

Estimating Seasonal Menhaden Abundance in Narragansett Bay from Purse Seine Catches, Spotter Pilot Data, and Sentinel Fishery Observations.

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November 27, 2007

Prepared for the Menhaden Science and Policy Symposium

Abstract- Adult Atlantic menhaden (*Brevoortia tyrannus*) entered Narragansett Bay in large numbers in the summer of 2007 and were subject to an active purse-seine fishery. Out of concern for escalating effort, RIDEM implemented a daily possession limit and rigorous reporting requirements in the fishery. In view of the ecological and social value of menhaden, an interim management policy was set that restricts fishery removals to 50% of the amount of adult menhaden that enter the Bay. In support of that policy, a depletion model for open populations was developed to estimate Bay abundance and track exploitation rates relative to management targets. The model used the spotter pilot observations as an index of abundance. Daily purse seine landings constituted the absolute, depletion quantity in the model. Additional fishery data from floating traps was used to index movement of menhaden in and out of the Bay to account for the recruitment effect. Regular biological samples were taken from both the purse seine and floating trap catches. Adult menhaden entered the Bay in May and were largely gone by August. Model estimates indicate that from an initial population of 4.52 million pounds in May, abundance increased to 9.13 million by July 10. Total exploitable abundance for the season was estimated at 12.39 million pounds. The purse seiners ceased fishing in early August when abundance dropped to unprofitable levels. The limit exploitation rate was not reached in 2007, that is less than 50% of the exploitable biomass was removed by purse seine. Over 6,800 fish were sampled for biological attributes. Mean length and weight were 282 mm and 400 grams respectively. Weight-length data indicated that adult fish remaining in the Bay late in the season had degraded body condition and insufficient food resources to sustain them. Real time abundance estimation and management of limit exploitation rates is expensive. It requires observers, analysts, managers, and deployment of enforcement assets. It will be challenging for the Department to sustain this level of activity in the current budget climate.

Introduction- Atlantic menhaden (*Brevoortia tyrannus*) are a member of the family Clupeidae, schooling pelagic fishes many of which are planktivores. They are important ecologically, economically, and to recreational anglers. Their life history has been well summarized by Arenholz (1991) and ASMFC (2004a, 2006). The following summary is taken directly from ASMFC (2006). “Atlantic menhaden are euryhaline species that

inhabit near shore and inland tidal waters from Florida to Nova Scotia, Canada (Arenholz 1991). Spawning occurs principally at sea with some activity in bays and sounds in the northern portion of the range. Eggs hatch at sea and the larvae are transported to estuaries by ocean currents where they undergo metamorphosis and develop into juveniles. Adults stratify by size during the summer with older larger individuals found further north. During the fall, Atlantic menhaden migrate south and disperse from near shore surface waters off North Carolina by late January or early February. Schools of adult menhaden reassemble in late March or early April and migrate northward. By June the population is redistributed from Maine to Florida (Arenholz 1991).” Atlantic menhaden are considered a single stock along the Atlantic coast. Estuarine specific stocks are not recognized, as there is no evidence for homing to natal spawning areas that could result in discrete stocks. The most recent coast wide resource assessment, conducted by the Atlantic States Marine Fisheries Commission (ASMFC), found that Atlantic menhaden were not over fished and that over fishing was not occurring at this time (ASMFC 2006). Recruitment of young fish has been declining, particularly in the Chesapeake Bay area, but this has not yet been considered as threatening to the health of the overall stock. An ASMFC research agenda has been set for 2007-2008 that includes study of the so-called “localized depletion issue” that is of concern in the Chesapeake Bay area. Low abundance of juvenile menhaden may be impacting the nutritional status and growth of striped bass (Overton et al. 2000). Another important research area is the use of LIDAR (Light Detection and Ranging) technology to estimate menhaden abundance from the air.

In Rhode Island, menhaden occur in Narragansett Bay in every month of the year (Table 1). Catches in the Division of Fish and Wildlife (DFW) monthly trawl survey are mostly young of the year (YOY) menhaden less than 12 cm in length taken in summer and fall cruises. Of note, is the occurrence of juveniles in the Bay during winter months that apparently leave in the spring before the new cohort appears in July. These winter juveniles may be holdovers from a second fall cohort. Adult menhaden are rarely taken in the DFW bottom trawl surveys because of their tendency to form discrete, dense schools in surface waters. Observations by staff and commercial landings indicate that adult menhaden are present in the Bay from May through September although their abundance and residence time can vary greatly from year to year. Eggs and larvae of menhaden once dominated the upper Bay ichthyoplankton community according to Bourne and Govoni (1988) who sampled the Bay extensively in 1971-1972. Menhaden eggs and larvae were much reduced in abundance by 1990 in repeat sampling done by Keller et al. (1999). This large decline in egg abundance is evident in ichthyoplankton sampling done by companies operating power plants at the head of the Bay (Figure 1). A large, commercial reduction fishery operated in Narragansett Bay in the 1970’s and took upwards of 18,000 metric tons of menhaden from populations as large as 23,000 tons (Oviatt 1977, Durbin and Durbin 1998). Commercial landings declined sharply during the 1980’s and were only a few thousand tons by 1990, too low to be economically viable for large-scale operations. The large decline in adult menhaden abundance as indexed by both egg production and commercial landings was coincident to a major reduction in plankton abundance and spring bloom activity in the Bay (Smayda and Borkman 2007).

Although large-scale fishing of menhaden for reduction purposes in Rhode Island was prohibited in 2003 (RIGL 20-4.1-3), purse seining of menhaden for bait, chum or purposes other than fishmeal has continued. Despite an extensive set of closed areas and seasonal limitations imposed by the Department of Environmental Management (DEM) and the Rhode Island Marine Fisheries Council (RIMFC) to regulate the menhaden fishery, controversy remains over the small-scale bait fishery. Just as in the Chesapeake Bay, concern over local depletion exists and recreational fishing interests and environmentalists have asked the General Assembly to ban commercial fishing for menhaden in the Bay charging that the fishery removes too many fish thereby denying the Bay critical ecological and recreational services. A bill to do so was introduced in 2007 but was not acted on prior to the end of the session. Oviatt (1977) found that large-scale commercial fishing in the Bay could take up to 80% of the adult menhaden present lending support to that view. However, with the elimination of reduction fishing, exploitation rates are likely much lower in the remaining bait fishery and Rhode Island commercial landings are now an order of magnitude lower than during peak reduction fishing years. On a coast wide basis, recent exploitation rates have only been about 32% of standing stock (ASMFC 2006) suggesting a much-reduced and sustainable fishery. Still, the lack of an adult abundance index has hampered DFW from fully assessing the local fishery although some progress has been made in developing a biomass dynamic model calibrated to egg density data. Concern remains that insufficient biomass is left in the Bay to provide essential water filtration and forage for apex predators. In this paper, a depletion method for open populations is developed for application to the Bay bait menhaden fishery. It is used to estimate 2007 Bay adult stock size and fishery exploitation rate.

Methods and Data Sources- DEM regulations require that purse seine vessels fishing for menhaden in Narragansett Bay report their catches and number of net sets each day to DFW. They also agree to carry a DFW observer on both the fishing vessel and the spotter plane upon request. When on the fishing vessel, DFW observers sample the catch and record the weight of catch offloaded. Catch sampling includes length frequencies, body weights, and determination of sex and gonad status. When in the air, DFW observers record the pilot counts of the number of menhaden schools observed, the estimated weight within the schools, and the location of the schools. Other commercial harvesters such as floating trap fishers are required to file logbook reports monthly with the DFW that detail daily fishing activities. These fixed gear fisheries are useful as sentinels, documenting the arrival and movements of menhaden in state waters. Other information on menhaden abundance and movements are obtained from scientific staff on DFW research cruises and a network of commercial fishers working the Bay. Collectively, these sources of information can be analyzed using the theory of depletion estimation as applied to open populations.

Estimating animal abundance using depletion methods has been thoroughly detailed in Seber (1982) and fisheries specific methods and applications are given in Hilborn and Walters (1992). The basic principle underlying depletion methods is that known removals from a stock have a quantifiable impact on the subsequent catch rates because the population is being depleted by the fishing operation so that successive units of effort

produce less catch. Essentially, one asks how much has to be removed before none is left? The estimation is relatively simple for a closed population but becomes more challenging when recruitment or emigration occurs. For a closed population, the estimate of population size is the x-axis intercept of the regression of relative abundance on cumulative catch. Hilborn and Walters (1992) provide the following discrete time step population dynamics model for open populations:

$$B_t = G_{t-1}[B_{t-1} - C_{t-1}] + R_t + \varepsilon_p \quad (1)$$

where: B= stock biomass
 C= catch
 R= recruitment
 G= combined survival and growth term
 t= time
 ε_p = a process error term.

The recursion in eq. 1 states that the stock size at any given time is equal to stock size one time step earlier minus the catch removed as adjusted by natural survivorship and growth of the survivors plus recruitment. It should be appreciated that in an application to Bay menhaden the recruitment term can either be positive or negative depending on the directionality of movements. Absolute stock size is not known so an observation model based on an index of abundance (spotter estimates) is needed as well:

$$B_t = I_t/q + \varepsilon_m \quad (2)$$

where: I= index of abundance
 q= constant of proportionality
 t= time
 ε_m = measurement error term.

For $q=1.0$, the spotter estimates of abundance are unbiased. In a statistical sense this means that deviations from true abundance have a mean of zero and constant variance. Note that the implied exponent of the quotient in eq.2 is unity so that abundance is a linear function of the index. This condition can be relaxed if necessary. Recruitment is also not known but can be accounted for provided that some constraints are imposed namely that during any time step recruitment is zero, a positive constant, or the negative of the constant:

$$\begin{aligned} R_t &= 0 \text{ for } t \text{ with no movement} \\ &= r \text{ for } t \text{ with immigration} \\ &= -r \text{ for } t \text{ with emigration.} \end{aligned} \quad (3)$$

The difficulty for the analyst is specifying for which time steps in the recursion equation that recruitment is either r , 0 , or $-r$. To make that specification, auxiliary data in the form of sentinel, fixed gear catch is needed in conjunction with spatio-temporal data from the

spotter pilots. Examined together, the analyst can make a judgment of the directionality of movements and specify the appropriate condition for R at each time step of the estimation equation. For example, when spotter estimates of abundance are increasing despite fishery removals, immigration into the Bay population is occurring. Conversely, if spotter estimates are declining faster than can be explained by fishery removals and sentinel traps at the mouth of the Bay are catching menhaden, emigration is underway.

