EVALUATION OF JUVENILE MENHADEN ABUNDANCE DATA FOR PREDICTION OF COMMERCIAL HARVEST

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Abstract: Juvenile gulf menhaden *(Brevoortia patronus)* data were extracted from otter trawl surveys conducted along the Louisiana coast since 1966. The relationships between various abundance indexes and commercial harvest of age-1 fish were determined by correlation and linear regression analyses. Several indexes were significantly correlated at the 0.95 and 0.99 level with commercial harvest. The strongest indexes, involving frequency of occurrence of more than 25 or 50 gulf menhaden in samples, were used to predict commercial landings. Recommendations were made to continue monitoring the relationship between these abundance indexes and commercial harvest.

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The development of methods to forecast commercial abundance of gulf menhaden has been considered since the 1950's. Accurate prediction of commercial harvest levels would be beneficial in developing short-term fishing strategies by the menhaden industry. Excessive fishing pressure could be prohibited on weak year-classes while additional effort could be expended to take advantage of strong year-classes. Current harvest projections are based on a multiple regression equation, using catch and effort purse-seine data (Schaaf et al. 1975). However, there was closer agreement between actual and predicted catches in the early years of the fishery (1947 to 1961) than in later years. Schaaf et al. (1975) postulated that as effort increased in later years and larger percentages of the available fish were caught, variations in year-class strength would exert more influence on the size of the catch.

A possible method of predicting commercial catches lies in the correlation of estuarine juvenile abundance indexes with harvest levels the following year. The gulf menhaden fishery in Louisiana is largely dependent upon catches of age-1 fish. Thus, the seasonal appearance of young gulf menhaden in estuaries may provide an excellent opportunity to assess year-class strength before recruitment into the commercial fishery. Sampling for juveniles in the estuarine reaches is more economical, more accurate, and less time consuming than egg or larval sampling in offshore areas or in tidal passes (Turner 1973). Several sampling methodologies were evaluated by the National Marine Fisheries Service (NMFS) in the early 1960's to determine the most feasible method of estimating relative abundance of juvenile menhaden. Based on these findings NMFS biologists began using a surface trawl modified from Massman et al. (1952) in bayous and canals located in the upper reaches of estuaries (Kroger et al. 1974). Ahrenholz (1979) analyzed all data collected in the survey and concluded that no simple, linear relationship existed between surface trawl estimates of juvenile abundance and the eventual harvestable population.

Other methods and/or approaches of sampling juvenile gulf menhaden in estuaries, however, may generate a strong correlation between juvenile abundance indexes and later harvest levels. With the passage of the Commercial Fisheries Research and Development Act of 1964 (PL 88-309), funding was made available for the establishment of coastal study areas along most of the Louisiana coast. Sampling was conducted on a regular basis with otter trawls in each area from 1966 through the present. With the exception of the Gulf of Mexico Estuarine Inventory Study (Perret et al. 1971), the sampling was largely conducted to obtain data on brown shrimp *(Penaeus aztecus)* and white shrimp *(Penaeus setiferus)* population dynamics. These otter trawl data were analyzed to determine the relationship between juvenile abundance indexes and later commercial harvest levels, and to test the predictive capabilities of the former with respect to the latter. The findings from this investigation are presented in this paper.

This work could not have been completed without the cooperation of the personnel listed below. The following Wildlife and Fisheries biologists allowed access to their data or reviewed the paper: Gerald Adkins, Robert Ancelet, Barney Barrett, Claude Boudreaux, Phil Bowman, Ronald Dugas, Pete Juneau, William Perret, John Roussel, Brandt Savoie, and Charles White. The study was conducted in cooperation with the U.S. Department of Commerce, National Marine Fisheries Service, Public Law 88-309, as amended, Project No. 2-364-R.

METHODS

Catch statistics of the purse seine fishery were provided by Bob Chapoton and Walter Nelson of the NMFS Beaufort Laboratory. Commercial landings data from the central (waters and plants west of the Mississippi River to longitude 92° W) and western (waters and plants west of longitude 92° W) regions (Fig. 1) as defined by Prístas et al. (1976) were used. The former includes the 2 plants at Empire, the 2 plants at Dulac, and the 1 plant at Morgan City; the later includes 1 plant at Intracoastal City and 3 plants at Cameron. From each region and for both regions combined catch per unit effort data (reported as 10^3 fish per vessel-ton-week) of age-1 menhaden was utilized.

