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Results of Abundance Surveys of Juvenile Atlantic and Gulf Menhaden, *Brevoortia tyrannus* and *B. patronus*

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U.S. Department of Commerce

NOAA TECHNICAL REPORT NMFS

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U.S. DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
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ABSTRACT

The estuarine populations of juvenile Atlantic and gulf menhaden (*Brevoortia tyrannus* and *B. patronus*) were sampled during two-boat, surface-trawl, abundance surveys extensively conducted in the 1970s. Juvenile Atlantic menhaden were sampled in 39 estuarine streams along the U.S. Atlantic coast from northern Florida into Massachusetts. Juvenile gulf menhaden were sampled in 29 estuarine streams along the Gulf of Mexico from southeast Texas into western Florida. A stratified, two-stage, cluster sampling design was used. Annual estimates of relative juvenile abundance for each species of menhaden were obtained from catch-effort data from the surveys. There were no significant correlations, for either species, between the relative juvenile abundance estimates and fishery-dependent estimates of year-class strength. From 1972 to 1975, the relative abundance of juvenile Atlantic menhaden in north Atlantic estuaries decreased to near zero.

Introduction

Fishery managers entrusted with determining population status, or more critically, the permissible level of harvest for fisheries with variable levels of recruitment, would be aided considerably by estimates of prerecruit year-class strength. With an additional knowledge of recruitment patterns, recommendations could ultimately be made that would maximize yield while reducing risk for a particular fishery resource. Biologists can use a variety of fishery-independent sampling techniques, such as sampling-gear catch-effort indices, hydroacoustic and sonar surveys, or mark-recapture programs, for obtaining estimates of prerecruit year-class strength.

The U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries,[1] expanded their menhaden research program in 1955 to determine whether seasonal fluctuations in commercial purse-seine landings of Atlantic menhaden (*Brevoortia tyrannus*) could be forecasted. This research received additional impetus in the 1960s as landings by the commercial purse-seine fleet steadily declined from the record highs of the mid-1950s (Ahrenholz et al. 1987). One approach used to pursue this objective was to estimate the relative abundance of prerecruit juvenile (young-of-the-year) Atlantic menhaden (Henry 1971, Turner 1973). In addition to the juvenile Atlantic menhaden sampling, which began in 1956, sampling for juvenile gulf menhaden (*B. patronus*) was started in 1964. In the early 1970s, sampling activities culminated in extensive Atlantic and gulf juvenile-abundance trawl surveys that were conducted through 1978. After 1978, the surveys were discontinued because preliminary analyses revealed that the objective of forecasting year-class strength with the survey data could probably not be attained (Ahrenholz et al. 1979). Results of subsequent analyses (presented here) with completed data sets confirmed the earlier finding.

The objectives of this report are to 1) present aspects of estuarine sampling that should be considered when attempting to estimate juvenile abundance, especially of a marine migrant species; 2) demonstrate the need, as well as the large time requirement for verifying juvenile survey results; and 3) document these menhaden surveys, since a large amount of ecological and biological information on menhaden were obtained from these studies.

In this report we first discuss the chronology and salient aspects of what we have termed the exploratory-developmental period of juvenile menhaden abundance sampling. During this period, biologists examined the results for several sampling techniques. We then discuss the trial-implementation period, when extensive, systematic trawl surveys were conducted. We then conduct verification analyses of the survey data. Finally, we examine some initial assumptions relating to geographical and temporal aspects of the sampling design, and suggest some additional directions for the enumeration attempts.

[1]Presently the National Marine Fisheries Service, NOAA, U.S. Dept. of Commerce.

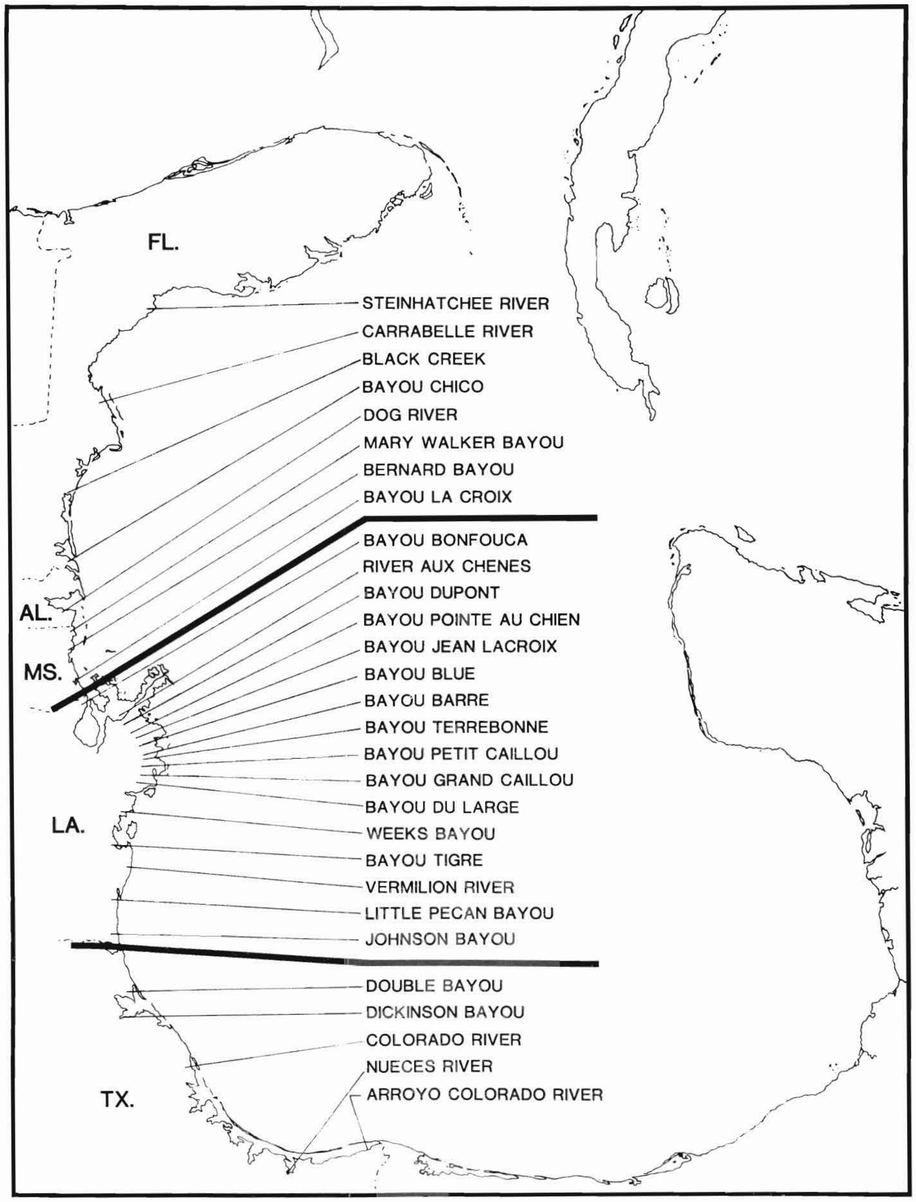

Figure 1
Juvenile gulf menhaden survey streams, 1971–78.

Exploratory-developmental period

Research emphasis for estimating year-class strength focused on the obligatory estuarine phase of the Atlantic menhaden's life history, following suggestions made by Massmann (1953) and Massmann et al. (1954). Because menhaden occupy relatively small estuarine streams during their late-larval and juvenile stages, each developing year-class appeared to be readily available for sampling. Furthermore, earlier workers believed this would result in more accurate estimates than those from larvae that occur in the ocean (Turner 1973).

Sampling began in 1956 and consisted of mark-recapture studies conducted in an estuarine tributary of Indian River, Delaware (Pacheco and Grant 1966). The program expanded into other areas and employed additional sampling techniques. By 1961, abundances of juvenile menhaden inhabiting four coastal estuarine streams (Broad Creek, North Carolina; Felgate Creek, Virginia; White Creek, Delaware; and Childs River, Massachusetts) were estimated using mark-recapture methods and catch-effort data from beach seining and surface trawling. These sampling methods were used in an increasing number of estuaries along the Atlantic coast through 1966. Although the results of all three were similar, Turner (1973) concluded that the surface trawl was the most expedient and widely applicable method. Trawling became the only estuarine sampling method retained. The number of streams sampled by surface trawl increased from 10 in 1962 to 65 in 1968. Trawl sampling for juvenile Atlantic menhaden was not conducted during 1970 or 1971.

