1973 (Table 9). The expected number of thread herring survivors at 15.5 mm/1,000 spawned eggs was similar to that estimated for round herring from the eastern Gulf (Houde 1977a), but greater than the number estimated for scaled sardines (Houde 1977b).

SUMMARY

1. Spawning by thread herring in the eastern Gulf of Mexico occurred from February to September, based on catches of larvae from March through September and eggs from May through August. Most spawning took place from April to August in depths <30m, within 50 km of the coast. Spawning was most intense between lat. 26°00′N and 28°00′N (Fort Myers to Tampa Bay, Fla.).

2. Eggs were collected when surface temperatures ranged from 22.5° to 30.3°C and when surface salinities were 32.4 to 36.8‰. Larvae ≤5.0 mm SL were collected at surface temperatures from 18.5° to 30.9°C and at surface salinities from 27.3 to 36.9‰. Most eggs and ≤5.0-mm larvae were taken when surface temperature exceeded 25°C and when surface salinity was above 35.0‰.

3. Estimates of adult biomass ranged from 108,000 to 372,000 metric tons in 1971 and 1973. The 0.95 confidence intervals on 1971 and 1973 estimates range from 72,800 to 428,800 metric tons.

4. The estimated concentration of adult thread herring biomass from the coast to the 50-m depth contour was in the range of 6.8 to 40.2 kg/ha. The total area in which thread herring occurred was 106.7×10^5 ha.

5. Estimates of annual potential yield to a fishery, based on 1971 and 1973 biomass estimates, ranged from 27,500 to 186,200 metric tons of adult thread herring. The potential yield, based on the mean of 1971 and 1973 biomass estimates, was between 60,300 and 120,600 metric tons.

6. Larval abundance was greater in 1973 than in 1971. Mortality rates for larval thread herring were estimated by length and for estimated ages. For lengths, the instantaneous coefficients of decline in catches were $Z = 0.3545$ in 1971 and $Z = 0.3942$ in 1973, corresponding to 29.9 and 32.6% losses per millimeter of growth. For age, the most probable daily mortality estimates were $Z = 0.2124$ in 1971 and $Z = 0.2564$ in 1973, which correspond to daily loss rates of 19.1 and 22.6%.

7. It is probable that >99% mortality occurred between spawning and the 15.5-mm stage in 1973, and that approximately 98% mortality occurred in 1971. About 20 larvae/1,000 spawned eggs were estimated to have survived to 18.5 to 19.0 days after hatching and 15.5 mm SL in 1971, but only 6 larvae/1,000 eggs were estimated to have survived to that stage in 1973.

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