Maryland American Eel Population Study

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Executive Summary

The objective of this study is to characterize the American eel population and commercial fishery in the Maryland portion of the Chesapeake Bay and selected tributaries. Characterization data, such as length, weight, age, and relative abundance (catch per unit effort) are collected from fishery dependent and fishery independent sampling. This information is critical in stock assessment and subsequent management of the species in Maryland and along the Atlantic coast.

Job 1: Characterize Maryland's commercial American eel fishery in the Nanticoke River and at least one other Maryland Chesapeake Bay tributary.

American eels from the commercial eel pot fishery were sampled in the following Maryland Chesapeake Bay tributaries during the study period: Nanticoke River (2004, 2005, and 2007), Patuxent River (2006 and 2008), Choptank River (2006 and 2007), Fishing Bay (2004 and 2008), and Sassafras River (2004).

Growth rates varied considerably among systems and among years within the same system. The ages present in the size structure were fairly uniform with the exception of the Nanticoke River, where eels aged 9+ were consistently captured in six out of the seven sampled years (2000-present). The age range of 2-7 (±1) was fairly standard for the other sampled tributaries.

The 2004 sampled Sassafras River eels had a significantly smaller mean length than any of the other tributaries sampled. Average annual growth estimated from the slope of the linear regression was approximately 15 mm less than any sampled tributary from 2004-2008

Choptank River eels (2006 and 2007) grew approximately 30+mm more annually than eels from any other sampled tributary from 2004-2008 based on estimated growth from the linear regression.

For the Nanticoke River, total instantaneous mortality (Z) showed little variability from 2000-2007 (range = 0.55 – 0.67). Calculated Z's were highly variable among other Chesapeake Bay tributaries sampled ranging from 0.46-1.35.

Maryland commercial eel landings averaged 242,747 pounds during 1983-2007. Landings have exceeded this mean five consecutive years since 2003 and have reflected a positive linear trend the over this 25 year period. Estimated annual relative abundance was 0.51 pounds/pot from 1992-2007. Relative abundance increased six out of seven years from 1999-2006 and reached a time series high of 1.01 pounds/pot in 2006. Since 1992, both American eel landings and relative abundance have shown an overall positive trend, while commercial eel pot effort has declined over the same time period.

Job 2: Collect biological data to describe American eel populations in the Sassafras River through a fishery independent pot survey.

Length distributions from sampled eels were quite similar for the years 2006-2008 and shifted to larger sizes compared to 1998-2000 sampled eels from the previous Maryland eel study. Less than 1% of the sampled eels from the earlier study were older than age 5 compared to 14.7% in the 2006-2008 study.

The slope of the linear regression indicated faster overall growth for the eels captured during the 2006-2008 survey. Eels from 2006-2008 were predicted to grow 46 mm per year compared to 36 mm per year in 1998-2000.

Catch curve analysis from pooled eel catches for the 1998-2000 study indicated a Z and F of 1.38 and 1.13, respectively. Catch curve analysis indicated that Z was 0.75, 0.68, and 0.71 for 2006-2008, respectively.

Job 3: Participate in multi-state management of American eels through Atlantic States Marine Fisheries Commission.

The Project Leader for this study is Maryland Department of Natural Resources' representative on the AETC (current Vice-Chair) and is a member of the American Eel Stock Assessment Sub-Committee (AESASC). Through these committees project personnel actively participated in the development and review of the coastwide stock assessment completed in 2005, the development of Addendums I and II and implementation of Addendum I to the American eel ISFMP.

Job 4: Refine Stock Assessment Models.

The Sequential Life-table and Yield-per-recruit (YPR) Model for the American Eel (SLYME) was used to evaluate current levels of fishing mortality for Maryland Chesapeake Bay tributaries in relation to target and limit biological reference points (BRP). In addition, Eggs-per-recruit (EPR) curves were derived from the SLYME model.

Two growth groups were classified as slow growth (SG) represented by the Sassafras River (2006-2008) and fast growth (FG) represented by Fishing Bay, Nanticoke, Patuxent, and Choptank rivers.

The YPR curves derived from models for the SG and FG were drastically different. The maximum YPR for the FG was estimated at more than three times the SG and occurred at a considerably higher F (0.52 vs. 0.39). The EPR for the FG was 2.0-2.4 times greater at respective fishing mortality rates than the SG.

The $F_{current}$ for the Sassafras River exceeded $F_{0.1}$ and slightly exceeded F_{max} at 0.46. Based on the reference points, growth overfishing appears to have occurred in the Sassafras River, yet YPR was over 99% of maximum yield at the current F.

For the FG, F_{max} (0.52) was greatly exceeded, indicating growth overfishing occurred in Fishing Bay ($F_{current}$=0.90) and the Choptank River ($F_{current}$=0.94). YPR was at 94% and 93% of maximum yield, respectively, for Fishing Bay and Choptank River.

Growth overfishing did not occur in the other two tributaries (Nanticoke, Patuxent). $F_{current}$ for the Nanticoke River (0.38) was between $F_{0.1}$ and F_{max} and YPR was 98% of the maximum. $F_{current}$ for the Patuxent River (0.21) was well below $F_{0.1}$ (0.31) and had a YPR that was 82% of the maximum.

Based on these reference points ($F_{MSP20\%}$ and $F_{MSP30\%}$), recruitment overfishing has occurred in 4 of the 5 tributaries sampled during the study period. Given the American eel is panmictic (one spawning population and passive drift of leptocephali), the number of recruits entering a certain river in a given year should not be related to the number of spawning eel that left that specific river in previous years, but rather related to the total number of eels from all geographic areas that spawned successfully.

Job 5: Assess American eel recruitment to Maryland's Coastal Bays.

A total of 840,386 American eel young-of-year (YOY) were collected over the nine year sampling period at Turville Creek. Peak one sample catches of YOY occurred as early as 10 March and as late as 20 April and have represented from 11-40 % of total annual YOY catches

The annual time series high arithmetic mean (AM) catch per-unit-effort (CPUE) was 217.2 YOY/hr. in 2007, however the AM CPUE was below the time series average of 110.7 YOY/hr. four out of the last 5 years. A slight non significant negative trend was indicated by the linear regression of the geometric mean (GM) index of relative abundance

Although moon phase was not significantly correlated with catch, the highest YOY catch occurred during the new moon (% moon illumination < 5%) 6 out of 9 sampling years.

Job 1: Characterize Maryland's commercial American eel fishery in the Nanticoke River and at least one other Maryland Chesapeake Bay tributary.

INTRODUCTION

The primary objective of Job 1 was to characterize the current estuarine American eel population of Maryland's Chesapeake Bay through a fishery dependent survey. This study was designed to collect size and age structure data, parasite infestation rates, and sex composition of eels in selected Maryland Chesapeake Bay tributaries. In addition, American eel catch and effort data from the Maryland commercial landings database were analyzed to develop a fishery dependent relative abundance index.

METHODS

I. Field Operations

A fishery dependent American eel study was conducted in the following tidal Chesapeake Bay tributaries: Nanticoke (2000-2005, 2007), Patuxent (2006 + 2008), Choptank (2006 + 2007), and Sassafras (2004) rivers and Fishing Bay (2004 + 2008). For each system sampled, approximately 100 pounds of American eels were purchased annually from commercial eel pot fishermen in mid April-mid May. On most occasions, samples were obtained twice during the spring fishery. Eels were either randomly sampled directly from the eeler's pots or dipped from their live box. Eels harvested for up to 10 days were kept in the live box or holding pen before being sold. Subsampling these aggregated and ungraded catches helped to minimize day-to-day variation in the sizes of eels caught and provided an accurate representation of commercial eel catches from those given areas.

Procured eels were placed in multiple coolers on ice, transported back to the lab and euthanized by an ice slurry, clove oil, or MS222. Each eel was then measured (mm), weighed (g), and subsamples taken for age, gonad, and swim bladder analysis.

Selected tidal tributaries

The Nanticoke River is located on the lower eastern shore of Chesapeake Bay (Figure 1-1). The drainage encompasses a total of 445.5 non-water km^2 (172.7 square miles). Salinities predominately range from 0 to 18 parts/thousand (ppt). From 2000-2005 the eels purchased were harvested from the middle to upper tidal portion (0-5 ppt) of the tributary. In 2006, the Nanticoke River was unable to be sampled due to the retirement of the cooperating commercial eeler and the absence of other commercial harvesters. Eels were sampled in 2007 from a different commercial eeler, who fished the lower to middle portions (0-18 ppt) of the Nanticoke. In 2008, cooperation could not be made with the one remaining eeler in the tributary and eels were not sampled.

The Patuxent River is located on the lower western shore of Chesapeake Bay. The drainage encompasses a total of 1,337.1 non-water km^2 (516.3 square miles). Salinities predominately range from 0 to 18 parts/thousand (mouth). American eels were purchased in 2006 and 2008 from the same eeler who fished the middle portion of the tributary. Salinities in this section of the tributary ranged from 3-12 ppt.

The Choptank River is located on the mid eastern shore of Chesapeake Bay. The drainage encompasses a total of 1,107.4 non-water km^2 (427.6 square miles). Salinities predominately range from 0 to 15 parts/thousand (mouth). The mouth of the Choptank River is approximately 25 miles north of the Patuxent River. American eels were purchased in 2006 and 2007 from the same eeler who fished the lower to middle portion of the tributary. Salinities in this section of the Choptank ranged from 5-18 ppt.

The Sassafras River is located on the upper eastern shore of Chesapeake Bay. The drainage encompasses approximately 195.6 non-water km^2 (75.5 square miles). Salinities predominately range from 0 to 5 parts/thousand. This tributary is located approximately 75 miles north of the mouth of the Choptank River. American eels were purchased in 2004 from an eeler who fished the mouth of the Sassafras River where salinities ranged from 1-5 ppt.

Fishing Bay is located on the lower eastern shore of Chesapeake Bay. This drainage encompasses a total of 397.0 non-water km^2 (153.3 square miles). American eels were purchased in 2004 and 2008 from the same eeler who fished Fishing Bay where salinities ranged from 6-18 ppt.

Age determination

Both saggital otoliths, the largest of the 3 ear bones in the American eel, were removed from the cranial cavity of each subsampled specimen. Otoliths were cleaned by soaking them in a 10% bleach solution for approximately 5 minutes, rinsed with distilled water and then patted dry. CrystalBond, a thermoplastic adhesive, was heated to a liquid state by placing microscope glass slides on a hotplate. Whole otoliths were then placed convex side up on the CrystalBond and the adhesive was then drawn over the dorsal side of the otolith. This allowed the small crevices on the otolith surface to be filled and increased clarity. The otoliths were examined at up to 40X magnification under a compound microscope with both a transmitted and an external fiber optic light source. Both light sources were used independently to increase precision for age estimation. If opaque and translucent zones were not readily apparent, the dorsal surface of the otoliths was lightly polished with moistened 600 grit wet/dry sandpaper until the primoridium (nucleus) was reached and the outer edge of the otolith was discernible. A small amount of immersion oil was then placed on the sanded otolith. The concave side of the otolith was sometimes read by flipping over the glass slides.

The first opaque zone out from the nucleus is the transition mark and is laid down as glass eels transition into elvers. Ages in this study were for freshwater ages, so the transitional mark was not counted. Opaque zones are formed during the summer growing period while the translucent zone is formed during the winter period. In normal conditions, only one opaque and one translucent zone are formed during a single year (Liew 1974). This interpretation of zones has been applied to American eels by various investigators (Vladykov 1967, Gray and Andrews 1971). One year in freshwater equaled one translucent zone and one opaque zone. If a full translucent zone was completed and any opaque zone formation was present on the edge of the otolith, it was included as a year.

When more than one growth ring occurs per year, it is denoted as a 'supernumary zone' (Deelder 1976). Supernumary zones can occur whenever growth rate changes. These changes are related to low oxygen, high water temperatures, handling stress or other factors. Fish may be over aged if supernumary zones are mistaken for true annuli (Deelder 1976, Berg 1985, Lecomte-Finiger 1992, Oliveira 1996). Established criteria were used to detect supernumary zones (Deelder 1976, Berg 1985 and Oliveira 1996) and any otoliths with suspected supernumary zones were excluded from analysis. The occurrence of false annuli (supernumary zone) was rare from most estuarine sampled eels, but did occur from eels sampled from freshwater to a slightly brackish environment (< 5 ppt).

Two biologists read each otolith in a double blind design. If disagreement occurred in age interpretation, both biologists re-read the otolith a second time. If the interpretation of annuli was still different, the specimen was excluded from age analysis.

Sex determination

Gross morphological examination was used to determine sex of subsampled Maryland eels. This technique is widely used for sexing Anguillid eel gonads (e.g. Vladykov 1967, Boëtius and Boëtius 1980, Krueger and Oliveira 1997). Eels < 280mm (11.0 inches) were not included because they could not be differentiated during gross morphological examination. All eels ≥ 400 mm (15.7 inches) have been determined to be female in Maryland (Weeder 2002). This size cut-off is 99% effective in distinguishing between sexes of yellow and silver eels coastwide (ASMFC 2000). Eels were classified as male by the presence of lobed or scalloped gonadal tissue, females by the presence of a frilled, ribbon-like tissue or undifferentiated (amorphous gonad) (Dolan and Power 1977). An aceto-carmine 'squash' method of gonad preparation(Guerrero and Shelton 1974), was used on a subsample of the morphologically sexed specimens and viewed at up to 40 X magnification under a compound microscope to confirm the presence of ova/oocytes (female) or spermatogonia/ spermatocytes (male) (Gray and Andrews 1971).

Sex ratio was determined from the present study based on the assumption that all eels > 400 mm are female and all eels < 280 mm were undifferentiated. The proportion of the subsampled eels classified as male, female, or undifferentiated between 280-399 mm was applied to all sampled eels in this size range. Proportions of each classification were then calculated.

Parasite infestation rates

American eels that were subsampled for either age and/or gonad analysis were examined as well, for the presence of *Anguillicolla crassus*. After the eels were euthanized for otolith extraction and gonad evaluation, the swim bladder was removed from the body cavity and the presence of any larval stage of the parasite was noted.

II. Data Compilation

Size structure

Length was used exclusively for size analysis because weight could be biased from bait ingested before capture. Mean lengths of commercially harvested eels were calculated for each sampled tributary by year. The percentage of the eels that would be considered large by commercial standards (> 400mm) was calculated and compared among years. For length distributions, eels were divided among 20 mm length groups starting at the smallest length group present in the sample. Length distributions for the Nanticoke river dataset was compared in 4 groups; three 2 year periods from 2000-2005 and 2007. Length distributions for the other selected tributaries were compared for each sampled year.

Age structure

Age structure of the population of American eels in each selected tributary was determined through the use of an age-at-length key. This was constructed by determining the proportion-at-age per 30mm length group from all subsampled eels from each system and applying that proportion to the total number measured in that length group.

Growth

The von Bertalanffy (VB) ($\text{Length}=L_\infty(1-e^{-K(t-t_0)})$) growth function (von Bertalanffy 1938) and linear regression were used to compare change in length with respect to age by year and by tributary. Excel Solver was used to fit VB model parameters L_∞, K, and t_0. Initial runs produced fits with unreasonable t_0, so t_0 was set equal to -1.0 years (the approximate time from egg hatch to arrival in Maryland's Chesapeake Bay) with Solver fitting L_∞ and K. Mean length-at-age was compared among systems that were sampled ($N \geq 5$). Eel mean length-at-age data for the Nanticoke River were compared in 4 groups; three 2 year periods from 2000-2005 and 2007. Data was pooled for the other four systems by tributary over the study period to compare mean length-at-age for common age groups.

Mortality estimates

Total instantaneous mortality rate (Z) included fishing and natural mortality. Instantaneous natural mortality rate (M) was assumed to be $3 / T_{max}$ (Anthony 1982), where T_{max} was the oldest age ever observed (12) at the site or one similar to it. M was assumed to be 0.25, a rate used in previous Maryland eel studies (Weeder 2002). Other estimates of M from the Hudson River, Prince Edward island, and the northwestern Gulf of the St. Lawrence were 0.16, 0.25, and 0.13 to 0.79, respectively (Secor 2002). The total instantaneous mortality rate (Z) was derived from the slope of the descending arm of the negative $\log_e$ transformed catch at age derived from an age-length key (Ricker 1975; Allen 1997). Instantaneous fishing mortality rate (F) was derived as $F = Z - M$, while total annual loss (A) was calculated by computing $1- e^{-Z}$.

There was no explicit term used for emigration effects, therefore these impacts were implicitly included in M. The degree to which emigration influenced Z is unknown and was not quantified. Age at full recruitment (highest catch at age) was the first year used to calculate the slope of the catch curve with the last year being the age at which no less than 5 individuals were captured.