The combined growth-survival term (G) in eq.1 is relatively minor when the time step is of short duration (1 day) but should be accounted for since the effect is compounded across the fishing season. Failure to account for these dynamics will bias estimates of fishing effects. Menhaden grow in mass during their residence in the Bay and are subject to predation (Durbin et al. 1983, Oviatt 1977). Survivors of the fishing process will add weight through growth and will be decremented by predation. It is generally not possible to reliably estimate G from the landings and abundance data because of confounding with other parameters (Hilborn and Walters 1992). Fortunately, there is independent information on growth and survival rate for menhaden. Tagging studies summarized in (ASMFC 2006) indicate that the instantaneous natural mortality rate (M) for age 3+ menhaden is about 0.50 per year. This translates to a daily survival probability of $S = 0.9986$. Growth rate of adult menhaden in Narragansett Bay was estimated from mid-year weight at age data for menhaden age three and older in ASMFC (2006). A daily absolute rate of 1.0006 was computed. The product of daily survival probability and growth rate (0.992) was used as the estimate of G for eq. 1.

Substitution of equations 2 and 3 into eq. 1 with accumulation of error terms yields an equation suitable for statistical estimation:

$$I_t = G_{t-1}[I_{t-1} - C_{t-1}/q] + r/q + \varepsilon \quad (4).$$

Estimates of the needed parameters I_0 , q , and r can be made by minimizing the residual sum of squares between observed and predicted spotter indices of abundance. I_0 is a parameter representing estimated spotter abundance at the beginning of the fishery and is needed to begin the recursion. The time step is one day. If additional indices of abundance are available such as fishery catch per unit effort (CPUE) or trawl surveys, they can be included in an expanded sum of squares with additional proportionality constants (q) to be estimated for each additional index. Caution should be exercised when using CPUE from purse seine fisheries pursuing schooling pelagic fish because of the well-known possibility that CPUE will not be proportional to abundance (Paloheimo and Dickie 1964). Hyper stability is likely whereby CPUE does not decline as fast as abundance (Quinn and Deriso 1999). If evident, this can be handled by estimating an additional parameter (b) and formulating fishery CPUE as a power function of abundance in eq.2.

The above depletion model was implemented in an EXCEL spreadsheet and solutions found using SOLVER configured with the quasi-Newton search method for non-linear problems. The data set used was from May 21st, the first day of purse seining to August 22nd, the final spotter over flight. A lognormal error structure was assumed with all error

specified as measurement. Initial model runs and standard theory suggested that fishery CPUE was a convex power function of abundance i.e. $b < 1.0$. It was not possible however to reliably estimate both parameters of the power function. Final model runs were made that fixed $b = 1.0$ and gave $\frac{1}{2}$ weighting to CPUE in the sum of squares. With estimates of parameters in hand, estimates of standing biomass were made from eq. 2. Total exploitable biomass was computed as the sum of initial biomass and positive recruitments up to the point of maximum standing stock. Fishery exploitation rate was computed as cumulative landings divided by exploitable biomass. These were tracked and compared to management targets. The ASMFC (2004) peer reviewed stock assessment for Atlantic menhaden specifies fishing mortality rate targets and thresholds. They are $F_{tar} = 0.75$ and $F_{thresh} = 1.18$ respectively. Given a natural mortality rate of $M = 0.5$, these correspond to fishery exploitation rates of 43% and 57%.

Uncertainty in estimated parameters and calculated quantities was evaluated with bootstrapping (Efron 1982). Residuals from the original model fit were randomly resampled and added to the estimated pilot abundance and purse seine CPUE indices. The model was then successively refit to the alternate input data series and output quantities accumulated over 1000 replications. Uncertainty in the recruitment parameter is understated by conventional bootstrapping since it does not consider the analyst's assessment of external, sentinel data and the setting of the time intervals for R . Means and variances for parameters and calculated quantities were estimated directly from the bootstrap results. Uncertainty was expressed as a coefficient of variation (CV). Parameter bias was examined following the method of Krebs (1989). Sensitivity runs were made to determine the effect of model assumptions and conventions on model output. Estimated exploitable biomass was the output examined since it is the critical quantity to know in a real-time quota based management system. I also examined the effect of the terminal data on stability of biomass estimates. This was done by taking the final model fit and progressively removing the last week of data before re-estimation.

Results- Adult menhaden entered coastal Rhode Island waters in late April of 2007 when the floating fish traps at Pt. Judith began catching significant quantities (Fig.2). Fish trap catches dwindled in late May when fish moved elsewhere. Spotter pilots for the purse seine fishery commenced search flights over Narragansett Bay and reported that significant quantities of menhaden had entered the Bay. The purse seine fishery began on May 21st after a spotter pilot observation of 3.6 million pounds was made. Rhode Island regulations prohibit weekend fishing so the fishery operated on a 5-day schedule. The fishery was prosecuted by a single purse seine vessel through early June at a rate of 270,000 to 310,000 pounds per week. During that time, spotter abundance declined to 1.6 million pounds consistent with fishery depletion of the initial standing stock. Fish trap landings resumed on June 6th and continued for about a week. They were followed by a rapid increase in spotter pilot estimates in the Bay to 6.1 million pounds by June 19th. This indicated that additional schools of menhaden had entered the Bay since the initial emigration. The fishery continued for several more weeks at a 450,000-500,000 pound catch rate per week while spotter pilot estimates remained stable at 5.5 to 6.0 million pounds.

A second purse seine vessel entered the fishery on July 3rd significantly increasing Bay harvesting capability. In response to concerns that the additional effort would harvest too many menhaden and deprive the Bay of important ecological and recreational services, DEM instituted a 75,000-pound daily catch limit via emergency rule and adopted an interim policy that no more than 50% of the Bay menhaden should be commercially harvested. On July 9th, the spotter pilot made his largest Bay biomass estimate yet, 9.0 million pounds. Numerous commercial fishermen reported large schools of menhaden entering the Bay during the period July 2-6 corroborated increasing abundance. The purse seine fishery continued fishing through July 20 with weekly catches at the regulated 750,000-pound level. Spotter pilot estimates dropped sharply from 9.0 to 3.5 million pounds during this period. That was too much to be explained solely by fishing given the possession limits in place. Spatial examination of the spotter pilot data indicated that menhaden were moving out of the lower Providence River and upper Bay down to the lower west passage. Emigration of menhaden from the Bay was confirmed when the large schools of fish spotted off of Bonnet Shores on July 12th disappeared and large catches resumed at the Pt Judith fish trap on July 16th (Fig.2). During the week of July 23-27, catches became more variable and purse seiners began targeting remaining schools in the Taunton River that empties into Mt Hope Bay. This area is in Massachusetts's marine waters and was not subject to the 75,000-pound possession limit. DFW tracked these landings and considered them part of the allowable Bay catch but had no jurisdiction to enforce daily limits or a closure in the Commonwealth's waters. During the week of July 30 to August 3, catches dropped to low levels that were not economically viable. Spotter pilot estimates remained at 3.5 million pounds but nearly all of the fish were in the upper Providence River and off limit to the commercial fishery. An over flight on August 22nd estimated abundance at 3.0 million pounds with nearly all of it in the upper Providence River. Few adult menhaden were observed anywhere else. The purse seine fishery responded by moving out of Narragansett Bay and to New Jersey where they fished through October. Elevated menhaden catches by the Pt Judith floating fish trap during the period August 25 to August 28 (Fig. 2) indicated that the adult menhaden that had sustained the purse seine fishery in the Bay had left. Coincident to the August decline of adult fish, juvenile menhaden became abundant in DFW seine surveys and were observed from the air by the spotter pilot. A small school of adult menhaden remained in the Providence River through October and was subject to a small cast net fishery for bait. By November, few adult menhaden remained. A final over flight by the spotter on November 11th estimated about 0.18 million pounds, mostly in the lower reaches of the west passage and Sakonnet River. Test fishing by a purse seiner produced no catch.

Parameter estimates and derived quantities for the depletion model are summarized in Table 2. The initial spotter index of population size on May 21st was estimated at 3.37 million pounds (SE=0.34). This corresponds to an absolute population size of 4.52 million pounds. The recruitment constant was estimated at 0.35 per day (SE=0.06). This means that during periods of movement, 350,000 index units of menhaden enter or leave the Bay per day. This corresponds to an absolute rate of 460,000 pounds per day. The parameter relating the spotter index to absolute abundance (q) was estimated at 0.75 with a standard error of 0.17. This suggests that the spotter is somewhat underestimating menhaden abundance. A simple explanation is that not all schools of fish can be observed

during a spotting run over the Bay. Still, the 95% confidence bound of 0.41 to 1.08 is not compelling evidence that the parameter is significantly less than 1.0. Further work is warranted, as this is the crucial parameter scaling abundance indices to absolute abundance. Observed and model predicted spotter pilot abundance is given in Fig. 3. Overall, the estimated trajectory fairly well tracks the observed data. The two periods of depletion and increase in biomass are obvious. Maximum standing stock occurred on July 10th at 9.13 million pounds. Total exploitable biomass for the season was estimated at 12.39 million pounds (SE=1.91). Cumulative landings by purse seine are plotted in Fig. 4 on a relative scale to protect confidentiality of the harvesters. The weekly fishing pattern is evident with cumulative landings reaching 72% of the DEM harvest cap by August 7. At the regulated harvest rate, approximately 2.7 weeks of fishing remained after purse seine operations ceased. It is doubtful that adult menhaden will return to open areas of Narragansett Bay and trigger renewed purse seining in 2007. Examination of long-term data from the weekly URIGSO trawl survey indicates that after a July peak, menhaden abundance declines in August and increases again in September (Fig. 5). This pattern of abundance was previously noted by Oviatt (1977).

Precision for estimated parameters and derived quantities was good with bootstrap coefficients of variation less than 22% (Table 2). It should be noted however that this level of precision is conditioned on the assumption that specification of the recruitment windows was correct. The bootstrap distribution for the key management quantity, exploitable biomass, is plotted in Fig. 6. It is somewhat right skewed as would be expected since by the central limit theorem, quantities that are combinations of several more elemental quantities, tend to follow lognormal distributions. A non-parametric 95% confidence interval on exploitable biomass from the cumulative distribution in Fig.6 is 10.0 to 17.5 million pounds. Bootstrap distributions for other model parameters were closer to normal so the parametric confidence bounds in Table 2 are sufficient. Bias calculations were less than 3% in all cases meaning that the bootstrap means were quite close to the final SOLVER estimates so that parameter bias is not a cause for concern (Hilborn and Walters 1992). The sensitivity of estimated exploitable biomass to various model assumptions and conventions are plotted in Figs. 7 to 9. Exploitable biomass was moderately sensitive to specification of the recruitment periods (Fig. 7). Errors of several days could increase or decrease biomass estimates by hundreds of thousands of pounds in accordance with the estimated value of r . The exponent of the power function relating CPUE to abundance had no influence on biomass estimates (Fig. 8). This occurs because CPUE data was given less weight relative to spotter data in the sum of squares minimization and also because the range of abundance was relatively low such that hyperstability did not operate. Biomass estimates were fairly stable for data sets with terminal dates declining from August 22 to July 13 (Fig. 9). Further truncation of the data set resulted in rapidly declining estimates of biomass. This occurs because major periods of emigration of menhaden into the Bay are missed emphasizing the need for continuous monitoring and model updating during the summer and the demands of real time management.