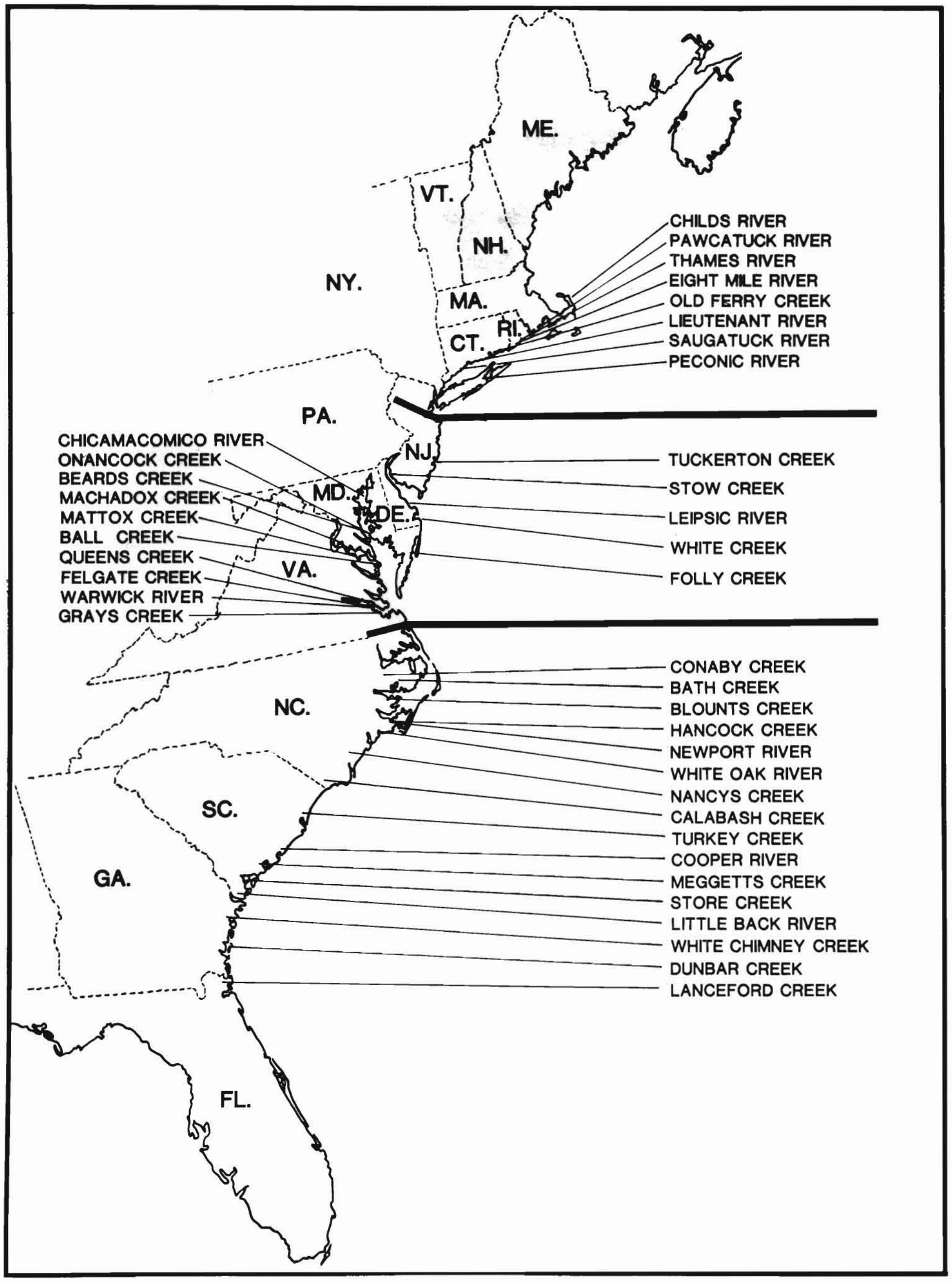

Figure 2
Juvenile Atlantic menhaden survey streams, 1972–78.

In 1964, the program was expanded to estimate the relative abundance of juvenile gulf menhaden along the U.S. coast of the Gulf of Mexico (Turner et al. 1974). Since the general life history of this species is similar to that of the Atlantic menhaden, the same basic strategy of sampling was employed. Surface trawling was the only sampling method used.

In addition to the sampling methods discussed, an aerial survey was initiated in 1962 on both the Atlantic and Gulf coasts to estimate the fish-school surface area of juveniles migrating from coastal estuarine streams into coastal waters. Plagued by several operational and interpretational problems, the aerial surveys were discontinued after 1971 (Ahrenholz et al. 1979).

Trial-implementation period

Surface-trawl surveys were conducted with nearly constant sampling effort from 1971 along the U.S. Gulf of Mexico coast and from 1972 along the U.S. Atlantic coast, through

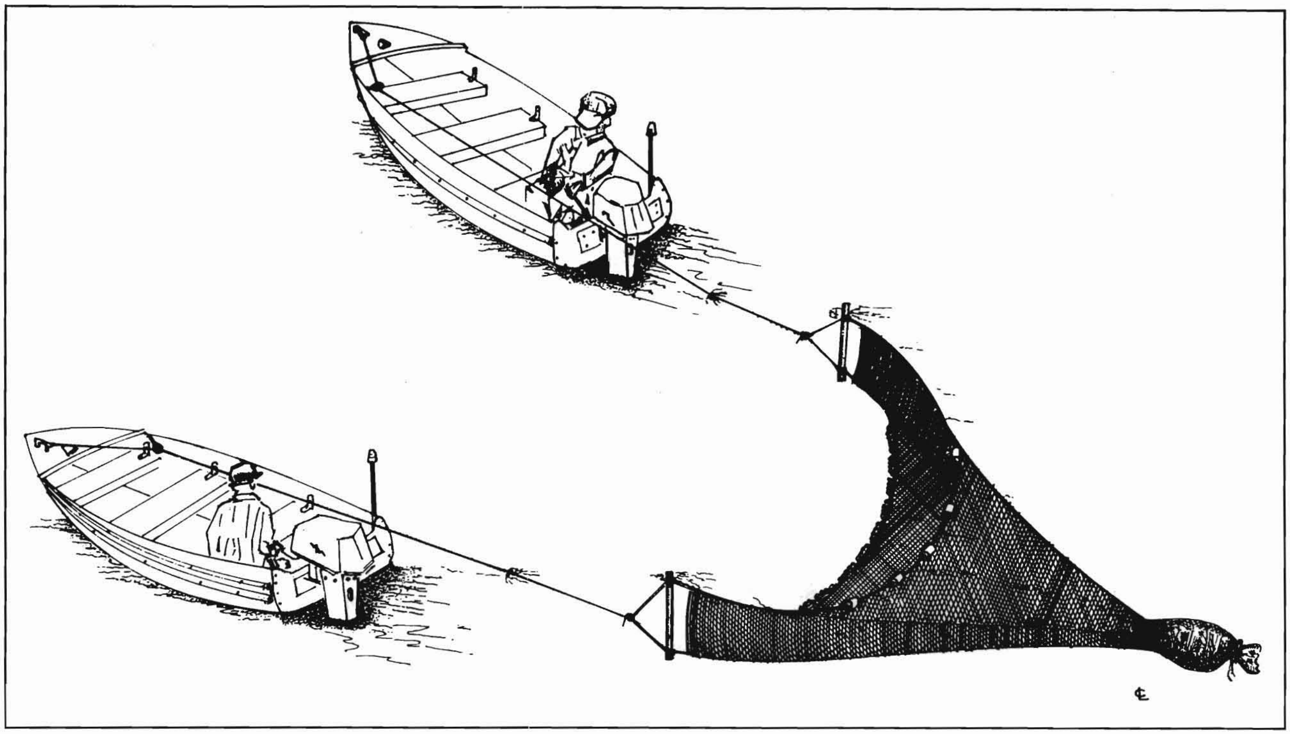

Figure 3
Operation of surface trawl for juvenile Atlantic and gulf menhaden surveys. (Drawing courtesy of Curtis Lewis, Beaufort Lab., Natl. Mar. Fish. Serv.)