Maryland commercial American eel landings and relative abundance

Since 1983 Maryland has required a license to harvest American eel and mandatory monthly reporting requirements. Commercial American eel landings were compiled from 1983-2007. In 1990, Maryland required harvesters to report effort as well as harvest information on their monthly reports. However, this was not fully implemented until 1992. A relative abundance index was created from 1992-2007 through the calculation of eel pot catch-per unit-effort (CPUE) and is reflected by total annual eel pounds harvested by eel pots / total annual # eel pots fished (eel pots*boat days fished). Commercial American eel landings for all Atlantic states (including Maryland) were reviewed from 1960-2007 (Source: National Marine Fisheries Service landings database).

RESULTS AND DISCUSSION

Size structure

Mean length of sampled eels from the Nanticoke River ranged from 325.8–355.3 mm with large eels comprising 11.8-20.2% of the total sample from 2000-2005 (Table 1-1). In 2007, Nanticoke River eels were significantly larger with a mean length of 431.0 and 53.6% of the sample considered large (Kruskal Wallis ANOVA, $P<0.001$; Dunn's multiple comparison, $P<0.05$). Dunn's multiple comparison test also indicated 2003 eel samples were significantly larger ($P<0.05$) than all years except 2007. Although length distributions for eels from the Nanticoke River showed a slight shift to larger sizes in 2002-2003, the composition of 2007 sample showed larger eels comprised a significant portion of the total sample relative to all previous samples and the distribution was more even across all size bins (Figure 1-2). There are, however, a few caveats that potentially could have contributed to such significant size differences seen in 2007. Most importantly, in 2006 there was no reported commercial eel harvest from the Nanticoke River. Consequently, the population of eels in this system were allowed to grow for approximately 1 ½ years in the absence of a commercial fishery. Secondly, the commercial eeler utilized the previous six years retired and a different eeler was used in 2007. Although gear mesh size for eel pots and resulting selectivity should be comparable, fishing efficiency may have been different. Although the fishing areas between the two eelers overlapped the eeler in 2007 fished the lower to mid sections of the river compared to the previous eeler who fished the middle to upper portions of the river. In addition, sample size in 2007 was small (296) compared to the average of the previous six years (508) due to the sample composition of predominately large eels and a standard purchase of approximately 100 pounds.

Mean length of sampled eels from the Patuxent River was 394.0 and 341.6 mm with large eels comprising 40.0 % and 11.3% of the total sample in 2006 and 2008, respectively (Table 1-1). Mean length of sampled eels was significantly smaller in 2008 than in 2006 (Mann Whitney rank sum test, $P<0.001$). Length distributions in 2008 for Patuxent River eels indicated 3-20 mm length groups (301-360mm) comprised 60% of the total eels sampled by number (Figure 1-3). The length distributions in 2006 were more evenly dispersed throughout the larger sizes with no 3 consecutive length groups (60 mm) comprising more than 30% of the total sample. The eel samples from the Patuxent River and the Nanticoke River had 40.0 and 53.6 % large eels in 2006 and 2007, respectively. No other tributary sample from 2004-2008 exceeded 23% large eels as a proportion of the total.

Mean length of sampled eels from the Choptank River was 331.9 and 348.4 mm with large eels comprising 12.9 % and 22.4% of the total sample in 2006 and 2007, respectively (Table 1-1). Although there was little difference in mean length between the two years, the length distributions indicate a slight shift to larger eels in 2007 (Figure 1-4).

Mean length of sampled eels from Fishing Bay was 362.5 and 304.3 mm with large eels comprising 18.9 % and 3.9% of the total sample in 2004 and 2008, respectively (Table 1-1). Mean length was significantly smaller in 2008 than in 2004 (Mann Whitney rank sum test, $P<0.001$). Length distributions for Fishing Bay eels in 2008 shifted to considerably smaller sizes compared to 2004 and were dominated (> 70%) by the 3-20 mm length groups that comprised eels from 260-320mm (Figure 1-5). This shift to smaller sizes in 2008 for Fishing Bay eels was reflected in the 2008 Patuxent River eel samples as well. There are several potential explanations for this shift to smaller relative sizes in 2008. First, although the sample from the commercial fishery is aggregated over several days and often purchased twice during the spring season which would help ameliorate the day-to-day variations in catch, the sample still may not be fully representative of that season's catch. Eelers believe younger, smaller eels are the first to become active, so cooler spring temperatures, as seen in Maryland in 2008, may have hampered the catch of inactive larger eels. Secondly, assuming the fishing area and eel pot mesh size remained similar for each year, good recruitment to the fishery may have occurred. The more abundant smaller eels would depress the percentage of large eels in the sample. Lastly, potential exists that not as many larger eels were available for capture, due to either removal from the fishery in the previous years, higher loss from spawning emigration, or other causes of natural mortality. Fishing mortality rates, estimated in a later section, and its relative change from previous sample years in each respective system may provide additional insight to smaller eels in 2008.

Mean length of sampled eels from the Sassafras River was 282.6 mm with 0.0 % of the sample eels large (Table 1-1). The 2004 sampled Sassafras River eels had a significantly smaller mean length than any of the other tributaries sampled (Kruskal Wallis ANOVA, $P<0.001$; Dunn's multiple comparison, $P<0.05$). The Sassafras River, a predominately oligohaline environment (<5ppt), was the only system sampled in the upper Chesapeake Bay. An oligohaline environment may result in regional size structure differences due to differences in habitat, food availability and quality, growth, regional fishing differences (gear selectivity), mortality, and sex ratio. In addition, there was always a potential that the supposedly ungraded sample purchased from the eeler may, in fact, have been graded and the larger more valuable eels culled off for higher market value. Fortunately, fishery independent sampling has occurred in the Sassafras river from 1998-2000 and again from 2006-2008 and the population in this tributary will be further characterized and compared between both study periods (Job 2).

Size and age structure

Overall age structure for commercially harvested Nanticoke River eels was similar over the seven sampling years. Two periods (2000-2003) showed captured eels ranging from 1-12 years in age. In 2004-2005 and 2007, eels ranged from 2-12 and 2-9 years in age, respectively. Mean length-at-age for ages 4-7 ($N \geq 5$ for each age and period) was compared among the 4 sampling periods. Slight increases in mean size were noted in ages 4-7 for each successive time period except in 2004-2005, where eels were smaller at each age (Figure 1-6).

For the Nanticoke River, the von Bertalanffy(VB) growth function parameters K and L_∞ ranged from 0.08-0.19 and 691.8-973.3mm, respectively over the seven sampling years with no apparent trend (Table 1-2). The slope (average annual increase in length (mm)) and the y-intercept for the linear regression varied from 39.0-57.4 and 143.0-251.3, respectively over the same time period with no apparent trend.

In 2006, ages 1-8 were present in commercially harvested Patuxent River eels compared to only 4 age classes (2-5) in 2008. When compared to 2006, decreases in mean length-at-age were noted for ages 2 through age 5 in 2008 (Figure 1-7).

For the Patuxent River, the VB growth function parameters K and L_∞ were 0.22 and 676.2mm in 2006 and 0.29 and 527.4mm in 2008 (Table 1-2). The slope and the y-intercept for the linear regression were 49.4 and 245.5 in 2006 and 42.0 and 233.0 in 2008. Although the growth coefficient (K) was higher in 2008, the predicted growth at each age from the VB and linear regression was greater in 2006. Maryland DNR landings database indicated average reported eel landings of approximately 14,000 pounds in the Patuxent River from 1992-2005. In 2006 and 2007 eel landings increased to approximately 40,000 pounds. The lower growth and contraction of the age structure could potentially be the result of the recent increase in harvest and the cropping of older larger eels from the resident population

The age structure and range of ages present for commercially harvested Choptank River eels showed little change from 2006(ages 1-7) to 2007(ages 1-6). Mean length-at-age for ages 1-5 were nearly identical over the two sampling years (Figure 1-8).

For the Choptank River, the VB growth function parameters K and L_∞ were 0.15 and 1000.8mm in 2006 and 0.13 and 1129.0mm in 2007(Table 1-2). The slope and the y-intercept for the linear regression were 79.9 and 192.4 in 2006 and 87.3 and 182.1 in 2007. Choptank River eels grew approximately 30+mm more annually than eels from any other sampled tributary from 2004-2008 based on predicted growth from the linear regression. The linear fit as indicated by r^2 =0.62 was also higher than any of the other sampled rivers over the same time period.

Commercially harvested Fishing Bay eels in 2004 (ages 1-7) and 2008 (ages 2-7) had similar age structures and age ranges. Mean length for 2008 eels 4-6 years of age were approximately 30mm shorter in total length at each age than 2004 eels (Figure1-9). The VB growth function parameters indicated moderate differences in growth for Fishing Bay eels between 2004 and 2008. Parameters K and L_∞ were 0.14 and 766.5mm in 2004 and 0.27and 508.9mm in 2008 (Table 1-2). The slope and the y-intercept for the linear regression were 49.0 and 188.8 in 2004 and 35.8 and 226.3 in 2008. The predicted lengths from the VB and linear regression indicated faster growth for 2008 eels aged 0-2, yet smaller sizes at ages 3+ compared to 2004 eels. Eel growth in 2008 was described as more asymptotic compared to the more linear growth described in 2004.

In 2004, ages 2-7 were present in the commercially harvested Sassafras River eels. The VB growth function parameters K and L_∞ were 0.34 and 355.6 and the slope and y-intercept for the linear regression were 23.9 and 188.2. Eels over 360 mm were absent from this sample, so predicted growth from the VB indicated a high growth coefficient (K) of 0.34, yet the asymptote was reached at an extremely small size of 355 mm. Average annual growth predicted from the slope of the linear regression was approximately 15 mm less than any sampled tributary from 2004-2008 (Table 1-2).

Mean length-at-age for common age groups (ages 2-5) were compared between all sampled rivers over the study period. Mean size at age was quite variable among sampled tributaries (Figure 1-10). The mean length for Choptank River eels (ages 3-5) was on average over 80 mm larger than eels from each of the other sampled systems. While mean length for Sassafras River eels was significantly smaller due to non-overlapping 95% confidence intervals at ages 3-5. With the exception of Sassafras River eels, mean length differences were relatively small (< 25mm) for age 2 eels from the other four tributaries.

Although length-at-age varied considerably among different systems, the ages present in the size structure were fairly uniform. With the exception of the Nanticoke River, where eels aged 9+ were consistently captured in six out of the seven sampled years, the age range of 2-7 (±1) was fairly standard for the other sampled tributaries.

Length-at-age plots indicated that not only did the growth rates vary considerably among systems and years, but also within the same system. The coefficient of determination (r^2), which describes the proportion of the variability in length explained by age, was fairly weak in many cases (range = 0.23-0.61). Although the reasons for the eel growth differences among rivers are unclear, they may be explained by a combination of factors that include differences in system productivity, food availability, diet composition (salinity regimes), water temperature, habitat (dissolved oxygen, condition of sediments and substrates, etc), and sex ratio. Eel densities relative to carrying capacity as a result of differences in exploitation or natural mortality and its effects on the previously mentioned factors should also be considered.

Sex ratio

Sex ratio was calculated for the Nanticoke River in 2007 and for the Patuxent River and Fishing Bay in 2008. The Nanticoke River in 2007 was dominated by females (81.4%) with males and undifferentiated eels accounting for 10.8% and 7.8% respectively. The 2008 Patuxent River eel population was comprised of 59.7 % females, 27.8 % males and 12.2% undifferentiated. Males were more abundant in the samples collected in Fishing Bay in 2008 (41.9 %) with females accounting for 34.3%, and undifferentiated eels at 23.8%. Published studies on American eel sex ratios in the U.S. were found to be quite variable with males ranging from 3% to 97% depending on life stage, habitat, and sampling location (Michener 1980; Harell and Loyacano 1982; Hansen and Eversole 1984; Helfman 1984; Oliveira and McCleave 2000; Rulifson et al. 2004).

Several studies have discovered eel gonads that morphologically appeared male or female, but were ambiguous with histological examination (Dolan and Power 1977). Since the determined sex of the subsampled eels in this study was not validated with a histological examination, uncertainties of successful sexing based on methods used should be considered.

Parasite infestation rates

A. crassus, a swim bladder parasite native to the Japanese eel (*Anguilla japonica*), invaded wild populations of the European eel (*Anguilla anguilla*), most likely through aquaculture, around 1982. In 1995, again likely a result of transported eels, American eels (*Anguilla rostrata*) in North America (Texas) were found with the presence of the swim bladder parasite (USFWS 2007). It has since spread north up the Atlantic coast and has infected

Chesapeake Bay eel populations for nearly ten years. Although death of wild eel hosts is uncommon, heavy infections by *A. crassus* can lead to hemorrhagic lesions, swim bladder fibrosis or collapse, skin ulcerations, decreased appetite, and reduced swimming performance (Moser et. al 2001).

Annual prevalence rates for eels with the presence of *A. crassus* for the tributaries sampled in 2004-2008 ranged from 16.0% - 63.2%. Prevalence rates for Nanticoke River eels were 49.3 % (N=73) over combined 2004 (56.0%) and 2007 (40.6%) samples. Prevalence rates for Patuxent River eels were 24.6% (N=69) over combined 2006 (24.0%) and 2008 (25.0%) samples. Prevalence rates for Choptank River eels were 47.8% (N=101) over combined 2006 (46.7%) and 2007 (50.0%) samples. Prevalence rates for Fishing Bay eels were 42.6% (N=101) over combined 2004 (63.2%) and 2008 (16.0%) samples. Prevalence rates for 2004 Sassafras River eels were 46.0% (N=87). Prevalence rates for sampled fishery dependent rivers from 2004-2008 show no apparent trend, however the cumulative 42.5% (N=379) rate is approximately double the 10-29% infection rate first determined in the mid and upper Chesapeake Bay in 1997 (Barse and Secor 1999).

Mortality estimates

The slope of the negative $\log_e$ transformed catch at age for the Nanticoke River used to indicate Z showed little variability from 2000-2007 (range = 0.55 – 0.67 ; Table 1-3). Nanticoke River eels were fully recruited to the pot fishery at age 4 for 6 of the seven sampled years. In 2000, Nanticoke River eels were fully recruited at age 3.

Catch curve analysis from the Patuxent River indicated a Z of 0.46 in both 2006 and 2008, the lowest among all sampled tributaries (Table 1-3). Patuxent River eels were fully recruited to the pot fishery at age 2 in 2006 and age 3 in 2008. It should be noted that the descending limb of the catch curve used to calculate the slope (Z) comprised ages 2-6 in 2006, but only ages 3-5 in 2008. Although a good fit of the regression line was indicated by r^2=0.99, accuracy may be limited because the regression only fit three data points. This relatively low F of 0.21 in the Patuxent River coupled with a nearly 3-fold increase in landings in 2006 and 2007 relative to average landings from 1992-2005, indicates a substantial population of eels in this system. Of the five rivers sampled since 2004, the Patuxent River is the largest drainage and may likely have the most adequate eel habitat.

Catch curve analysis from the Choptank River indicated a Z of 1.23 (A=0.71) and 1.19 (A=0.69) in 2006 and 2007, respectively (Table 1-3). In both sampled years Choptank River eels were fully recruited to the pot fishery at age 2. The Maryland DNR landings database indicated average reported eel landings from the Choptank River has increased to an average of 45,000 pounds from 2005-2007 compared to an average of 10,000 pounds during 1992-2004. Although the drainage size is the second largest of the sampled rivers, the heaviest fishing activity is concentrated in the Choptank River in a relatively small area (mouth to10 miles upstream). This concentrated effort and 4-fold increase in Choptank River eel landings since 2005 produced a high exploitation rate, with F nearly four times the estimated natural mortality rate (M) of 0.25.

Catch curve analysis from Fishing Bay indicated a Z of 1.35 (A=0.74) and 1.15 (A=0.68) in 2004 and 2008, respectively (Table 1-3). Fishing Bay eels were fully recruited to the pot fishery at age 4 in 2004 and age 3 in 2008. Fishing activity is concentrated on this relatively small drainage and as a result, exploitation levels were high with F in both years sampled being 3-4 times the assumed M.

Catch curve analysis from the Sassafras River in 2004 indicated a Z of 1.32 (A=0.73) (Table 1-3). Sassafras river eels in 2004 were fully recruited to the pot fishery at age 4. Exploitation was high in 2004 with F estimated at four times M, similar to Choptank River and Fishing Bay.

The calculation used to compute F assumes a constant M of 0.25. Since emigration loss was not quantified by system, it is implicitly included in M. In *Anquilla* species, researchers have found the maturity and resultant emigration of silver eels was often more dependent on length and fat content than age (Helfman et al., 1987; De Leo and Gatto, 1996). Systems with an exceptional growth rate, such as in the Choptank River, may experience higher emigration loss that is not fully accounted for in M, possibly resulting in biased estimates of F. Given the sexual dimorphism in *Anquilla* species (males max size < 400mm), emigration loss could be strongly influenced by sex ratio. Natural mortality may likely be underestimated and F overestimated for a system dominated by male eels due to high emigration loss. The mean size of male silver eels from two southern Delaware streams was 330mm with a range of 264-412mm (Barber 2004). Maryland Chesapeake eels are capable of attaining this mean size in 2-5 years depending on the growth capabilities dictated by the system and would, therefore, be potentially excluded from commercial exploitation.

