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Mullet Stock Biomass Estimation using Aerial Visual, Shipboard, and Photogrammetric Sampling

by

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ABSTRACT

A fishery independent sampling survey design was implemented in the Everglades National Park's Florida Bay to estimate the monthly biomass of mullet (Mugil spp.) in the area. The method employed involved the application of aerial visual sampling, photogrammetric sampling, and shipboard sea-truth sampling. Aerial visual sampling was used to estimate the density (D) and number of "muds" in the study area. Photogrammetric sampling was used to estimate mud surface area (s), and shipboard sampling was used to estimate the proportion of muds containing mullet (p) and the biomass of mullet per unit area of mud (b). Total biomass was estimated as the product of these four variables.

The method applied proved to be appropriate for silver mullet. Biomass estimates were found to be characterized by a high degree of variation, owing primarily to variability of estimates of b, p and s. Mud density estimates were found to be a precise index of presumed mullet abundance based on fishery CPUE data. Bias was estimated to result in underestimation of mullet biomass on the order of a factor of 10 to more than 18.5. The major source of bias was due to estimates of b. Estimated monthly harvest of silver mullet in April-December 1984 ranged from 3.6 - 17.8% of the bias adjusted estimates of biomass.

INTRODUCTION

Mullet (Mugil spp) are a principal prey of numerous gamefish stocks in the marine waters of the Everglades National Park's Florida Bay (see Figure 1). Commercial mullet fishing is hypothesized to be detrimental to stocks of gamefish in the Florida Bay through food web effects. However, there are few data on mullet stock biomass in the region with which to test this hypothesis. The objective of the research described in this paper was to apply a fishery independent resource sampling survey to estimate monthly mullet biomass in Florida Bay.

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Mullet and other species aggregate in turbidity fields in the relatively shallow Florida Bay (Schomer and Drew 1982). The turbidity fields, or "muds", may be the result of benthic feeding activities by mullet (Odum 1966, 1970). However, Shinn et al. (1985), studying similar turbidity fields on the Bahama Bank, supported Cloud's (1962) hypothesis that the turbidity fields are the result of $CaCO_4$ precipitation from the water column.

In Florida Bay, commercial fishermen locate mullet by searching for muds, concentrating effort on silver mullet. The term "silver mullet" is applied to all Florida marine mullets except the striped mullet (M. cephalus). Three species of silver mullet are recognized from Florida: white mullet (M. curema), fantail mullet (M. trichodon) and redeye mullet (M. gaimardianus). Silver mullet are utilized as trolling, live strips, chunk or cut fishing baits (Nickerson 1984). The catch in Florida Bay consists mainly of white mullet. In 1983 and 1984, the average monthly estimated harvest of silver mullet in Florida Bay ranged from 7,715 to 64,260 kg (Figure 2).

After Scholl (1966), Florida Bay is defined as the "triangular-shaped embayment immediately south of the Florida peninsula." The southern and eastern boundaries of the bay are defined by the Florida Keys archipelago (conveniently taken as U.S. Highway 1 over open water sections); the western boundary is defined by longitude 81°05'W between Cape Sable, Florida, and Vaca Key, Florida. The portion of Florida Bay (FB) within the boundaries of the Everglades National Park is a subset of the above and is defined by the Intercoastal Waterway to the south and east and by boundary markers to the west (Figure 1). The surface area of FB is approximately 1698 km^2.

METHODS

Biomass Estimation

Mullet biomass density (D_B) was estimated per survey and mud size class as the product of mud density (D_m), proportion of muds with mullet (p), mullet biomass per unit area of mud (b), and mud surface area (s):

$$\hat{D}_B = \hat{p} \cdot \hat{D}_m \cdot \hat{b} \cdot \hat{s} \quad (1)$$

Similarly, biomass abundance (B) was estimated substituting mud abundance (M) for D_m:

$$\hat{B} = \hat{p} \cdot \hat{M} \cdot \hat{b} \cdot \hat{s} \quad (2)$$

The variance of these functions was estimated using the delta method (Seber 1983) as a one-term Taylor series expansion. For (1) the variance estimator used was

$$\widehat{V}(D_B) = \widehat{V}(D_m)\,\overline{\frac{\delta D_B}{\delta D_m}}^2 + \widehat{V}(p)\,\overline{\frac{\delta D_B}{\delta p}}^2 + \widehat{V}(b)\,\overline{\frac{\delta D_B}{\delta b}}^2 + \widehat{V}(s)\,\overline{\frac{\delta D_B}{\delta s}}^2 \quad (3)$$

Note that covariance terms are assumed negligable. The variance for (2) was likewise estimated, substituting B for D_B and M for D_m.

Total biomass density (D_B) and biomass (B) was taken as the sum over the mud size-class estimates.

$$\hat{D}_B = \sum_{i=1}^{3} \hat{D}_{Bi}$$

$$\hat{B} = \sum_{i=1}^{3} \hat{B}_i$$

with corresponding variance terms,

and

$$\widehat{V}(D_B) = \sum_{i=1}^{3} \widehat{V}(D_{Bi}) + 2 \left[\sum_{j=1}^{2} \sum_{k=2}^{3} \widehat{COV}\ (D_{Bj},\ D_{Bk}) \right];\ j<k$$

$$\widehat{V}(B) = \sum_{i=1}^{3} \widehat{V}(B_i) + 2 \left[\sum_{j=1}^{2} \sum_{k=2}^{3} \widehat{COV}(B_j,\ B_k) \right];\ j<k$$

Confidence intervals on the mean estimates were constructed using the Student's t method.

We employed aerial visual sampling to estimate the variables D_m and M, photogrammetric sampling to estimate s, and shipboard sea-truth sampling to estimate b and p. The specific methods employed follow in the subsequent sections.

Aircraft Sampling

Mud Density (D_M) and Abundance (M)

Aerial-visual sampling techniques were employed to provide monthly density and abundance estimates of muds in FB. The sampling we describe was conducted in two phases. The pilot study phase was conducted by National Park Service (NPS) personnel in 1983. In the pilot study, 10 samples were taken along predetermined transects between January-September 1983 (Table 1). Sampling was conducted by a single observer from a single-engine, amphibious Laker aircraft at an altitude of 275 m (900 ft) and an airspeed of 222 km/hr (120 knots). The size and position of muds were recorded on large-scale navigational charts of FB. Right angle distance from transect measures were made from the charts for analysis. Muds were classified by three size classes: large (> 0.92 km in longest dimension), medium (> 60 m - 0.92 km in longest dimension), and small (≤ 60 m in longest dimension). Muds were classified after sampling by measuring outlines of the muds drawn on charts.

The second phase (sampling survey) was started in April 1984 and continued monthly through May 1985 (Table 1). Approximately biweekly samples were taken from October 1984 - May 1985. Sampling was conducted using two observers and a data recorder in a single-engine, 4-place Cessna aircraft. Airspeed was reduced to 166 km/hr (90 knots) to improve sighting conditions. For navigation along transects we employed a II Morrow Loran-C receiver. The observers recorded the size and position of muds observed along the transects and reported this information to the data recorder stationed in the co-pilot seat over the on-board intercom system. Muds were classified by size class during sampling and were cross-classified by right angle distance intervals by means of reference marks placed on the observation windows and wing struts. The distance intervals used for this study were: 1 (>0.0 - 0.142 km), 2 (> 0.142 - 0.394 km), 3 (> 0.394 - 0.858 km), 4 (> 0.858 - 1.320 km), and 5 (> 1.320 - 1.784 km). Observation of muds greater than 1.784 km from the transect were not recorded. Other than the differences described, survey parameters were consistent between the two phases.

Mud density estimates ($\hat{D}_m$) were achieved using line transect analytical techniques. From Burnham et al. (1980), density is estimated as

$$\hat{D}_m = \frac{n\hat{f}(0)}{2L} \tag{4}$$

with variance

$$\widehat{V}(D_m) = \hat{D}_m^2 \left[\frac{\widehat{V}(n)}{n^2} + \frac{\widehat{V}(f(0))}{f(0)^2} \right], \tag{5}$$

where n is the number of muds observed per transect length L and f(0) the sighting probability density function evaluated at zero distance from the transect. Mud abundance estimates (M) were made as the product of density (D_m) and study area (A). Note that in the pilot study, a single observer was used, thus the estimate of density was made by removing the constant 2 in the denominator of Equation 4.

The sampling design employed in the second phase was based on results of the pilot study. Data collected during the pilot study supported a pooled estimate of f(0) over all size classes and surveys of 0.643 km^{-1} based on a one-term Fourier model (Burnham et al. 1980). From this estimate we inferred an average effective sampling one-half swath of 1.5 km. Based on this estimate, the transects sampled in the second phase were drawn from the pool of possible transects placed at approximately 3.0 km intervals. Since the desired design was a systematic sample with single random start, a random starting position was generated within the first 3.0 km interval within the study area. Transects were made over FB from northwest to southeast. Transect length was determined as below.

The data collected during the pilot study were also used in determining sample size requirements for the second phase surveys. From Burnham et al. (1980), the transect length, L (km), necessary to achieve a given level of precision, CV(D), is:

$$L = \frac{g}{CV(D)^2} \left(\frac{L_1}{n_1} \right),$$

where

$$g = n_1/(CV(D_1))^2,$$

and L_1 and n_1 are the transect length and number of targets observed in the pilot study resulting in a density estimate, D_1, with associated precision $CV(D_1)$.

From the pilot study, it was found that the low mud abundance period of January yielded a sample of $n_1 = 22$ from $L_1 = 306$ km (one observer) and a resulting $CV(D_1) = 0.15$. Monthly samples in the second survey were thus taken with a minimum target transect length of 306 km (153 km with 2 observers) with $g = 0.50$. This transect length was expected to result in pooled mud density estimates with CV's of 0.15 or less assuming a constant g term.

Mud Size Estimation (s)

Photogrammetric samples were obtained of randomly selected muds to allow mensuration of mud size and input into mullet biomass estimation. Photographic samples were obtained using two vertically oriented camera systems. A 5-inch format Fairchild K-24 "strike" camera with 1/900th sec. shutter curtain and a 7-inch, f:4 lens was mounted in the aft baggage compartment of the survey aircraft in a manner that allowed through the fuselage vertical imagery of muds. A 35-mm camera system was mounted in a PVC housing suspended from the right wing-strut and oriented for vertical imagery. The 35 mm system consisted of a Canon F-1 body, motor drive, 100-frame bulk back and 50 mm f:1.4 lens.

Imagery was taken at either 275 m or 457 m altitude, resulting in photo scales of 1:1550 or 1:2550 for the 5-inch system and 1:5500 or 1:9150 for the 35 mm system. Kodak Aerochrome MS 2448 film was used in the 5-inch system and Ektachrome 200 in the 35 mm camera. The photoscales used resulted in the need to mosaic medium- and large-sized muds for mensuration.

Shipboard Sampling

Biomass per Unit Mud (b)

A commercial fishing boat, with Fish and Wildlife Service (FWS) personnel in addition to commercial fishermen on board, was employed to sea-truth sample for estimation of mullet biomass per unit area of mud (b). Initially the project design included at least one sampling date per month. As of October 1984, sampling was conducted twice a month with each sampling date approximately two weeks apart. Sea-truth sampling was conducted only in eastern FB owing to consistently high turbidity in western FB and logistical difficulties in reaching that part of the Bay from the commercial fishing ports.

The boat was postioned along a randomly chosen transect on each sampling day. The vessel, 9.1 m in length with a 3.7 m beam, was used to sample muds found along the transect. The ship was directed to muds by the aircraft using VHF transceivers. When the mud was located, the commercial fisherman encircled either a segment of the mud or the entire mud using a semi-purse seine approximately 325 m in length and 5 m in depth with 12.7 mm bar mesh. Forty to fifty meters of net were pursed by ropes tied to the float and leadline. NMFS personnel took aerial photographs of the mud both before and after the net was set (see Figure 3). As the net was being drawn into the boat, a hand counter was used to count the mullet that jumped over the encircling net. The catch was processed as quickly as possible to facilitate the sea-truthing of three or more muds per sampling date, while the airplane was available for aerial photography.

All fish were removed from the net, placed into a holding tank and enumerated by species. Individual length and weight data were collected for all mullet. Fish lengths and a subsample of weights were taken from other species that predominated the catch [i.e., Atlantic thread herring (Opisthonema oglinum), pinfish (Lagodon rhomboides), silver jennys (Eucinostomus gula)]. Biomass per standard net set was calculated for mullet, Atlantic thread herring, silver jenny, and pinfish. For species where complete weight data were not collected, weight was predicted based on length-weight regressions calculated from the subsamples. Biomass of mullet encircled per set was estimated by including mullet counted escaping over the cork line. Weights for mullet which escaped were estimated using length-weight regression assuming a length equal to the sample average. Data were summarized by both number and biomass for silver mullet, Atlantic thread herring, silver jenny, and pinfish on a catch per unit of effort (CPUE) basis. Effort is defined as one net set with the purse seine using 325 m of net (approximately 8400 m^2).