1978. These surveys represented an application of knowledge acquired during the earlier feasibility sampling. Data from the 1970s were comparable and were used to estimate year-class strength and, thus, the efficacy of the survey design.

Estuarine streams selected as sampling areas for each coast appeared to be representative of other streams in the respective surrounding areas. These streams were, for the most part, drawn from the larger set of estuarine streams that had been sampled during the earlier exploratory-developmental period of the program. Selection of a stream during the earlier portion of the program, or the final inclusion into the survey itself, was not purely random. Selection required that each stream be accessible with a launching ramp for trailered boats. Secondly, the streams would have at one time or another been shown to contain menhaden. Estuarine locations ranged from eastern Texas into western Florida on the Gulf of Mexico (Fig. 1), and from northern Florida into Massachusetts along the Atlantic coast (Fig. 2).

Each stream was sampled by a series of tows evenly distributed along the length of the stream. Sites generally ranged from an upstream limit, where the stream was just large enough to deploy sampling gear, to the stream mouth. Each stream would normally have a salinity gradient along its length, which usually ranged from somewhere near 0‰ to 10 or 20‰. The actual number of tow sites per stream varied, ranging on the Gulf coast from 3 to 11, and on the Atlantic from 3 to 8.

Because of the large number of estuaries and vast area involved, each estuary was sampled only once during a single annual survey. The Gulf of Mexico estuaries were surveyed in June, Atlantic estuaries from Florida to New Jersey in June and July, and the estuaries north of New Jersey in September.

Since juvenile menhaden are not effectively sampled in daylight hours when the water is relatively clear, those streams which normally had relatively clear water were sampled at night. Night sampling was, however, impractical to adopt for all streams. On the Gulf coast, streams east of the Mississippi River delta were surveyed at night. On the Atlantic coast, several individual streams from Florida to New Jersey, as well as all streams north of New Jersey, were sampled at night.

Each tow site was sampled by a 5-minute surface-trawl haul. A standardized surface trawl was pulled between two outboard-motor boats (Fig. 3). The trawl was modified after one reported by Massmann et al. (1952) (Fig. 4). Variables recorded for each tow site were surface salinity, secchi depth, temperature, and number of juvenile menhaden captured. Relatively small catches were saved in their entirety, while large catches were subsampled. Samples were preserved in formaldehyde solution. The juvenile menhaden were counted and measured (fork length) in the laboratory.

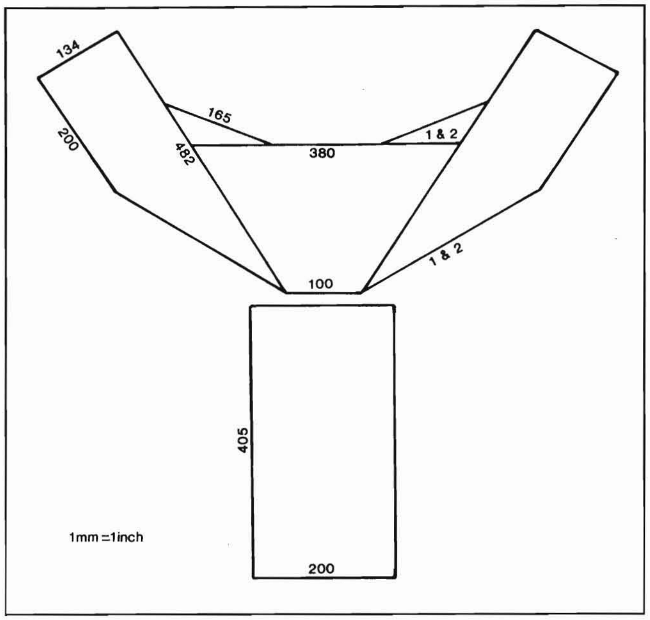

Figure 4
Standard surface trawl used in juvenile Atlantic and gulf menhaden surveys. Head rope 7.5 m, foot rope 6.7 m, length 6.1 m, and height 0.9 m. Constructed of 6 mm bar-length multifilament knotted nylon netting.

Table 1
Planned distribution of sampling effort by region and estuarine stream for juvenile Atlantic menhaden survey, 1972–78.

Region	Number of streams	Number of tows
North Atlantic	8	32
Middle Atlantic	5	27
Chesapeake Bay	10	50
South Atlantic	16	91
Totals	39	200

Table 2
Planned distribution of sampling effort by region and estuarine stream for juvenile gulf menhaden survey, 1971–78.

Region	Number of streams	Number of tows
Texas	5	38
Louisiana	16	111
Eastern gulf	8	45
Totals	29	194

Verification analysis

Catch-per-tow (CPT) values calculated from trawl samples are measures of relative juvenile menhaden abundance, not actual (or absolute) population size. A series of consistently derived, annual estimates of relative juvenile abundance can be functionally compared (e.g., by regression analysis) with a second, independently derived estimate of absolute population size, and thus "calibrated" (see Eberhardt 1978). The estimates of absolute population (year-class) size for this study were derived from commercial-fishery catch statistics. If a significant, positive relationship exists, the results of the survey have been verified, i.e., there is a high probability that the survey is providing the type of information it was designed to provide.

Estimation of relative abundance

Sampling activities can be described by a stratified two-stage cluster sampling design. Each coast was divided into several regions (strata). Individual streams were the primary sampling units, and individual tows were taken as secondary units. For analysis, the Gulf coast was divided into three geographic regions: Texas, Louisiana, and the eastern Gulf (Mississippi, Alabama, and the Gulf coast of Florida) (Fig. 1). The Atlantic coast was divided into four regions: South Atlantic, Chesapeake Bay, middle Atlantic, and north Atlantic (after June and Reintjes 1959) (Fig. 2). The total numbers of streams and tow sites by region planned for the Atlantic and Gulf coast are given in Tables 1 and 2. Weighting factors for regional means were obtained from estimates of relevant habitat area given in the literature (USFWS 1970) (Tables 3 and 4). Estimates of estuarine area were retained as acre units (as opposed to hectares) for convenience in calculation, as each tow of the trawl sampled approximately one surface acre. Hence, each acre of potential estuarine habitat represents a potential secondary sampling unit for purposes of the computations.

The weighted-mean CPT (estimate of relative abundance) and confidence intervals for each coast and year were then calculated using formulae from Cochran (1963) (Appendix). Regardless of size, all fish captured by the trawl were assigned equal weight to estimate the mean. Results for this series of calculations, done with arithmetic (nontransformed) data, are given in Tables 5 and 6 for the Atlantic and Gulf surveys. Results for computations with $\log_e(y+1)$ transformations are presented as antilogarithms minus one in Tables 7 and 8. Since the antilogarithms of the means (minus one) of the transformed data closely approximate geometric means, they are referred to as such here.

Because of the fixed (nonrandom) nature of the particular streams and tow sites, these estimates of relative abundance are biased. This is not a serious problem, however. With respect to within-years, the only real violation of the random assumption is that the tows are arranged more or less systematically along the length of each estuarine stream. This characteristic increases the probability that the entire range of fish densities in a stream is sampled. With respect to among-year comparisons, it was assumed that differences (variance) in CPT associated with stream and local site factors would be minimized among-years by using the same sites.

Table 3

Estimated habitat of Atlantic menhaden in U.S. Atlantic estuarine areas, adjusted for losses to dredge and fill operations, and used to obtain regional weights for juvenile abundance estimates.

Region and state	Acres[1]
North Atlantic	
Massachusetts	29,000
Rhode Island	13,800
Connecticut	18,200
New York	112,700
Total	173,700
Middle Atlantic and Chesapeake Bay[2]	
New Jersey	357,400
Delaware	143,900
Maryland	375,300
Virginia[3]	425,700
Total	1,302,300
South Atlantic	
North Carolina	785,700
South Carolina	265,100
Georgia	124,200
Florida[4]	73,650
Total	1,248,650

[1]USFWS (1970)
[2]Virginia and Maryland acreage was divided between middle Atlantic (0.15) and Chesapeake Bay (0.85).
[3]Middle Atlantic acreage totaled 621,450 and Chesapeake Bay totaled 680,850.
[4]This value represents 10% of all Florida's estuaries and is assumed to represent that portion of the state's estuaries within the coastal range of Atlantic menhaden.