Over 6,800 fish were sampled from the purse seine and floating trap fishery in 2007 (Fig. 10). Menhaden ranged in length from 215 to 351 mm with a mean of 282 mm. The

majority of samples were between 260 and 305 mm. Age-length data in ASMFC (2006) indicates that most of these would be menhaden age 3 to 5 years old. Female menhaden were slightly heavier at length than males (Fig. 11). The discrepancy was about 20 grams at 260 mm and increased to about 30 grams at 305 mm. The heavier weight for females of a given length is likely due to differential mass of gonad tissue. Average weight of fish sampled was 400 grams (0.88 pounds). Menhaden sampled from the Providence River late in the year had degraded body condition compared to fish sampled during the height of the purse seine fishery (Fig. 12). Menhaden undergo an ontogenetic shift in branchiospinule spacing (Friedland et al. 2006) such that juveniles can filter small phytoplankton while adults are more efficient grazers of larger phytoplankton and zooplankton (Durbin and Durbin 1998). The large size of menhaden in the commercial catch coincides with the asymptote of the Friedland et al. (2006) sigmoid curve of branchiospinule spacing vs. fork length indicating that they are most efficient at filtering particles greater than 30 μm in diameter. The weight loss indicates that there were inadequate food resources present late in the year to sustain adult menhaden and may explain the exodus of the main body of fish during the summer. A decline in Bay zooplankton occurs in August (Durbin and Durbin 1981) and is related to predation by menhaden and ctenophores, another prominent zooplanktivore.

Discussion -

Adult menhaden returned to Narragansett Bay in significant numbers in May of 2007 and were subject to an active purse seine fishery. It may have been the highest abundance in over a decade based on long-term fishery surveys, power plant records of impingement and entrainment, and commercial fishing activity. It is uncertain why abundance has increased. The most recent coast wide stock assessment indicated that the 2002 and 2003 year classes of menhaden were relatively strong as YOY year fish (ASMFC 2006). A similar pattern exists in data from local fishery surveys and power plant monitoring that encounter mostly YOY fish (Fig. 13). Agency trawl and seine surveys as well as impingement at power plants drawing coolant water from the Bay show increasing abundance from the mid-1980's to 2003. Since menhaden stratify along a latitudinal gradient with older fish further north, increased abundance of adults in 2007 in Rhode Island is consistent with an earlier increase in YOY. Low freshwater input to the Bay may also have influenced abundance by improving feeding opportunities since high flushing rate can inhibit the plankton blooms on which menhaden feed (Oviatt et al. 2002). Regardless of the reason, it is clear from the historical data that local menhaden abundance will fluctuate considerably from year to year (note the logarithmic scale in Fig. 13). It is also increasingly clear that menhaden play a major role in the ecology and fisheries of coastal ecosystems. Menhaden provide an efficient link between planktonic material and fish biomass, influencing the transfers of energy within food webs (Lewis and Peters 1984). Their filtration efficiency is a nonlinear function of body size with juveniles adapted for estuarine feeding on phytoplankton while adults are adapted for feeding in coastal waters on zooplankton (Friedland et al. 2006). They are an important bait source for the commercial lobster industry and forage for recreationally important game fish (Oviatt 1977). Their ability to influence water quality has been known for some time (Oviatt et al. 1972, Durbin and Durbin 1998). It is crucial therefore that

allocation decisions for menhaden be made consistent with their diverse roles. The Commission's coast wide fishery management plan for menhaden specifically recognizes these roles in plan objectives (ASMFC 2001) and in Addendum I they set precautionary reference points based on population fecundity (ASMFC 2004b). The reference points are set to insure that sufficient spawning stock is sustained. The Commission continues development of a multispecies stock assessment model with menhaden as the keystone prey species (NEFSC 2006). Addendum II established a precautionary landings cap for Chesapeake Bay and adopted an ambitious research agenda in response to concerns over localized depletion and declining juvenile production (ASMFC 2005).

With the exception of Virginia, Atlantic coastal states are not required to manage individual quotas or allocations but ASMFC allows states to practice more conservative management if they deem it appropriate to do so. Because of the annual debate over commercial menhaden fishing and a growing body of ecosystem science, DEM chose in 2007 to manage the local menhaden resource more rigorously than required by ASMFC. Specifically, DEM set a policy that a fraction of the adult menhaden entering Narragansett Bay could not be harvested but would remain to provide essential ecological and recreational services. As a first cut and in view of the ASMFC reference points, 50% was established as the limit exploitation rate. This limit can be adjusted as ecosystem based management science and state fishery policy evolve. The limit was not reached in 2007 as the bulk of the fishable menhaden left the Bay by August followed shortly thereafter by the purse seiners. Setting an exploitation limit required the development of a rigorous fishery monitoring and stock assessment capability. The observer and fishery sampling program described above and the depletion model developed provide for a real time management system. Population estimates can be made and updated regularly for comparison to accumulated landings and management targets. DEM authority allows for closure of the fishery when allowable landings have been reached. It also allows for re-opening of the fishery should additional waves of immigration occur. DEM's use of emergency authority to limit daily landings was not taken lightly and is a clear evidence of the Department's commitment to sustainable management and appropriate resource allocation. The Department's actions clearly meet our statutory requirements to comply with ASMFC management plans (RIGL 20-8-7) and to operate consistent with the fishery conservation standards set forth by the Rhode Island General Assembly (RIGL 20-2.1-9). In particular, standard B requires that "*Conservation and management measures shall be based upon the best available scientific information available and analysis of impacts shall consider ecological, economic and social consequences of the fishery as a whole.*" Further, under RIGL 20-3.2-1(e) the General Assembly has found "*Rhode Island has historically managed its marine fisheries for the benefit of the people of the state, as an ecological asset, and as a source of food, income and recreation*". These standards and findings guide the Department's view to menhaden management by succinctly embracing all of the roles and values that menhaden are recognized to have.

Real time assessment and management of menhaden with catch limits is not without pitfalls. It is expensive, requiring observer/sampling coverage of multiple fisheries and is heavily dependent on cooperation from commercial fishers. It also requires analytical expertise, administrative oversight, and enforcement. A full time DFW observer is

required during the months of April to September to make trips with purse seine vessels and their spotter planes. The observer must also enter all the data collected. A DFW fishery technician responsible for port sampling must add sampling trips to floating traps and expedite logbook processing. The purse seiners and trap industry must be committed to provision of data and DFW access to their operations on a real time basis. The Department has to take on the duties of developing/refining the depletion model and exercising management and enforcement oversight of the fishery. In that regard, the depletion model needs additional work and testing. In particular, experimental purse seining should be conducted on spotted schools to better estimate the parameter relating relative to absolute abundance. Ganz (1975) found that purse seiners caught on average 80% of a school spotted by pilots. However, it is not clear from that work if this was due to overestimation by the pilot or incomplete capture by the fishing vessel. Model enhancements should also directly link sentinel data to recruitment in the population dynamics process to eliminate the subjective need to specify recruitment periods. Hilborn and Walters (1992) provide the theoretical basis to do so. It requires a relative index of recruitment that may be provided by the sentinel fisheries. Floating trap catches of menhaden at a site near the mouth of the Bay and at another several miles up the west passage may provide a directionally defined recruitment index for incorporation into the model. A complete data set is not available at this time but will be once logbook submission is complete for 2007. Still, real time management would require close monitoring of the trap catches and voluntary, expedited provision of data. In the challenging fiscal climate that exists today, it may not be possible for DFW to devote the resources necessary to manage Bay menhaden in the above manner. DFW contractual workers conduct much of the fieldwork described above. Cost cutting measures may restrict contractual services and prevent filling of full time DFW staff positions when vacancies occur. Should that occur, DFW would not be able to maintain this and other new initiatives. Alternatives to real-time management of menhaden include adjustment of the seasonal-area closures to target the allowable exploitation rate, restricting daily possession limits to low levels, or reducing the efficiency of the purse seine gear. Input controls such as these will be much coarser management than output control by catch limits and could lead to large management errors to the detriment of the Bay ecosystem or fishing industry. They will also reduce profitability in the menhaden fishery.

Research Recommendations-

Should funding and staff resources be available, the following research recommendations are made:

1. Experimental fishing should be conducted to examine the relationship between spotter pilot estimates of abundance and actual catch by the purse seine vessel. An independent estimate of the spotter catchability parameter is needed for the depletion model.
2. Acquire all SAFIS and logbook trip level data from the floating trap fishery and evaluate the utility of constructing a directionally based index of recruitment to the Bay population of menhaden.

3. Explore the possibility of embedding the in season depletion model estimation of stock biomass into the biomass dynamic model that estimates historical abundances retrospectively.
4. Evaluate the utility of the using the NMFS/DEM mariner shuttle survey data on Bay plankton density in determining menhaden distribution and abundance.
5. Consider adding a juvenile biomass component to the depletion model based on spotter pilot and DFW survey data.
6. Continue menhaden biological sampling program in cooperation with ASMFC.

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Table 1- Length Frequencies of Menhaden Caught in the Division of Fish and Wildlife
 Narragansett Bay Monthly Trawl Survey, 1990-2006

Length cr	Month												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
2	0	0	0	0	0	0	0	39	0	0	0	0	39
3	0	0	0	0	0	0	435	2977	806	0	42	326	4586
4	2	0	0	0	0	1	153	5993	2076	6	424	1173	9828
5	44	2	0	0	0	0	0	12389	3617	8	2536	941	19537
6	195	62	3	0	0	0	2	21349	5800	3	3347	755	31516
7	131	71	98	0	0	0	0	2042	6078	8	3415	763	12606
8	108	77	359	0	0	0	0	21	2170	22	1712	315	4784
9	63	38	620	0	0	0	0	10	841	159	1121	150	3002
10	58	7	209	0	0	0	0	2	127	644	775	83	1905
11	16	0	68	1	0	1	0	0	29	139	643	22	919
12	7	1	69	1	0	0	0	0	8	11	260	16	373
13	3	1	0	0	1	0	0	0	0	0	32	5	42
14	14	1	0	0	0	0	1	0	0	1	0	7	24
15	2	0	0	0	1	0	16	10	0	0	25	3	57
16	0	0	0	0	0	0	4	0	0	1	15	5	25
17	0	0	0	0	1	0	0	0	0	0	15	4	20
18	0	0	0	0	2	0	0	0	0	0	1	8	11
19	0	0	0	0	3	0	0	0	0	0	1	2	6
20	0	0	0	0	3	1	0	0	0	0	0	0	4
21	0	0	0	0	2	0	0	0	0	0	0	0	2
22	0	0	2	0	3	0	0	0	0	0	0	1	6
23	0	0	0	0	0	0	0	0	0	0	1	0	1
24	0	0	1	0	0	0	0	0	0	0	0	0	1
25	0	1	0	0	0	0	0	0	0	0	0	1	2
26	0	0	0	0	0	0	1	0	0	0	0	0	1
27	0	0	0	1	0	0	0	0	0	0	0	0	1
28	0	0	0	0	0	0	0	1	0	0	0	0	1
29	0	0	0	0	0	1	0	0	0	0	0	0	1
30	0	0	0	0	0	1	0	0	0	0	1	0	2
31	1	0	0	0	1	0	0	0	0	0	0	2	4
32	0	0	0	0	0	0	0	0	1	0	0	0	1
33	0	0	0	0	0	0	0	0	0	1	0	1	2
	644	261	1429	3	17	5	612	44833	21553	1003	14366	4583	89309

Table 2- Parameter Estimates and Derived Quantities for the Narragansett Bay Menhaden Depletion Model. Uncertainty was Evaluated Using 1000 Bootstraps.