Proportion of Muds with Mullet (p)

Beginning in October 1984, transect sampling on each overflight sampling date was conducted by FWS personnel on two additional randomly chosen transects in the eastern portion of Florida Bay. This sampling was conducted to estimate the proportions of muds containing mullet (p). Each mud along the transect was sampled by encompassing a portion of the mud with a runaround gill net. This gill net was 305 m in length and 2 m deep with 6.5 mm stretch mesh. The catch was enumerated by number and species. Additional transects (approximately 4 per month) were sampled between October 1984 and January 1985.

Beginning in March 1985, paired sets were made during regular overflight sampling using the purse seine and a runaround gill net (see above paragraph). The gill net was set by FWS personnel using a 7 m Mon Ark workboat. Approximately the same length of net was used for the gill net set as used by the purse seine. The two nets were set in the same mud simultaneously, usually 50-75 m apart. Table 2 lists the dates, types of sample, and number of samples taken by the sea-truth vessels.

RESULTS AND DISCUSSION

Mud Density and Abundance

The five sighting probability function models recommended by Burnham et al. (1980) and available in program TRANSECT (Laake et al.1979) were fit to the data shown in Figure 4. No fits were found to be adequate for any of the distributions shown, primarily due to higher than expected frequencies in the first sighting interval. The Cox-Eberhardt non-parametric method (Eberhardt 1978) was then used to estimate f(0) as:

$$\hat{f}(0) = \frac{(C_1 + C_2)}{C_1 C_2}\left(\frac{n_1}{N}\right) - \frac{C_1}{C_2(C_2 - C_1)}\left(\frac{n_2}{N}\right),$$

where C_1 and C_2 are distance intervals from the transect with n_1 and n_2 observations ($n_1 + n_2 = N$). A jackknife approach using four replicates was used to estimate f(0) from each distribution. Since the data were collected in groups and were truncated at 1.784 km, we defined C_1 for each replicate as the outside cutpoint of each of the four closest intervals used in data collection. The value of C_2 was defined as $1.784\text{-}C_1$. Weighted mean and sampling variance terms were estimated by replication over all samples taken. Replicates were defined by sampling date conditional on adequate sample size (i.e. 30 observations) for each mud size-class. Data from sampling dates with fewer than 30 distance classified observations for a mud size-class were pooled with successive samples until the minimum sample size was reached.

This technique resulted in estimates of f(0) for the large, medium-, and small-sized muds of 4.566 (V(f(0)) = 0.492), 3.033 (V(f(0)) = 0.443), and 3.415 (V(f(0)) = 1.015) respectively. These estimates imply effective half-swaths for the large-, medium-, and small-sized muds of 0.219, 0.330, and 0.293 km.

Applying the same technique to the pilot study sighting frequency data (Figure 5) resulted in a pooled estimate of f(0) of 1.050 with variance 0.120. The data from the pilot study are, however, much less spiked than those from the second sampling phase. A one-term Fourier Series (FS) model (Crain et al. 1979) was found to provide an adequate fit to these data (X^2 = 0.367, $p > 0.80$). The resulting estimate of f(0) was 0.643 with variance of 2.0×10^{-4}. In this case, the Cox-Eberhardt point estimate is 63.3% higher than the FS estimate. The FS estimate of f(0) was used for estimating biomass density and abundance with the pilot study data.

Size-class information cross-classified with distance interval information was not available for analysis from the pi lot study. Therefore, a pooled estimate of f(0) was obtained. The pilot study estimate of f(0) implies a pooled effective half-swath of 1.55 km (the effective sampling half swath is the inverse of f(0)) while the average from the second sampling phase was 0.28 km. This difference may be attributed to physical differences between platforms, varying survey conditions, and/or methodological differences in data collection. In the pilot study, distance from transect information was obtained by measuring the position of the mud drawn on a navigational chart to the estimated right angle position of the aircraft. This technique is likely to account for a significant portion of the observed difference in effective half swath. We have no method for estimating the magnitude of bias due to this technique. It is likely, however, that the pilot study method resulted in overestimating distance and thus imparted an unknown negative bias to the density estimates.

Simulation results given by Burnham et al. (1980) show the Cox-Eberhardt method to be relatively model robust. However, given a convex, or spiked distribution, as seen in Figure 4, the estimator results in a negative bias. Using a negative exponential as the underlying pdf this bias ranged from -3.4 to -22.4% depending on interval selection (Burnham et al. 1980). For this reason, we feel the estimates used for f(0) for the survey sampling phase also impart a negative bias to density.

In the second phase of sampling, we used the replicate line information available per survey to estimate V(n) (Equation 5), weighting by line length. In the pilot study, number of muds per line by size-class was not available for analysis and we assumed n to be distributed as a Poisson random variate with V(n) = n. Table 3 presents the estimates of mud density by size class and their associated variance component estimates.

It is evident from Table 3 that the pilot survey estimates are much more precise than those of the sampling survey data. As described above, this is principally due to differences in the empirical sighting probability functions from the two surveys. Although they are more precise, it is also likely that these estimates are negatively biased.

Due to differences in the sighting functions, the sampling survey design used resulted in total mud density estimates with CVs up to 24.8% (see Total row values in Table 3) rather than the expected 15% or less. Partitioning the data by mud-size class greatly increases the variance in some of the size class components. In the pilot study, virtually all variance for all size classes is accounted for by V(n) (see % variance columns in Table 3). For the sampling survey data, the small mud estimates are equally sensitive to V(f(0)) and V(n), while medium mud variance estimates are dominated by V(f(0)). The large mud estimates tend from equal sensitivity to domination by V(f(0)) in the later surveys. These observations suggest the small mud data to have a high V(n) throughout the survey period and the medium muds a low V(n). The apparent trend in the large mud V(n) term suggests that a significant portion of the information relative to mullet abundance may occur in this size class.

Biomass per Unit Mud (b)

A total of 64 purse-seine sets were made on randomly chosen large and medium-sized muds in the eastern FB. A total of 58 sets contained mullet, of these, 23 were made on large- and 35 on medium-sized muds. Three small muds were also sampled with the purse-seine. The relatively low effort for this mud size class resulted from logistical difficulties in directing the surface vessel to specific small mud targets from the survey aircraft. The small mud sample is likely not representative of this size class and, for this reason small muds were not treated separately. The dominant species collected in the purse seine sets are shown in Table 4. Striped mullet were sampled on only one occasion and were not considered further in the analysis.

The estimated purse seine CPUE data were first examined for size class differences (large and medium). CPUE for silver mullet in large muds sampled ranged from 0-6.4 kg; in medium muds, the range was 0-17.6 kg (Figures 6a and 6b). In muds from which mullet were captured, the large mud average CPUE was 1.99 kg (b_1, $V(b_1) = 3.37$); the medium mud average was 2.56 (b_2, $V(b_2) = 19.59$). The relatively high medium mud mean is strongly influenced by the results of a single set from June 1984 when the average CPUE was 17.6 kg. Treating this set as an outlier, the medium mud mean is 1.56 with variance, $V(b_2) = 1.72$. The large mud average CPUE was found not to statistically differ at $\alpha = 0.05$ from either the high average medium ($t_{b1-b2} = 0.34$; 1-tail $t_{0.05,19} = 1.729$) or low average medium mud biomass CPUE ($t = 0.84$). The biomass CPUE data were then pooled and a grand mean was calculated, excluding the high June 1984 medium mud set. The pooled average CPUE was 1.73 kg with variance of 2.39. From photo mensuration of the purse seine sets, this gear encircled 8438 m^2. The average estimated CPUE in units of kg/km^2 is 205.02 with variance 3.36×10^4. These values were used in subsequent biomass estimation.

Proportion of Muds with Mullet (p)

A total of 88 muds were sampled along the random boat transects. Of these, 14 were of small-, 54 of medium-, and 12 of large-sized muds. The average proportion of small muds sampled containing mullet was 0.81 (p_3, $V(p_3) = 0.11$). The average medium mud proportion (p_2) was 0.59 ($V(p_2) = 0.19$ and that for the large muds was 0.44 (p_1, $V(p_1) = 0.21$). No statistical differences were found comparing the mean proportion by size-class data at $\alpha = 0.05$ ($t_{p1-p2} = 0.69$, $t_{0.05,23} = 1.714$, 1-tail; $t_{p1-p3} = 1.28$, $t_{0.05,26} = 1.706$; $t_{p2-p3} = 1.28$, $t_{0.05,11} = 1.796$; here daily transect samples were used as replicates). Thus, the data were pooled to compute a grand mean ($p. = 0.60$) with variance ($V(p.) = 0.17$). These estimates were used in subsequent mullet biomass estimates.

Mud Size Estimation (s)

A total of 12 large-, 42 medium-, and 27 small-sized muds was successfully imaged for mensuration purposes. Large muds sampled ranged in area from 0.186-2.050 km^2 ($s_1 = 0.935$, $V(s_1) = 0.3826$); medium muds ranged from 0.012-0.372 km^2 ($s_2 = 0.111$ km^2, $V(s_2) = 0.0090$); and small muds from 1398 m^2 - 0.075 km^2 ($s_3 = 0.015$ km^2, $V(s_3) = 1.96 \times 10^{-4}$). The Brown and Forsythe (1974) F* statistic was significant for each size class comparison of both the untransformed and log transformed data (Figure 7). As such, these size class estimates were used in subsequent biomass and mud area estimation.

Relative Mud Density Distribution

The distribution of relative mud density by survey was plotted using a three-dimensional grid representative of FB (Figure 8). Each transect line sampled was divided into grids of 5.678 km^2 and sightings of muds were assigned to the appropriate grid by placing a grid template over the observer log maps. The relative mud density per grid was calculated as total observed mud area per grid. The area of large, medium, and small muds were equilibrated by multiplying the number of small and medium muds observed in each grid by factors of 0.014 and 0.119 respectively. The factors were computed as s_3/s_1, and s_2/s_1.

Nineteen surveys were plotted; the surveys not plotted were excluded because of different transect patterns or low effort. The plots (Figure 8) show most of the muds were concentrated in the middle to eastern parts of FB. Very little mud area was observed in the southwest and northwest portion. We note that the initial surveys of the sampling survey phase of the work described show relatively low relative mud density in Figure 8. This may be attributed to the relative inexperience of observers and, for that reason may not reflect the true pattern. Mud area estimates per survey are presented in Table 5.

Mullet Biomass Density (D_B) and Mullet Biomass (B)

Estimates of silver mullet biomass density (D_B) and biomass (B) by size class were made as described in Equations (1) and (2). Estimates of total density and biomass were taken as the sum of the size class values. The variance of the total was estimated using the correlation matrix:

	Large	Medium	Small
Large	1.0000		
Medium	0.1483	1.0000	
Small	0.0904	0.2814	1.0000

based on the size class survey density estimates in Table 3. These estimates, by survev, are presented in Table 5. For the pilot survey, our point estimates of biomass range from 1092.8 kg during April to 3643.6 kg in January. However, as previously stated, these estimates are likely negatively biased due to reasons previously cited and those discussed below. Weather conditions, confounded by inexperience in the January and March pilot survey samples likely contributed to the bias. For the sampling survey data, biomass point estimates range from a low of 9018.6 kg in the first survey to 85028.4 in early April 1985. Disregarding the first survey estimate as low due to inexperienced observers, the estimates range upward from 11703.1 kg in June 1984. These data are presented graphically in Figure 9.

The data in Figure 9 are bimodal, with estimated biomass peaks during early spring and fall. CPUE data from the silver mullet fishery in FB also show this bimodal pattern (Figure 10), suggesting that the estimation technique tracks the relative abundance of mullet in FB fairly well. The estimate of biomass, however, are highly variable, with characteristic CV's of 100% or more (Table 5).

We investigated the sensitivity of the estimates to their various components by examining the proportion of total variance of the estimator attributed to each component. These data are presented in Table 6. Biomass per unit area of mud (b) was found to contribute most heavily to the overall variance of the estimate, accounting for up to 46% of the total variability in the biomass density estimates. The variance of the estimate of biomass density was generally least sensitive to mud density variability, although this sensitivity was considerably higher in the pilot study samples where biomass density estimates were low. Relative contributions by V(s) and V(p) were approximately equal, averaging about 25% of the total each.

Given that our estimation technique involved the use of time invariant mean values, it is obvious that all information relative to the seasonal trends in silver mullet abundance is contained in the mud density estimates. Previous discussion suggested that the size class of muds with the highest information content was the large mud class. As is evident in Table 3, the large mud density estimates are relatively imprecise for low values, but the most precise of the size class estimates in the higher ranges (Figure 11), a characteristic that may allow detection of interannual variability in peak relative abundance of silver mullet. This assumes, of course, consistent methodology and size classification. As a means of indexing relative abundance, an alternative is a more extensive use of photogrammetric techniques to photo-mosaic the FB and census the muds by size class. Use of this technique would reduce the mud density variance to 0 and allow precise mensuration of mud area.

For the months sampled in 1984, biomass estimates track the harvest estimates trend reasonably well (Figure 2 and 9). During presumed low abundance periods (based on fishery CPUE data, Figure 10), our biomass point estimates are generally very close to the estimated harvest. During high abundance periods, estimated harvest is below the point estimate of biomass. Upon first examination, these data suggest the fishery may be harvesting nearly all available biomass during the low abundance periods and a substantial portion of the available standing stock during high abundance periods. Alternatively, our biomass estimates may be significantly negatively biased.