Table 4

Estimated habitat of gulf menhaden in U.S. Gulf of Mexico estuarine areas, adjusted for losses to dredge and fill operations, and used to obtain regional weights for juvenile abundance estimates.

Region	Acres[1]
Texas	260,000
Louisiana	2,011,500
Eastern Gulf	
Mississippi	74,600
Alabama	130,800
Florida[2]	184,125
Total	389,525

[1]USFWS (1970)
[2]25% of Florida acres were considered to be within the range of gulf menhaden.

Table 5

Actual sampling effort, annual stratified arithmetic mean catch/tow, and 95% confidence intervals (CI) for juvenile Atlantic menhaden survey, 1972–78.

Year class	No. of streams	No. of tows	y_{st}	95% CI
1972	39	200	3215.8	<0.0–6738.8
1973	39	200	1578.2	639.8–2516.6
1974	39	200	1417.4	741.4–2093.4
1975	39	200	653.3	392.4– 914.2
1976	39	200	2753.5	830.7–4676.3
1977	36	183	5248.5	951.4–9545.6
1978	39	200	1850.4	442.8–3258.0

Table 6

Actual sampling effort, annual stratified arithmetic mean catch/tow, and 95% confidence intervals (CI) for juvenile gulf menhaden survey, 1971–78.

Year class	No. of streams	No. of tows	y_{st}	95% CI
1971	29	194	10,517.2	5,716.3–15,318.1
1972	29	191	3,448.4	1,790.3– 5,106.5
1973	29	194	7,439.9	2,031.4–12,848.4
1974	27	186	7,363.8	2,752.9–11,974.7
1975	27	183	2,580.8	520.4– 4,641.2
1976	29	191	6,927.1	2,864.5–10,989.7
1977	29	194	3,626.8	1,457.5– 5,796.1
1978	29	194	8,732.9	4,146.1–13,319.7

Table 7

Actual sampling effort, annual stratified geometric mean catch/tow, and 95% confidence intervals (CI) for juvenile Atlantic menhaden survey, 1972–78.

Year class	No. of streams	No. of tows	y_{st}	95% CI
1972	39	200	86.7	28.0–264.7
1973	39	200	88.9	39.8–197.0
1974	39	200	52.7	21.5–127.3
1975	39	200	27.2	11.3– 63.4
1976	39	200	70.8	29.0–171.5
1977	36	183	135.6	28.0–633.3
1978	39	200	59.1	24.6–141.2

Table 8
Actual sampling effort, annual stratified geometric mean catch/tow, and 95% confidence intervals (CI) for juvenile gulf menhaden survey, 1971–78.

Year class	No. of streams	No. of tows	y_{st}	95% CI
1971	29	194	950.1	421.5–2145.2
1972	29	191	212.7	88.3– 510.6
1973	29	194	497.5	167.6–1474.1
1974	27	186	622.6	277.0–1399.1
1975	27	183	245.3	105.4– 564.3
1976	29	191	490.0	237.4–1010.2
1977	29	194	352.3	137.0– 903.5
1978	29	194	407.0	128.3–1287.4

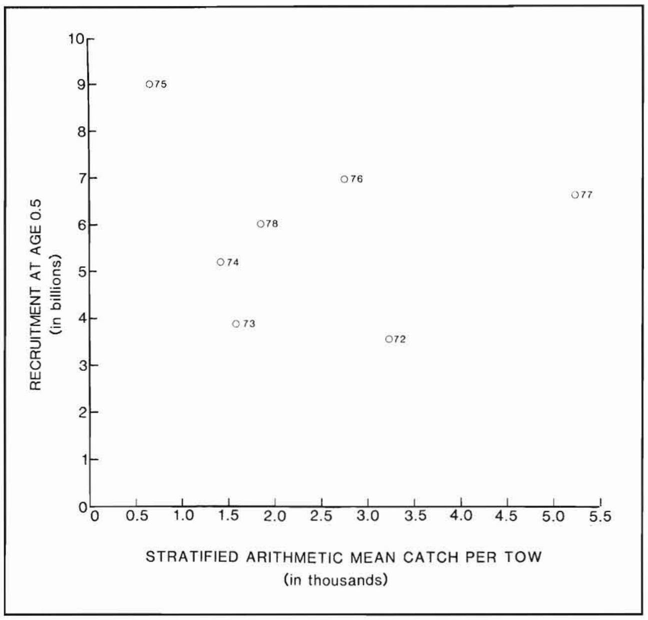

Figure 5
Stratified arithmetic mean catch-per-tow of juvenile Atlantic menhaden in relation to subsequent recruitment at age 0.5.

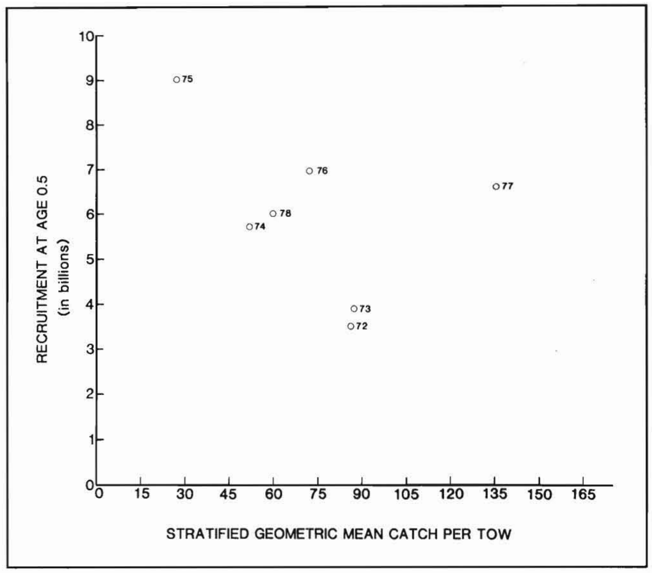

Figure 6
Stratified geometric mean catch-per-tow of juvenile Atlantic menhaden in relation to subsequent recruitment at age 0.5.

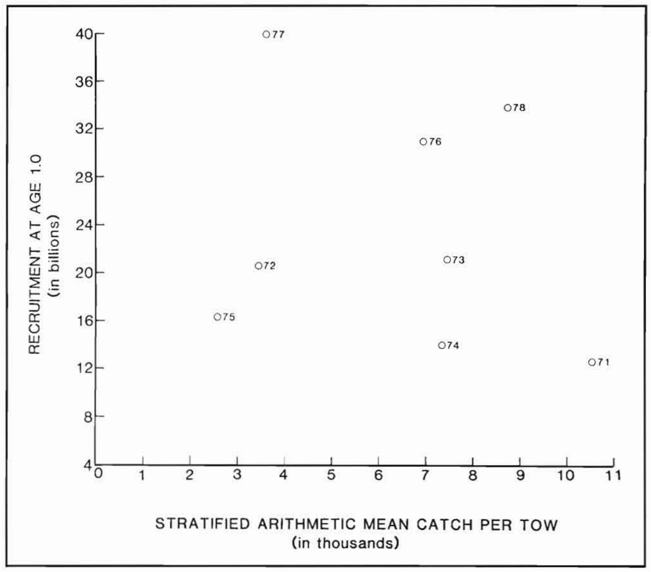

Figure 7
Stratified arithmetic mean catch-per-tow of juvenile gulf menhaden in relation to subsequent recruitment at age 1.0.

Correlation tests of survey means with year-class strength estimates

Virtual population analysis (VPA) year-class size estimates for Atlantic menhaden from the 1972–78 year-classes were obtained from Ahrenholz et al. (1987), and for gulf menhaden from the 1971–78 year-classes from Vaughan (1987). Correlation analyses of the arithmetic and geometric weighted-mean CPT estimates with appropriate recruitment estimates were performed. Resultant correlation coefficients were not significant ($p>0.10$). Any apparent relationships are too weak to be useful for forecasting year-class strength (Figs. 5–8).