Maryland commercial American eel landings and relative abundance

Since a commercial license was required to harvest American eel in Maryland (1983), over 95% of all landed eels were caught with eel pots. Mean annual eel landings from 1983-2007 was 242,747 pounds. Landings have exceeded this average five consecutive years since 2003 and have reflected a positive linear trend the over this 25 year period (Figure 1-11).

Mean annual CPUE was 0.51 pounds/ pot from 1992-2007. CPUE increased six out of seven years from 1999-2006 and reached a time series high of 1.01 pounds/ pot in 2006. CPUE was slightly lower in 2007 than in 2006, but was the second highest over the time series (Figure 1-12). Since 1992, both American eel landings and CPUE have shown an overall positive trend, while commercial eel pot effort has declined over the same time period (Figure 1-13). In 2007 total eel pot effort was nearly 40 % less than the time series average and 60% less than the time series high which occurred in 1997.

The positive trend in the relative abundance index since 1992 would indicate an increase in overall abundance in American eel in the Maryland's Chesapeake Bay. However, overall fishing efficiency may have increased through the time series if the reduction of effort was largely a result of part time or less efficient eelers becoming inactive. For this reason, actual eel abundance may have increased but not at the same rate as the CPUE index.

Total commercial Atlantic coastal American eel landings increased steadily from 1960 to a peak of 3.9 million pounds in 1979. Landings then declined to 940,000 pounds in 1997. Since 1997, landings appear to have stabilized at these lower levels fluctuating between 650,000-1 million pounds (Figure1-14). Maryland commercial eel landings have shown a slight positive trend since 1960 and their catches have comprised over 40% of total Atlantic coastal landings 10 out of 11 years through 2007.

Figure 1-1: Maryland Chesapeake Bay tidal river fishery dependent eel pot sampling locations and number of American eels sampled 2004-2008.

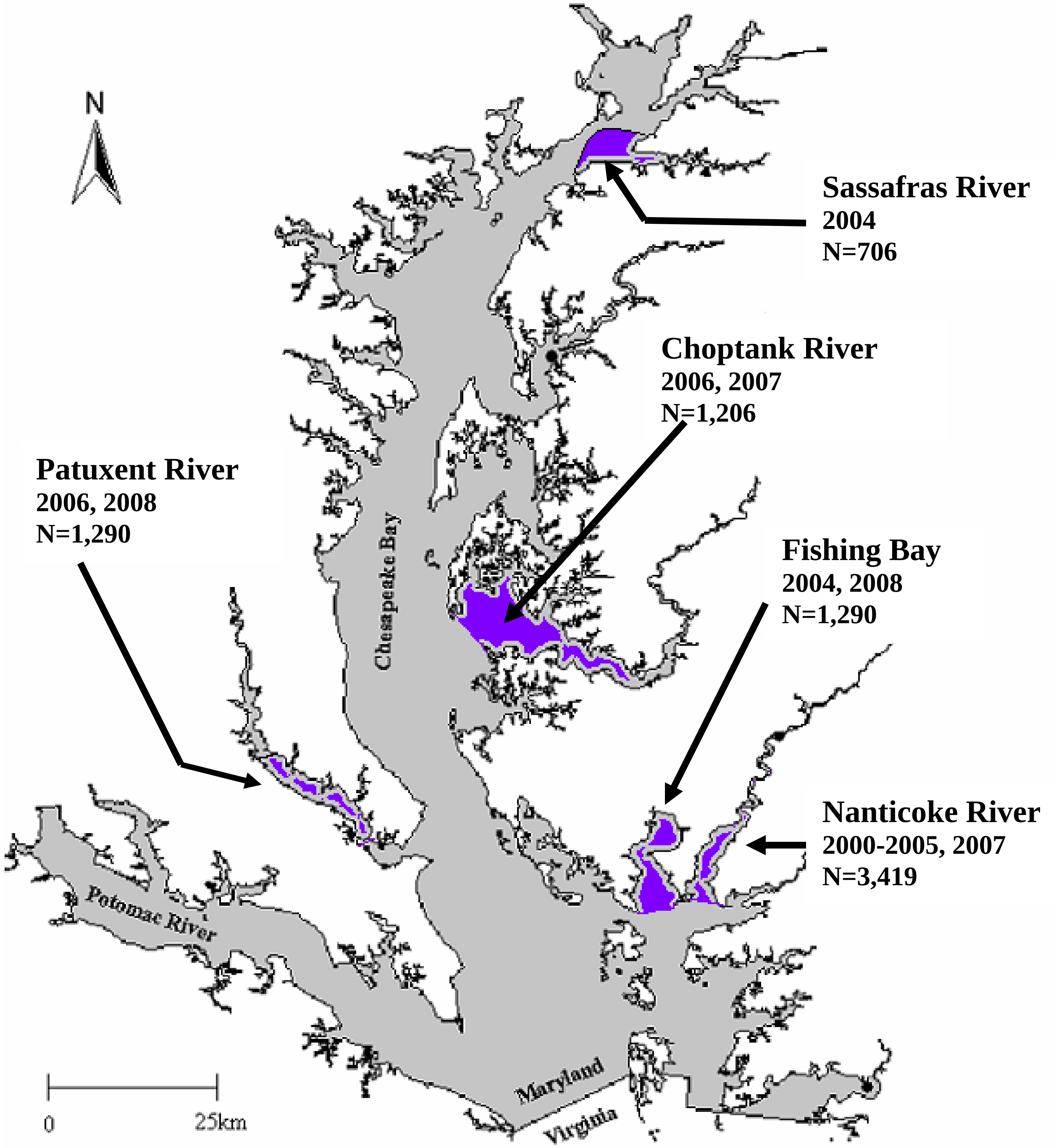


Figure 1-2: American eel length distributions from the commercial fishery in the Nanticoke River, 2000-2007.

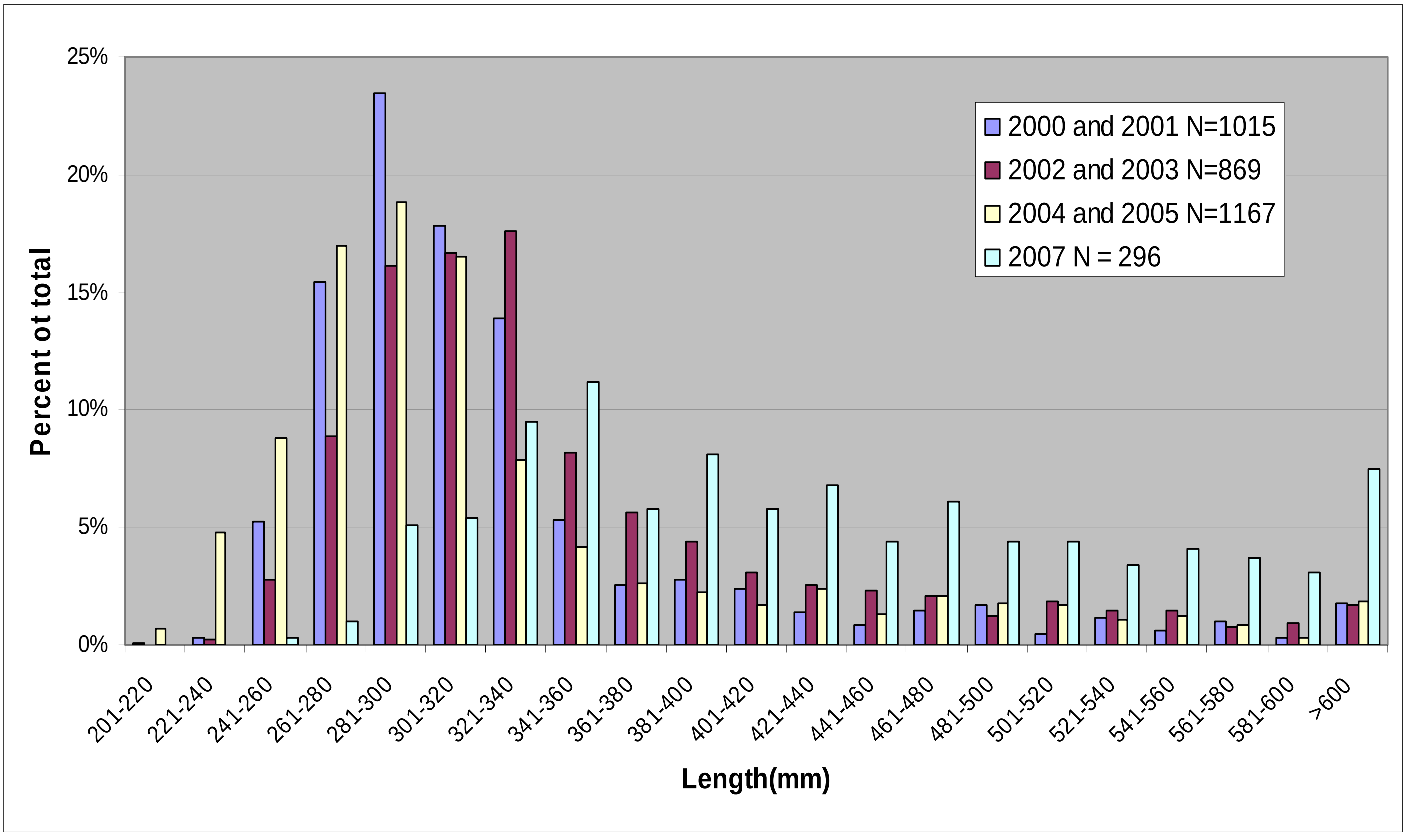


Figure 1-3: American eel length distributions from the commercial fishery in the Patuxent River, 2006 and 2008.

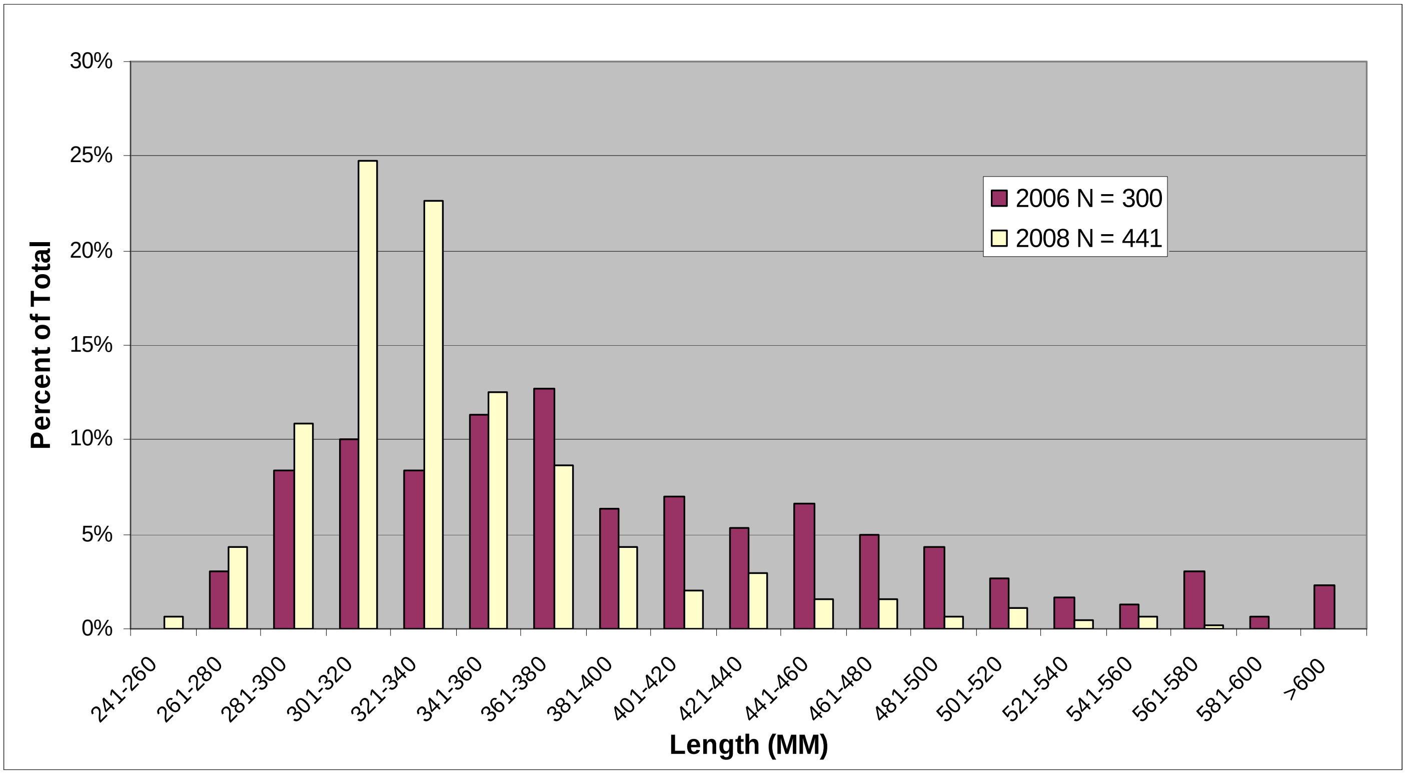


Figure 1-4: American eel length distributions from the commercial fishery in the Choptank River, 2006 and 2007.

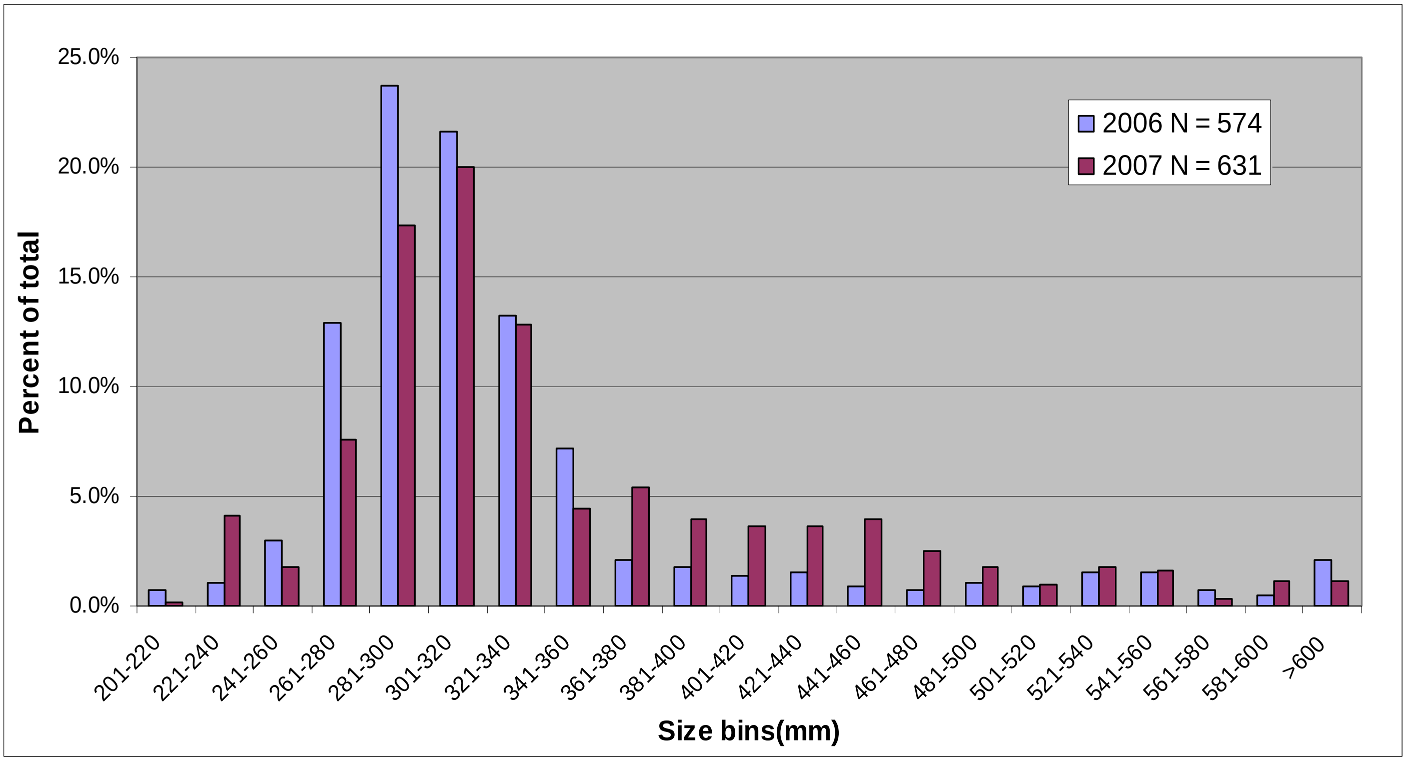


Figure 1-5: American eel length distributions from the commercial fishery in Fishing Bay, 2004 and 2008.