Parameter	SOLVER Solution	Bootstrap Mean	Bootstrap SE	Coefficient Variation	Lower 95% CL	Lower 95% CL
Initial Index 10 ⁶ lbs	3.366	3.359	0.337	0.100	2.691	4.041
Recruitment Parameter	0.345	0.345	0.061	0.178	0.222	0.467
Spotter Pilot qhat	0.745	0.741	0.165	0.223	0.414	1.075
Purse Seine qhat	1.017	1.017	0.081	0.080	0.854	1.179
Exploitable Biomass	12.392	12.814	1.907	0.149	8.579	16.205
Allowable Harvest	7.082	7.323	1.090	0.149	4.903	9.261

Fig.1- Abundance of Menhaden Eggs in Narragansett Bay Power Plant Surveys

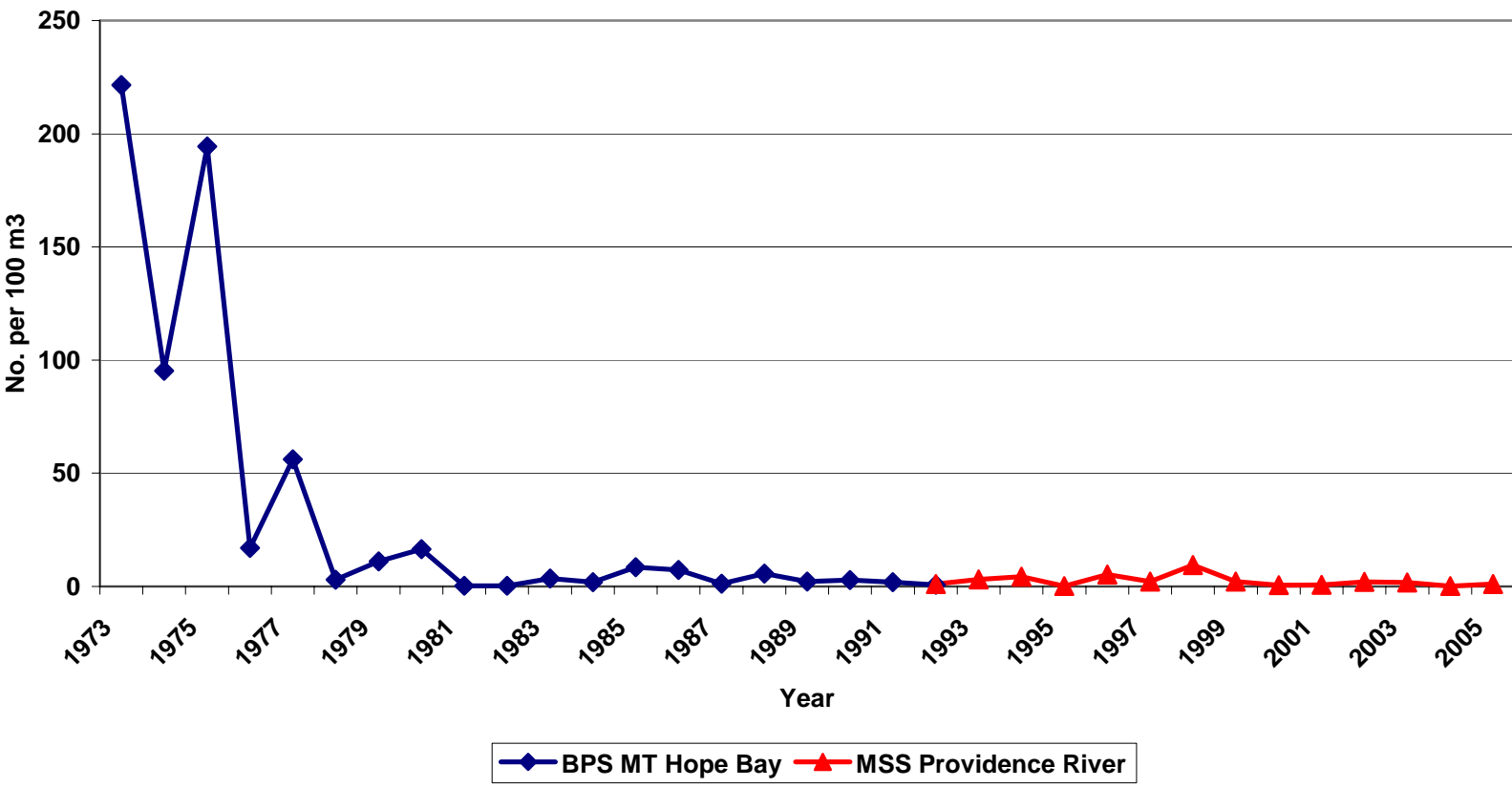


Fig.2- Menhaden Landings in 2007 by a Point Judith Fish Trap

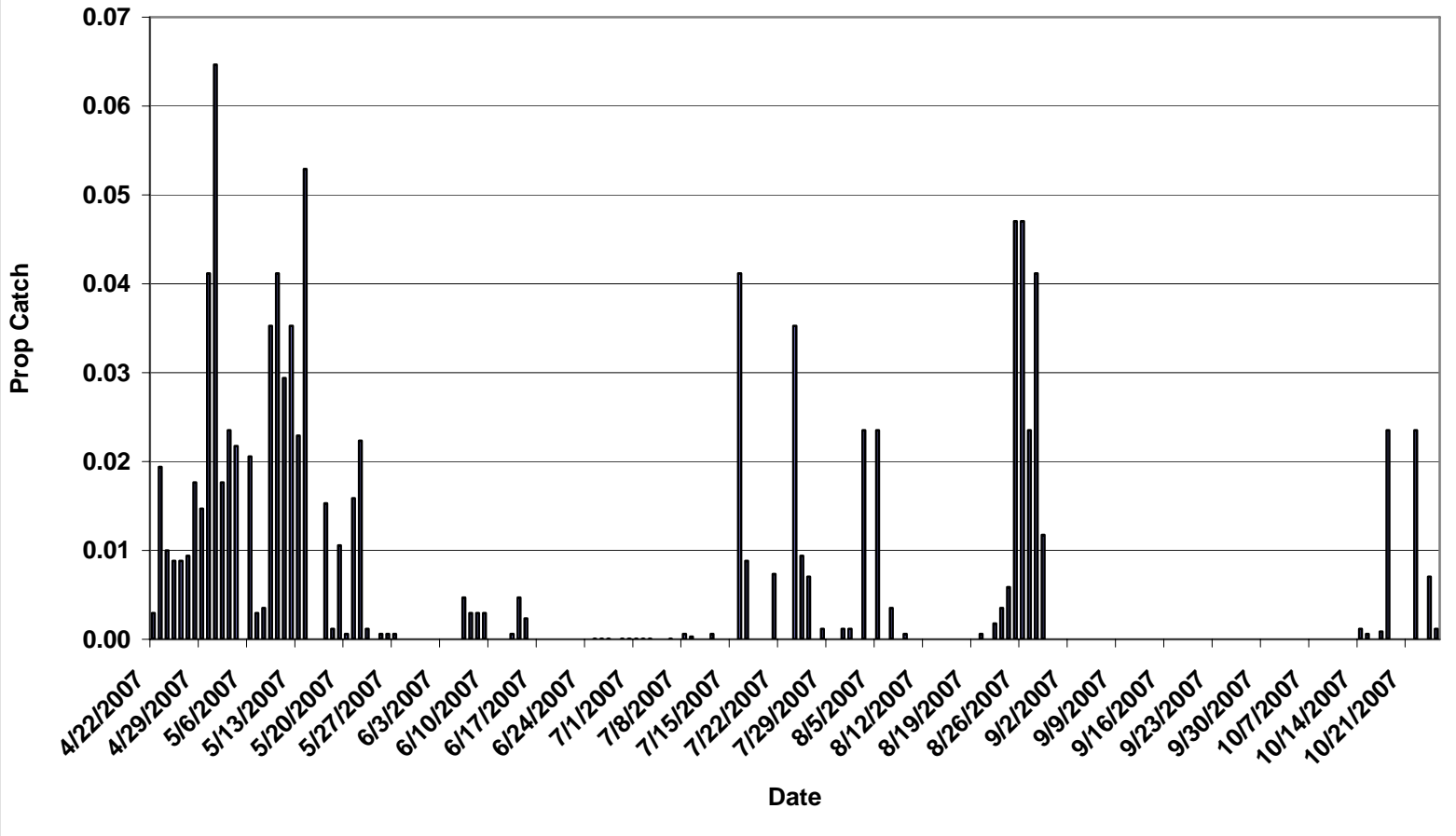


Fig.3- Observed and Model Estimated Spotter Index of Menhaden in Narragansett Bay in 2007