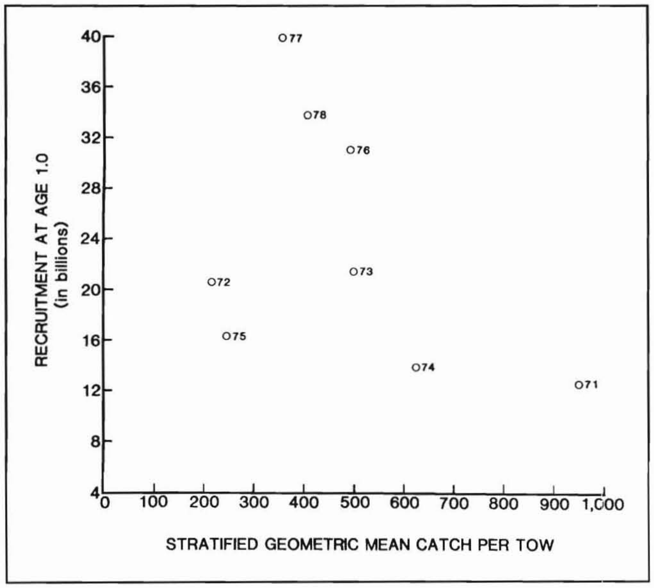

Figure 8
Stratified geometric mean catch-per-tow of juvenile gulf menhaden in relation to subsequent recruitment at age 1.0.

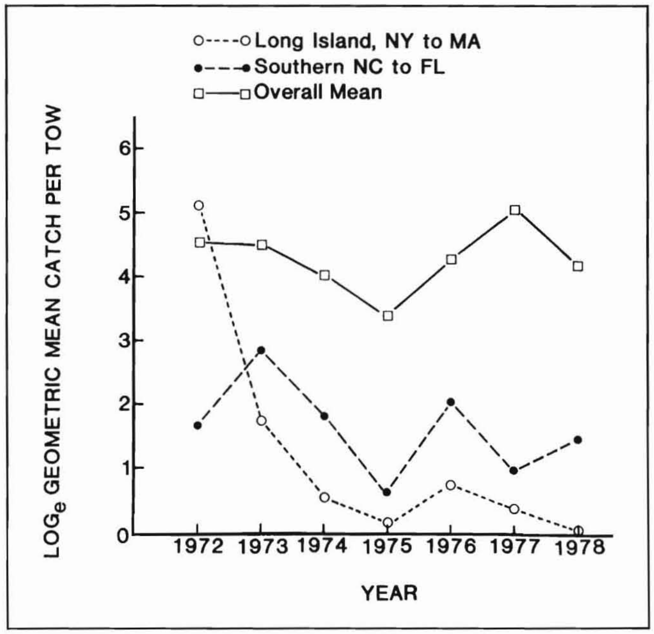

Figure 9
Log_e of the geometric mean catch-per-tow of juvenile Atlantic menhaden in the north Atlantic area, in the southern portion of the south Atlantic area, and in all areas combined.

Trends in regional abundance

Although combined regional estimates of abundance appear to be insensitive to the degree of fluctuations actually observed in year-class strength, some regional trends in reproductive success were documented by the survey. In the north Atlantic area during 1972–75, numbers of juveniles caught per tow fell from a geometric mean of about 200 to near 1, and did not recover during the remaining years of the survey (through 1978) (Fig. 9). Based on field observations associated with other studies, recovery had not occurred through the 1985 year-class.

A similar but less extreme reduction in reproductive success has occurred in the more southerly portion of the south Atlantic area (from Calabash Creek, North Carolina, to northern Florida). Fluctuations in abundance for the remainder of the south Atlantic area and the remaining two regions more or less parallel total abundance estimates.

Critical conditions and assumptions

Although many minor factors can affect the relationship of relative abundance estimates and estimates of year-class strength, a strong correlation would be expected if the following major conditions were met:

1 A strong functional relationship exists between the true number of juveniles alive at the time of the survey and the number that are subsequently recruited into the fishery.

2 Catches per 5-minute trawl sample reflect what is actually in the stream. (A consistent bias is acceptable here.)

3 The annual survey was conducted at a time when juvenile populations in the estuarine streams are reasonably stable, comprising individuals that will compose the bulk of the recruited year-class, and are of a size that makes them vulnerable to the trawl (~35–60 mm).

4 Regional stream densities are a constant proportion of the population in that general area each year. Stream densities could have a degree of bias, higher or lower than surrounding estuarine waters (bays, sounds, and rivers), as long as the bias is consistent among years.

5 The survey is conducted in a uniform manner each year (e.g., same gear, fished the same).

6 A suitable, reasonably accurate (or consistently biased) and precise estimate of recruited year-class strength is used.

Since a poor correlation exists between survey values and independent fishery estimates of abundance, any or all of the above conditions are suspect.

Inherent relationship between juveniles and recruits

A fundamental but apparently tacit assumption of all the juvenile sampling activity was that year-class strength was established by (or was very early into) the juvenile stage. This notion is generally accepted for most fishes (Savoy and Crecco 1988). A significant relationship between the relative abundance estimates and VPA year-class strength estimates could have provided direct evidence for this assumption.

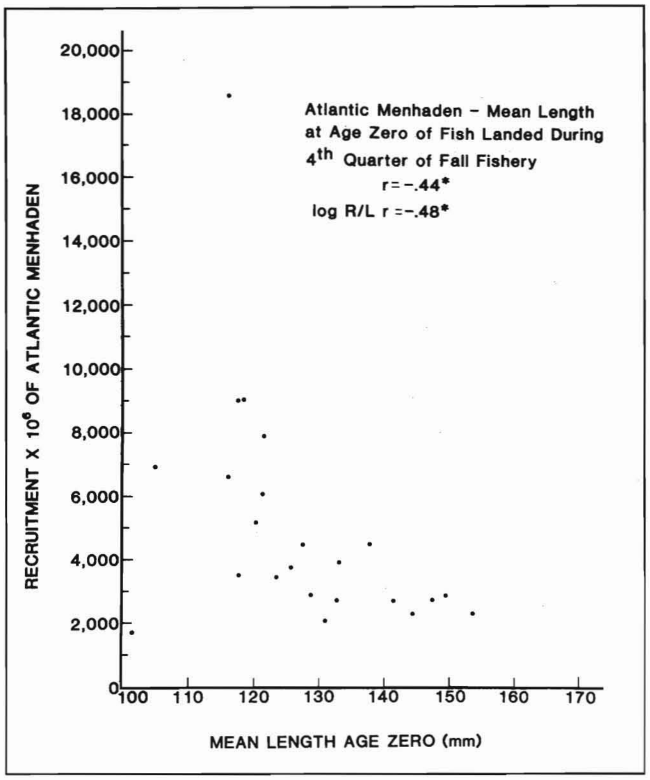

Figure 10
Estimates of year-class recruitment at analytical age 0.5 against mean length of young-of-the-year Atlantic menhaden landed December–January off North Carolina (* significant at 95% level).

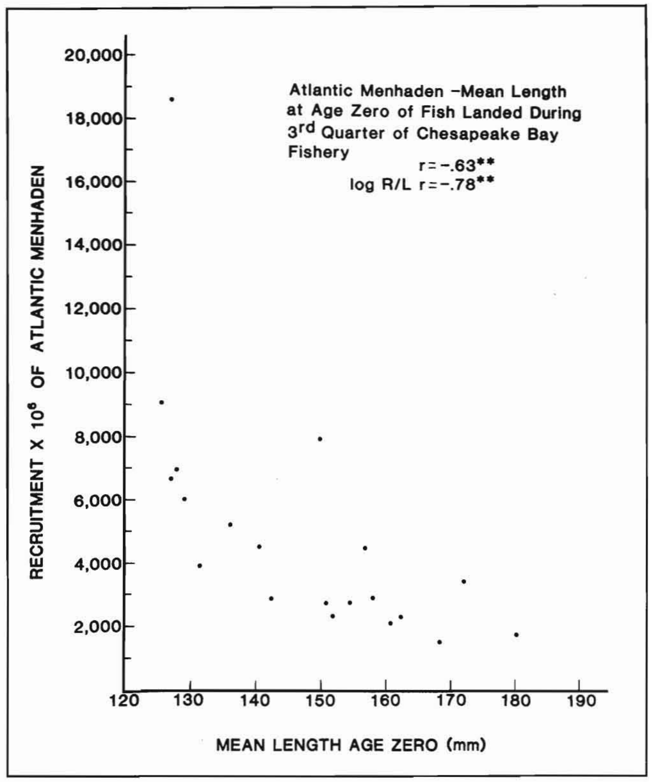

Figure 11
Estimates of year-class recruitment at analytical age 0.5 against mean length of young-of-the-year Atlantic menhaden landed September–November in Chesapeake Bay (significant at 99% level).**

Even stronger evidence (but not conclusive) would be provided if the relationship was subsequently persistent in future years of sampling. The converse is not necessarily true, however. The surveys were designed to take advantage of this relationship, not to test for it.