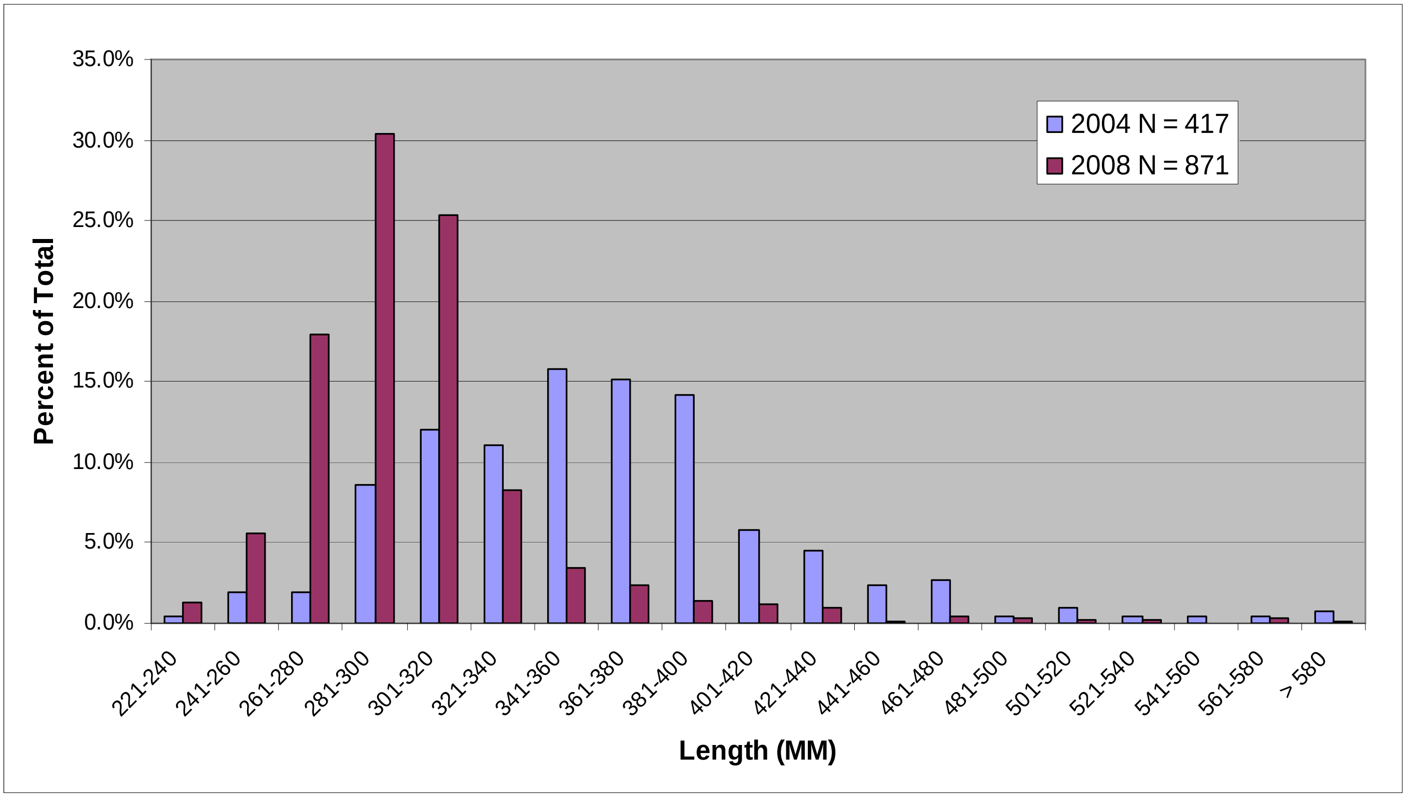


Figure 1-6: Mean length at age and 95% CI's of commercially harvested Nanticoke River American eels, periods 2000-2001, 2002-2003, 2004-2005, and 2007.

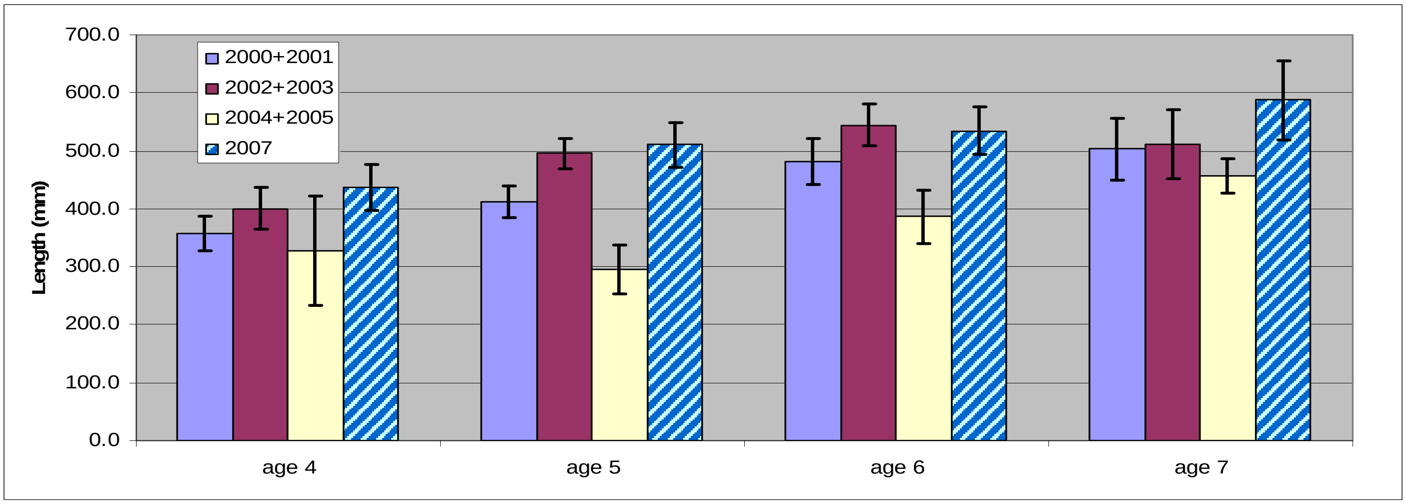


Figure 1-7: Mean length at age and 95% CI's of commercially harvested Patuxent River American eels, 2006 and 2008.

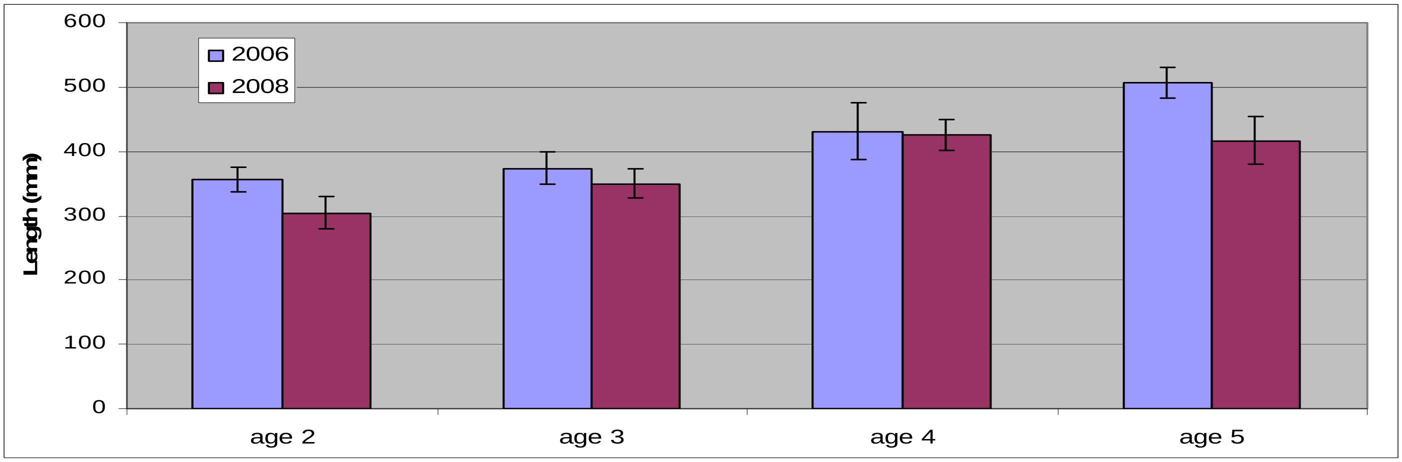


Figure 1-8: Mean length at age and 95% CI's of commercially harvested Choptank River American eels, 2006 and 2007.

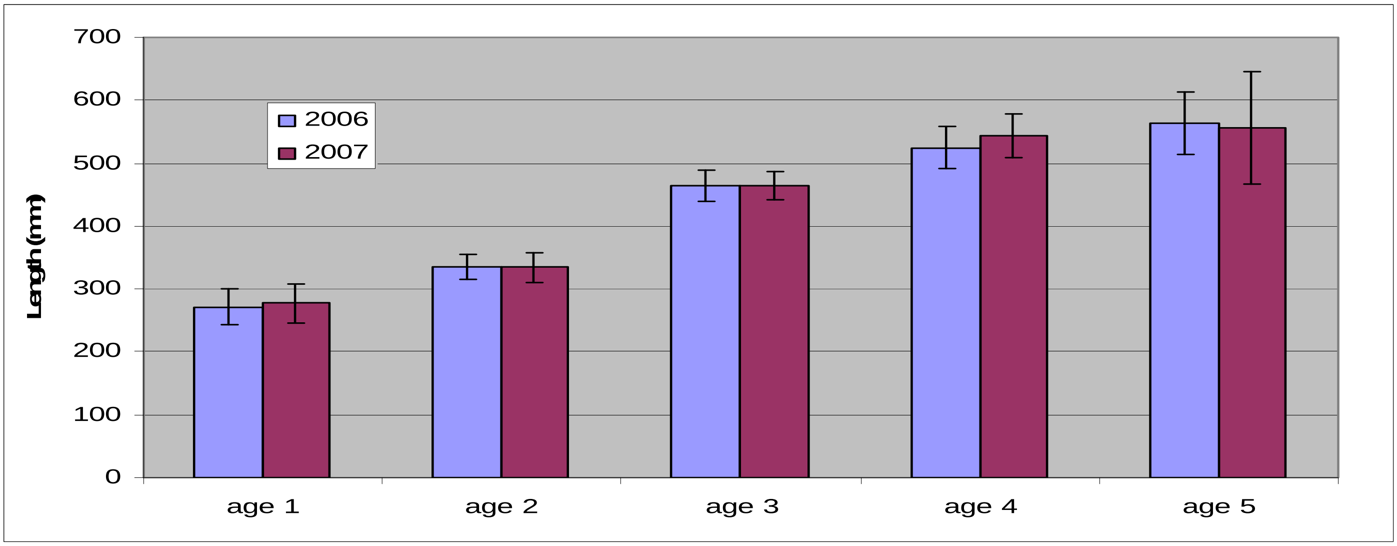


Figure 1-9: Mean length at age and 95% CI's of commercially harvested Choptank River American eels, 2006 and 2007.

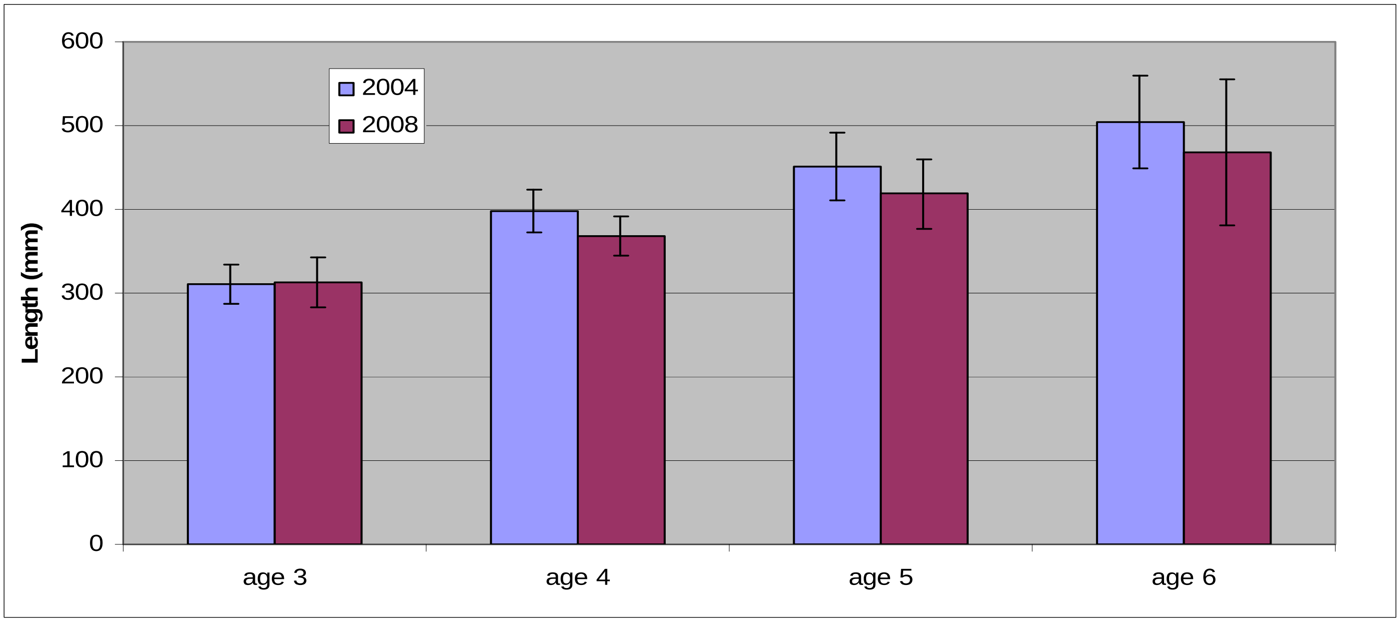


Figure 1-10: Mean length at age and 95% CI's for comparable ages of commercially harvested American eels from fishery dependent sampling, 2004-2008.

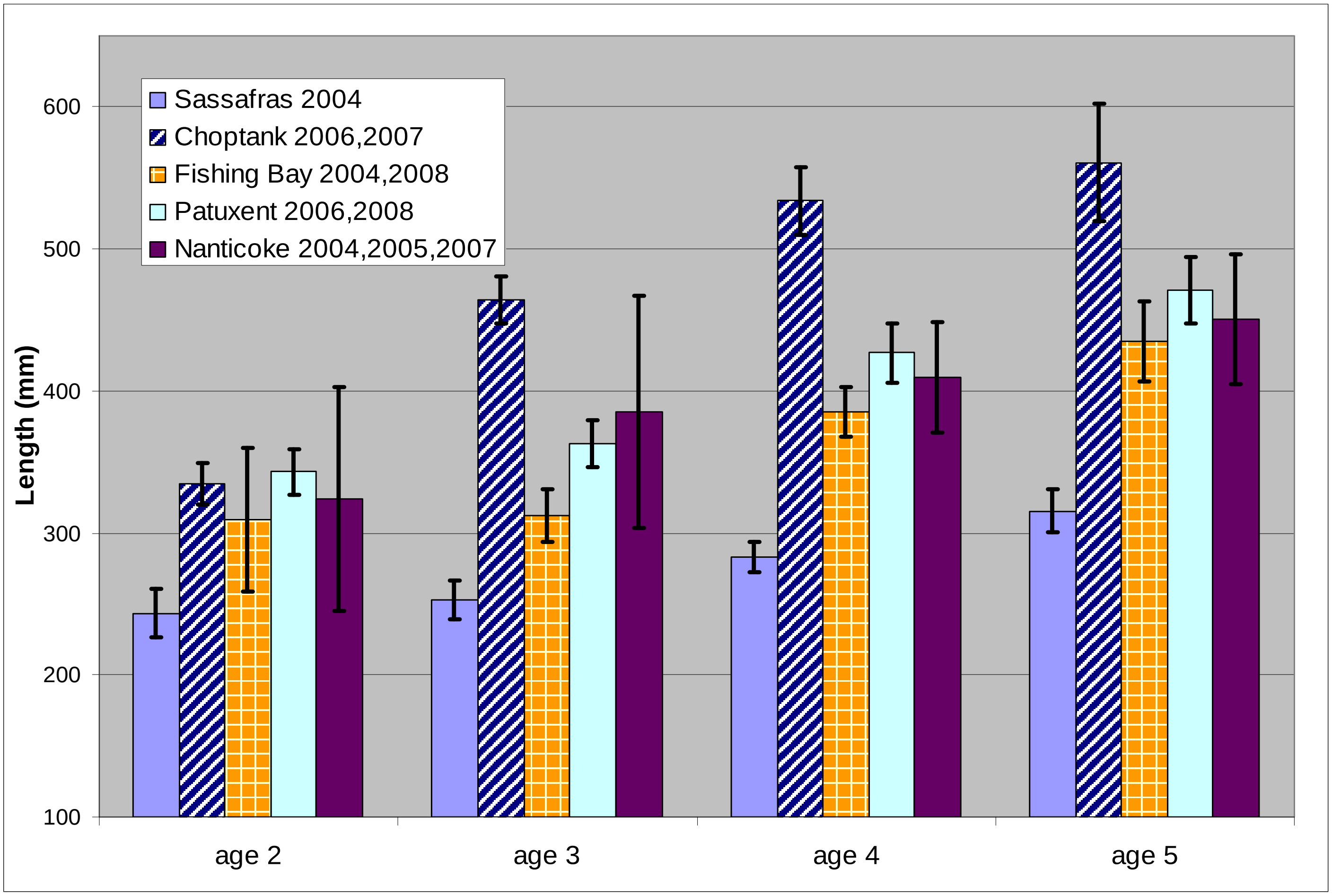


Figure 1-11: Reported American eel landings from Maryland Chesapeake Bay with linear trend, 1983-2007 (Annual Mean= 242,747 pounds). Landings source: Maryland DNR Fisheries landings database.