Sampling Bias

The alternative above can be addressed by examining two of the critical assumptions of the estimation technique. Firstly, we assumed our sea-truth sampling gear to be 100% efficient. Second, we assumed all silver mullet in the FB to be within muds.

We were able to test the first assumption by examining the data from our paired net samples (Table 7). Commercial gill net catch rate was equilibrated to purse-seine catch rate using the area encircled ratio as determined from the photogrammetric samples of the net sets. In terms of biomass captured, the estimated relative efficiency of the purse seine to gill net is only 6.6%. In terms of estimated biomass encircled, the purse-seine is estimated to be 14.4% as efficient as the commercial gill net.

The length class distribution of mullet captured by the two gear types (Figure 12) suggests that mullet are fully recruited to the gill net at 255-259 mm. Assuming the purse-seine length distribution of mullet is representative of the FB population, we can estimate the biomass undersampled by the gill net using the weight-length non linear regression model

$$W(g) = 7.610^{-5}\ l_{(mm)}^{2.64}$$

based on the pooled silver mullet sample from the purse-seine and gill net sets. Relative biomass undersampled was estimated as:

$$RB = \frac{\sum_{i=1}^{n} (ps_i - gn_i)\ W_i}{\sum_{i=1}^{n} ps_i\ W_i + \sum_{i=n+1}^{m} ps_i W_i}$$

where ps_i and gn_i are the proportions of the total sample in length class i, n the number of length classes from minimum length to length at full recruitment to the gill net (255 mm), and m the number of length classes from n to maximum length sampled. The value of W_i is the predicted weight from the regression model above for a fish of length l_i, taken as the midpoint of interval i. Using this technique on the data in Figure 12 (Table 8) we estimate that the gill net under samples the assumed population biomass by 33.92%.

Since we used the estimated biomass encircled by the purse seine in our estimate of mullet standing stock, the total estimated relative efficiency of the sampling gear is taken as the product of the relative efficiency of the purse seine to gill net using purse seine estimated catch (0.144) and the complement of the estimate of gill net biomass undersampled (0.661) based on the assumed population length distribution. Thus, the estimated efficiency of the purse seine is 9.52%. Using this value, the estimates of mullet biomass need be adjusted upward by a factor of 10.51.

We were unable to sample muds in much of the FB, especially the shallow northern, and turbid western regions. This resulted from the sea-truth boat being unable to maneuver in water of less than 1.2 m in depth and the inability to easily discriminate muds in the turbid waters in the western portion of FB. The estimates presented are for silver mullet since striped mullet were only sampled once in the eastern FB during the study. Striped mullet are frequently caught in commercial nets set in the western FB and it is obvious that the sampling we conducted was inappropriate for this species stock. The direction and magnitude of bias, if any, due to sample location on the silver mullet estimates is unknown.

The second critical assumption was that all silver mullet in the FB are found within muds. Literature suggests that striped mullet feed continually (or nearly so) and mainly do so, according to Odum (1970), either by "sucking up the surface layer of mud or by grazing on submerged plant or rock surfaces". Both these mechanisms presumably stir up bottom sediments, thereby creating muds. Odum (1970) also cites other feeding mechanisms occasionally used by striped mullet, but attributes the above as the main mechanisms. Collins (1981) found intensity of feeding by striped mullet to peak mid-day. It is unclear what this observation implies relative to the number of muds formed. However, our sampling was centered about the presumed peak of feeding intensity. Assuming that silver mullet as a group behave analogously to striped mullet, then this second critical assumption may be essentially met. We have no direct means of testing this assumption, but deviations would impart a negative bias.

A source of bias previously discussed is that due to estimating f(0) for density estimation. As discussed, Burnham et al. (1980) found a negative bias in the Cox-Eberhardt estimator of f(0) for a negative exponential pdf. The bias ranged from -3.4 to -22.4%. If we assume the estimate of f(0) for the sampling surveys is negatively biased in the same magnitude range, then the estimates need be further adjusted upward by a factor of between 1.035 and 1.289. Relative to the estimated bias due to sea truth sampling, bias due to estimating f(0) is small. Using the conservative figure of 1.035 and that previously estimated for net sampling (10.51) results in a bias adjustment estimate of 10.88. Misclassification error for visual mud size-class assignment is another likely source of bias. We estimated the probability of misclassification as the overlap in tail frequencies of the photomeasured muds by size class (Figure 7). For the large size-class, 16.7% overlapped the medium-size range. For the medium size-class, 16.7% overlapped the large- and 47.6% overlapped the small-size range. A total of 37.0% of the small muds overlapped the medium size range. No overlap was observed between the large and small size classes.

Percentage bias (MB) attributable to misclassification error was estimated as:

$$MB = 100 - 100 \left[\frac{\sum_{i=1}^{3} \sum_{j=1}^{3} \left(s_i (n_i - a_{ij} n_i + a_{ji} n_j) \right)}{\sum_{i=1}^{3} s_i \, n_i} \right] ; \; i \neq j,$$

where s_i is the surface area estimates for mud size class i, n_i the number of muds classified into size class i, and a_{ij} the misclassification probability for a mud of size class i into size class j. The misclassification probability matrix used was:

		i: 1 (Large)	2 (Medium)	3 (Small)
j	1 (Large)	-	.167	0
	2 (Medium)	.167	-	.476
	3 (Small)	0	.370	-

Misclassification bias was estimated to range from -70.03 to 6.06% depending upon sighting classification frequencies and total sample size by survey. The general trend was to cause an underestimation of biomass using the unadjusted size-class frequencies. MB estimates by survey and total bias adjustment factors are presented in Table 9.

Biomass point estimates, adjusted for bias, are presented in Table 10. These estimates range from a low of 132.08 MT (132,080 kg) to a peak of 936.73 MT (936,730 kg). Estimated harvest for silver mullet ranged from 3.6% -17.8% of the presumed standing stock for months where data were available. During low abundance periods (<400 MT), percentage estimated harvest was slightly higher, ranging from 3.9-17.8% (6.6% mean), while the high abundance period harvest ranged from 3.6-6.2%. This result implies a potential for seasonally variable effect of the fishery on predator stocks dependent upon silver mullet in FB.

SUMMARY

In summary, the results presented indicate that estimates of mud density track the fishery related indicies of silver mullet abundance reasonably well. Our estimates of standing stock are characterized by a high degree of variation owing principally to variability about our estimates of biomass per unit area of mud, the proportion of muds with mullet, and the surface area of a mud. The density of large muds was found to contain most of the information content on relative abundance of silver mullet. This index may serve as a precise measure of relative abundance and allow for interannual comparisons, providing consistent methodology is applied. An alternative to visual sampling of FB for estimating mud density is the application of a photo census of the study area whereby all muds are enumerated and accurately measured. Bias due to sea-truth sampling, estimation of f(0), and visual misclassification error was estimated to cause underestimation of silver mullet biomass by a factor of from 10 to 18.5 or more. Bias adjusted point estimates of mullet biomass in FB by sampling survey date range from 132.1 to 936.7 MT, while monthly harvest estimates ranged from 3.6 - 17.8% of the estimated standing stock.

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REFERENCES CITED

Brown, M.B. and A.B. Forsythe. 1974. The small sample behavior of some statistics which test the equality of several means. Technometrics 16: 129-132.

Burnham, K.P., D.R. Anderson, and J.L. Laake. 1980. Estimation of density from line transect sampling of biological populations. Wildl. Mono. 72:202pp.

Crain, B.R., K.P. Burnham, D.R. Anderson and J.L. Laake. 1979. A Fourier series estimator of population-density for line transect sampling. Utah State University Press, Logan, Utah, 25pp.

Cloud, P. E. 1962. Environment of calcium carbonate deposition west of Andros Island, Bahamas. U.S. Geological Survey Professional Paper.

Collins, M.R. 1981. The feeding periodicity of striped mullet, Mugil cephalus L., in two Florida habitats. J. Fish. Biol. 19:307-315.

Eberhardt, L.L. 1978. Transect methods for population studies. J. Wildl. Manage. 42(1):1-31

Laake, J.L., K.P. Burnham, and D.R. Anderson. 1979. User's manual for program TRANSECT. Utah State University Press, Logan, Utah. 26pp.

Matuszewski, A. and D. Stores. 1980. 80% Interval testing as an alternative procedure for comparing two parameters. American Statistical Association Stat. Comp. Proc. 1980:279-283.

Nickerson, D. K., Jr. 1984. A description of the eastern Florida silver mullet (Pisces: Mugilidae) bait fishery. Florida Marine Research Publications. Florida Department of Natural Resources. No. 41. 14 p.

Odum, W.E. 1966. The food and feeding of the striped mullet, Mugil cephalus in relation to the environment. MS Thesis, Institute of Marine Sciences, University of Miami, Miami, Fl. 118p.

Odum, W.E. 1970. Utilization of the direct grazing and plant detritus food chains by the striped mullet, Mugil cephalus. pp.222-240, In: Steele, J.H. (editor) Marine Food Chains. Univ. California Press, Berkeley.

Scholl, D.W. 1966. Florida Bay: a modern site of limestone formation. pp 282-288. In: Fairbridge, R.W. (ed), Encyclopedia of Oceanography, Encyclopedia of Earth Sciences, Volume I.

Schomer, N. S. and R. D. Drew. 1982. An ecological characterization of the lower Everglades, FLorida Bay and the Florida Keys. FWS 10BS-82/58.1. 246 p.

Seber, G.A.F. 1983. The estimation of animal abundance, 2nd edition. MacMillan Publ. Co., Inc. New York, N.Y. 654 pp.

Shinn, E.A., R. P. Steinez, B.H. Lide and B. B. Halley. 1985. Bahamian whitings - No fish story. Amer. Assoc. Pet. Geol. 69:(2):307.

Table 1. Sampling dates, transect lengths, aircraft type and number of observers used in the pilot and survey sampling phases of the study.

DATE[1]	SURVEY PHASE	AIRCRAFT	TRANSECT[2] LENGTH (km)	OBSERVERS
830125	Pilot	Laker	306.5	1
830307	"	"	268.4	1
830418	"	"	417.6	1
830602	"	"	263.2	1
830720	"	"	337.2	1
830721	"	"	262.8	1
830722	"	"	273.6	1
830830	"	"	283.4	1
830913	"	"	319.2	1
830915	"	"	331.6	1
840413	Survey	Cessna	535.9	2
840511	"	"	535.9	2
840612	"	"	619.3	2
840727	"	"	524.2	2
840821	"	"	619.3	2
840912	"	"	524.2	2
841004	"	"	619.3	2
841025	"	"	619.3	2
841113	"	"	619.3	2
841130	"	"	683.7	2
841214	"	"	619.3	2
850111	"	"	619.3	2
850125	"	"	619.3	2
850301	"	"	665.6	2
850329	"	"	578.1	2
850405	"	"	578.1	2
850419	"	"	578.1	2
850503	"	"	631.1	2
850517	"	"	578.1	2

[1] Date: year, month, day (YYMMDD)

[2] Transect length searched = transect flown x observers

Table 2. Sampling dates, number, and type of sea-truths samples taken from shipboard during the study period.

DATE[1]	NUMBER OF SAMPLES		
	PURSE-SEINE	GILLNET	TRANSECT
840413	2	0	0
840612	2	0	0
840727	4	0	0
840821	4	0	0
840912	3	0	1
841004	4	0	2
841011	0	0	1
841012	0	0	1
841023	0	0	2
841025	3	0	2
841113	2	0	2
841114	0	0	1
841130	4	0	2
841214	4	0	2
841220	0	0	2
850104	1	0	3
850111	5	0	3
850116	0	0	1
850117	0	0	2
850125	2	0	3
850215	2	0	3
850301	4	4	2
850405	4	4	0
850419	5	5	3
850426	5	5	3
850503	4	4	2
850517	2	2	2
850531	0	0	2
TOTAL	64	20	45

[1] Date = year, month, day (YYMMDD)

Table 3. Estimated Mud Density (km^{-2}), and abundance with associated variance components.