A relationship between numbers of Atlantic menhaden juveniles and subsequent numbers of recruits was observed indirectly by examining density-dependent growth. There was a significant inverse relationship between year-class size and the mean size (fork length) in purse-seine landings (Ahrenholz et al. 1979, Reish et al. 1985). This relationship is reviewed here with additional data. The average sizes of age-0 fish in purse-seine landings were inversely correlated with VPA estimates of year-class strength at age 0.5 (Figs. 10, 11). Since fork length is inversely correlated to estimates of year-class size, the numbers of juveniles alive during the estuarine growth period should also be correlated (positively) to estimates of year-class size. No similar relationship was found for gulf menhaden sampled from the commercial fishery (Nelson and Ahrenholz 1986). However, Guillory and Bejarano (1980) found a significant inverse relationship between mean length of juvenile gulf menhaden and commercial catch-per-unit-effort (CPUE) for age-1 fish. It should be noted, however, that their CPUE values (surrogate for year-class strength estimates) were not significantly correlated to Vaughan's (1987) VPA estimates of year-class size.

Representative nature of trawl catches

The accuracy and precision of trawl catch rates for estimating abundance are dependent upon local (site-specific) vulnerability of juvenile menhaden to the surface trawl. The width and depth of the stream where a haul is made influence vulnerability. Frequently, higher catches in any general area are made where the stream is narrow and/or shallow. This may be due to a decrease in potential avenues of escape for fish avoiding the trawl, but could be a real difference between habitat types. While the trawl is an effective means of capturing juvenile menhaden in coastal streams, it is less effective for capturing larger individuals in larger rivers and in bays and sounds.

Water clarity affects vulnerability. Quite simply, the clearer the water, the sooner fish can see the trawl and avoid it. A comparison of day- and night-tow trawl catches was made for some Gulf estuarine streams surveyed in 1971. The natural logarithms of the ratio of paired night and day tows were plotted against the mean secchi disc values measured during the day portion of the sampling (Fig. 12). These data pairs display a birectilinear relationship. When the mean secchi value is less than about 45 cm, the relative magnitude (and rate of change) of the difference between night and day catches is less than when the secchi exceeds 45 cm.

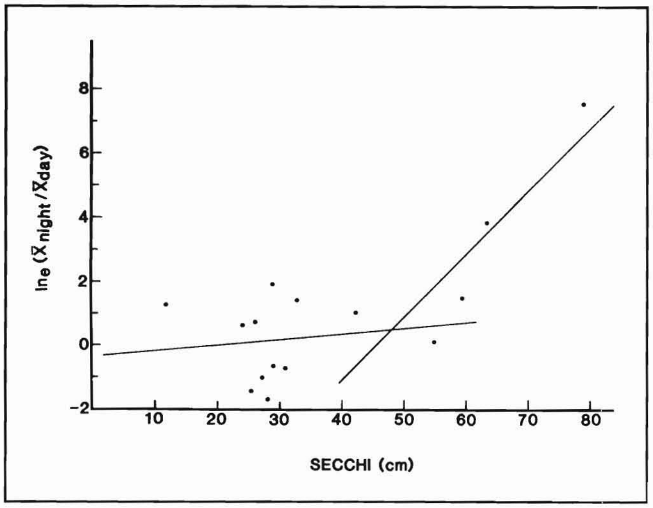

Figure 12
Log$_e$ of night/day catch-per-tow of juvenile gulf menhaden in relation to secchi depth (data fitted by eye).

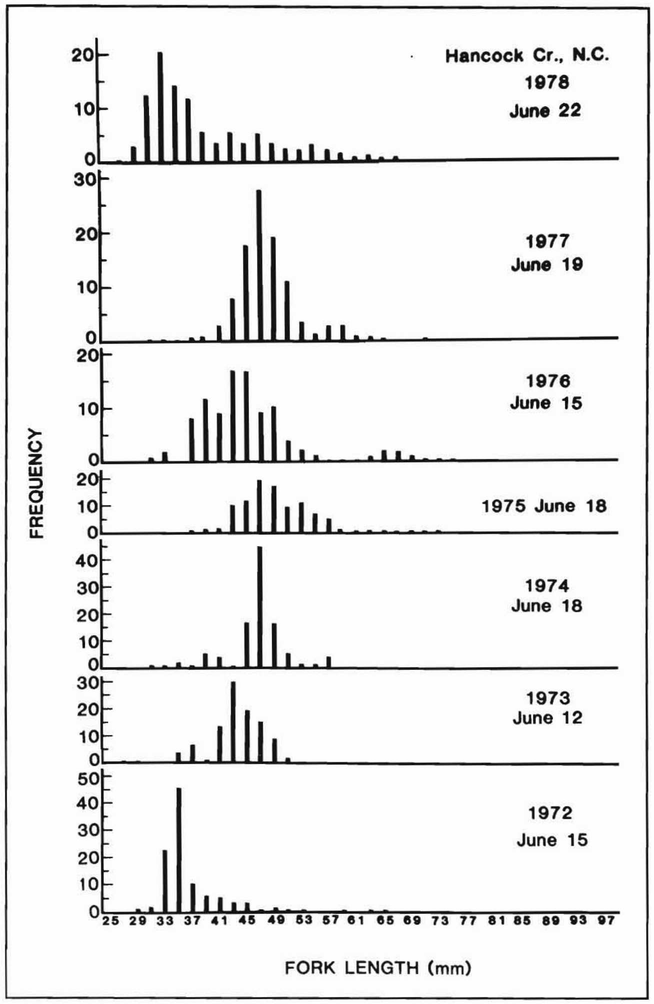

Figure 13
Weighted length-frequency distribution of trawl catches of juvenile Atlantic menhaden in Hancock Creek, North Carolina, 1972–78.

The size of fish affects its vulnerability to a surface trawl. Small fish can pass through the mesh, and larger fish can more readily avoid the trawl. Kroger et al. (1974) hypothesized that the trawl is best suited for juvenile menhaden 35–60 mm in fork length. Because it is believed that the survey was conducted at a time when most juveniles fall within this size range, size-induced sampling bias was not evaluated. A theoretical treatment of this potential problem is given by Kjelson and Colby (1976).

Any factors which affect the surface schooling behavior of young menhaden also affect the vulnerability of these fish to the trawl, because only the upper portion of the water column is sampled. Effects of temperature, tide, time of day, and wind on surface schooling of menhaden are unknown. Despite these difficulties, comparisons of trawl catches with haul-seine and mark-recapture studies reveal that the trawl is reasonably effective within the bounds described (Turner 1973, Kroger et al. 1974).

Timing of the survey

Survey timing was adopted in the late 1960s from results of earlier mark-recovery tests and catch-effort sampling. Size of fish was a principal criterion, but early workers also felt that the important fall-winter spawned juveniles were vulnerable during the June–July period. The survey was also conducted in September from waters surrounding Long Island, New York, northward to accommodate spring-summer spawned individuals (Kroger et al. 1974).

The suitability of the timing of the survey was evaluated by examining length-frequency distributions of juveniles in the catches. The distributions by stream were examined to determine if some orderly pattern or shape occurred. If an orderly distribution occurred, it was examined to determine if its modal group(s) was (were) within the range of effective vulnerability.

In some years, many estuarine streams whose data displayed orderly length progressions have a skewed length-frequency distribution, in which the left tail (smaller fish) has not yet formed, and the mode is in the late larval-prejuvenile size range. This indicates that larval or prejuvenile Atlantic menhaden may still be immigrating into the estuarine stream at the time of the survey. These small fish are not completely vulnerable to the trawl, as many will pass through the 6 mm bar-mesh tailbag. An example is given for Hancock Creek, North Carolina (Fig. 13). Similar conditions frequently occurred in Virginia and Maryland estuaries. During 1972 and 1978, the sampling season was apparently too early to adequately sample juveniles. During 1973–77 the small fish seemed to have been adequately sampled. Also, there appeared to be an incomplete representation of larger juveniles (>50 mm) in middle Atlantic and Chesapeake Bay estuarine waters. Thus, the survey may have been too late for early-spawned individuals, as these fish may have already emigrated from the sampling area. Similar but less-pronounced problems were also detected with some of the gulf menhaden length-frequencies.