Collection sites, sampling gear, field procedures, data evaluation, and reporting techniques were standardized along most of the Louisiana coast at the inception of the shrimp monitoring program in 1966, although some minor modifications and refinements were later implemented.

Data were extracted from 5 coastal areas (Fig. 1) from 1966 through 1977. Stations were selected in each study area to cover a broad range of ecological and hydrological conditions that would be representative of conditions existing in the estuarine zone. Area 1 is outside the central harvest region but was included in our analyses because gulf menhaden harvested by Louisiana purse-seine boats in this area are landed in the central region at plants located in Empire.

Samples were taken with an otter trawl 4.9 m in length with 19.1 mm bar mesh wings and 6.4 mm bar mesh tail. The trawl was towed for 10 minutes at approximately 3 knots. In general, each site was sampled weekly or biweekly year round. A maximum of 50 gulf menhaden were measured (total length) in 5-mm group intervals. Remaining individuals in excess of 50 were counted.

Kroger et al. (1974) and Ahrenholz (1979) used a number of different annual indexes of relative juvenile abundance (as determined by surface trawls) for comparison with subsequent commercial catches. These included average catch per tow, average catch per tow per stream, highest single tow catch for each stream, number of tows with catches greater than 100, number of tows with catches greater than 1000, and age-zero size index. For this study, the mean catch per tow (c/e), log mean catch per tow (log c/e), percent samples containing menhaden (F), percent samples containing more than 10 menhaden ($F > 10$), percent samples containing more than 25 menhaden ($F > 25$), percent samples containing more than 50 menhaden ($F > 50$), percent samples containing more than 75 menhaden ($F > 75$), percent samples containing more than 100 menhaden ($F > 100$), and mean and modal sizes for each age-0 year class were calculated. Catch per tow data was transformed to logarithms because Clark (1974) and others have shown that counts of marine organisms often do not confirm to a normal distribution. Another advantage of the geometric mean is that it tends to give less weight to extreme values than to those near the