							% VARIANCE	
DATE	SIZE	F(0)	N	DM	M	%CV	F(0)	N
830125	SMALL	0.643	58	0.122	206.61	13.3	2.7	97.3
	MEDIUM	0.643	26	0.055	92.62	19.7	1.2	98.8
	LARGE	0.643	5	0.010	17.81	44.8	0.2	99.8
	TOTAL			0.187	317.00	12.3		
830307	SMALL	0.643	88	0.211	357.97	10.9	4.1	95.9
	MEDIUM	0.643	8	0.019	32.54	35.4	0.4	99.6
	LARGE	0.643	5	0.012	20.34	44.8	0.2	99.8
	TOTAL			0.242	410.00	11.1		
830418	SMALL	0.643	87	0.134	227.46	10.9	4.0	96.0
	MEDIUM	0.643	12	0.018	31.37	29.0	0.6	99.4
	LARGE	0.643	1	0.002	2.61	100.0	0.0	100.0
	TOTAL			0.154	261.00	11.2		
830602	SMALL	0.643	87	0.213	360.90	10.9	4.0	96.0
	MEDIUM	0.643	11	0.027	45.63	30.2	0.5	99.5
	LARGE	0.643	2	0.005	8.30	70.7	0.1	99.9
	TOTAL			0.244	414.00	11.2		
830720	SMALL	0.643	94	0.179	304.36	10.5	4.3	95.7
	MEDIUM	0.643	3	0.006	9.71	57.8	0.1	99.9
	LARGE	0.643	3	0.006	9.71	57.8	0.1	99.9
	TOTAL			0.191	323.00	10.9		
830721	SMALL	0.643	95	0.232	394.68	10.5	4.4	95.6
	MEDIUM	0.643	2	0.005	8.31	70.7	0.1	99.9
	LARGE	0.643	2	0.005	8.31	70.7	0.1	99.9
	TOTAL			0.242	411.00	10.8		
830722	SMALL	0.643	84	0.197	335.21	11.1	3.9	96.1
	MEDIUM	0.643	12	0.028	47.89	29.0	0.6	99.4
	LARGE	0.643	4	0.009	15.96	50.0	0.2	99.8
	TOTAL			0.235	399.00	11.3		
830830	SMALL	0.643	87	0.197	335.17	10.9	4.0	96.0
	MEDIUM	0.643	7	0.016	26.97	37.9	0.3	99.7
	LARGE	0.643	6	0.014	23.12	40.9	0.3	99.7
	TOTAL			0.227	385.00	11.1		
830913	SMALL	0.643	88	0.177	301.00	10.9	4.1	95.9
	MEDIUM	0.643	9	0.018	30.78	33.4	0.4	99.6
	LARGE	0.643	3	0.006	10.26	57.8	0.1	99.9
	TOTAL			0.201	342.00	11.2		
830915	SMALL	0.643	89	0.173	293.04	10.8	4.1	95.9
	MEDIUM	0.643	3	0.006	9.88	57.8	0.1	99.9
	LARGE	0.643	7	0.014	23.05	37.9	0.3	99.7
	TOTAL			0.192	325.00	11.0		
830413	SMALL	3.415	38	0.242	411.15	31.8	48.3	51.7
	MEDIUM	3.033	13	0.074	124.92	23.4	88.3	11.7
	LARGE	4.566	4	0.034	57.87	19.7	60.8	39.2
	TOTAL			0.350	593.00	24.1		
840511	SMALL	3.415	69	0.440	746.55	31.3	49.6	50.4
	MEDIUM	3.033	31	0.175	297.89	25.9	71.7	28.3
	LARGE	4.566	6	0.051	86.80	19.8	60.0	40.0
	TOTAL			0.666	1131.00	23.8		
840612	SMALL	3.415	96	0.529	898.90	29.9	54.3	45.7
	MEDIUM	3.033	27	0.132	224.54	23.4	87.8	12.2
	LARGE	4.566	5	0.037	62.60	22.8	45.5	54.5
	TOTAL			0.698	1186.00	24.5		
840727	SMALL	3.415	57	0.371	630.48	30.3	53.1	46.9
	MEDIUM	3.033	59	0.341	579.60	22.8	92.9	7.1
	LARGE	4.566	4	0.035	59.16	32.1	23.0	77.0
	TOTAL			0.747	1269.00	20.8		
840821	SMALL	3.415	165	0.910	1544.99	30.1	53.8	46.2
	MEDIUM	3.033	48	0.235	399.18	22.9	92.1	7.9
	LARGE	4.566	6	0.044	75.12	23.4	43.2	56.8
	TOTAL			1.189	2019.00	24.8		
840912	SMALL	3.415	155	1.010	1714.47	30.5	52.4	47.6
	MEDIUM	3.033	35	0.202	343.83	23.0	91.1	8.9
	LARGE	4.566	17	0.148	251.42	18.0	72.6	27.4
	TOTAL			1.360	2309.00	24.1		

Table 3. (Continued)

							% VARIANCE	
DATE	SIZE	F(0)	N	DM	M	%CV	F(0)	N
841004	SMALL	3.415	175	0.965	1638.62	30.0	54.3	45.7
	MEDIUM	3.033	25	0.122	207.90	24.8	78.6	21.4
	LARGE	4.566	53	0.391	663.53	16.5	86.6	13.4
	TOTAL			1.478	2510.00	21.1		
841025	SMALL	3.415	60	0.331	561.81	30.2	53.3	46.7
	MEDIUM	3.033	28	0.137	232.85	23.6	86.6	13.4
	LARGE	4.566	30	0.221	375.58	19.4	62.4	37.6
	TOTAL			0.689	1170.00	18.3		
841113	SMALL	3.415	31	0.171	290.27	31.5	49.1	50.9
	MEDIUM	3.033	14	0.069	116.43	23.3	88.4	11.6
	LARGE	4.566	31	0.229	388.10	18.7	67.3	32.7
	TOTAL			0.468	794.00	16.7		
841130	SMALL	3.415	127	0.634	1077.09	29.8	54.8	45.2
	MEDIUM	3.033	43	0.191	323.89	22.8	92.4	7.6
	LARGE	4.566	9	0.060	102.06	19.0	65.5	34.5
	TOTAL			0.885	1503.00	23.4		
841214	SMALL	3.415	77	0.425	720.99	29.9	54.6	45.4
	MEDIUM	3.033	41	0.201	340.96	23.3	88.4	11.6
	LARGE	4.566	14	0.103	175.27	18.5	69.1	30.9
	TOTAL			0.729	1237.00	20.7		
850111	SMALL	3.415	32	0.176	299.63	35.4	38.9	61.1
	MEDIUM	3.033	17	0.083	141.37	23.1	90.4	9.6
	LARGE	4.566	18	0.133	225.35	18.5	69.2	30.8
	TOTAL			0.392	666.00	19.7		
850125	SMALL	3.415	66	0.364	618.00	30.8	51.3	48.7
	MEDIUM	3.033	30	0.147	249.48	24.6	79.7	20.3
	LARGE	4.566	34	0.251	425.66	16.8	83.4	16.6
	TOTAL			0.762	1293.00	18.2		
850301	SMALL	3.415	97	0.498	845.08	30.4	52.7	47.3
	MEDIUM	3.033	50	0.228	386.88	23.0	91.3	8.7
	LARGE	4.566	46	0.316	535.84	16.6	85.6	14.4
	TOTAL			1.041	1767.00	18.0		
850329	SMALL	3.415	88	0.520	882.69	30.5	52.5	47.5
	MEDIUM	3.033	47	0.247	418.70	22.7	93.2	6.8
	LARGE	4.566	49	0.387	657.15	17.5	76.8	23.2
	TOTAL			1.153	1958.00	17.5		
850405	SMALL	3.415	68	0.402	682.08	30.9	51.1	48.9
	MEDIUM	3.033	56	0.294	498.88	22.9	91.4	8.6
	LARGE	4.566	50	0.395	670.56	16.8	83.6	16.4
	TOTAL			1.090	1851.00	16.4		
850419	SMALL	3.415	97	0.573	972.96	30.5	52.3	47.7
	MEDIUM	3.033	69	0.362	614.69	23.2	89.3	10.7
	LARGE	4.566	30	0.237	402.34	18.2	71.3	28.7
	TOTAL			1.172	1989.00	19.1		
850503	SMALL	3.415	99	0.536	909.69	30.1	53.7	46.3
	MEDIUM	3.033	54	0.260	440.69	22.9	92.0	8.0
	LARGE	4.566	20	0.145	245.72	16.5	86.2	13.8
	TOTAL			0.940	1596.00	20.4		
850517	SMALL	3.415	69	0.408	692.11	31.7	48.3	51.7
	MEDIUM	3.033	19	0.100	169.26	23.9	84.1	15.9
	LARGE	4.566	15	0.118	201.17	17.9	73.5	26.5
	TOTAL			0.626	1062.00	22.7		

Table 4. Dominant species collected in a purse seine during seatruth sampling (by number and percentage of total catch).

Species	Number Collected	Percent of Total Catch
Opisthonema oglinum (A. thread herring)	4476	39.5
Eucinostomus gula (silver jenny)	4180	36.8
Mugil spp. (silver & striped)	758	6.8
Lagodon rhomboides (pinfish)	551	4.9
Eucinostomus argenteus (spotfin mojarra)	485	4.3
Harengula pensacolae (scaled sardine)	198	1.7
Elops saurus (ladyfish)	122	1.1
Thirty-two species, each less than 1.0% of total numerical abundance	340	4.9
Total	11,340	100.0

Table 5. Estimated mud area, mullet biomass density, and mullet biomass per survey date.

DATE	MUD AREA (km^2)	%CV	BIOMASS[1] DENSITY	%CV	MULLET[2] BIOMASS	UPPER 80% CI
830125	29.620	60.8	2.146	102.2	3643.58	8415.15
830307	27.283	64.1	1.977	108.0	3356.15	8003.76
830418	8.884	70.1	0.644	104.0	1092.85	2549.38
830602	17.514	66.0	1.269	100.7	2154.41	4935.75
830720	14.117	68.9	1.023	108.8	1736.58	4159.61
830721	13.822	72.9	1.001	109.3	1700.29	4082.17
830722	24.598	62.9	1.782	103.2	3025.82	7029.67
830830	28.964	64.4	2.098	111.0	3562.86	8633.55
830913	16.924	64.9	1.226	102.8	2081.91	4825.33
830915	26.456	66.4	1.917	116.5	3254.37	8115.98
840413	73.315	57.9	5.311	107.5	9018.64	21447.81
840511	123.927	56.6	8.978	102.8	15244.50	35343.65
840612	95.138	56.2	6.892	100.3	11703.10	26756.87
840727	127.844	60.7	9.262	102.3	15726.33	36349.17
840821	134.628	56.3	9.753	97.4	16560.82	37234.71
840912	295.527	59.2	21.410	111.5	36353.40	88324.25
841004	664.783	64.6	48.160	124.4	81776.24	212229.70
841025	384.322	64.4	27.842	122.9	47276.20	121793.61
841113	379.574	66.4	27.498	127.2	46692.18	122861.49
841130	145.376	56.1	10.532	102.3	17883.05	41336.83
841214	211.100	58.9	15.293	110.6	25967.82	62786.34
850111	230.291	64.3	16.683	123.0	28328.53	72986.44
850125	433.721	64.0	31.421	123.0	53352.92	137491.58
850301	554.936	63.3	40.202	121.5	68263.78	174614.03
850329	672.389	64.0	48.711	122.7	82711.94	212854.06
850405	691.220	63.5	50.076	122.0	85028.41	218068.66
850419	457.066	60.4	33.112	114.5	56224.59	138752.38
850503	290.487	58.9	21.044	111.5	35733.36	86833.60
850517	215.879	62.1	15.639	118.4	26555.70	66880.23

1 kg/km^2

2 kg

Table 6. Contribution to the total variance by the variables used to estimate biomass density.