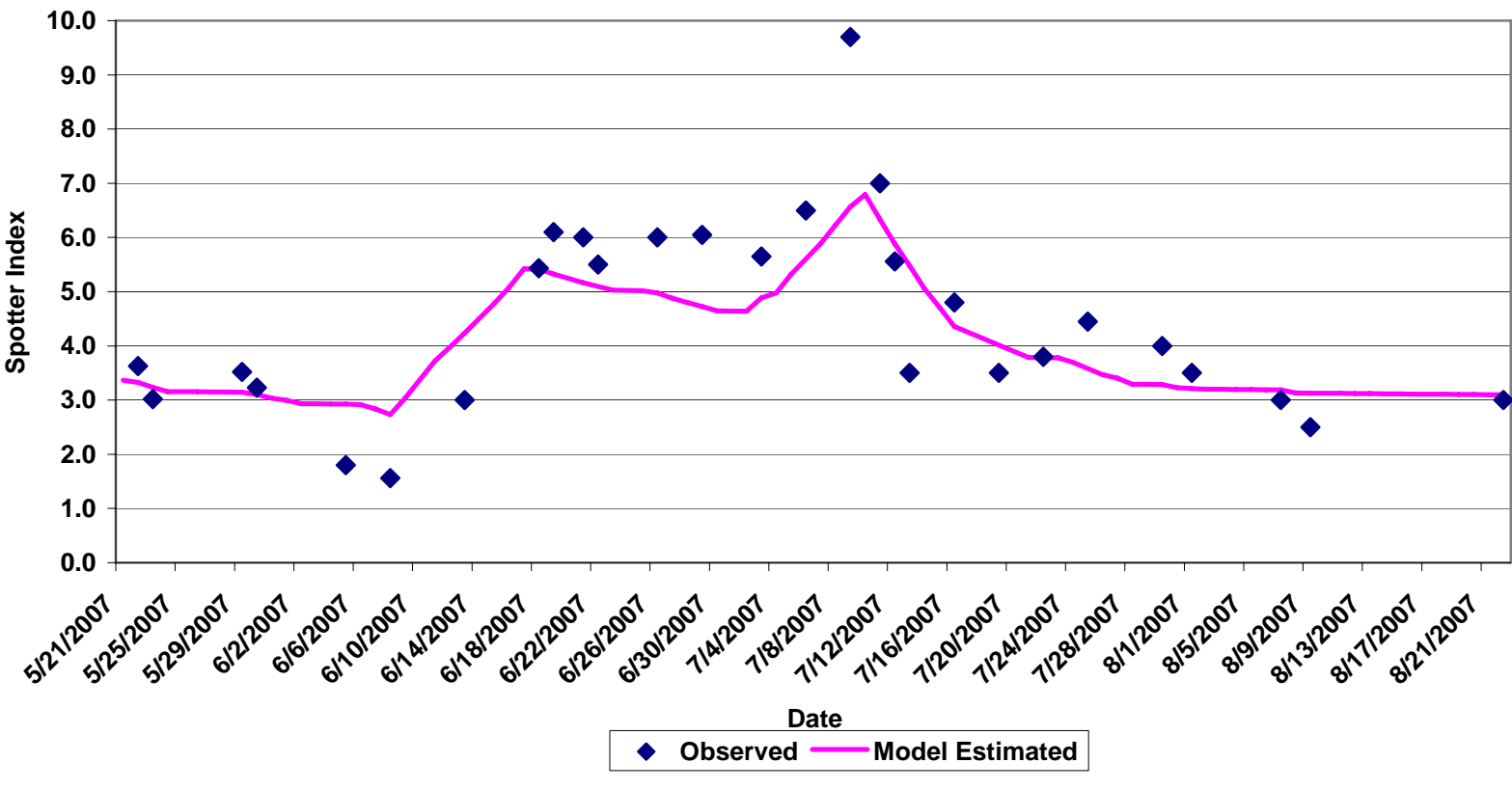


Fig.4- Cumulative Landings of Menhaden by Purse Seine from Narragansett Bay in 2007