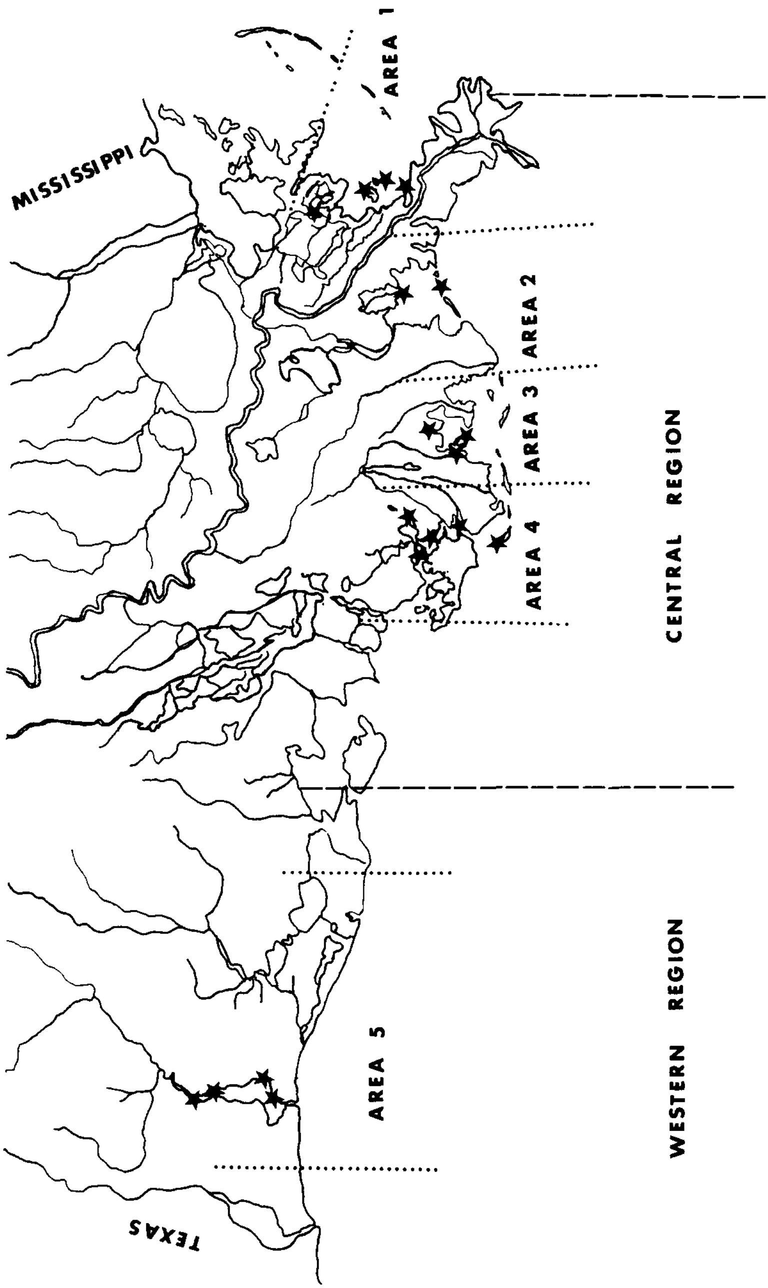

Fig. 1. Location of sampling stations (indicated by stars), coastal study areas, and commercial harvest regions along the Louisiana coast.

center of the distribution. The above indexes were computed for individual areas, for various combinations of areas, and for several time frames. All indexes or area combinations were not initially visualized, but as the analyses progressed many additional calculations were made as promising approaches were further explored. In some cases, weaker indexes were not calculated for each area or area combinations.

Correlation coefficients were calculated to measure the relationship between juvenile menhaden abundance indexes and commercial harvest and to determine if the indexes may be used to predict harvest with acceptable levels of precision. A total of 124 correlation coefficients were computed. Regression calculations were then employed on selected juvenile abundance indexes and appropriate harvest data that yielded high correlation coefficients. The dependent variable may thus be predicted through the use of the standard linear regression formula: $y = a + bx$, where y is the dependent variable (commercial catch of age-1 menhaden in 10^3 fish/vessel-ton-week), a is the y-intercept, b is the slope, and x is the independent variable (juvenile menhaden abundance index).

RESULTS AND DISCUSSION

Commercial harvest of age-1 fish for the gulf menhaden purse-seine fishery from 1967 to 1978 is presented in Table 1. Various annual indexes of juvenile gulf menhaden abundance from 1966 through 1977 for individual coastal areas and for various combinations of coastal areas were summarized but, for brevity, have not been included.

Correlation coefficients were calculated between commercial harvest data and various juvenile abundance indexes to determine the relationship between the 2 variables (Table 2). Correlations between c/e and harvest, with the exception of 1 negative value, usually resulted in either weak or moderately positive values. A significant ($P \leq 0.05$) correlation coefficient of +0.72 was obtained between area 5 (June-Oct.) and western region harvest. The next highest r values were +0.70 for area 3 (Jan.-Dec.)/central region harvest and +0.66 for area 2 + 5 (June-Oct.)/central + western region harvest. Ahrenholz (1979) analyzed mean catch per tow data from the NMFS surface trawl survey and found no consistent relationship between index and catch. Mean catch indexes may be affected dramatically by large catches in only a few samples (Kroger et al. 1974).

Table 1. Commercial harvest (10^3 menhaden/vessel-ton-week) of age-1 Gulf menhaden in the central region, western region, and the 2 regions combined.

Year	Central	Western	Central/Western
1967	7.80	11.03	8.94
1968	5.30	13.99	8.55
1969	9.90	18.81	12.82
1970	4.99	18.87	7.82
1971	9.90	17.28	12.55
1972	6.83	11.21	8.63
1973	5.66	9.27	7.09
1974	5.30	9.83	6.99
1975	2.34	8.61	4.50
1976	6.17	11.75	8.10
1977	5.56	12.62	8.07
1978	8.28	19.25	12.31

Table 2. Correlation coefficients between various juvenile abundance indexes and commercial harvest.

	Coastal Area (s)						
Index of Abundance	1[1]	2[1]	3[1]	4[1]	1+2[1]	2+3+4[1]	5[2]
Mean catch per sample A[1]	+0.12	+0.48	+0.70	+0.01	+0.20	+0.05	+0.38
Mean catch per sample B[2]	—	-0.04	—	—	—	—	+0.72
Log mean catch per sample A	—	+0.39	+0.45	+0.00	—	+0.07	+0.65
Log mean catch per sample B	—	+0.17	—	—	—	—	+0.65
Percent frequency of samples with greater than:							
0 menhaden A	-0.13	+0.32	-0.29	+0.12	+0.04	+0.12	+0.48
0 menhaden B	—	+0.56	—	—	—	—	+0.54
5 menhaden A	-0.37	+0.33	-0.04	+0.27	—	+0.22	+0.78
5 menhaden B	—	+0.39	—	—	—	—	+0.70
10 menhaden B	—	+0.39	—	—	—	—	+0.65
25 menhaden A	-0.03	+0.47	+0.02	+0.26	+0.24	+0.25	+0.88
25 menhaden B	—	+0.28	—	—	—	—	+0.69
50 menhaden A	0.00	+0.43	+0.68	+0.15	—	+0.23	+0.91
50 menhaden B	—	+0.34	—	—	—	—	+0.75
75 menhaden A	0.00	+0.34	+0.66	+0.11	—	+0.16	+0.86
75 menhaden B	—	0.00	—	—	—	—	+0.82
100 menhaden A	0.00	+0.33	+0.65	+0.04	—	+0.09	+0.80
100 menhaden B	—	0.00	—	—	—	—	+0.82
Mean length B	—	-0.60	-0.33	-0.09	—	-0.31	-0.07