			PERCENT OF TOTAL VARIANCE DUE TO												
DATE	BIOMASS DENSITY	%CV	DL	DM	DS	BL	BM	BS	SL	SM	SS	PL	PM	PS	TOTAL
830125	2.146	102.2	7.5	0.5	<0.1	30.0	11.1	<0.1	16.4	10.1	<0.1	17.7	6.5	<0.1	100.0
830307	1.977	108.0	10.1	0.2	<0.1	40.4	1.4	<0.1	22.1	1.2	<0.1	23.8	0.8	<0.1	100.0
830418	0.644	104.0	22.1	1.6	<0.1	17.6	15.4	<0.1	9.7	14.1	<0.1	10.4	9.1	<0.1	100.0
830602	1.269	100.7	17.6	1.0	<0.1	28.1	8.5	<0.1	15.4	7.8	<0.1	16.6	5.0	<0.1	100.0
83-720	1.023	108.8	16.1	0.2	<0.1	38.6	0.4	<0.1	21.1	0.4	<0.1	22.8	0.3	<0.1	100.0
830721	1.001	109.3	22.4	0.2	<0.1	35.8	0.3	<0.1	19.6	0.3	<0.1	21.1	0.2	<0.1	100.0
830722	1.782	103.2	11.4	0.4	<0.1	36.4	4.2	<0.1	19.9	3.8	<0.1	21.5	2.5	<0.1	100.0
830830	2.098	111.0	8.7	0.1	<0.1	41.7	0.8	<0.1	22.8	0.7	<0.1	24.7	0.4	<0.1	100.0
830913	1.226	102.8	14.7	0.5	<0.1	35.3	3.7	<0.1	19.3	3.4	<0.1	20.8	2.2	<0.1	100.0
830915	1.917	116.5	7.7	<0.1	<0.1	43.0	0.1	<0.1	23.5	0.1	<0.1	25.4	0.1	<0.1	100.0
840413	5.311	107.5	2.1	0.2	<0.1	42.5	2.8	<0.1	23.3	2.5	<0.1	25.1	1.6	<0.1	100.0
840511	8.978	102.8	1.9	0.5	<0.1	38.3	6.2	<0.1	21.0	5.7	<0.1	22.6	3.7	<0.1	100.0
840612	6.892	100.3	2.5	0.4	<0.1	37.8	6.5	<0.1	20.7	5.9	<0.1	22.3	3.8	<0.1	100.0
840727	9.262	102.3	2.3	1.5	<0.1	17.7	23.3	<0.1	9.7	21.3	<0.1	10.5	13.8	<0.1	100.0
840821	9.753	97.4	2.2	0.7	<0.1	32.0	11.4	<0.1	17.5	10.4	<0.1	18.9	6.7	<0.1	100.0
840912	21.410	111.5	1.8	0.1	<0.1	44.5	1.2	<0.1	24.4	1.1	<0.1	26.3	0.7	<0.1	100.0
841004	48.160	124.4	1.6	<0.1	<0.1	46.0	0.1	<0.1	25.2	0.1	<0.1	27.1	<0.1	<0.1	100.0
841025	27.842	122.9	2.2	<0.1	<0.1	45.5	0.2	<0.1	24.9	0.2	<0.1	26.9	0.1	<0.1	100.0
841113	27.498	127.2	2.0	<0.1	<0.1	45.8	0.1	<0.1	25.1	0.1	<0.1	27.0	<0.1	<0.1	100.0
841130	10.532	102.3	1.8	0.4	<0.1	39.4	5.4	<0.1	21.6	5.0	<0.1	23.3	3.2	<0.1	100.0
841214	15.293	110.6	1.8	0.2	<0.1	43.2	2.3	<0.1	23.6	2.1	<0.1	25.5	1.4	<0.1	100.0
850111	16.683	123.0	1.9	<0.1	<0.1	45.6	0.3	<0.1	24.9	0.2	<0.1	26.9	0.1	<0.1	100.0
850125	31.421	123.0	1.6	<0.1	<0.1	45.7	0.2	<0.1	25.0	0.2	<0.1	27.0	0.1	<0.1	100.0
850301	40.101	121.5	1.6	<0.1	<0.1	45.6	0.3	<0.1	25.0	0.3	<0.1	27.0	0.2	<0.1	100.0
850329	48.711	122.7	1.8	<0.1	<0.1	45.6	0.3	<0.1	25.0	0.2	<0.1	27.0	0.2	<0.1	100.0
850405	50.076	122.0	1.6	<0.1	<0.1	45.6	0.4	<0.1	25.0	0.3	<0.1	26.9	0.2	<0.1	100.0
850419	33.112	114.5	1.8	0.1	<0.1	44.2	1.5	<0.1	24.2	1.3	<0.1	26.1	0.9	<0.1	100.0
850503	21.044	111.5	1.5	0.1	<0.1	43.7	2.0	<0.1	23.9	1.8	<0.1	25.8	1.2	<0.1	100.0
850517	15.639	118.4	1.8	<0.1	<0.1	45.7	0.5	<0.1	24.8	0.4	<0.1	26.8	0.3	<0.1	100.0

[1] DL, DM, DS = density of large, medium and small muds
BL, BM, BS = biomass per unit area of large, medium and small mud
SL, SM, SS = area of large, medium and small muds
PL, PM, PS = proportion of large, medium and small muds with millet

Table 7. Biomass (g) per net set for the paired net samples.

Date	Set	Purse Seine Catch	Purse Seine Estimate[1]	Gill Net Catch	Net[2] Area Ratio	Equilibrated[3] Gill Net Catch
850301	1	304	608	65197	3.72	17526.1
	2	690	935	56641	1.50	37760.8
	3	0	0	385	1.36	283.1
	4	0	200	155	2.47	81.0
850405	1	0	0	370	1.42	260.2
	2	544	2176	45956	1.42*	32317.2
	3	158	474	9491	1.42*	6674.4
	4	0	0	1959	1.42*	1377.6
850419	1	80	160	1030	1.12	919.6
	2	197	591	945	1.05*	900.0
	3	0	400	5487	1.01	5432.7
	4	188	940	7205	1.08	6671.3
	5	278	2224	5507	1.00	5507.0
850426	1	0	400	0	1.34	0
	2	4010	4010	1856	0.61	3062.7
	3	152	304	4435	1.20	3686.6
	4	949	1749	1661	0.89	1860.0
	5	355	355	80	0.67	119.2
850503	1	0	0	0	2.54	0
	2	0	360	0	0.67	0
	3	375	1752	108	1.12	96.7
	4	0	300	0	1.72	0
TOTAL		8280	17938			124536.2
P/G[4]		0.066				
P/G[5]			0.144			

1 Estimate includes fish jumping cork line

2 Ratio of area encircled by gill net: area encircled by purse seine from photogrammetric samples where data are unavailable, this ratio is estimated as the daily average ratio, indicated with an astrix

3 gill net catch/net area ratio

4 $\sum$ purse seine catch/$\sum$ equilibrated gill net catch

5 $\sum$ estimated purse seine catch/$\sum$ equilibrated gill net catch

* estimates from daily average ratio

Table 8. Estimation of relative biomass undersampled by the gill net assuming the purse-seine length distribution is representative of the population.

i	l(mm)	ps_i	gn_i	$w_i(g)$	$(ps_i-gn_i)wi$	$ps_i \cdot w_i$
1	112	.0037	0	19.53	.0723	.0723
2	127	.0146	0	27.22	.3974	.3974
3	132	.0146	0	30.14	.4400	.4400
4	137	.0256	0	33.25	.8511	.8511
5	142	.0220	0	36.55	.8040	.8040
6	147	.0773	0	40.04	.2923	.2923
7	152	.0110	0	43.74	.4811	.4811
8	157	.0337	0	47.64	.1762	.1762
9	162	.0146	0	51.75	.7556	.7556
10	167	.0073	.0018	56.01	.3084	.4094
11	172	.0110	0	60.62	.6668	.6668
12	177	.0183	0	65.38	1.1965	1.1965
13	182	.0146	.0018	70.37	.9008	1.0274
14	187	.0073	0	75.59	.5518	.5518
15	192	.0110	.0018	81.04	.7456	.8915
16	197	.0037	0	86.74	.3209	.3209
17	202	.0037	.0018	92.67	.1761	.3429
18	207	.0110	0	98.85	1.0873	1.0873
19	212	.0073	0	105.28	.7685	.7685
20	217	.0183	0	111.96	2.0489	2.0489
21	222	.0402	0	118.90	4.7798	4.7798
22	227	.0183	.0055	126.10	1.6141	2.3077
23	232	.0220	.0018	133.57	2.6981	2.9384
24	237	.0623	.0018	141.30	8.5488	8.8031
25	242	.1282	.0238	149.31	15.5879	19.1414
26	247	.0623	.0439	157.59	2.8997	9.8179
27	252	.0952	.0896	166.15	.9305	15.8179
$\sum_{i=1}^{n}$					50.1005	77.1882
$\sum_{i=n+1}^{m}$						70.4918
						147.6800

$\widehat{RB} = 0.3392$

Table 9. Estimated percentage basis due to misclassification probability and resulting total bias adjustment for biomass estimates by survey date.

Date	Misclassification[1] Bias (%)	Total Bias Adjusment	Date	Misclassification[1] Bias (%)	Total Bias Adjustment
840413	-34.66	14.65	841214	-24.35	13.53
840511	-44.36	15.71	850111	- 1.16	11.05
840612	-57.11	17.09	850125	- 1.17	11.06
840727	-61.89	17.61	850301	- 3.42	11.25
840821	-70.43	18.54	850329	- 1.34	11.25
840912	-28.88	14.02	850405	- 1.26	11.02
841004	- 2.22	11.12	850419	-15.23	12.54
841025	- 1.80	11.07	850503	-21.88	13.26
841113	6.06	10.22	850517	-12.42	12.23
841130	-47.87	16.09			

[1] A negative value implies percent underestimated by the unadjusted distribution of size-class frequencies. Positive values imply percentage overestimated.

Table 10. Silver mullet biomass point estimates adjusted for estimated bias by survey date and harvest as a percentage of estimated biomass.

Date	Estimated Biomass (MT)	Estimated % Harvest	Date	Estimated Biomass (MT)	Estimated % Harvest
840413	132.08	17.8	841214	351.24	7.4
840511	239.42	5.3	850111	312.94	-
840612	199.96	3.9	850125	589.90	-
840727	276.84	5.6	850301	767.73	-
840821	306.94	7.8	850329	930.38	-
840912	509.52	3.9	850405	936.73	-
841004	909.07	3.6	850419	704.85	-
841025	523.10	6.2	850503	473.68	-
841113	477.05	3.7	850517	324.67	-
841130	287.63	6.1			

[1] Estimated harvest of silver mullet in FB from ENP data, expressed as percentage of bias adjusted biomass estimates.

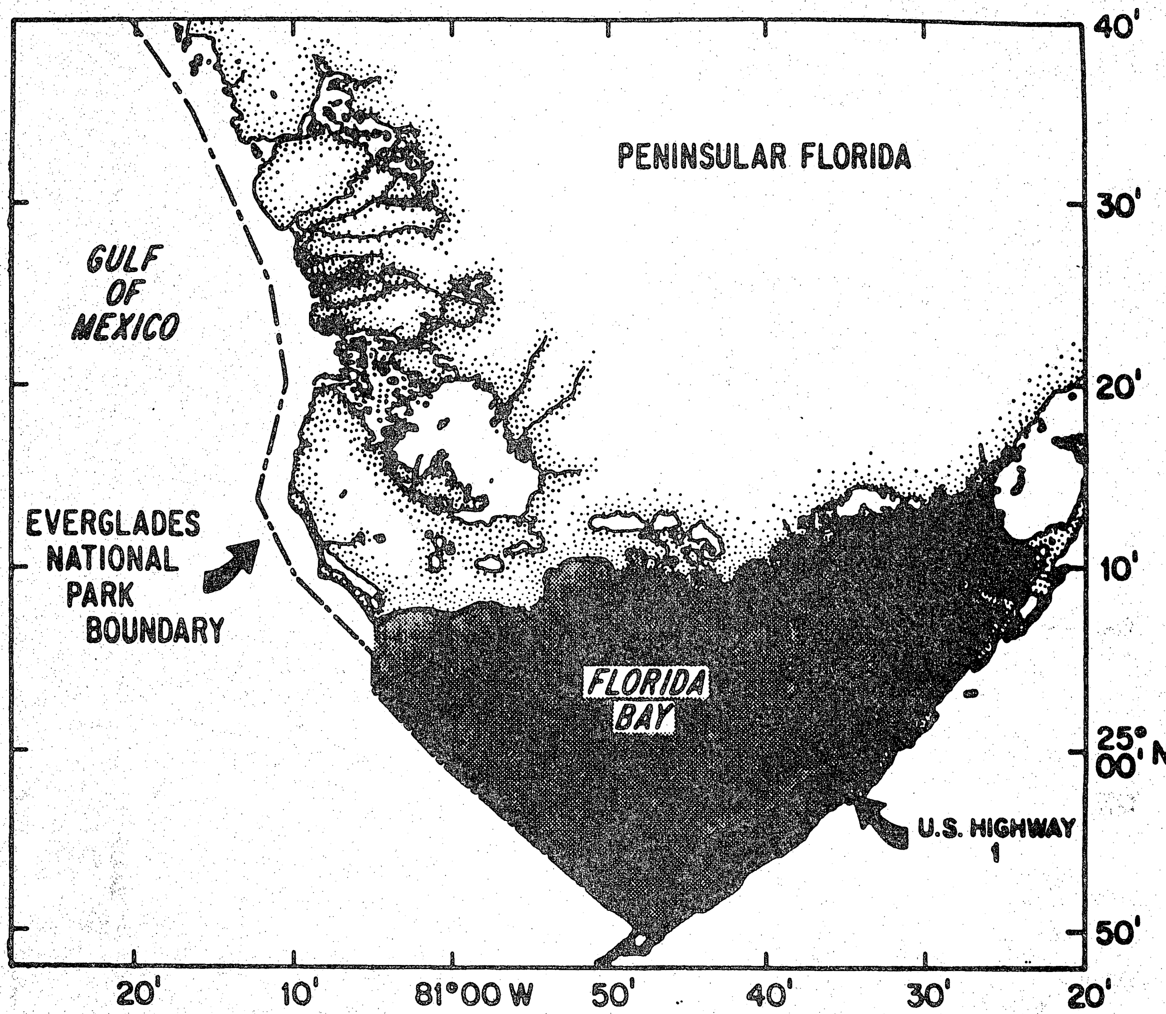

Figure 1. The study area. Sampling was restricted to the area of stippeling. Sampling transects in the area were oriented northwest to southeast.