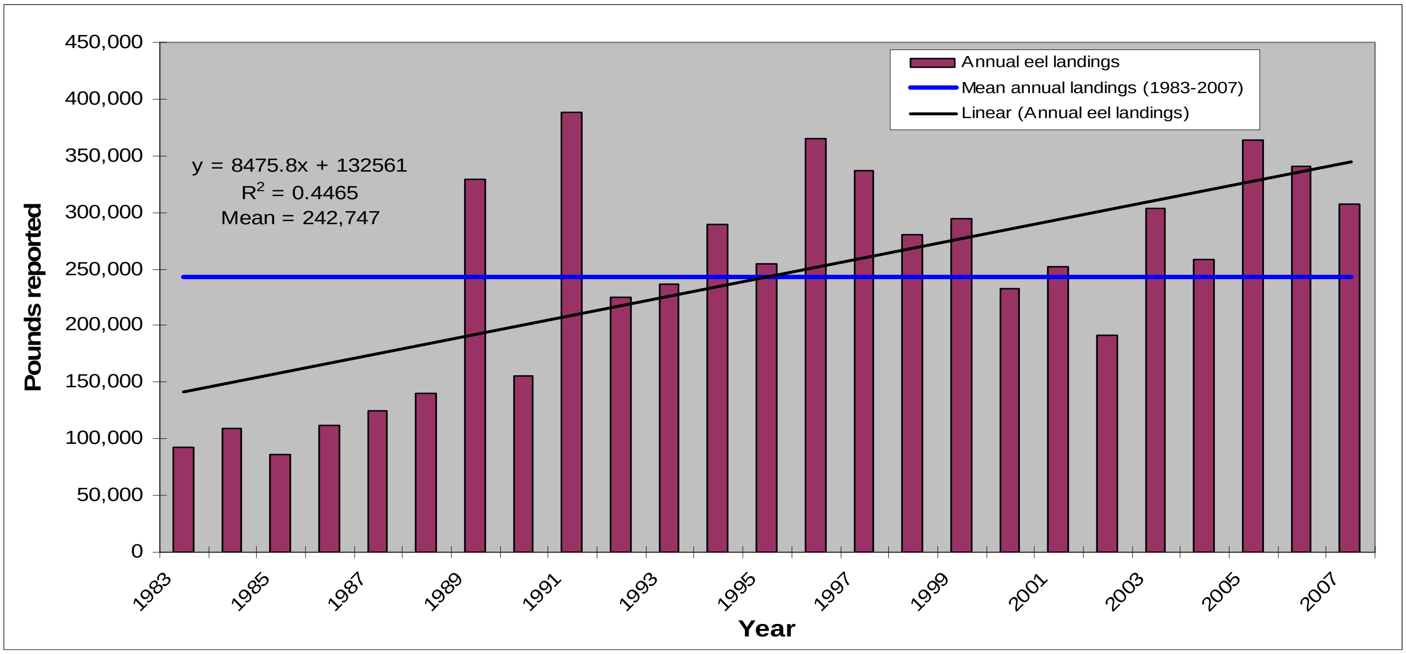


Figure 1-12: Reported American eel landings from Maryland Chesapeake Bay and annual commercial eel pot CPUE in total annual pounds harvested by pots/total annual # eel pots fished (eel pots*boat days fished) 1992-2007 (Annual mean CPUE= 0.51). Landings and effort source: Maryland DNR Fisheries landings database.

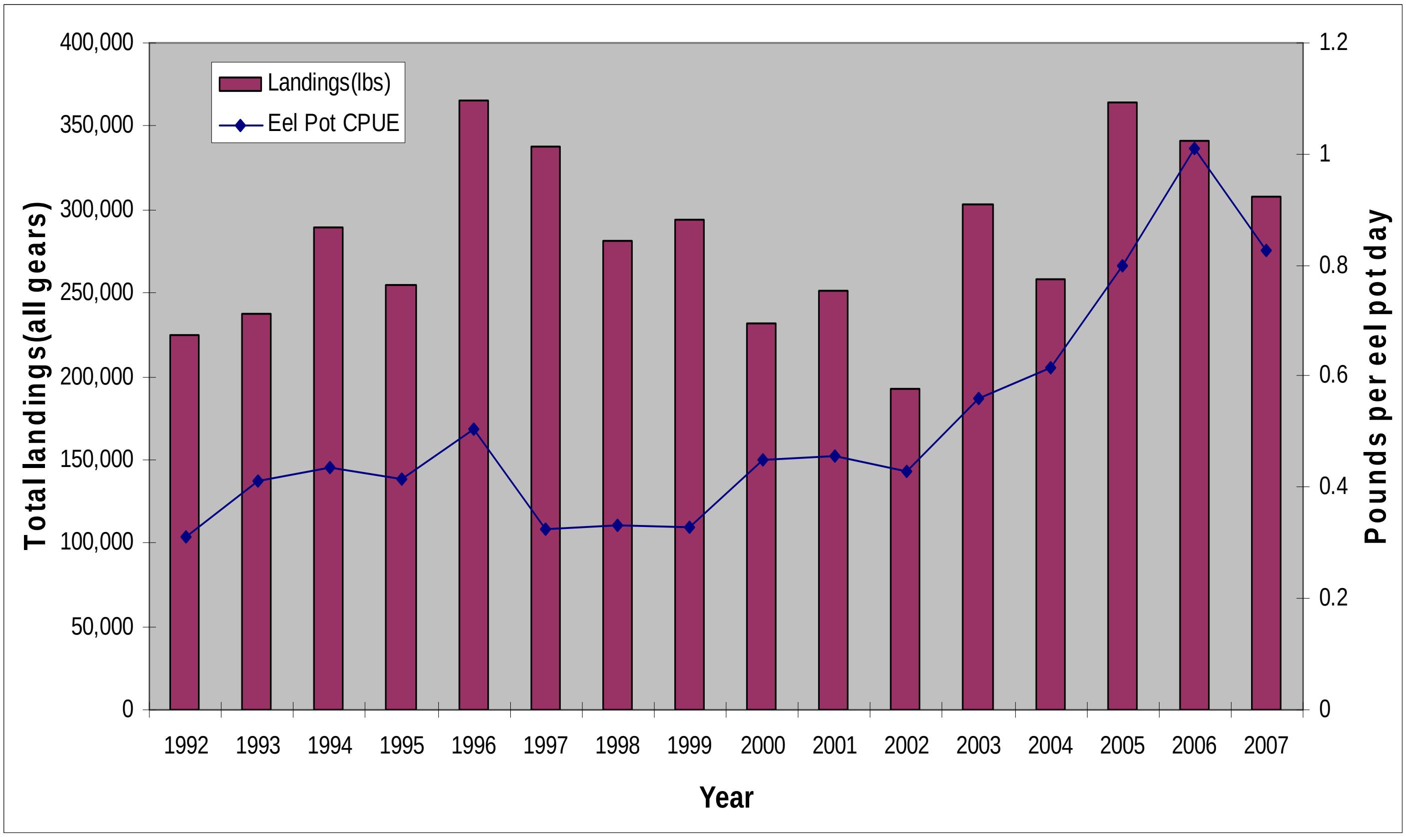


Figure 1-13: Commercial eel pot effort (pots*boatdays) and number of licenses reporting eel harvest, 1992-2007 (Mean annual effort=565,358) Landings/effort source: Maryland DNR Fisheries landings database.

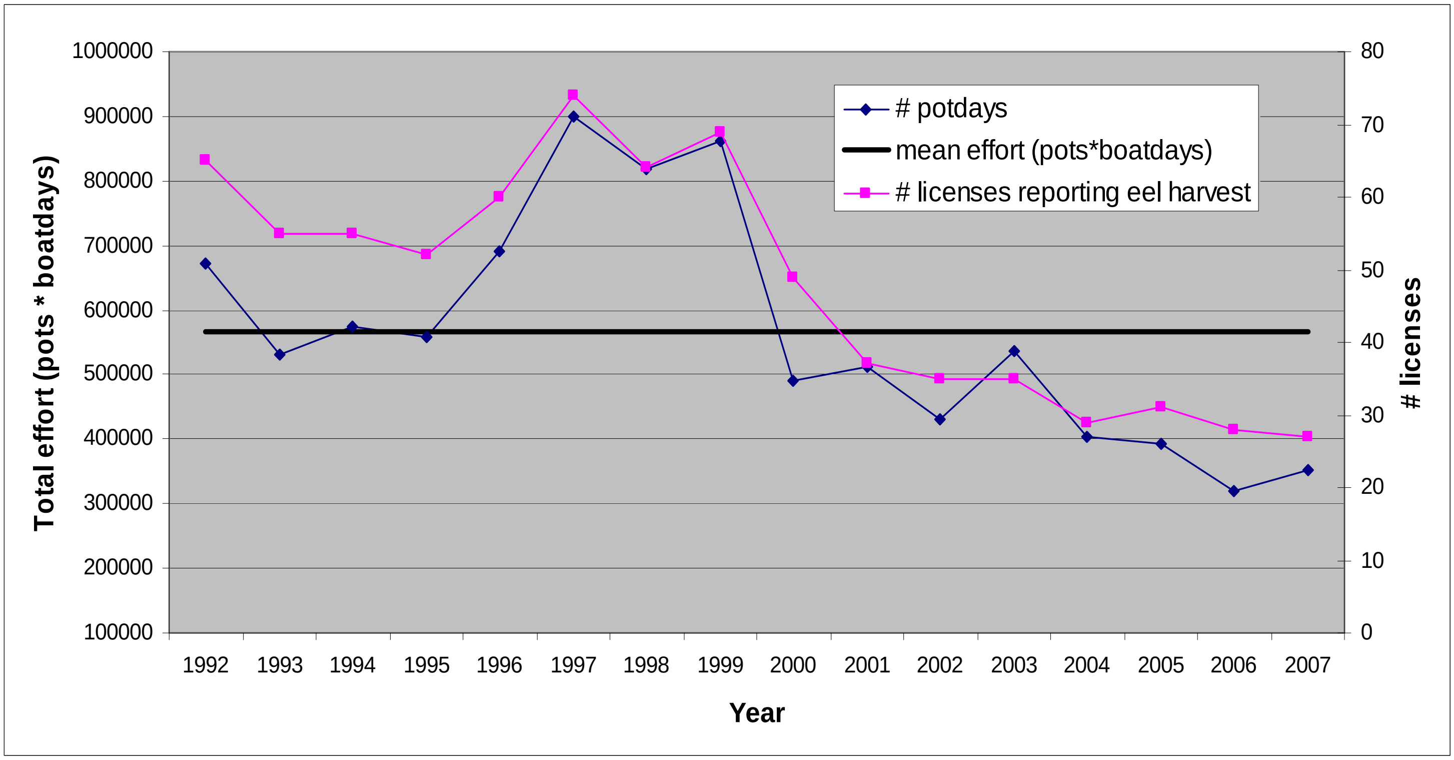


Figure 1-14: Total Atlantic coastal and Maryland commercial American eel landings, 1960-2007. Landings source: National Marine Fisheries Service landings database

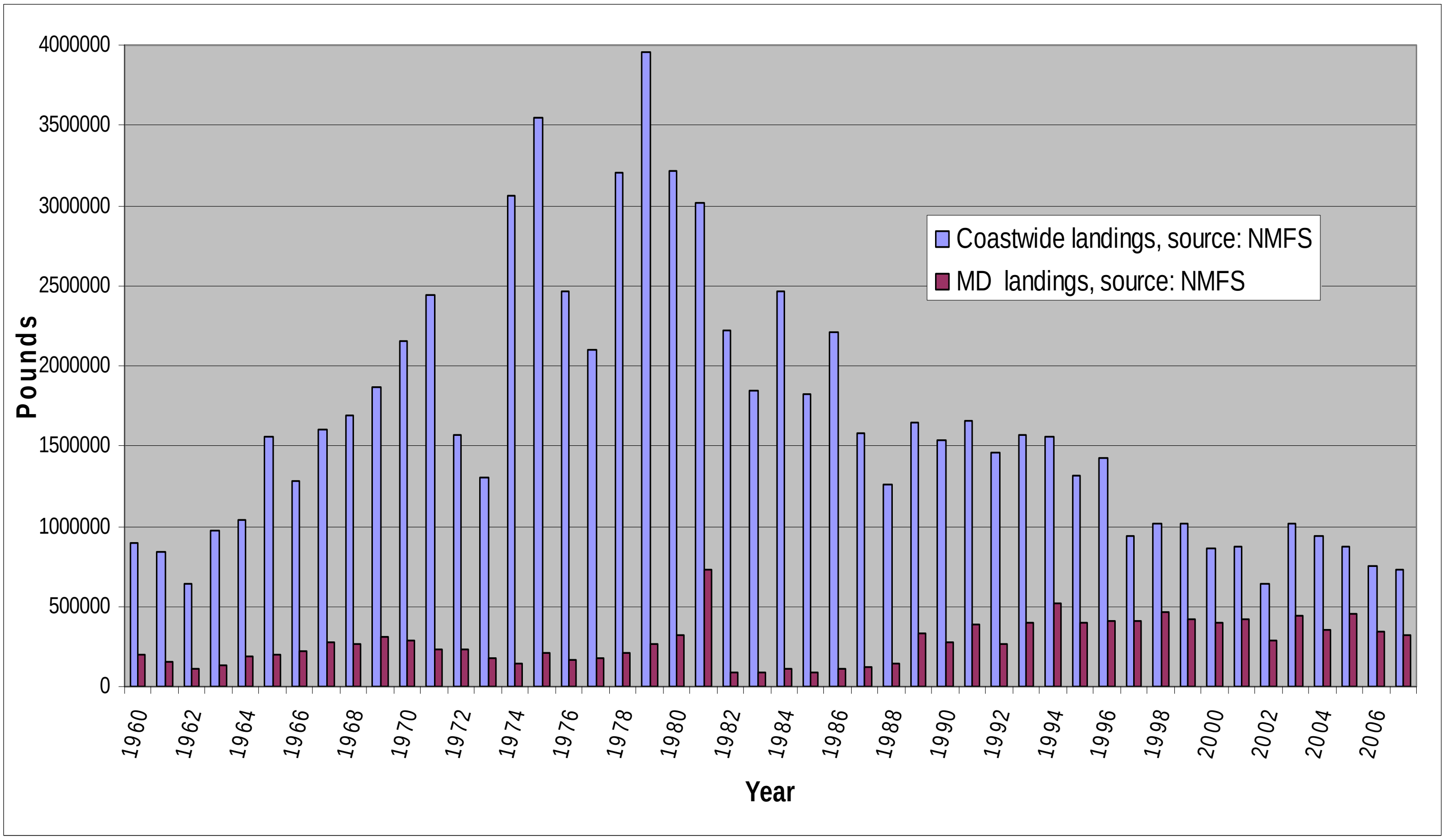


Table 1-1: Mean length, 95 % CI of the mean, % 'large' (> 400mm), and number sampled by year for Maryland Chesapeake Bay fishery dependent sampling locations, 2004-2008.

River	Year	N	Mean length (mm)	95% CI of Mean	% Large
Nanticoke	2000	688	325.8	5.9	11.8
Nanticoke	2001	327	337.9	8.3	15.9
Nanticoke	2002	250	341.9	10.6	18.0
Nanticoke	2003	619	353.3	6.5	20.2
Nanticoke	2004	537	342.0	7.9	20.1
Nanticoke	2005	629	335.2	6.3	13.2
Nanticoke	2007	295	431.1	11.7	53.6
Patuxent	2006	300	394.0	9.6	40.0
Patuxent	2008	441	341.6	5.0	11.3
Choptank	2006	574	331.9	6.6	12.9
Choptank	2007	630	348.4	6.6	22.4
Fishing Bay	2004	417	362.5	5.8	18.9
Fishing Bay	2008	871	304.3	2.9	3.9
Sassafras	2004	705	282.6	2.0	0.0

Table 1-2: American eel age-length relationship described by von Bertalanffy growth equation (Length=$L_\infty(1-e^{-K(t-t_0)})$) and linear regression for Maryland Chesapeake Bay fishery dependent sampling locations, 2004-2008.