Table 2 Cont.

Index of Abundance	Coastal Areas 1+5[5]	2+5[5]	1+2+5[4]	2+3+4+5[5]
Mean catch per sample A	+0.62	+0.65	+0.27	+0.32
Mean catch per sample B	—	+0.66	—	—
Log mean catch per sample A	—	+0.49	—	+0.42
Log mean catch per sample B	—	+0.73	—	—
Percent frequency of samples with greater than:				
0 menhaden B	—	+0.59	—	—
5 menhaden A	—	+0.65	—	+0.27
10 menhaden A	+0.57	+0.67	-0.11	+0.35
25 menhaden A	+0.76	+0.79	-0.02	+0.32
25 menhaden B	—	+0.66	—	—
50 menhaden A	—	+0.83	—	+0.37
50 menhaden B	—	+0.73	—	—
75 menhaden A	—	+0.77	—	+0.17
75 menhaden B	—	+0.77	—	—
100 menhaden A	—	+0.76	—	+0.15
100 menhaden B	—	+0.75	—	—
Mean length B	—	-0.71	—	-0.13

[1]A = January to December data

[2]B = June to October data

[3]Compared with central region harvest

[4]Compared with western region harvest

[5]Compared with central + western region harvest

The strongest correlations using log values for numbers of menhaden were observed between area 2 + 5 (June-Oct.) and central/western commercial catch and area 5 (both time frames) and western region harvest. Both of these correlations were significant ($P \leq 0.05$). In 6 of the correlation determinations, use of the geometric mean resulted in only slightly higher r values than with the arithmetic mean.

A weak or moderately negative relationship was found between juvenile gulf menhaden size (mean and modal lengths) and commercial harvest. The 2 highest correlations were noted for area 2/central harvest (r = -0.60) and for area 2 + 5/central + western region harvest (r = -0.71). The latter was significant at the 0.95 level. The remaining correlation coefficients ranged from 0.00 to -0.43. Ahrenholz (1979) and Kroger et al. (1974) also noted an inverse relationship between year-class strength and fish size at age +0. Some aspect of gulf menhaden size is apparently affected by density. Reintjes and Pacheco (1966) postulated that crowding of juvenile menhaden may produce intense competition for space or food; consequently, high population levels of menhaden may result in less available food and smaller fish size. Also, larger schools may form in years of high menhaden abundance. Large schools of fish feed less efficiently per individual fish than smaller schools (MacGregor 1959). Stronger correlations between fish size and commercial harvest may have been obtained had individual gulf menhaden been weighed and measured instead of using 5-mm size groups.

The strongest correlations for all indexes were obtained with frequency of occurrence data. Several interesting points were revealed after scrutinizing frequency indexes. First, in most cases, the r values increased to a peak at either F>25 or F>50 and then declined. Second, most indexes based on the whole year had higher r values than those using June-Oct. data. The highest r values obtained initially were +0.91 for F>50 area 5 (Jan.-Dec.)/western harvest and +0.83 for F>50 area 2 + 5 (Jan.-Dec.)/central + western harvest. Annual area 2 F>25 and area 5 F>50 indexes ($F{>}25_2/F{>}50_5$) were combined by averaging their percentages. This index yielded a r value of +0.87 when correlated with central/western harvest. All of the above were highly significant ($P \leq 0.01$). Other frequency indexes for the above areas or area combinations were also significant, but only the strongest correlation for each area is mentioned. The annual F>50 index for area 5 (or some combination thereof) showed the best correlation between juvenile menhaden abundance and subsequent production of age-1 fish. This index may measure the number of schools encountered by the sampling gear. As pointed out by Reintjes and Pacheco (1966), the number of schools of menhaden in an estuary is related to year-class abundance. Kroger et al. (1974) also concluded that F>100 and F>1000 indexes from the NMFS surface trawl survey were the best indicators of relative year-class strength.