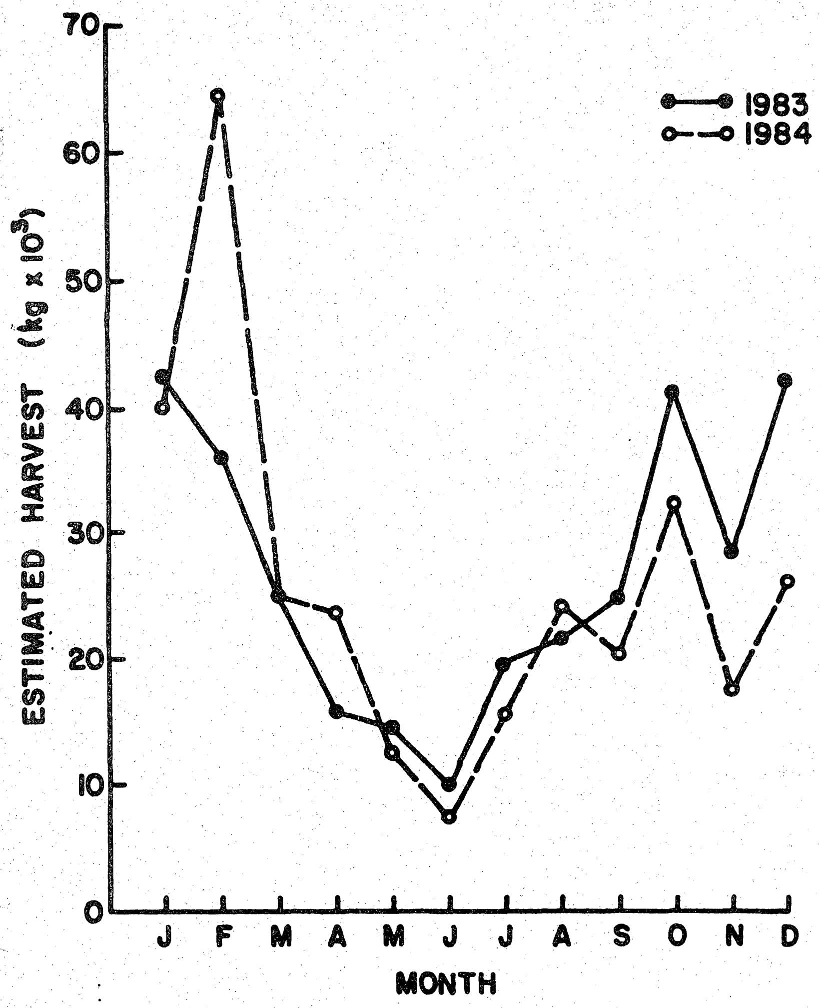

Figure 2. Estimated monthly harvest of silver mullet from the Florida Bay for 1983 and 1984.

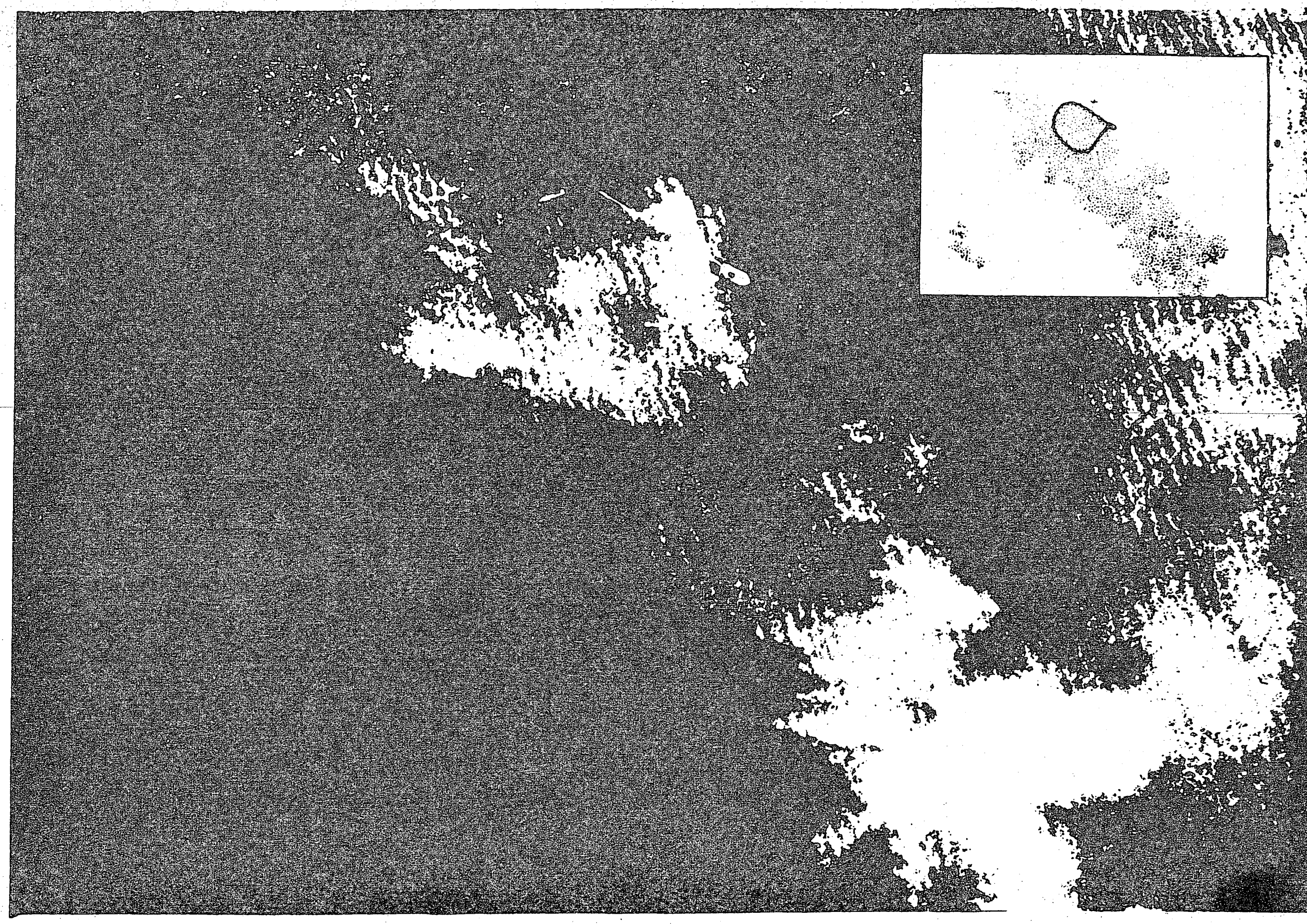

Figure 3. The sea-truth vessel sampling a randomly selected mud using purse-seine gear. The image was taken with the 5" vertical camera. Inset, traced from original photograph, shows actual area of mud and position of net for clarification.

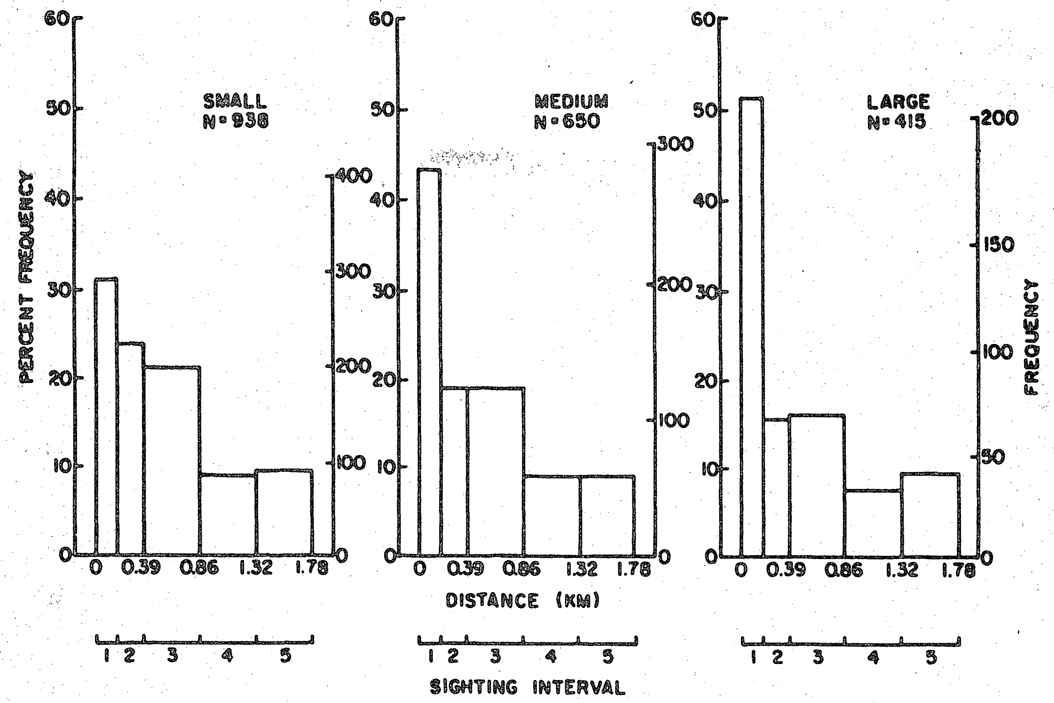

Figure 4. Sighting frequency histograms by mud size class and right angle distance interval for the sampling survey data.

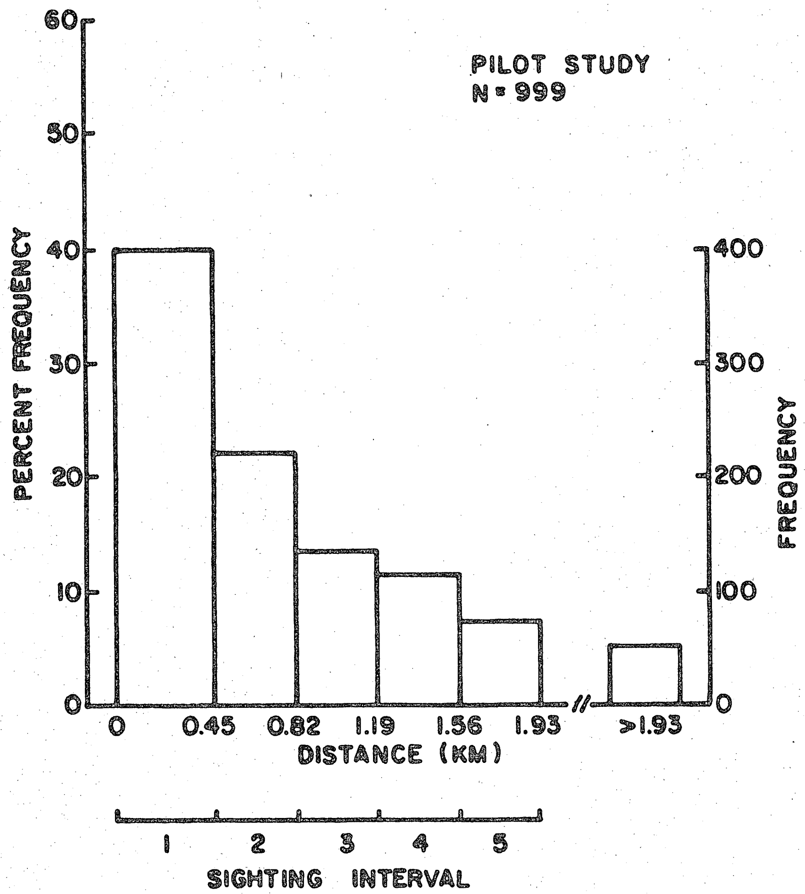

Figure 5. Sighting frequency histogram of the pilot survey mud data.