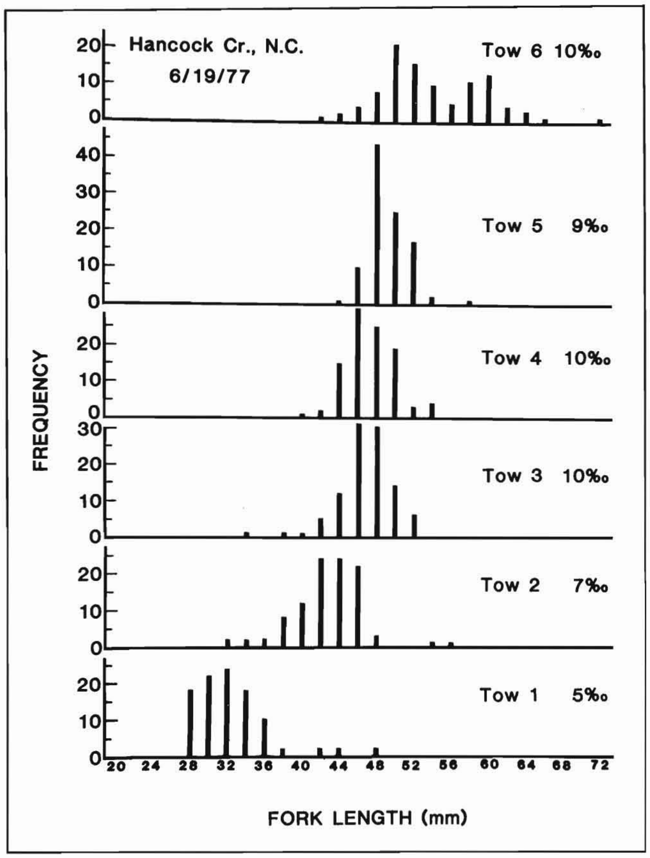

Figure 14

Length-frequency distribution by tow with salinity values for juvenile Atlantic menhaden from the 1977 trawl survey in Hancock Creek, North Carolina. (The 1977 weighted distribution of Figure 10 resulted from these distributions.)

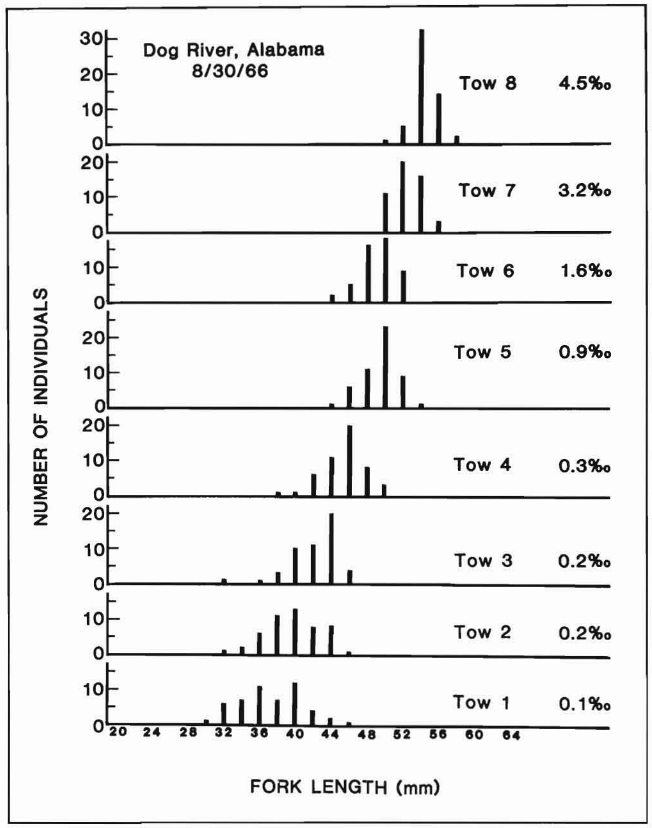

Figure 15

Length-frequency distribution by tow with salinity values for juvenile gulf menhaden from the 1966 trawl sampling activities in Dog River, Alabama.

Proportional representation of regional stream densities

Proportional representation of fish densities in regional streams in the survey was evaluated using length-frequency distributions. It was assumed that a near-constant proportional cross-section of the juvenile population was not sampled each year if patterns of length-frequency distributions were not similar within streams among years, when patterns were differentially mixed among streams within years.

Some survey design problems can be attributed to early assumptions on life history and the concept of ''primary nursery area.'' The hypothesis, developed early in the studies, was that young (late-larval and prejuvenile) menhaden migrate upstream into small estuarine streams, where near 0‰ salinity occurs, and then progressively move downstream as they grow. This hypothesis was supported by observed length-frequencies in a large portion of the streams sampled, as juveniles appeared to be stratified by size along the salinity gradient (Figs. 14 and 15). Not infrequently, however, similar size distributions were observed when no apparent salinity gradient existed (Fig. 16). Implicit to a survey design based on streams selected for the occurrence of a salinity gradient is the assumption that a population of fish once immigrated into a stream will remain in that stream until emigration in late summer or fall. Often, however, length-frequency distributions have missing portions, i.e., the right, left, or middle of an expected size-frequency distribution was not represented in the catches in one stream but was present in another stream during the same year. Thus, it appears that there are varying degrees of interchange between survey streams and the larger estuarine system to which they are tributary. The interchange appears to be especially common in the Chesapeake Bay system.

Uniform format of survey

Considerable care was exercised during the 1971–78 Gulf of Mexico and 1972–78 Atlantic surveys to keep all aspects of the survey as constant as possible. Some minor problems were created when a stream could not be adequately sampled due to periodic plant growth such as water hyacinths (*Eichornia crassipes*) or duck weed (*Lemna* sp.) as well as by irregular boat or barge traffic (note differences in sampling effort between Tables 1 and 2, and 5–8).

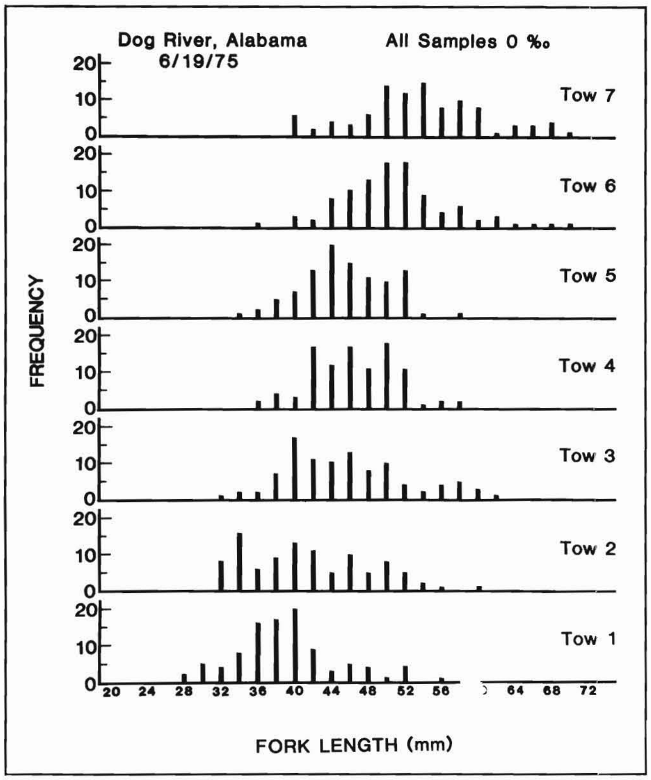

Figure 16

Length-frequency distribution by tow for juvenile gulf menhaden from the 1975 trawl survey in Dog River, Alabama (all salinity measurements were 0‰).