In summation, the strongest correlations for a particular harvest region and juvenile index are as follows: a) +0.91 between F>50 for area 5 and western region harvest; b) +0.70 between c/e for area 3 and eastern region harvest (this correlation was disregarded because it was not significant); and c) +0.87 between $F{>}25_2/F{>}50_5$ and central and western region harvest. Several factors probably contribute to the relatively high correlations between the above area 5 and area 2 abundance indexes and commercial harvest. First, as pointed out previously, F>50 (or F>25) may be the best measure of juvenile gulf menhaden density. Second, both areas support large numbers of juvenile gulf menhaden (as shown by their first and third rankings in c/e). Third, the number of sets made by menhaden boats (Christmas 1980) are generally high in offshore zones immediate or adjacent to areas 2 and 5. Finally, these 2 areas were probably most consistent with respect to sampling periodicity, sampling locations, and data summations. Correlations were also run on the above indexes with total harvest and catch per effort of all age groups. In all cases these r values were much lower than those obtained with catch per effort of age-1 fish. Consequently, a strong linear relationship is characteristic of only the juvenile menhaden abundance indexes and catch per effort of age-1 fish.

The high level of correlation obtained with the above juvenile menhaden abundance indexes allows for prediction of commercial harvest with linear regression calculations. The following 2 equations may thus be used to predict the commercial havest of gulf menhaden: a) $Y_W = 8.4052 + (0.2806)\ x$, where Y_W is the commercial harvest, as defined previously, for the western region and x is the annual F>50 index for area 5; and b) $Y_{CW} = 5.6479 + (0.2811)\ x$, where Y_{CW} is the commercial harvest, as defined previously, for the central plus western region and x is the $F > 25_2 / F > 50_5$ index.

The associated coefficients of determination for these two predictive models indicate that 83 percent and 75 percent of the variation between actual and expected harvest for the western and central/western regions, respectively, during the study period can be attributed to juvenile gulf menhaden abundance. Using these models, landings from 1968 to 1978 were predicted. There is fairly close agreement in most years between actual and estimated landings of age-1 fish (Fig. 2). The average error was 10.3 percent for the western region and 13.7 percent for the central + western regions. However, while the average deviation may be fairly small, the error for a specific year was much larger in some instances.

Several criteria must be satisfied if commercial menhaden harvest is to be predicted from juvenile abundance estimates (Kroger et al. 1974). First, a constant relationship must exist between the annual abundance of young and the resulting adults. Second, the fish must behave similarly in their migration and recruitment patterns each year. Finally, abundance of the young must be accurately estimated.

It must be assumed that the first 2 of the listed criteria are satisfied. Commercial harvest data is now available on the relative proportion of each age group. This leaves possibly the most important criterion—that is, the accuracy of juvenile abundance indexes. Otter trawls are obviously biased because the gear is more selective towards demersal species as compared to more pelagic fishes such as gulf menhaden. However, despite this limitaton, otter trawls still capture large numbers of gulf menhaden. Simoneaux (1979) found higher catch rates of gulf menhaden in the otter trawl than in a surface push trawl (per Herke 1969). Loesch (1975) has suggested that the trawl boat scares gulf menhaden from the surface towards the bottom; this movement would make the species more susceptible to the otter trawl. Regardless, abundance estimates from otter trawls do not yield a density (number per unit area) estimate but rather an index that is functionally related to density. As suggested by Eberhardt (1978), it was assumed that abundance indexes were consistently biased and thus may be manipulated in much the same way as one may treat actual density estimates.

Despite the significance of findings presented in this manuscript, this represents only a progress report of findings, and additional refinement will continue. The first 2 abundance indexes in the above listings should be monitored for 3 or 4 more years and then correlation and linear or multiple regression analyses be calculated again between the indexes and commercial harvest. This recommendation is justified for a number of reasons. First, even though the relationship between the indexes and harvest was significant, the error between actual and estimated harvest for a specific year may be fairly large. Increased precision may result with additional data points and degrees of freedom. Second, the consistency of the predictive equations must be tested over a longer period. Kroger et al. (1974) noted strong correlations for several of his indexes with commercial harvest from 1962-1969. However, Ahrenholz (1979) tested the same indexes with additional years of survey and harvest data and concluded that no simple, linear relationship existed between the abundance indexes and eventual population size; indeed, some indexes displayed inverse trends over different segments of the study. Third, NMFS is