			VB Parameters			**Linear Regression**		
River	**Year**	**# Aged**	**L_∞**	**K**	**T_0**	**Slope**	**Y-intercept**	**R^2**
Nanticoke	2000	104	691.9	0.17	-1.00	39.6	237.8	0.57
Nanticoke	2001	143	786.0	0.11	-1.00	37.5	204.7	0.47
Nanticoke	2002	79	973.3	0.10	-1.00	57.4	143.0	0.45
Nanticoke	2003	75	752.6	0.19	-1.00	49.5	251.3	0.38
Nanticoke	2004	95	954.6	0.08	-1.00	39.0	162.4	0.46
Nanticoke	2005	20	NA	NA	NA	NA	NA	NA
Nanticoke	2007	106	730.3	0.19	-1.00	43.8	267.6	0.32
Patuxent	2006	130	676.2	0.22	-1.00	49.4	245.5	0.60
Patuxent	2008	97	527.4	0.29	-1.00	42.0	233.0	0.25
Choptank	2006	148	1000.8	0.15	-1.00	79.9	192.4	0.61
Choptank	2007	119	1129.0	0.13	-1.00	87.3	182.1	0.62
Fishing Bay	2004	90	766.5	0.14	-1.00	49	188.8	0.44
FishingBay	2008	93	508.9	0.27	-1.00	35.8	226.3	0.23
Sassafras	2004	82	355.6	0.34	-1.00	23.9	188.0	0.5

Table 1-3: Estimated age distribution, number of eels sampled (N), total instantaneous mortality rate (Z), instantaneous fishing mortality rate (F), and actual annual mortality rate for Maryland Chesapeake Bay fishery dependent sampling locations, 2004-2008. Instantaneous natural mortality rate (M) = 0.25.

						Estimated # at age based on age-length key											
River	**Year**	**N**	**Z**	**F**	**A**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Nanticoke	2000	688	**0.61**	**0.36**	**0.46**	13	84	199	177	133	25	32	11	7	4	1	2
Nanticoke	2001	327	**0.67**	**0.42**	**0.49**	4	35	84	87	71	16	16	6	4	3	1	1
Nanticoke	2002	250	**0.67**	**0.42**	**0.49**	4	26	64	66	54	12	12	5	4	2		1
Nanticoke	2003	619	**0.55**	**0.30**	**0.42**	6	57	143	164	144	35	32	16	11	7	2	2
Nanticoke	2004	537	**0.57**	**0.32**	**0.43**		63	26	132	121	114	35	22	10	6	4	4
Nanticoke	2005	629	**0.62**	**0.37**	**0.46**		74	34	154	140	140	40	24	10	5	3	5
Nanticoke	2007	295	**0.63**	**0.38**	**0.47**		24	41	95	59	58	12	2				
Patuxent	2006	300	**0.46**	**0.21**	**0.37**	3	113	86	31	48	15	2	2				
Patuxent	2008	441	**0.46**	**0.21**	**0.37**		93	167	114	67							
Choptank	2006	574	**1.23**	**0.98**	**0.71**	91	354	92	26	9	2	1					
Choptank	2007	630	**1.19**	**0.94**	**0.69**	89	325	142	33	11	2						
Fishing Bay	2004	417	**1.35**	**1.1**	**0.74**	2	6	128	194	75	6	5			1		
Fishing Bay	2008	871	**1.15**	**0.9**	**0.68**		157	487	146	67	6	8					
Sassafras	2004	705	**1.32**	**1.07**	**0.73**		85	175	296	128	13	8					

<u>Job 2</u>: Collect biological data to describe American eel populations in the Sassafras River through a fishery independent pot survey.

<u>INTRODUCTION</u>

The primary objective of Job 2 was to characterize the population of American eels in the Sassafras River through a fishery independent eel pot study. This study was designed to provide size and age structure data, parasite infestation rates, and sex composition of eels in the Sassafras River, as well as a fishery independent relative abundance index. The Sassafras was specifically chosen because of a prior Maryland DNR fishery independent eel pot study from 1998-2000. Current characterization information was compared to the previous study to note if changes in the American eel population have occurred in this river system.

<u>METHODS</u>

III. Field Operations

The 2008 Sassafras river eel pot study was replicated from field methods developed by Weeder (1998, 1999, 2000) with slight modifications. The Sassafras River is located on the upper eastern shore of Maryland's Chesapeake Bay (Figure 2-1). This drainage encompasses approximately 195.6 non-water km^2 (75.5 square miles) with nearly 21 km (13 miles) accessible by small boat from Route 301 to the Chesapeake Bay. Normal tide range is approximately 0.55 meters (1.8 feet). Salinities predominately range from 0 to 5 parts/thousand. In the current study, approximately 30 pots with galvanized wire mesh of either 0.83 x 0.83cm (1/3" * 1/3") or 1.27 * 1.27cm (1/2"*1/2") were set on individual lines at depths ranging from 3-16 feet. The cylindrical pots, typical of those fished by commercial eelers in Maryland's portion of the Chesapeake Bay, are approximately 2 feet in length with a diameter ranging from 16-21 cm (6.5-8.5 inches). Sample area totaled 8.7 river miles and was divided equally between an upper and lower pot set (Figure 2-2). Sampling during 2006-2008 occurred for 4-6 weeks from the middle of May through early July. Upper and lower pot sets were sampled on alternate weeks.

Temperature and salinity were recorded from the lowest downstream and highest upstream pot location for each set, while depth was recorded at each pot. The pots were baited with razor clams (*Tagellus plebius*) and soaked for 48 hours. Eels were placed in a 1.27 cm (1/2 inch) galvanized metal grader in order to separate large eels (approximately ≥ 400 mm) from small eels by pot. Commercially caught eels are commonly graded to separate the large live-market food eels from the smaller bait eels. All eels were retained and placed in separate coolers according to the pot mesh in which they were caught. The eels were then transported back to the lab and euthanized by an ice slurry, clove oil, or MS222. Each eel was then measured (mm), weighed (g), and subsamples were taken for age, gonad, and swimbladder analysis.

Field method differences from 1998-2000 survey

In 1999, Maryland passed a law that required a 4"square 1/2" * 1/2" mesh escape panel to be installed in the retention chamber for pots with less than 1/2" * 1/2" mesh. In the 1998-2000 survey only 1/3" * 1/3" mesh pots were used and only a portion of the pots contained an escape panel. All 1/3" * 1/3" mesh pots used in the current study had the escape panel. Menhaden (*Brevoortia tyrannus*), horseshoe crabs (*Limiulus polyphemus*), and razor clams were used for bait in the previous study, while only razor clams were utilized in 2008. The 1998-2000 study sampled approximately 4.5 river miles and consisted primarily of the current study's upper pot set. Sampling in 2000 only occurred on 2 days, both of which were in July as opposed to 8-11 days over approximately two months for each of the three years of the present study.

Age determination

Refer to JOB 1: METHODS/Field Operations-Age determination

Sex determination

Refer to JOB 1: METHODS/Field Operations -Sex determination

Parasite infestation rates

Refer to JOB 1: METHODS/Field Operations - Parasite infestation rates

IV. Data Compilation

Size structure

Refer to JOB 1: METHODS/Data Compilation- Size structure

Lengths were combined from the 1998-2000 study to compare against length frequencies observed in 2006-2008.

Age structure

Refer to JOB 1: METHODS/Data Compilation- Age structure

Growth

Growth differences among the study periods were described with standard fishery equations. Both 1998-2000 and 2006-2008 data were pooled separately. Pooled groups were compared using the von Bertalanffy (VB) growth function (von Bertalanffy 1938) and linear regression. $\text{Length}=L_{\infty}(1-e^{-K(t-t_0)})$ described change in length with respect to age. Parameters L_{∞} and K were fit while t_0 was set equal to -1.0 years. The length-weight relationship for each pooled group was described using the allometric equation: $W = aL^b$ (W = weight (g), L = length (mm) and a and b are model parameters). Both equations were fit using Excel Solver.

Relative abundance

Catch per unit effort (CPUE) was reflected as total daily catch (pounds) / # of pots fished. A relative abundance index was created by calculating an arithmetic annual mean (AM) from daily sample CPUE's (pounds/pot) with 95 % confidence intervals.

Mortality estimates

Refer to JOB 1: METHODS/Data Compilation- Mortality estimates

Total instantaneous mortality rate (Z) was calculated for the Sassafras River each year from 2006-2008. Catches were pooled (1999-2000 and 2006-2008) to compare Z among survey periods. The pooling of catches from each respective survey may ameliorate the effect of variable recruitment on the catch curves (Ricker 1975). Age at full recruitment (highest catch at age) was the first year used to calculate the slope for the catch curve with the last year being the age at which no less than 5 individuals were captured.

RESULTS AND DISCUSSION

Size structure

Length distributions from the Sassafras River 2006-2008 fishery independent eel pot study for were compared with pooled eel catches from the 1998-2000 study. Length distributions from sampled eels were quite similar for the years 2006-2008 and shifted to larger sizes compared to 1998-2000 sampled eels (Figure 2-3). Mean length of captured eels for 2006-2008 were nearly identical at 334.3, 333.4, and 336.8 mm, respectively. These values were approximately 40 mm greater (293.4mm) than eels captured in the 1998-2000 study. Eels larger than 400 mm in the Sassafras River have increased from 2% of the total catch in the 1998-2000 study to 10.4% in 2006, 12.5 % in 2007, and 14.6 % in 2008. The use of smaller mesh pots without escape panels in the 1998-2000 study could bias the catch to smaller eels. However, mean length of eels captured from comparable 1/3” * 1/3” paneled pots between study periods were significantly longer in 2006-2008 (308.7mm vs. 338.8mm) (Kruskal Wallis ANOVA, $P<0.001$; Dunn’s multiple comparison, $P<0.05$).

Size and age structure

Captured eels from the 2006-2008 study exhibited greater mean length at age for ages 2-5 than eels captured during 1998-2000 study (Figure 2-4). Overall age structure was drastically different between the two studies. Less than 1% of the sampled eels from the earlier study were older than age 5 compared to 14.7% in the 2006-2008 study. Modal age or age at full recruitment derived from catch curve analysis was age 3 for the 1998-2000 study compared to age 4 for 2006, 2007, and 2008. The length-weight relationship for American eels in the

Sassafras River showed little change between the two studies. Predicted weights ($W = aL^b$) were nearly identical when raw length and weights for each study period were plotted (Figure2-5).

Both VB growth function and linear regression were used to describe the growth of Sassafras River eels for both studies. The parameters solved for in the VB equation indicated different growth rates between sampling periods. The growth coefficient (K) and L_∞ in the 1998-2000 and 2006-2008 studies were 0.33 and 0.08 and 409 mm and 997mm, respectively. Because of low abundance of large eels in the 1998-2000 samples, the VB predicted faster growth at earlier ages (0-3) than in 2006-2008. The lack of larger eels also produced unrealistic L_∞ (400 mm; Figure 2-6). The growth described by the VB for the 2006-2008 eels was nearly linear with respect to age. The slope of the linear regression indicated faster overall growth for the eels captured during the 2006-2008 survey. Eels from 2006-2008 were predicted to grow 46 mm per year compared to 36 mm per year in 1998-2000. This growth difference between study periods, however, was insignificant as indicated by overlapping 95 % confidence intervals for both the y-intercept and the slope (Linear regression).

The apparent growth difference may be explained by differences in sex ratios between study periods. Although a sex ratio was not calculated for the 1998-2000 study, samples may have been dominated by male eels. The maximum size for male eels is approximately 400mm, quite similar to the predicted L_∞ of 409mm.

Sex ratio

Calculated sex ratios from the 2006-2008 study indicated the Sassafras River eel population was comprised of 61 % females, 24 % males, and 15 % undifferentiated. Mean length and age of males captured from 2006-2008 was 304.0 mm and 4.1 years (range = 3-6 years), respectively. Female mean length and age was 381.1 mm and 5.2 years (range = 3-10 years), respectively.

Parasite infestation rates

A total of 132 swim bladders from subsampled Sassafras River eels were examined for the presence of *Anguillicolla crassus* during the current study period (2006-2008). Prevalence rates increased from 48-76% over the three year sampling period with a combined rate of 64%. The 2004 Sassafras River eels sampled from the commercial fishery had a prevalence rate of 46%. These rates are more than double the 10-29% infection rates seen from other Maryland Chesapeake Bay tributaries in 1997 (Barse and Secor 1999).

Relative abundance

The daily CPUE ranged from 0.02-2.00 eel pounds per pot fished over 46 sampling days across the 6 sampling years. The lowest and highest mean annual CPUE occurred in 1998 (0.09 lbs/pot) and 2000 (1.52lbs/pot), respectively (Figure 2-7). A one-way analysis of variance indicated significant differences among annual mean CPUE's (Kruskal Wallis ANOVA, $P<0.001$). A pairwise multiple comparison procedure indicated significantly higher means for 2000 and 2008 relative to 1998 (Dunn's: $P<0.05$). Sample mean CPUE from 2000 (1.52 lbs/pot) was five times larger than the second highest annual mean (2008, 0.30lbs/pot), but was comprised of only 2 sampling days. The extremely large confidence intervals around the 2000 estimate produced significant differences with only 1998. In the 1998-2000 study, small mesh pots (1/3" * 1/3") without escape panels were used, and that may have allowed retention of smaller eels, thus creating a possible positive bias in CPUE. However, it should be noted that CPUE was the lowest for 1998 and 1999.

Mortality estimates

The slope of the negative $\log_e$ transformed catch at age (ages 4-7) indicated that Z was 0.75, 0.68, and 0.71 for 2006-2008, respectively (Table 2-1). Given $M = 0.25$, F was 0.50, 0.43, and 0.46 over the same time period. Catch curve analysis from pooled eel catches for the 1998-2000 study indicated a Z and F of 1.38 and 1.13, respectively (Figure 2-8). A Sassafras River fishery dependent sample in 2004 indicated a Z of 1.32, similar to that calculated for the 1998-2000 study period. Catch curve analysis from pooled eel catches from the 2006-2008 study indicated a Z and F of 0.69 and 0.44, respectively. The fishing mortality during the period of 1998-2000 accounted for an annual loss of 68% compared to 36% in 2006-2008. The Maryland DNR landings database indicate average reported eel landings for the Upper Chesapeake Bay including the Sassafras River have declined from an average of approximately 33,000 pounds from 1992-2004 to 11,400 pounds for 2005-2007. The decrease in annual loss as a result of declining fishing mortality in 2006-2008 is supported by harvest declines in recent years.

Figure 2-1: Survey location for fishery independent eel pot survey 1998-2000 and 2006-2008 on the Sassafras River, upper east Chesapeake Bay.