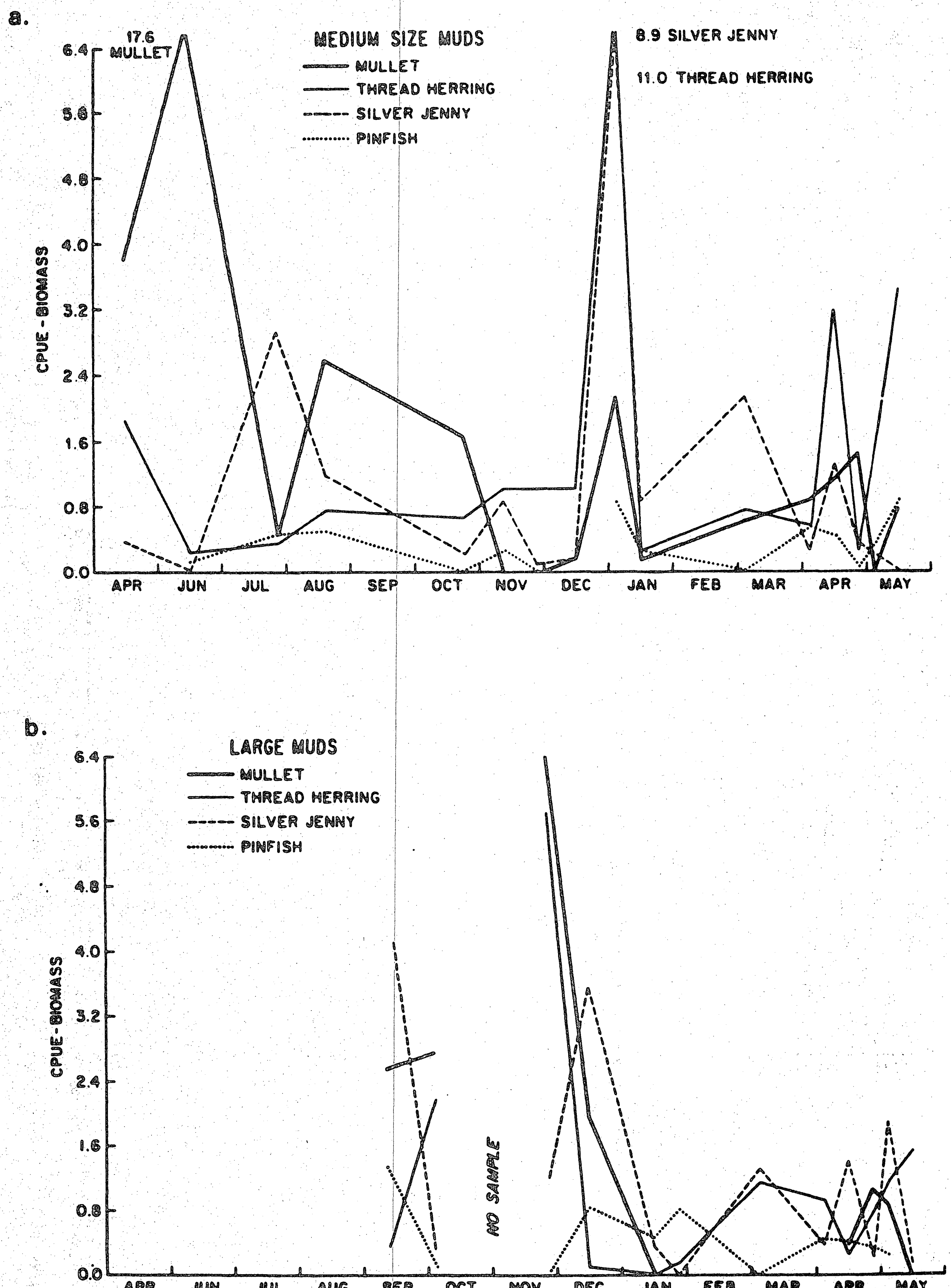

Figure 6a. Average catch per standard net set by month for predominant species sampled in medium-sized muds.
b. Average catch per standard net set by month for predominant species sampled in large-sized muds.

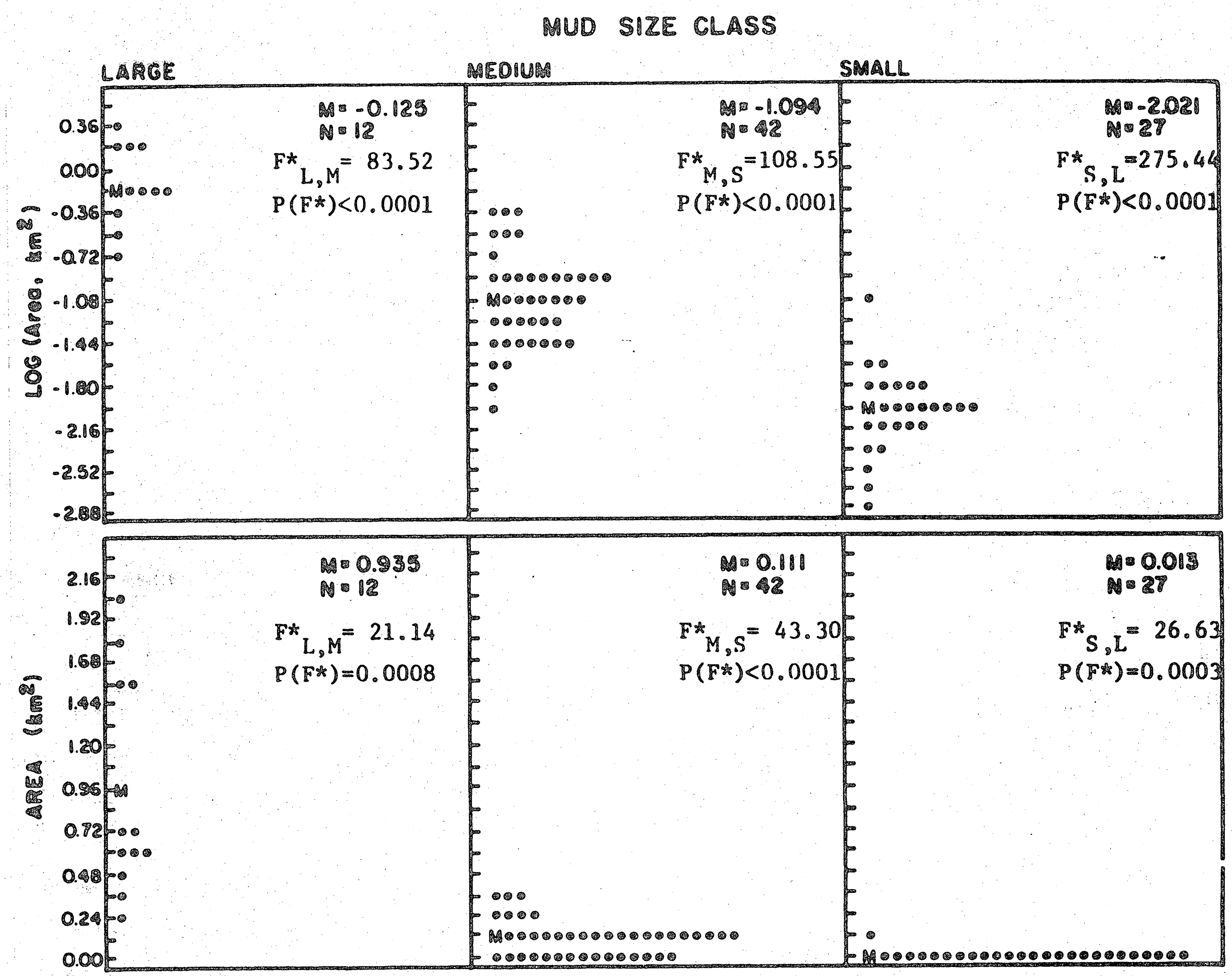

Figure 7. Size frequency distributions for photo measured small-, medium, and large muds. The upper row is log transformed data. In the figure, M represents the group mean. F^* is the Brown-Forsyth F statistic; subscripts L, M and S represent large, medium and small. $P(F^*)$ is the probability of a larger F^* due to chance alone.

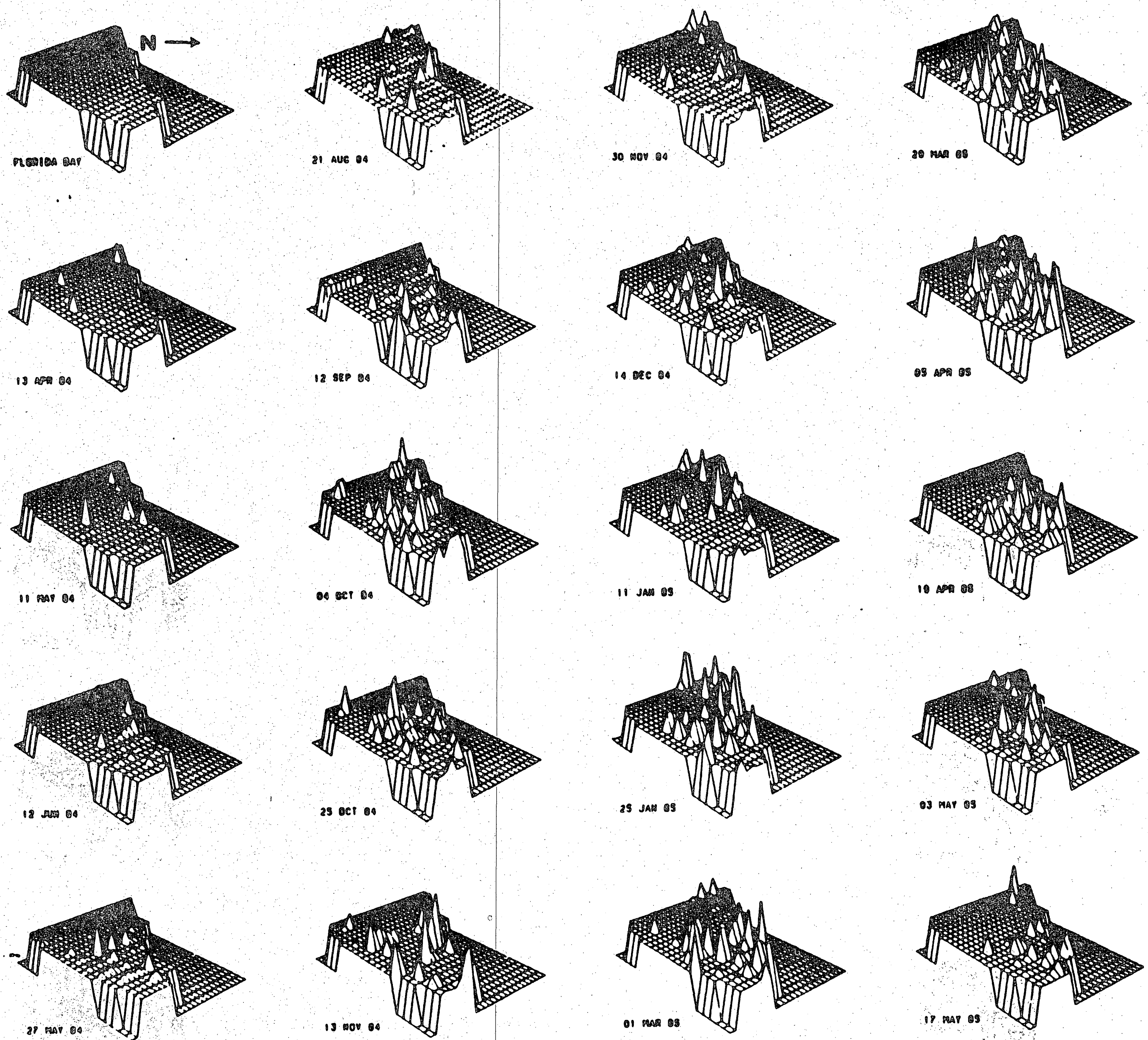

Figure 8. The relative mud density distributions in Florida Bay by sampling survey date. The study area surface is shown in the upper left hand plate as the elevated platform. Grids below the elevated platform were outside the study area.

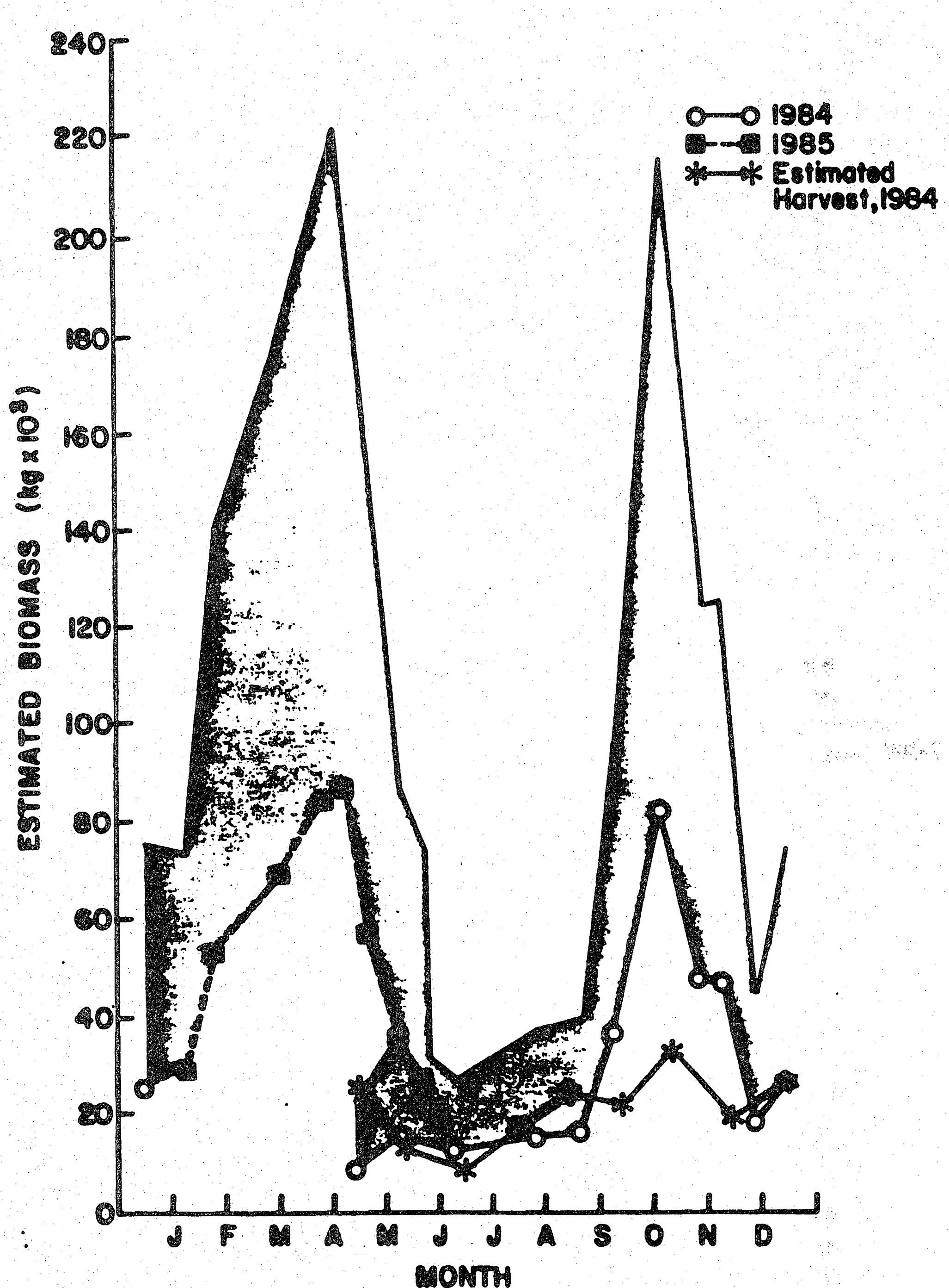

Figure 9. Estimates of silver mullet biomass with upper 80% CI tail shown (stipple). Also depicted as astrix are the estimated monthly harvest of silver mullet from FB based on unpublished ENP data.