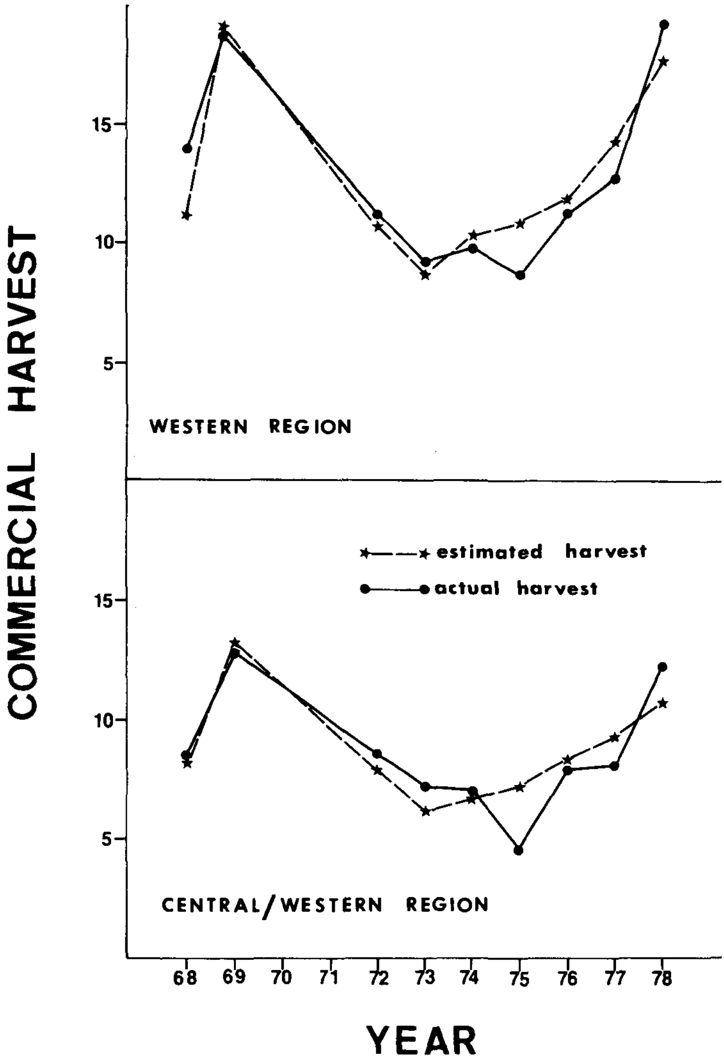

Fig. 2. Actual and predicted landings (10^3 menhaden/vessel ton week) of age-1 gulf menhaden, 1968-1978.

currently evaluating the gulf menhaden purse-seine fishery to determine the most effective unit of fishing effort (Walter Nelson, pers. comm.). A new unit of effort may prove to be more accurate and, consequently, result in higher correlations between juvenile abundance and commercial catch. The definition of fishing effort in the purse-seine fishery is a problem (Chapoton 1973). Catch per unit effort data must, however, be used in these analyses because effort has increased over the years with resultant increases in total harvest. A relative index of fishing effort (vessel-ton-week), using vessel size as documented by registered tonnage, has been used by NMFS. Historically, there has been a strong correlation between catch per vessel week and net vessel tonnage; however, in recent years the correlation has declined. Finally, the model used by the NMFS (Schaaf et al. 1975) to forecast menhaden harvest is useful to the industry but it does not at present consider variation in number of young fish entering the fishery. Consequently, deviations from predicted harvest that may result from year class strength variations of age-1 fish are not accounted for in the average expected trend resulting from the historical catch/effort relationship. Schaaf et al. (1975) found closer agreement between actual and estimated catches from 1947 to 1956 than in later years. They postulated that as effort increased in later years and larger percentages of the available fish were caught, variations in year class strength exerted more influence. This model could possibly be modified to incorporate recruitment data in the form of juvenile abundance indexes.

In conclusion, juvenile gulf menhaden indexes and associated predictive models are promising and warrant additional monitoring. In addition, hydrological and climatological data will be analyzed with reference to juvenile menhaden abundance indexes to determine the importance of environmental parameters to abundance of menhaden. Stone (1976) and Nelson et al. (1977) used this approach for menhaden harvest and year class projections.

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