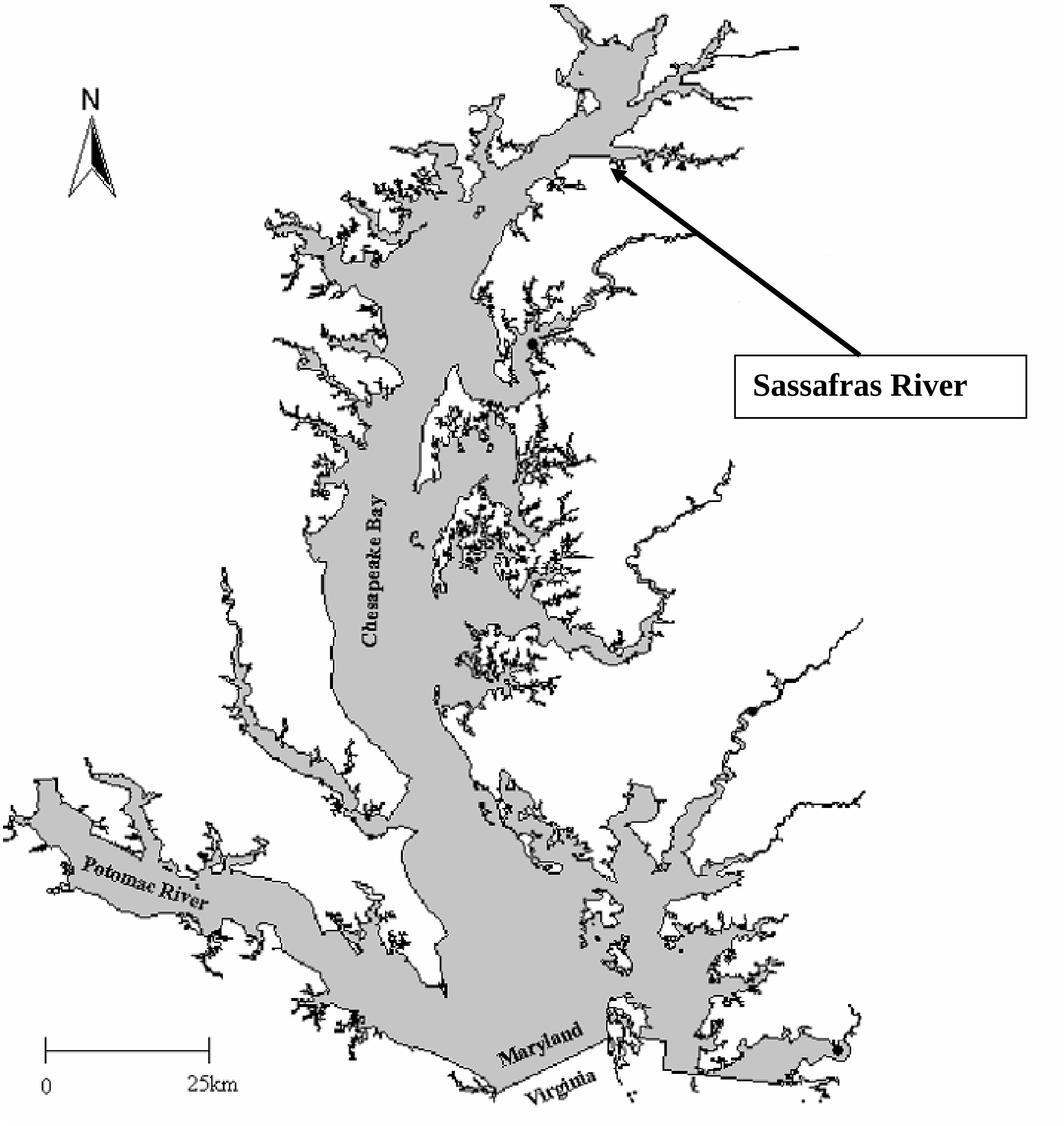


Figure 2-2: Eel pot locations for the ‘upper’ and ‘lower’ set for the Sassafras River pot survey, 2006-2008.

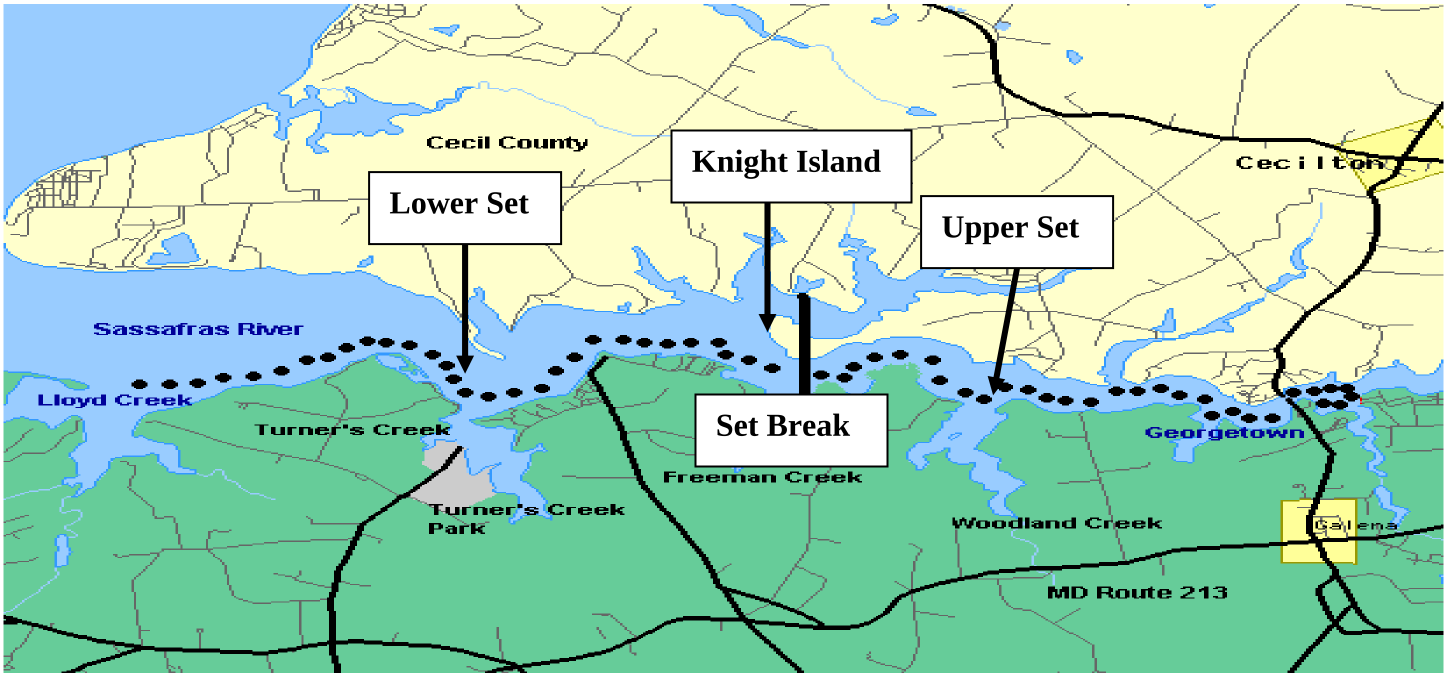


Figure 2-3: Sassafras River American eel length distributions from fishery independent eel pot surveys, 1998-2000 and 2006-2008.

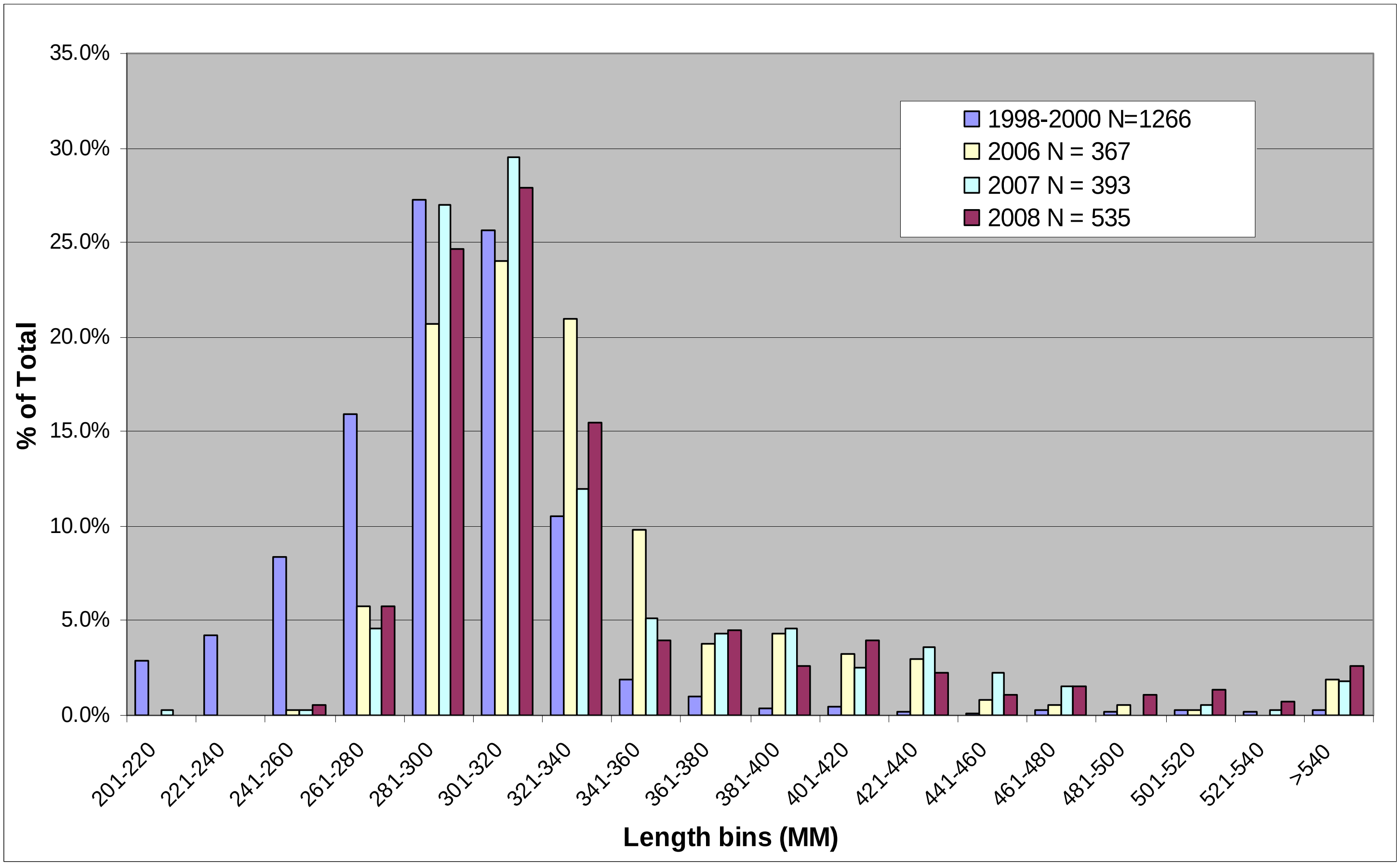


Figure 2-4: Mean length at age with 95% CI's for the 1998-2000 versus 2006-2008 Sassafras River fishery independent eel pot surveys.

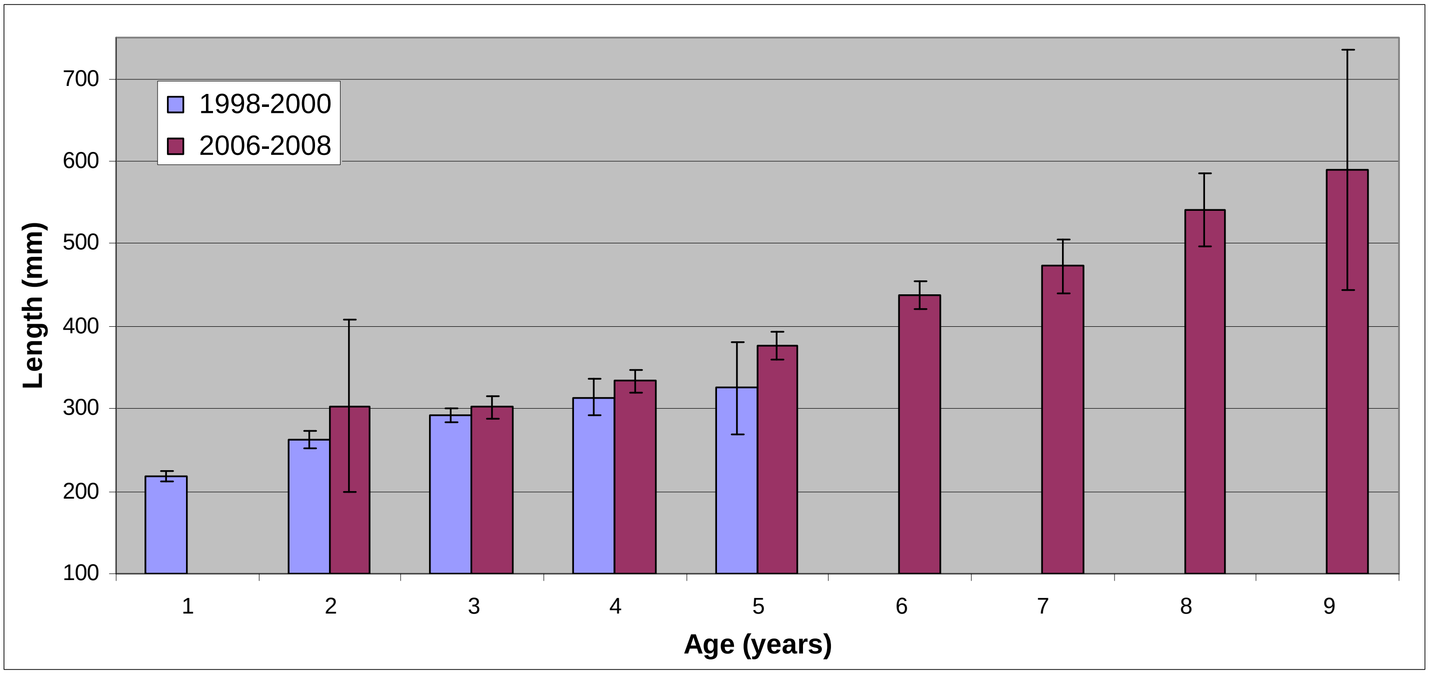


Figure 2-5: Sassafras river American eel length-weight relationship described by allometric equation ($W = aL^b$), 1998-2000 and 2006-2008. (1998-2000 a=1.88 X 10^6, b=3.00; 2006-2008 a=4.48 X 10^{-7}, b=3.23)

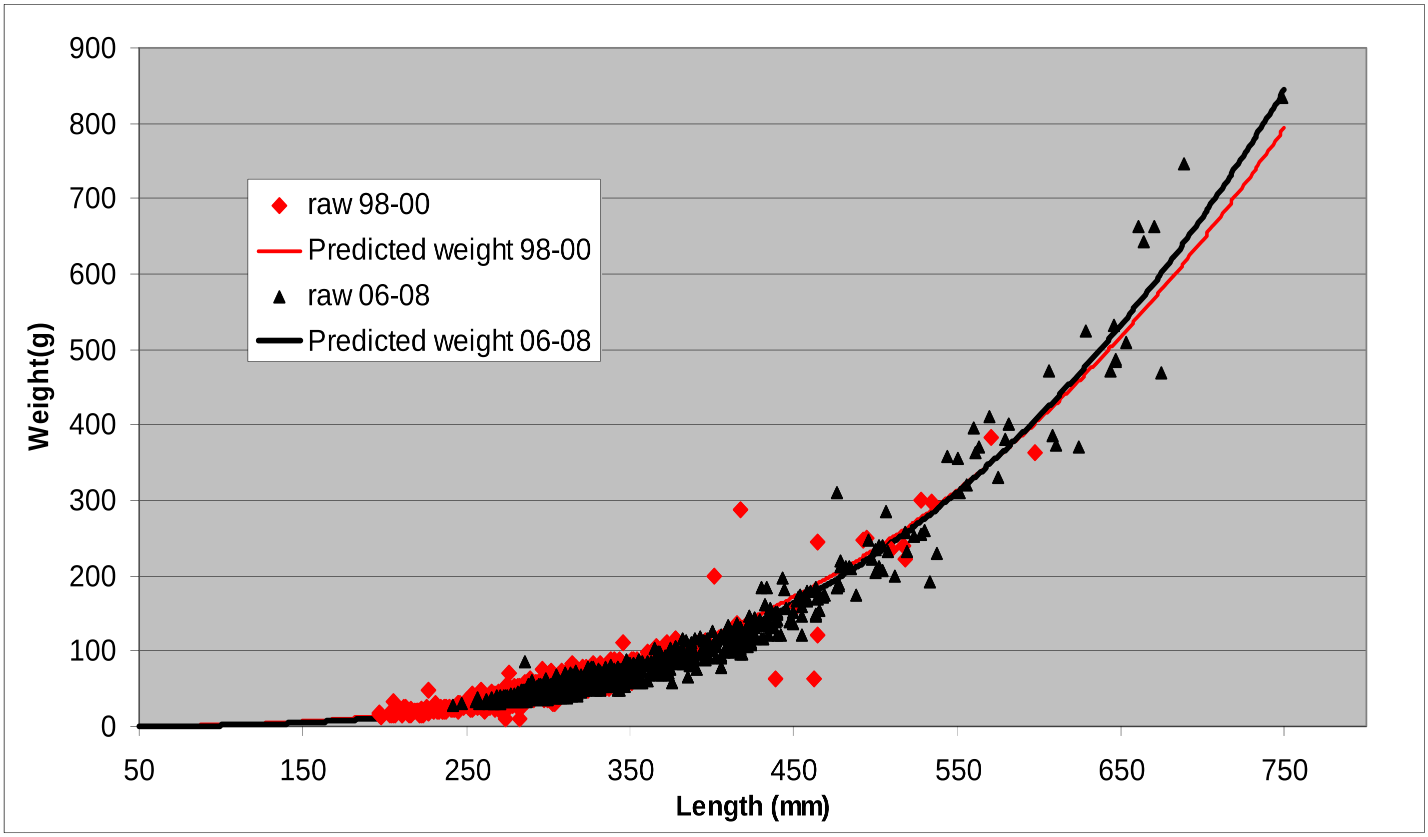
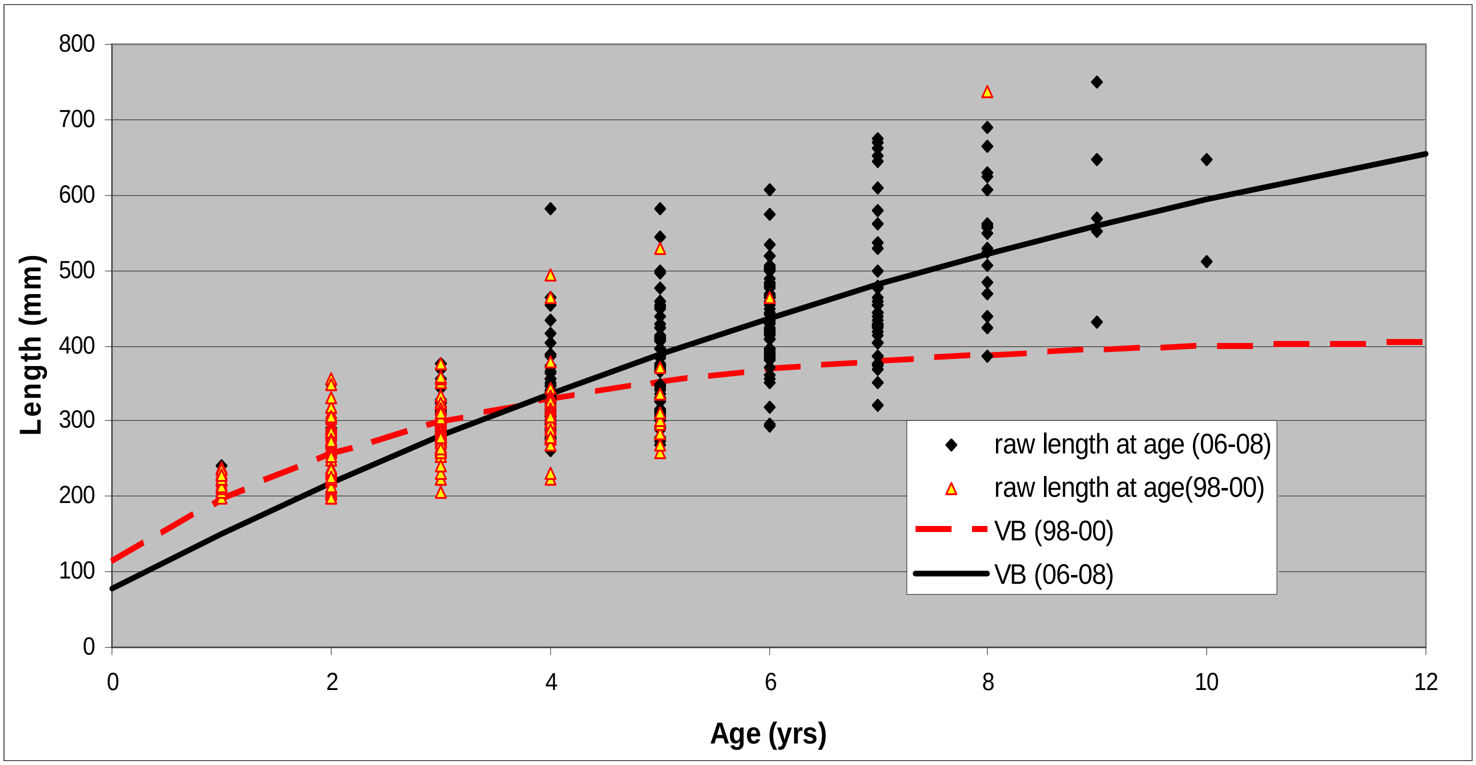