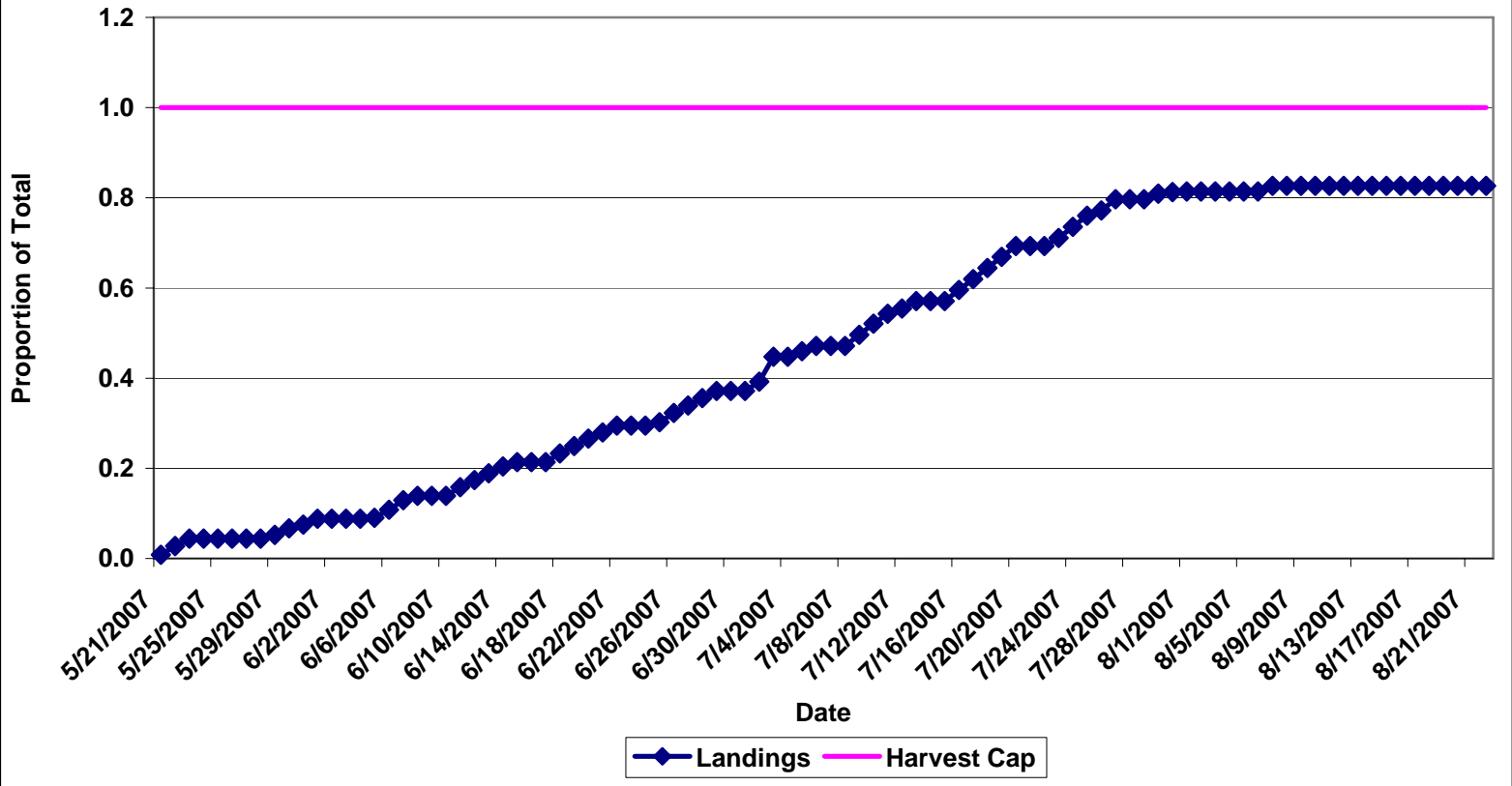


Fig. 5- April to September Catch of Menhaden in the URIGSO Trawl Survey

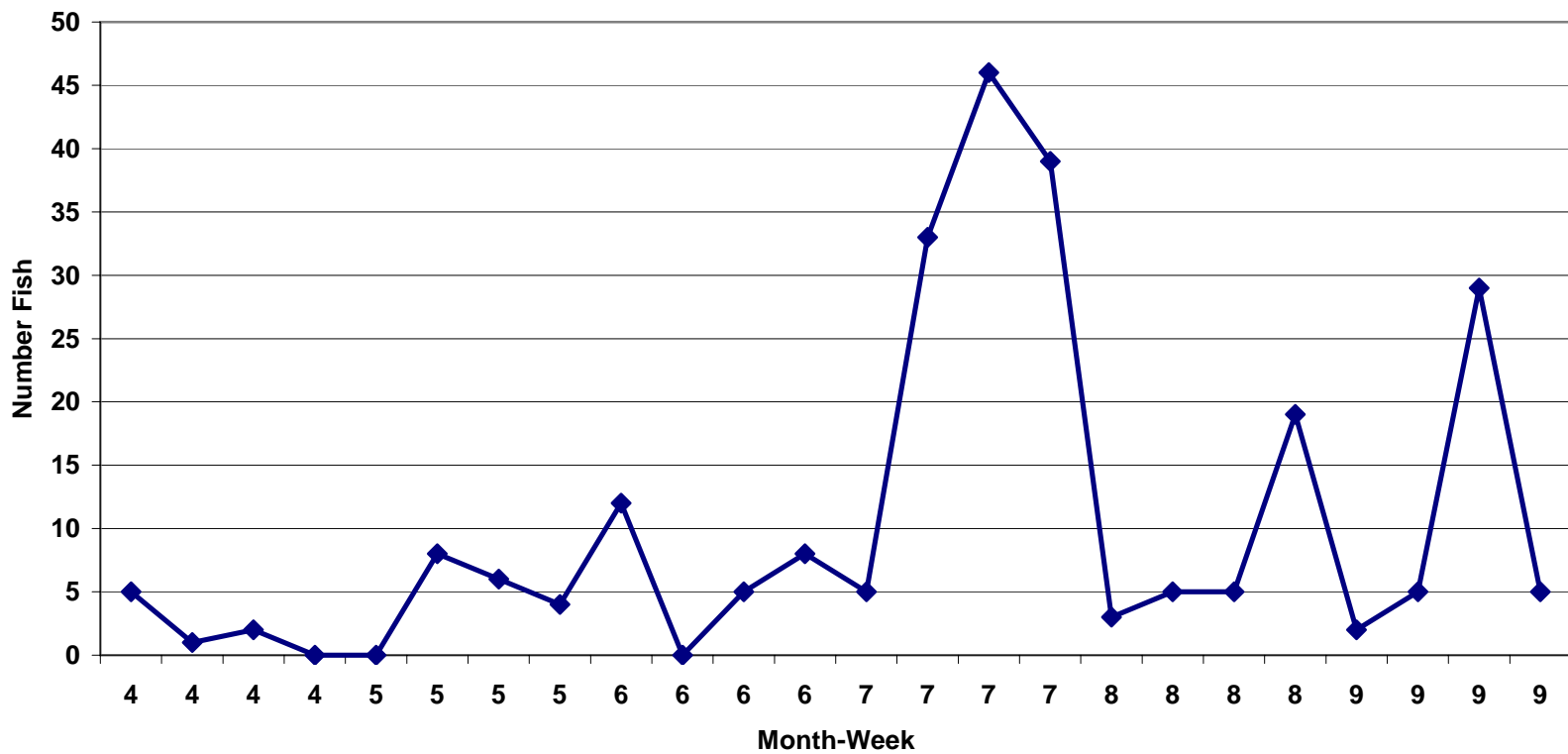


Fig.6 - Bootstrap Distribution for Estimates of Menhaden Exploitable Biomass

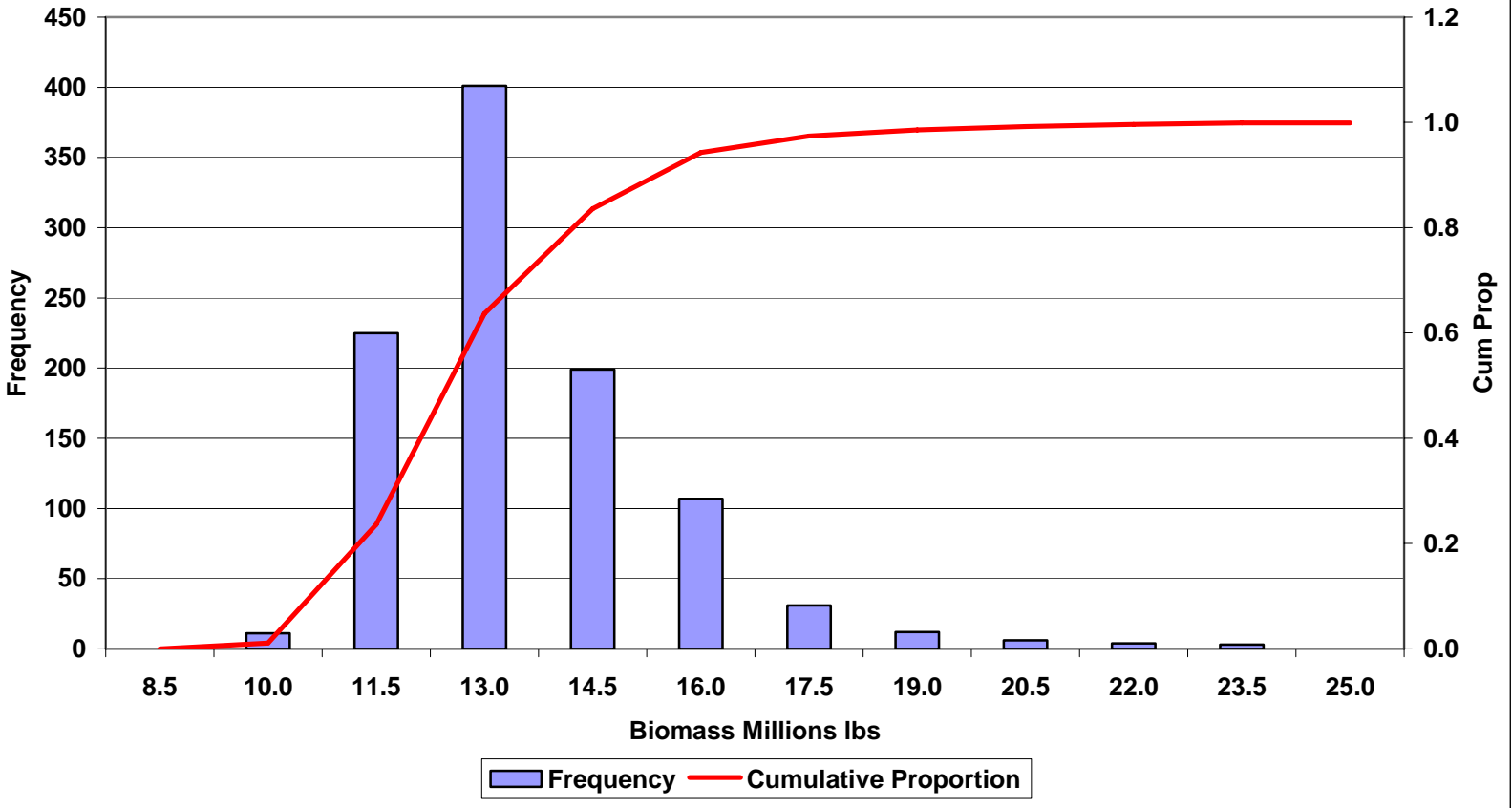


Fig.7- Sensitivity of Exploitable Biomass to Duration of Recruitment Events

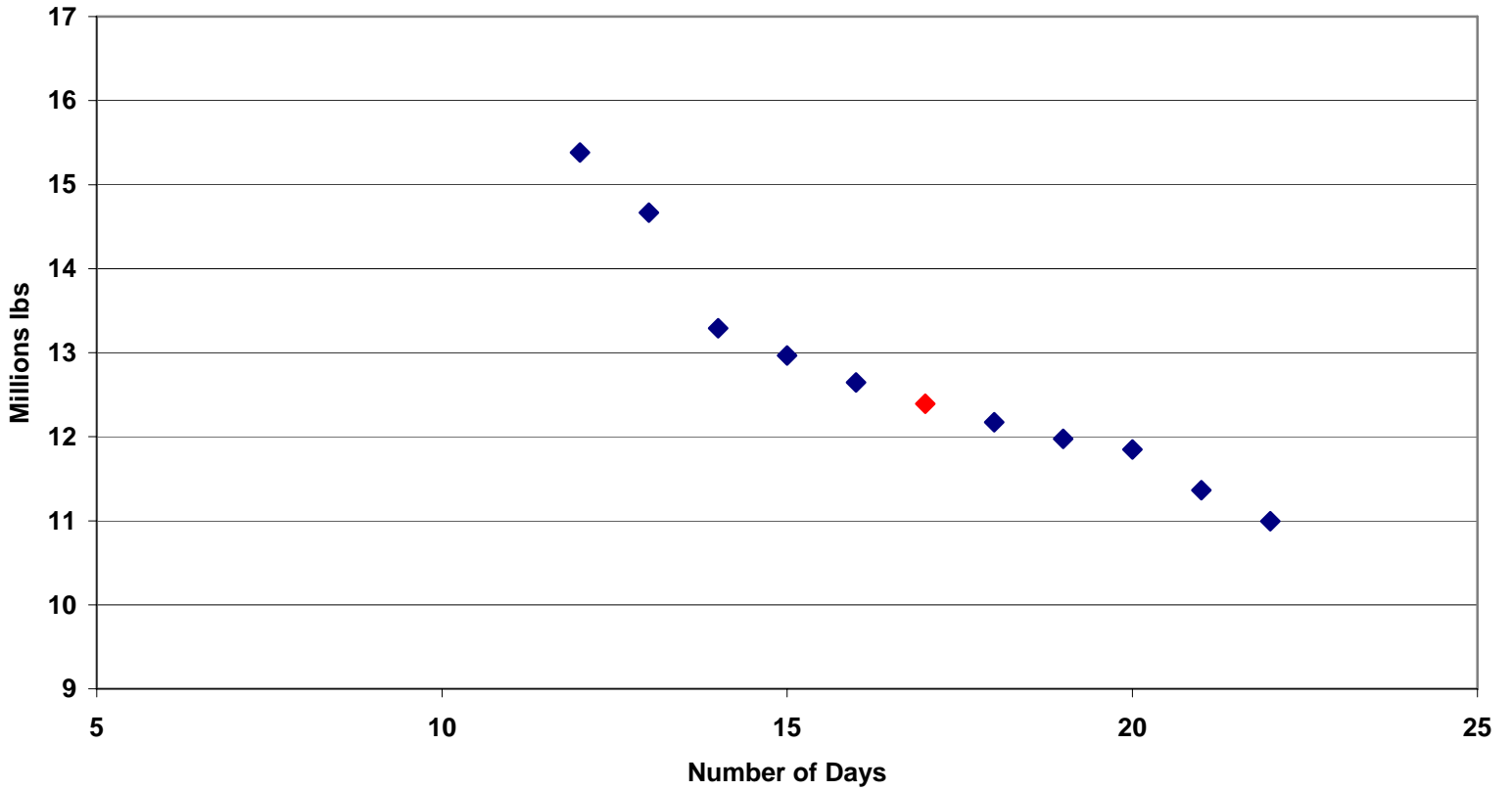


Fig.8- Sensitivity of Exploitable Biomass to Purse Seine CPUE Exponent

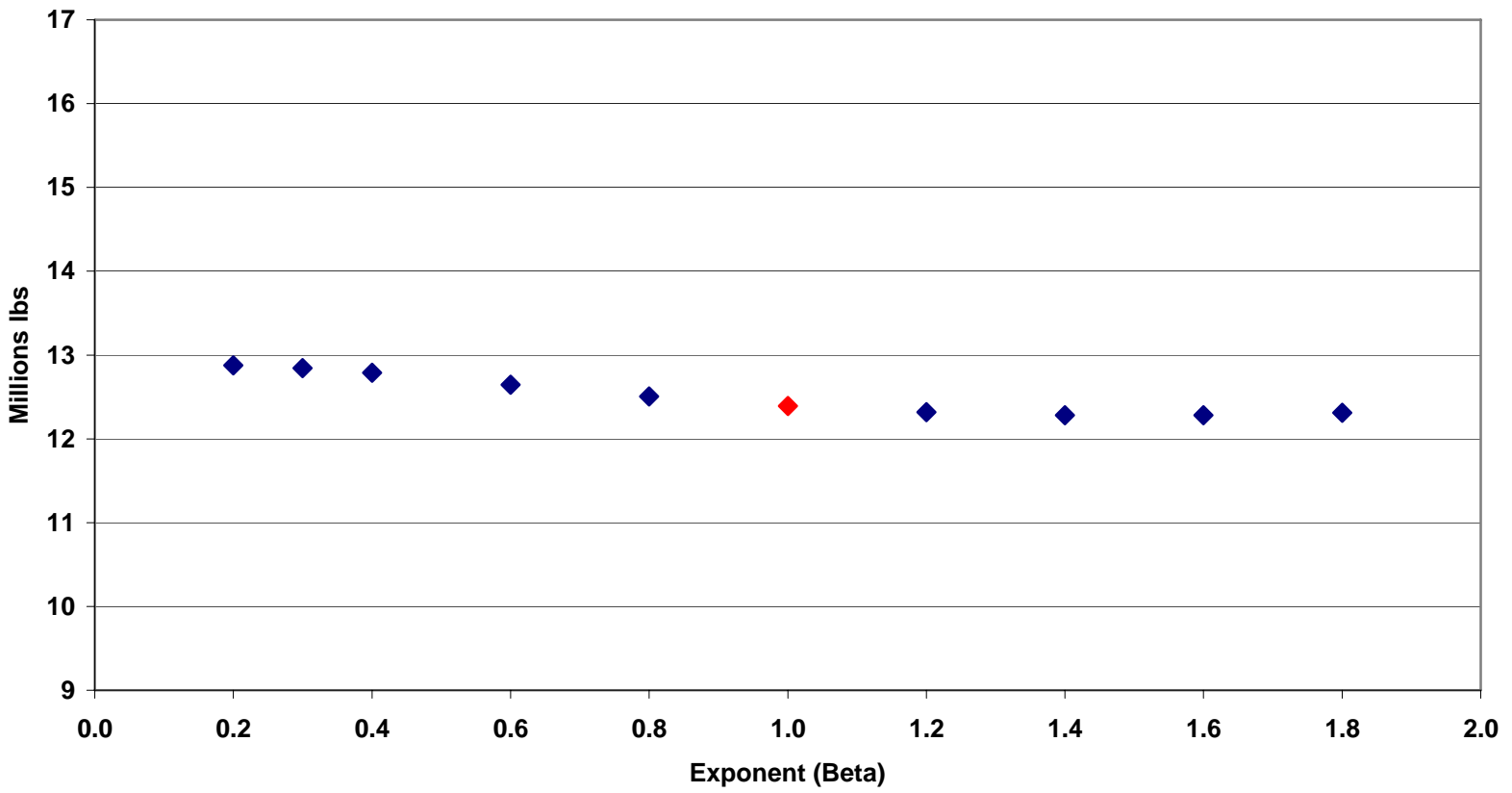


Fig.9- Sensitivity of Exploitable Biomass to Length of Dataset Used

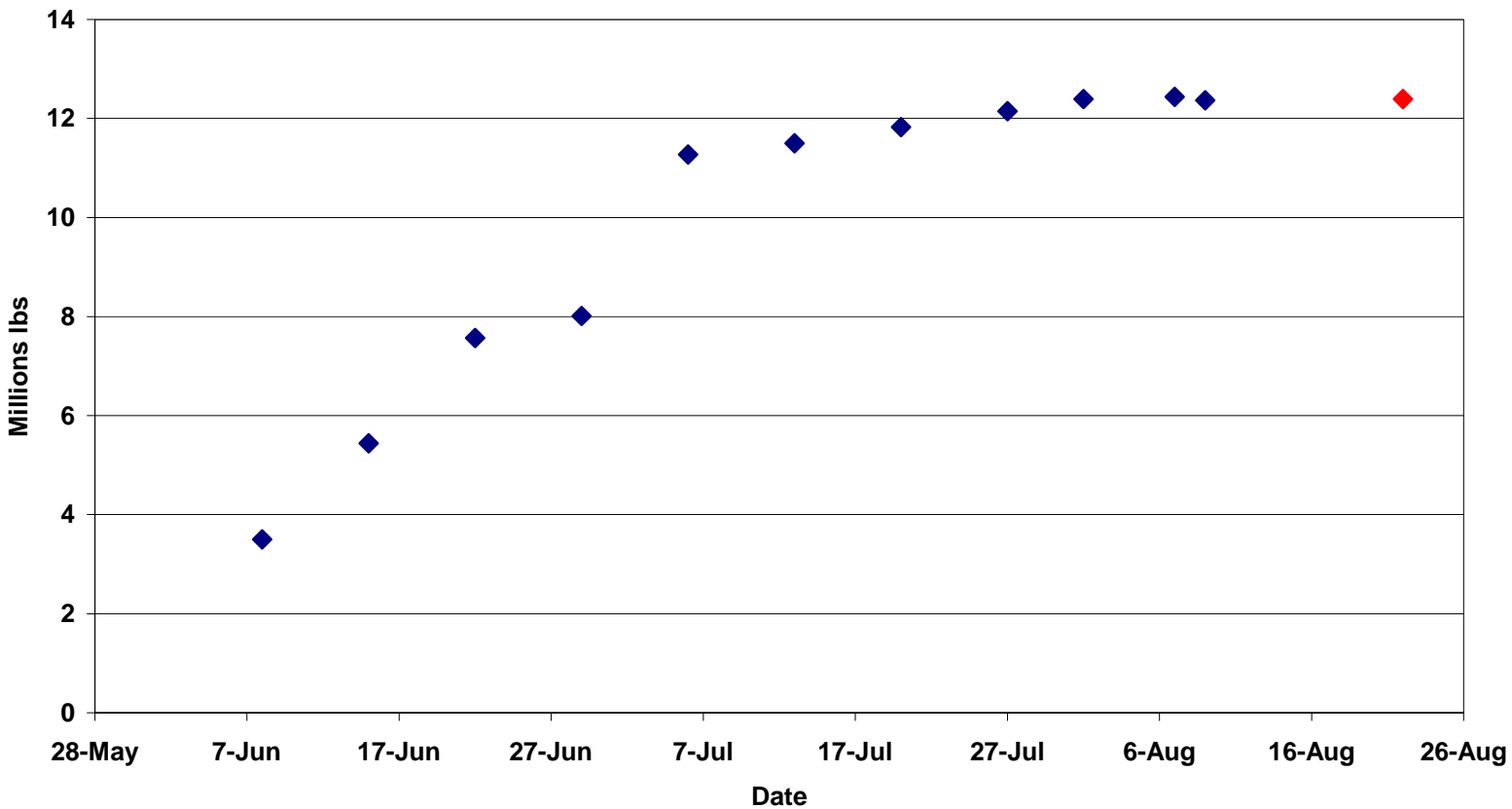


Fig.10- Length Frequency of Menhaden Caught by Purse Seine in May-July 2007

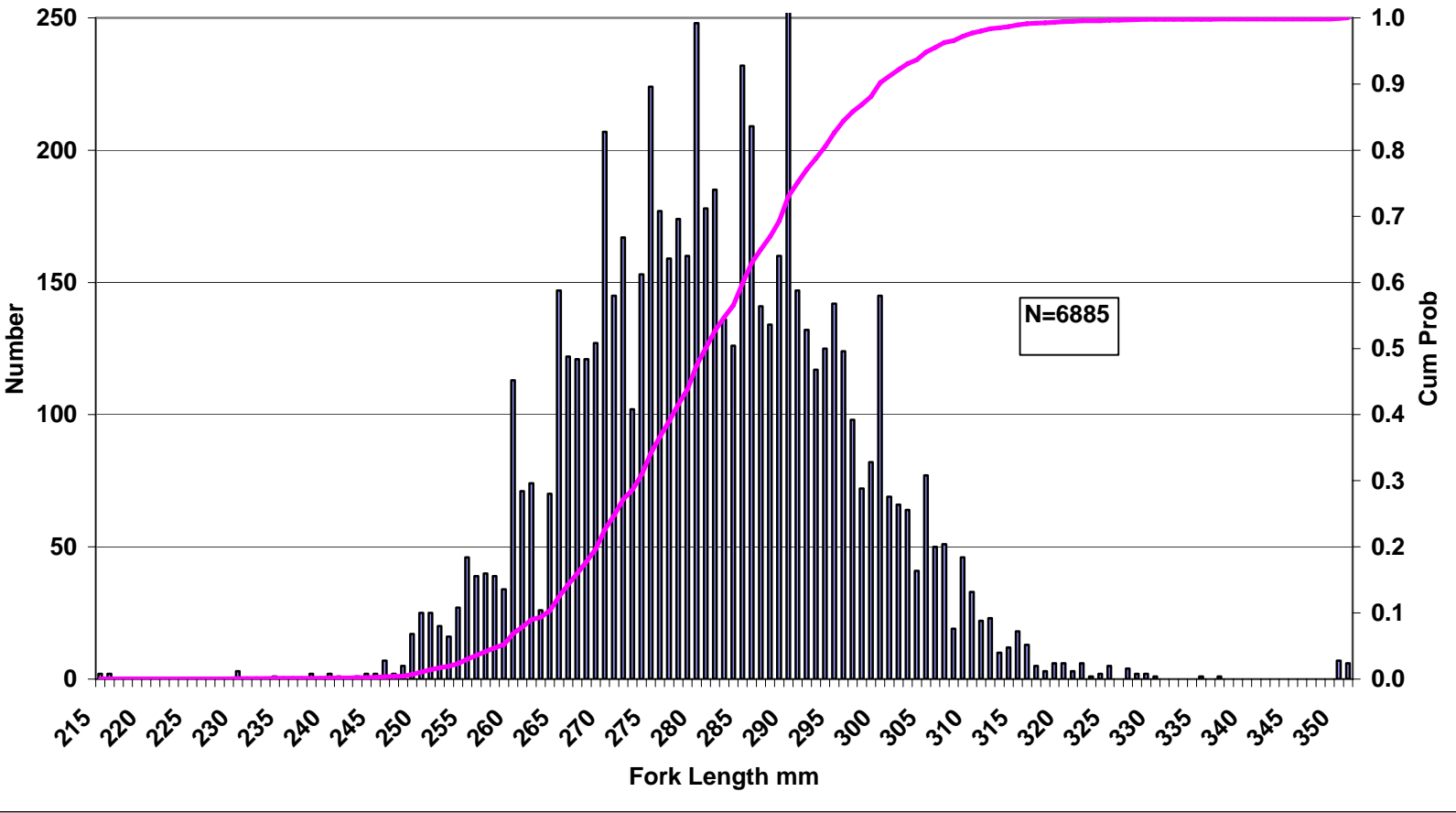