Suitability of independent estimates of year-class strength

Several potentially comparative estimates of year-class strength can be obtained from commercial purse-seine landing statistics and port samples: Landings in biomass in a fixed number of subsequent years, landings in numbers at a fixed age for a given year-class, catch-per-unit-effort for a given age, or VPA or cohort (backward sequential) analysis which estimates number of recruits at a fixed age for a given year-class. Each has advantages and disadvantages.

Estimates of landings in biomass, which during the time of the survey were dominated by age-2 fish on the Atlantic and age-1 fish in the Gulf of Mexico, are readily obtainable and are the most accurate. Strong correlations with survey means would depend on constant growth rates among age-classes, as well as each age group comprising a near-constant percentage of the landings among years. Also, the rate of fishing would have to be nearly constant. These conditions are not well met, so more adjustments would be needed.

To use age-specific landings in numbers as a measure of year-class strength, the rate of fishing on the age group would have to be (nearly) constant from year to year. This condition is only marginally met over short spans of years, so again adjustments need to be made. Sampling errors about estimates for the numbers-at-age landed appear to be at acceptable levels (see Chester 1984, Chester and Waters 1985).

CPUE estimates in some fisheries may be useful as a measure of abundance, if the interacting effects of other age groups can be separated. CPUE is usually inappropriate for use with the commercial menhaden purse-seine fishery. For CPUE to reflect true abundance, the catchability coefficient must be (nearly) constant. It is, however, inversely related to population size for both the Atlantic menhaden (Schaaf 1975) and gulf menhaden (Nelson and Ahrenholz 1986) fisheries.

VPA estimates are the closest to being true estimates of year-class strength. This analysis provides an estimate of number of recruits for a fixed time-period before significant fishing has taken place on the year-class. VPA for Atlantic menhaden should include age-0.5 fish, as large catches of estuarine-emigrating juveniles are frequently made. This is not the case for gulf menhaden, where age-1 is an appropriate recruitment age. A preliminary VPA estimate can be obtained only for the Atlantic fishery after landing and port-sampling data are processed for the complete fishing season on 3-year-old fish of a given year-class. The VPA estimates appear to be stable after the fifth year for the Atlantic and the third year for the Gulf fishery. Because of these constraints, a preliminary correlation analysis of the first 3 years of a survey would not have been possible for either fishery until about 7 years after the survey was initiated.

General discussion and conclusions

Although substantial biogeographical and life-history information for these two species of menhaden resulted from juvenile surveys, the original objective of the sampling was not achieved, i.e., the ability to forecast year-class strength. It appears that the survey suffered from assumptions that were not met.

Following the preliminary life-history studies and technique developments of the 1950s and 1960s, the survey was initiated and the format was "locked in." Since success would depend on the survey being conducted in a constant fashion, any new information pertinent to the survey design could not be implemented. Quite simply, a substantial investment had already been made in research funds and time. Initial assumptions could not be adequately evaluated as to whether or not the survey was effective until a sufficient number of years had passed. Continued adjustments would require additional years of data for testing, since the historic database would be incomplete or noncomparable.

Once sufficient data were in hand, the straightforward comparison of weighted mean CPT, using weighting factors derived independently from survey and catch data, with what are believed to be analytically the best available estimates of year-class strength, is fundamental. The lack of a reasonably strong (and significant) relationship is a logical and prudent stopping point for a survey of this type. A risk is present, however, as some analytical fault may lie with estimates of ages, numbers landed, and other factors associated with purse-seine, fishery-dependent measures of year-class strength.

The results of an extensive number of analyses were not reported here. These included multiple regressions, various weighting schemes, a number of derived measures of abundance, and stream or regional combinations in correlation analyses with a variety of types of fishery-derived measures of year-class strength. Without a preconceived hypothesis of cause and effect for variables selected in these analyses, approaches of this type are simply trial-and-error searches, and will no doubt result in one or more apparent significant relationships due simply to chance. The risk here, of course, is that one of the potential trial-and-error solutions is correct.

Development of a new survey format should be undertaken to incorporate new information from other studies and types of analyses that were not available or apparent during the inception of the discontinued survey. Emphasis should be placed on the geographic timing of the survey relative to parental spawning in the region, and on obtaining more useful sampling-stratification criteria.

The stratification criteria used here were geographic. These criteria apparently did not relate that strongly to actual differences in juvenile fish density. Significant reductions in the variance about the stratified mean CPT were not gained over a single-stage model (tow being the primary sampling unit), or a purely random sampling model.

Some promise with respect to an alternate approach is offered by the density-dependent growth relationship. While the observed correlations are not extremely strong, at least for forecasting purposes, they are encouraging considering the degrees of bias associated with length parameters derived from samples of purse-seine landings. The purse-seine catches are not systematic relative to time of year, and tend to be selective towards larger individuals. This tends to distort the apparent relationship on the left-hand portion of Figures 10 and 11, particularly for fishery data from North Carolina (Fig. 10).

Because of the selective size bias and attempts to reduce commercial catches of younger-age Atlantic menhaden (ASMFC 1981), no attempt was made to refine this relationship. Estimates of mean length from field sampling, which would parallel relative abundance sampling, may be a plausible approach. The discussions presented earlier on length-frequencies indicate that this aspect of sampling will also require substantial refinement. If this approach proves useful, a verification of the technique may be possible using data from historic surveys, once more in-depth analytical explanations of the observed length-frequency distributions are obtained.

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Appendix

Estimates of weighted mean catch-per-tow were obtained from the following stratified two-stage cluster sampling design. Equations are from Cochran (1963).

Given:

- L = number of regions (geographical strata),
- N_h = number of potential streams in region h,
- n_h = number of streams sampled in region h,
- $\bar{M}_h$ = mean stream size (of those sampled) in region h (equivalent to mean number of potential tows),
- M_{hi} = size of stream i, region h,
- m_{hi} = number of tows in stream i, region h,
- f_{1h} = finite population correction for streams by region (n_h/N_h),
- f_{2hi} = finite population correction for tows by stream (m_{hi}/M_{hi}),
- y_{hij} = catch-per-tow j, in stream i, region h,
- $\bar{y}_{hi}$ = mean catch-per-tow in stream i, region h,
- $\bar{\bar{y}}_{R,h}$ = weighted mean catch-per-tow for region h,
- $\bar{\bar{y}}_{st}$ = stratified mean catch-per-tow for entire coast,
- W_h = regional weight $(N_h\bar{M}_h / \sum_{h=1}^{L} N_h\bar{M}_h)$,
- $v(\ )$ = estimate of the variance of an estimate ( ), and
- s_{2hi}^2 = estimate of variance of catch-per-tow for stream i, region h.

Estimates of means and variances were obtained from:

$$\bar{y}_{hi} = \frac{\sum_{j=1}^{m_{hi}} y_{hij}}{m_{hi}} \tag{1}$$

$$\bar{\bar{y}}_{R,h} = \frac{\sum_{i=1}^{n_h} \bar{y}_{hi} M_{hi}}{\sum_{i=1}^{n_h} M_{hi}} \tag{2}$$

$$\bar{\bar{y}}_{st} = \sum_{h=1}^{L} W_h \bar{\bar{y}}_{R,h} \tag{3}$$

$$s_{2hi}^2 = \frac{\sum_{j=1}^{m_{hi}} (y_{hij} - \bar{y}_{hi})^2}{m_{hi} - 1} \tag{4}$$

$$v(\bar{\bar{y}}_{R,h}) = \frac{1 - f_{1h}}{n_h \bar{M}_h^2} \cdot \frac{\sum_{i=1}^{n_h} M_{hi}^2 (\bar{y}_{hi} - \bar{\bar{y}}_{R,h})^2}{n_h - 1} + \frac{f_{1h}}{n_h^2 \bar{M}_h^2} \cdot \sum_{i=1}^{n_h} \frac{M_{hi}^2 (1 - f_{2hi})\, s_{2hi}^2}{m_{hi}}, \tag{5}$$

$$v(\bar{\bar{y}}_{st}) = \sum_{h=1}^{L} W_h^2\, v(\bar{\bar{y}}_{R,h}). \tag{6}$$

Confidence intervals (CI) were estimated as follows using the appropriate value of Students t:

$$95\%\ \text{CI} = \bar{\bar{y}}_{st} \pm t\,[v(\bar{\bar{y}}_{st})]^{1/2}. \tag{7}$$