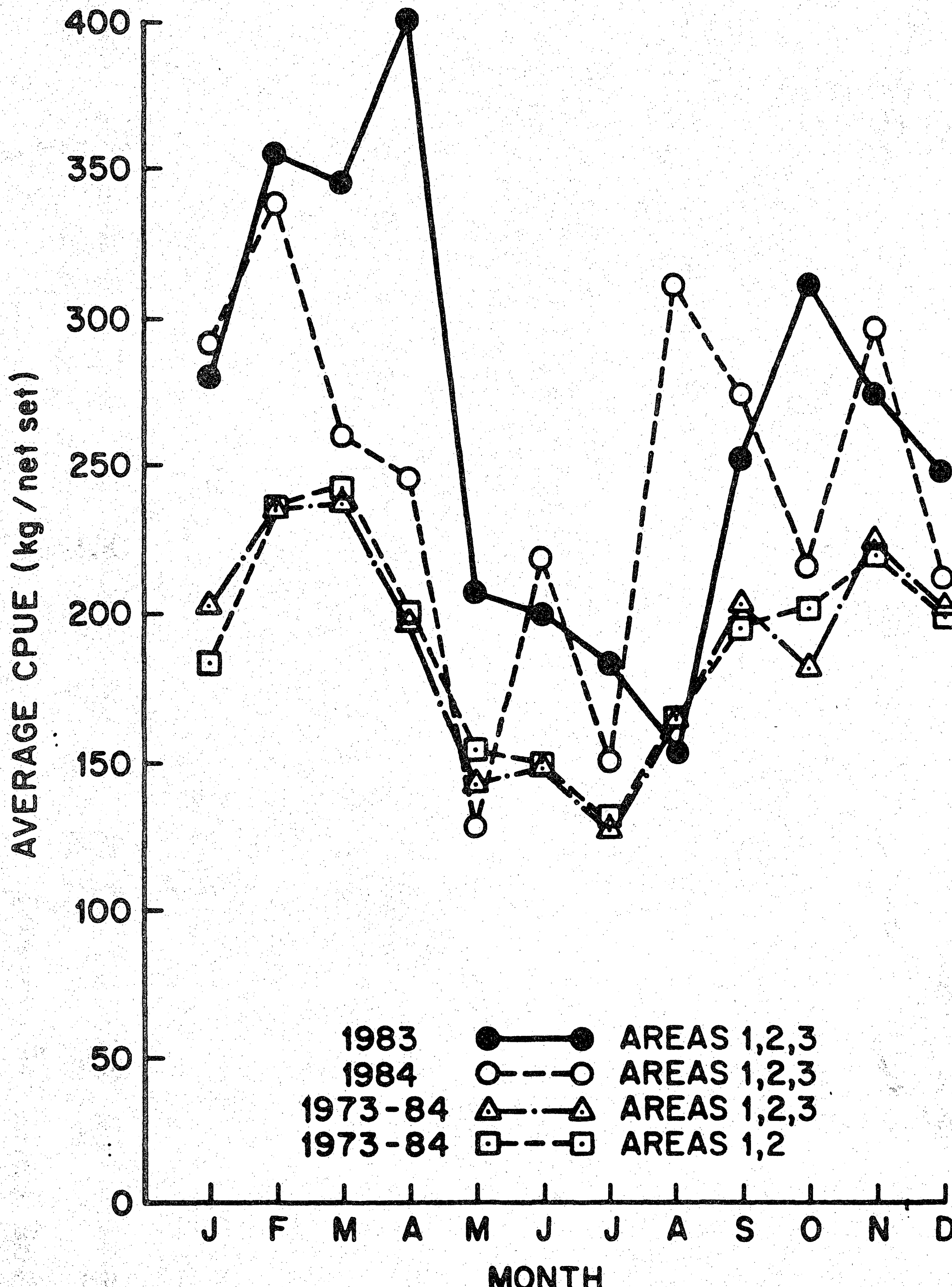

Figure 10. CPUE trends in the ENP commercial harvest of silver mullet. CPUE data are based on unpublished ENP data. Statistical areas 1 and 2 represent the eastern Florida Bay. Statistical area 3 is the western part of the bay.

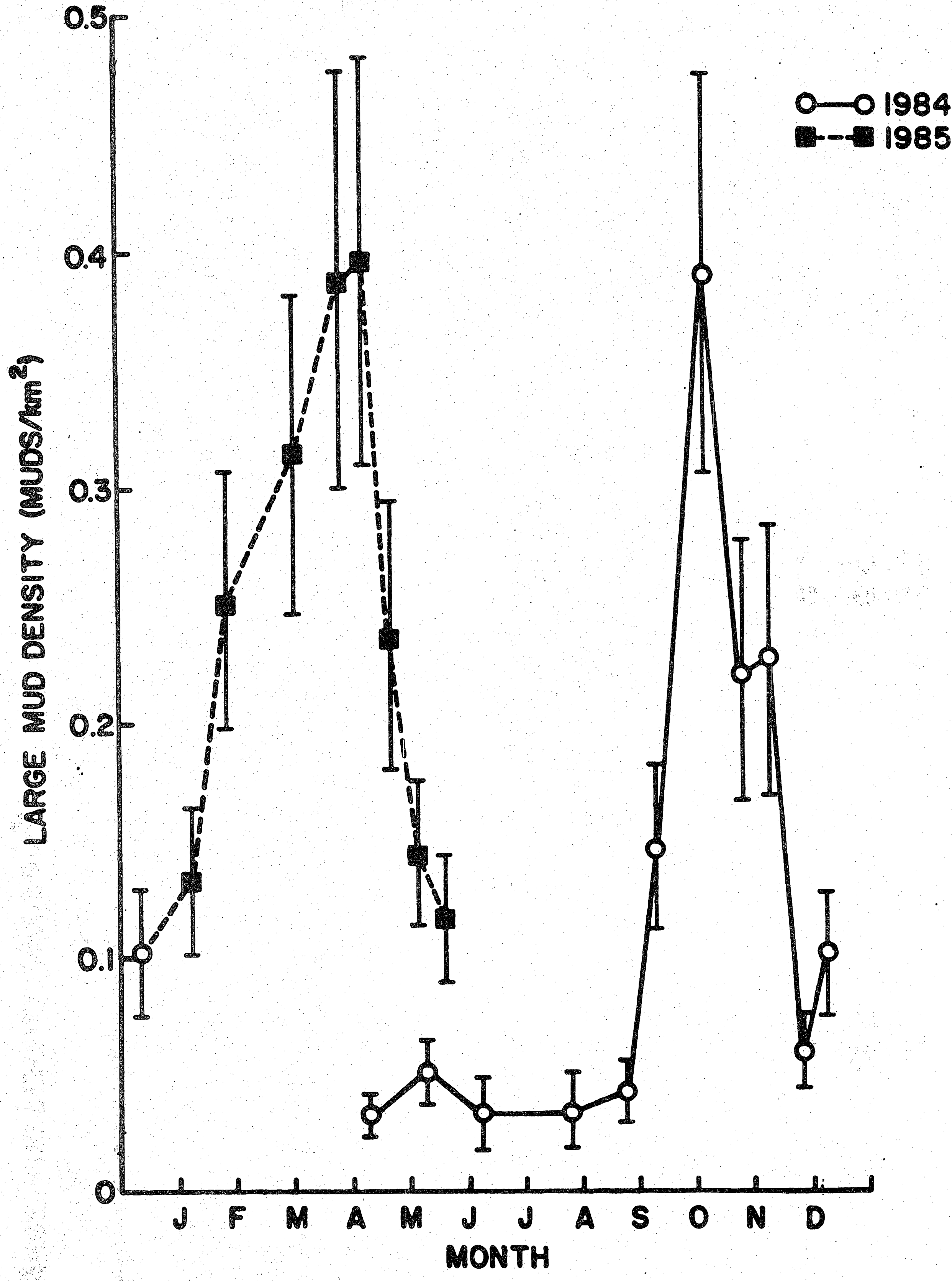

Figure 11. Large mud density estimates with associated 80% CIs. Non overlap of the CI tails implies statistical significance at an approximate α of 0.05 (Matuszewski and Stores 1980).

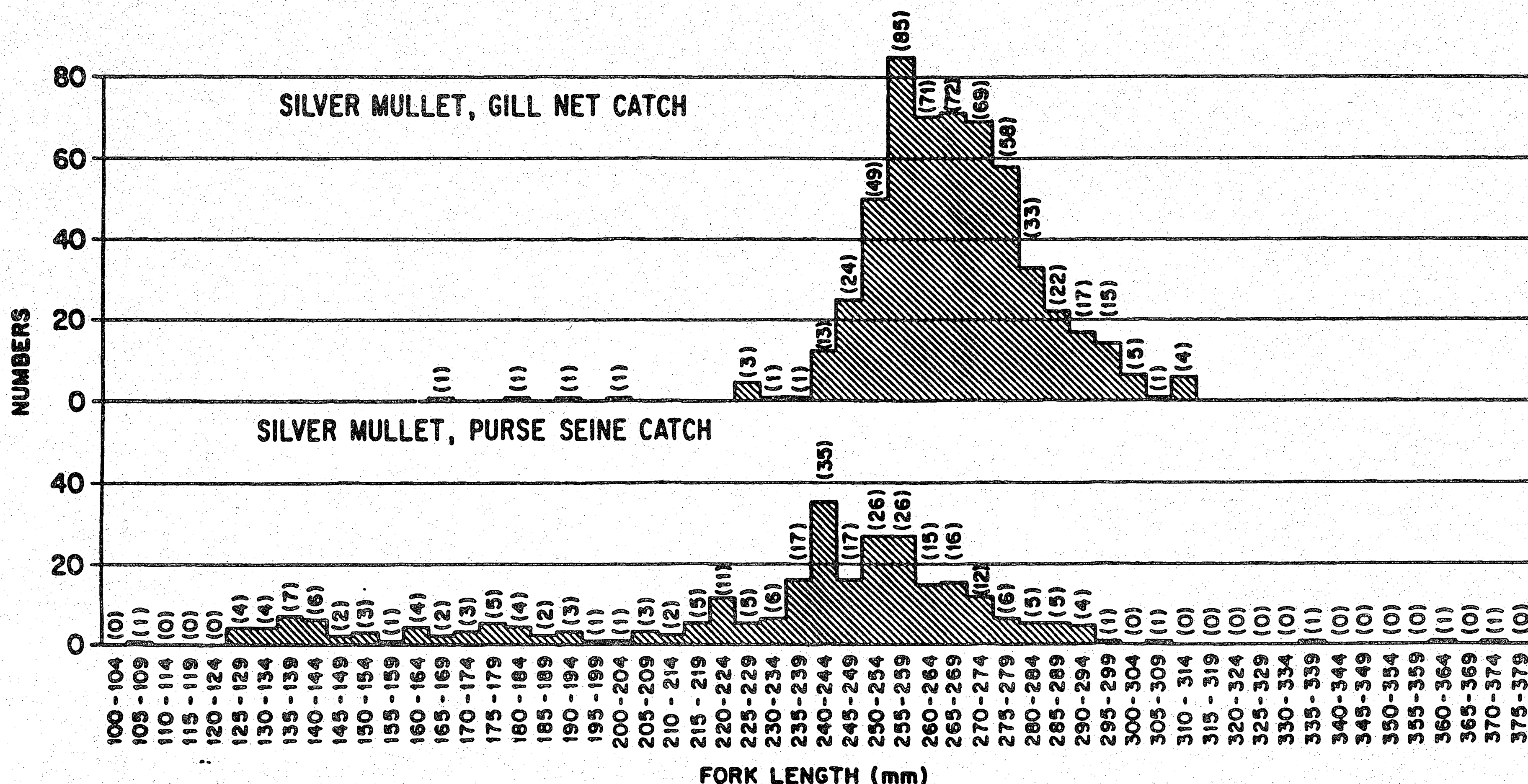

Figure 12. Length class distributions of silver mullet captured by the purse-seine and commercial gill net.