Fig. 11- Menhaden Length-Weight Relationship from Purse Seine Samples

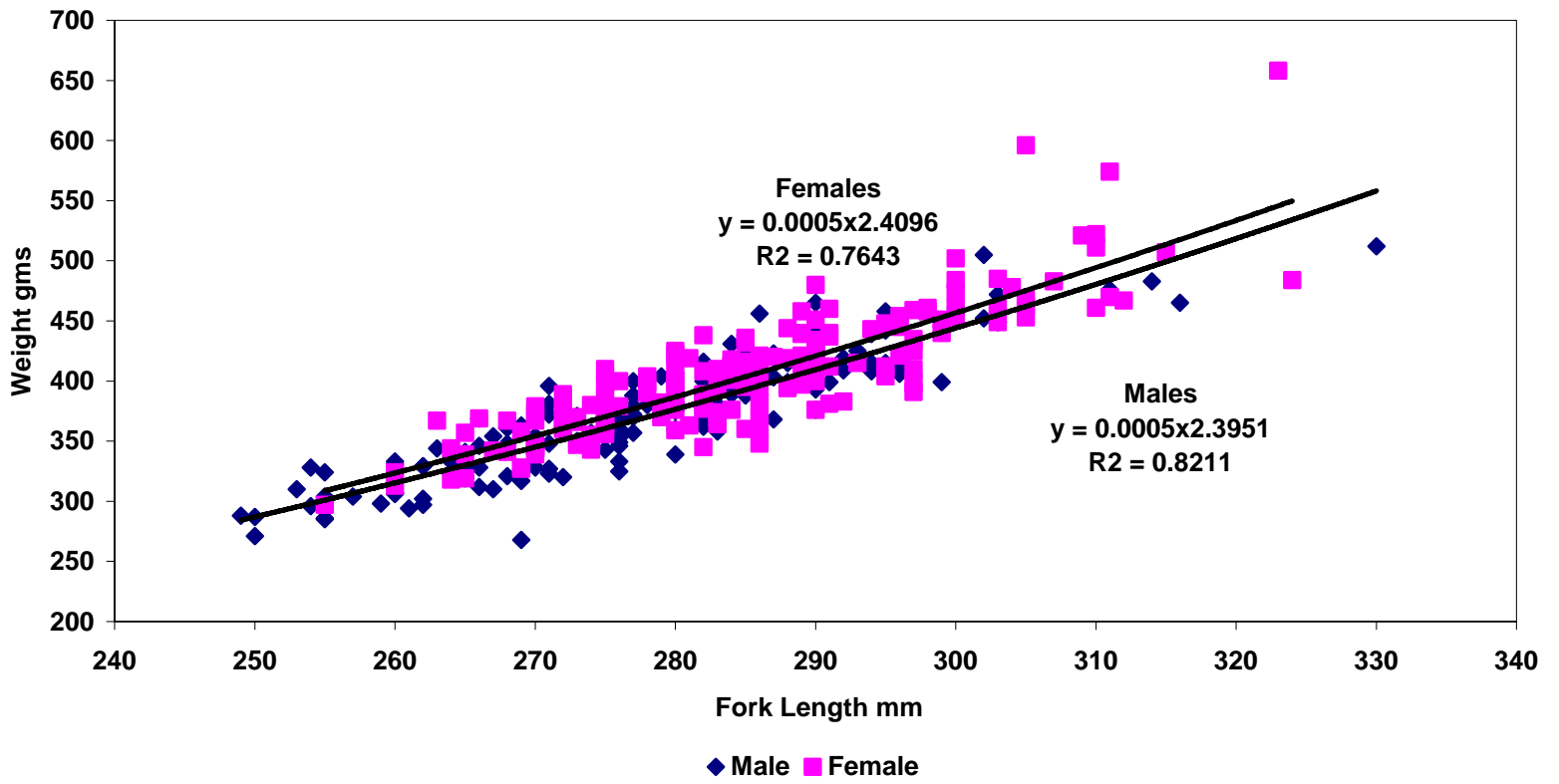


Fig.12- Comparison of Menhaden Length-Weight Relationships for Summer and Fall Samples

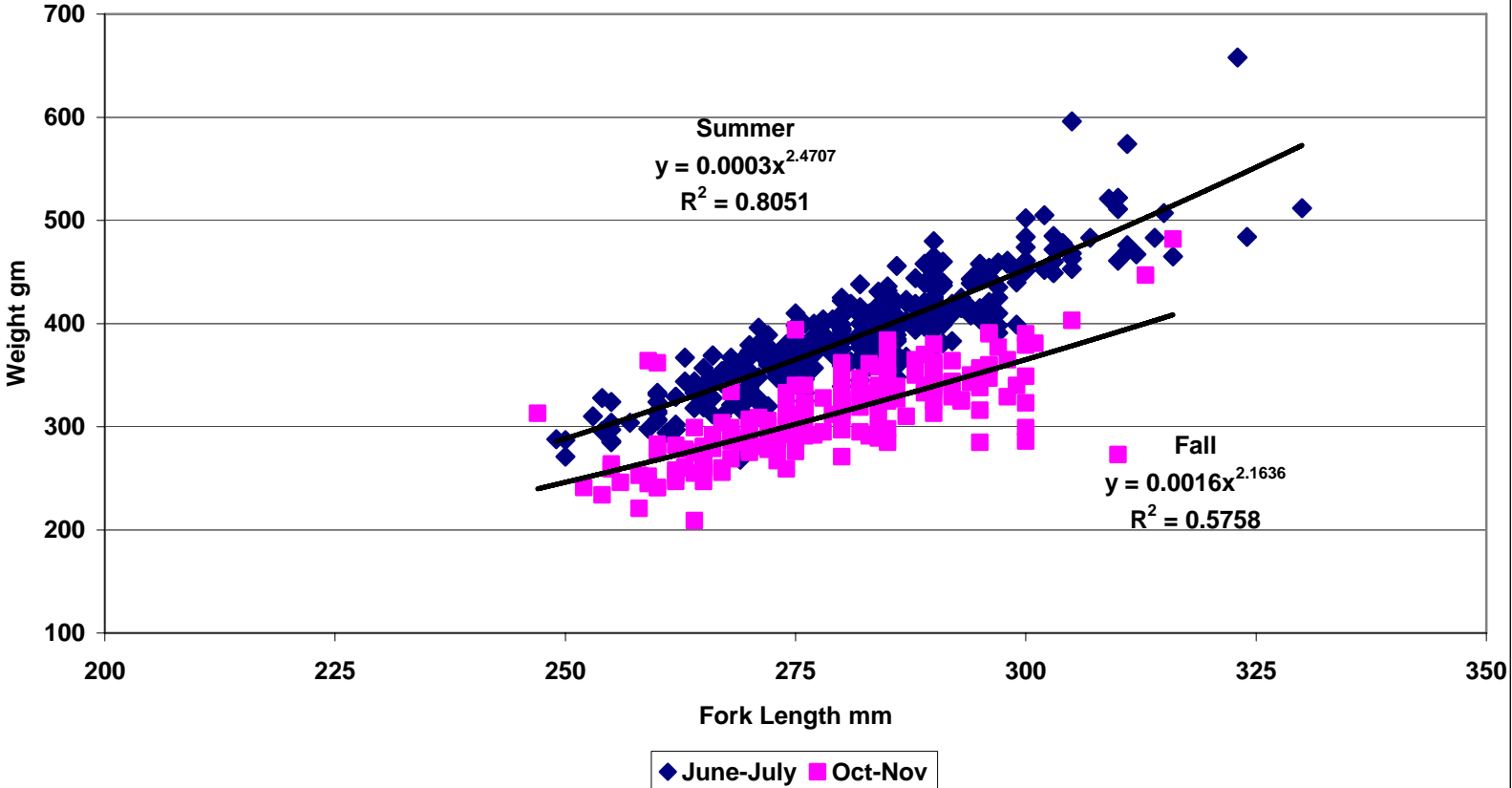
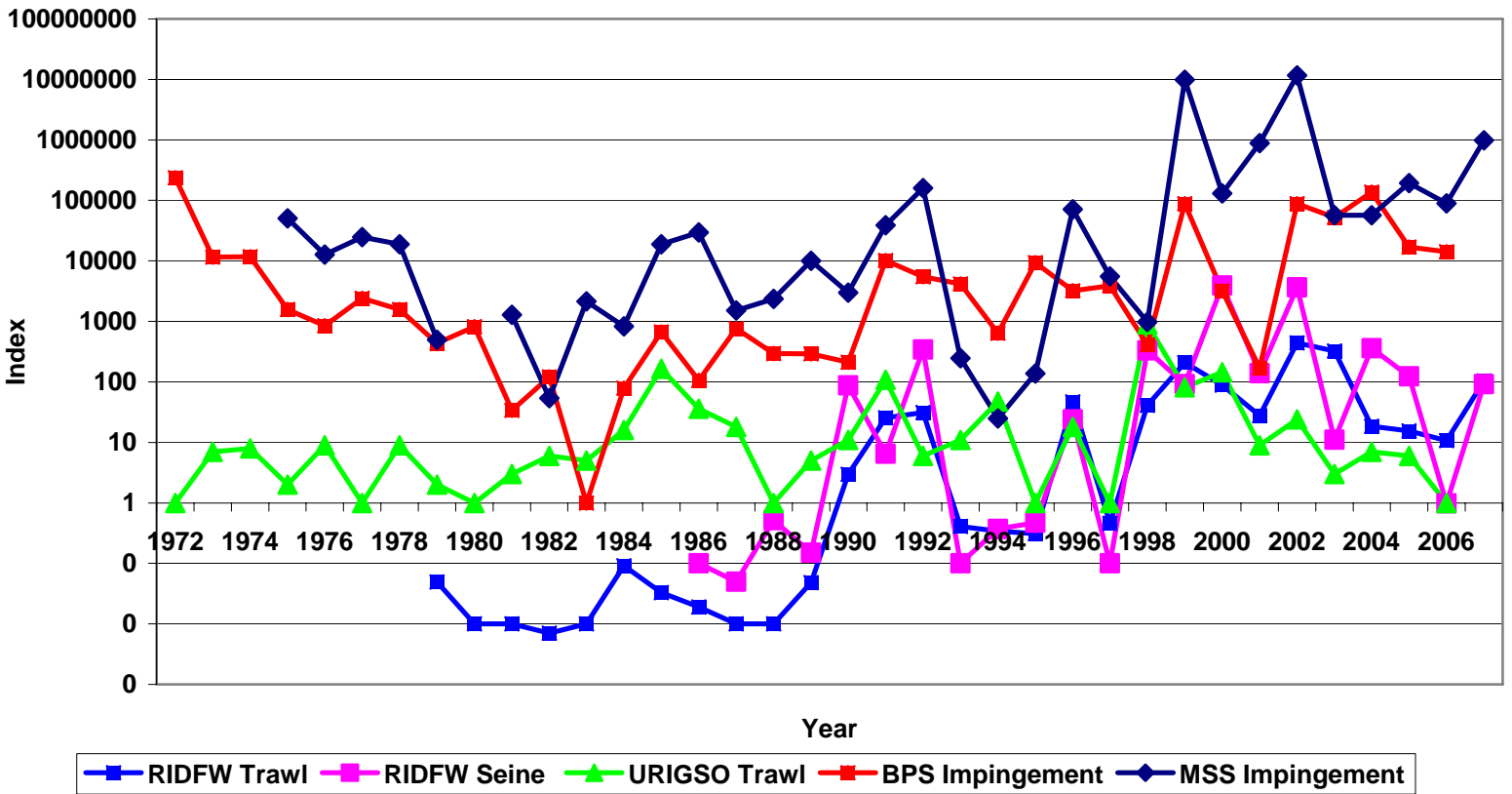


Fig. 13- Atlantic Menhaden Abundance in Narragansett Bay and RI Coastal Waters from the RIDFW Surveys and Power Plant Data



Acknowledgments

This study would not have been possible without the considerable efforts of a number of Fish and Wildlife staff members. Matt Griffin observed purse seine operations, flew in the spotter plane, and compiled data. Nicole Calabrese sampled the floating trap fishery and processed vessel trip reports. Tim Lynch, Michelle Burnett, and Chris Powell provided catch data from DFW fishery independent surveys. Jason McNamee provided menhaden regulatory history and insight into ASMFC menhaden management. Najih Lazar provided valuable comments on earlier versions of the depletion model. Dr. Jeremy Collie at the University of Rhode Island Graduate School of Oceanography provided additional trawl survey data. Jerry Sousa, Tom Hoxie and Everett Mills, commercial fishermen, provided invaluable data and access to their operations. Special thanks go to W. Michael Sullivan, Director of DEM, who recognized the ecological value and social relevance of menhaden in the bay and required this study. I also thank members of the RI General Assembly and the RI Saltwater anglers for their continuing interest and concern for Narragansett Bay menhaden.