Figure 2-6: Sassafras river American eel age-length relationship described by von Bertalanffy growth equation (Length=L∞(1-$e^{-K(t-t_0)}$)) and linear regression, 1998-2000 and 2006-2008. (1998-2000 L∞=409 mm, K=0.33, T₀=-1.00; 2006-2008 L∞=997 mm, K=0.08, T₀=-1.00



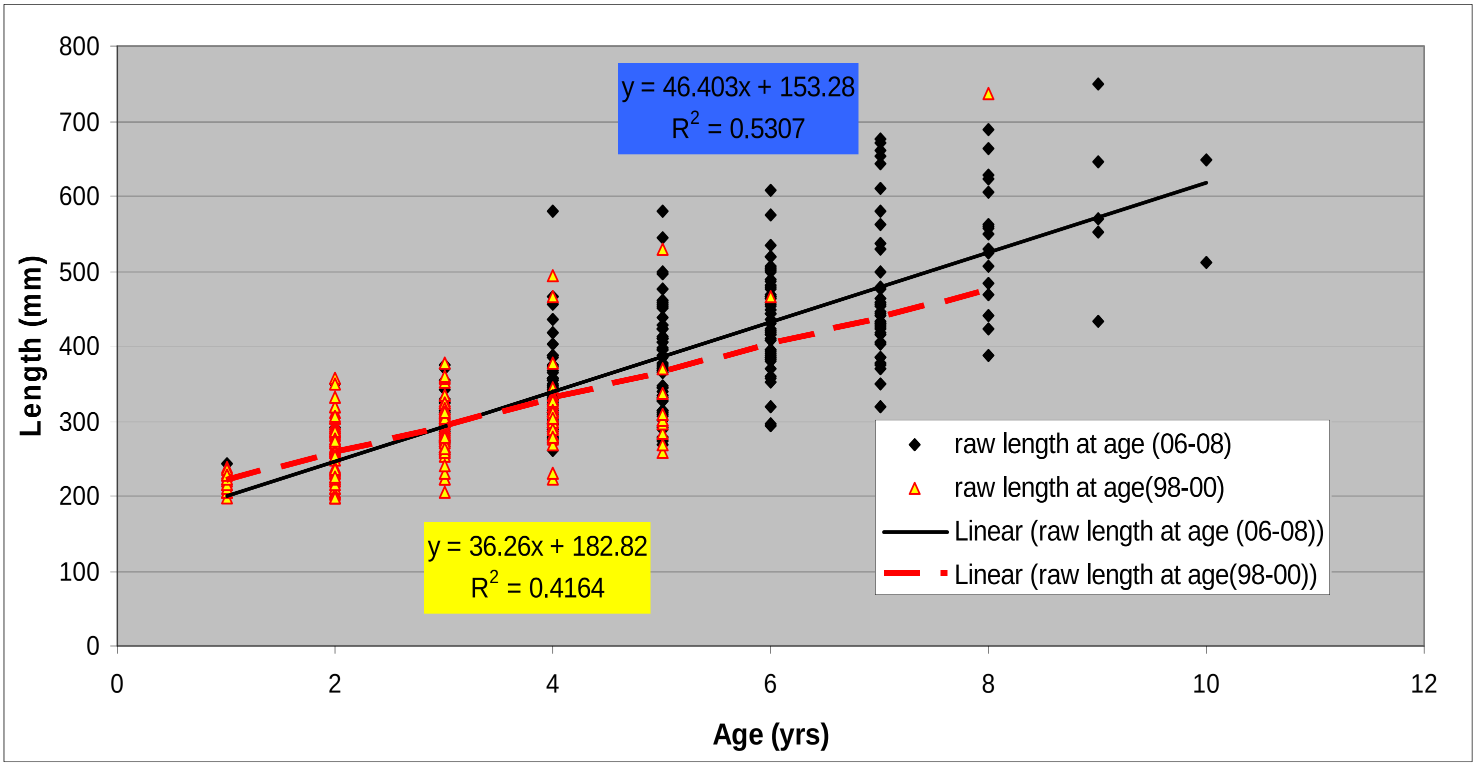


Figure 2-7: Mean annual CPUE and 95 % CI's for the Sassafras River fishery independent eel pot survey 1998-2000 and 2006-2008.

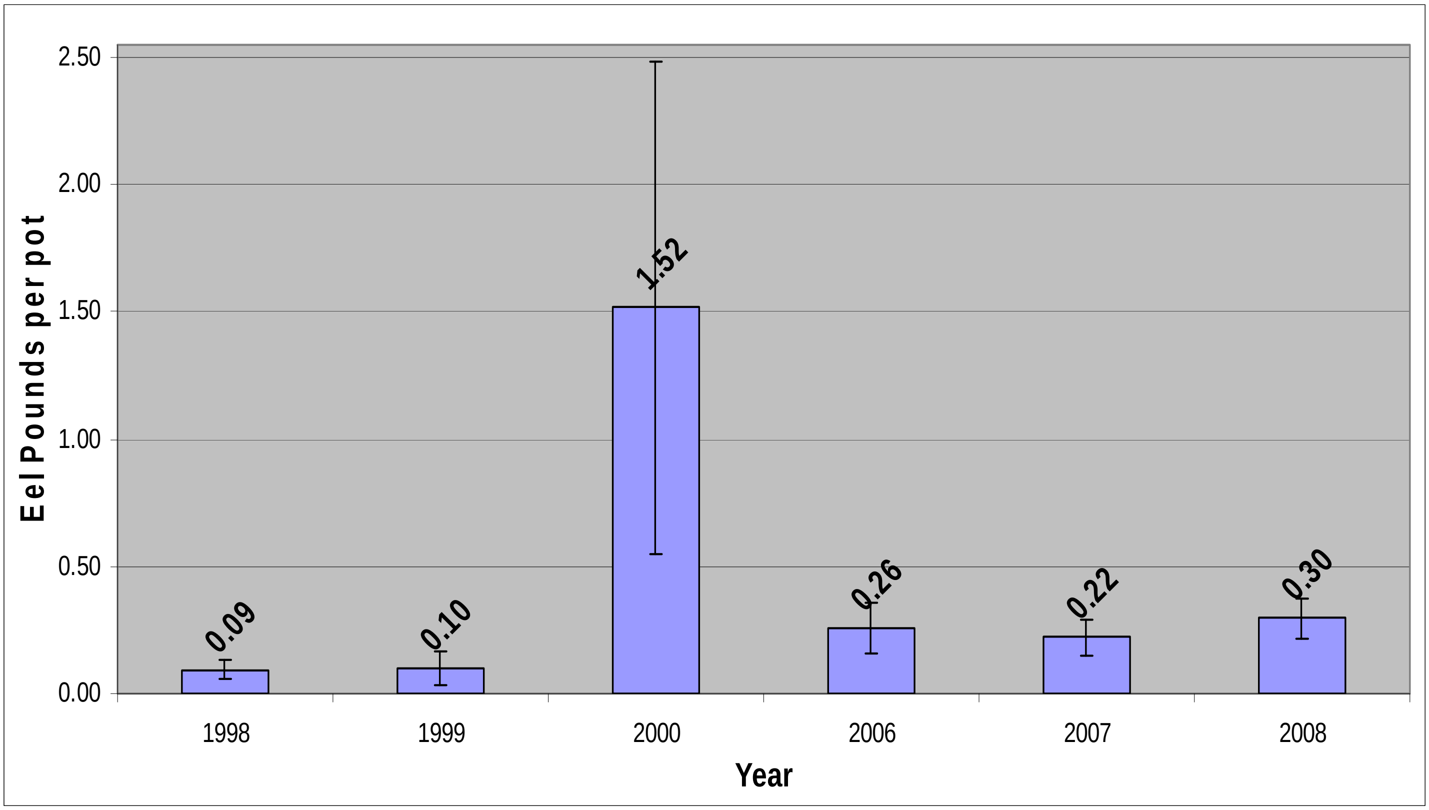


Figure 2-8: Log$_e$ transformed catch at age used to calculate Z (slope of the regression line) for Sassafras River fishery independent eel pot surveys, 1998-2000 and 2006-2008.

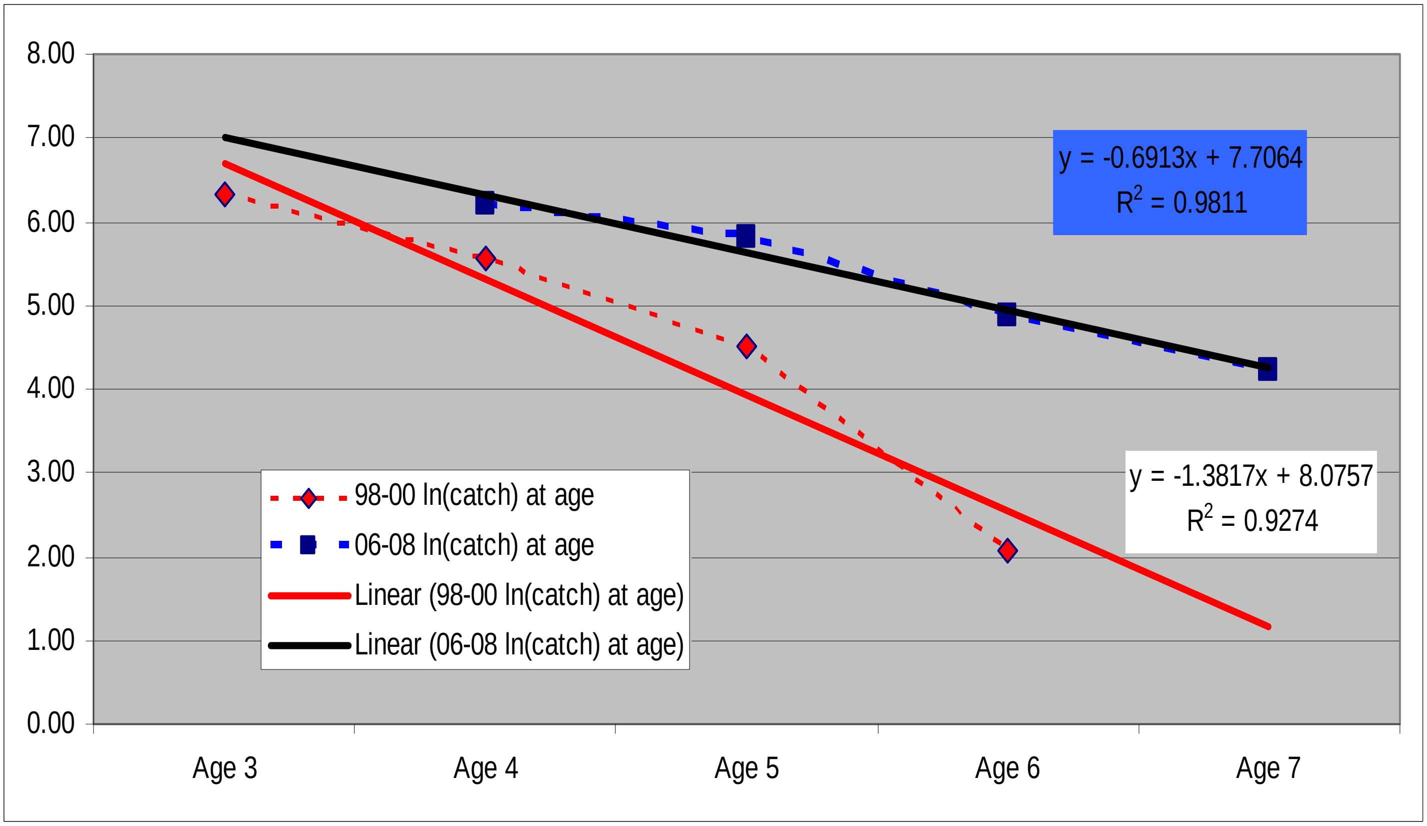


Table 2-1: Estimated catch at age for 1998-2000 and 2006-2008 Sassafras River fishery independent eel pot survey and calculated instantaneous mortality rates (Z) and (F).

Location	Year	Z	F	Estimated catch at age based on age-length key AGE 1	2	3	4	5	6	7	8	9	10
Sassafras River	**1998-2000**	**1.38**	**1.13**	**45**	**383**	**564**	**260**	**91**	**8**	**1**	**1**	**0**	**0**
Sassafras River	**2006**	**0.75**	**0.50**	**0**	**8**	**55**	**146**	**98**	**33**	**17**	**3**	**1**	**0**
Sassafras River	**2007**	**0.68**	**0.43**	**0**	**9**	**58**	**153**	**101**	**43**	**21**	**4**	**1**	**0**
Sassafras River	**2008**	**0.71**	**0.46**	**0**	**12**	**84**	**207**	**135**	**54**	**26**	**8**	**2**	**0**
Sassafras River	**2006-2008**	**0.69**	**0.44**	**0**	**29**	**196**	**506**	**334**	**131**	**69**	**19**	**7**	**2**

Job 3: Participate in multi-state management of American eels through Atlantic States Marine Fisheries Commission.

The Atlantic States Marine Fisheries Commission (ASMFC) approved an interstate fishery management plan (ISFMP) for American eel in 1999. This plan, adopted by the 15 Atlantic coastal member states, provides a necessary framework to guide the coastal management of American eel. The goal is to protect and enhance the abundance of American eel in inland and territorial waters of the Atlantic States and jurisdictions while providing the opportunity for its commercial, recreational, scientific, and educational use. Each member state/jurisdiction is required to implement management measures set forth in the ISFMP. Specifically this Plan requires the following: the completion of an annual young-of-year abundance survey, jurisdictions maintain existing or institute more conservative commercial eel fishery regulations, jurisdictions institute licensing and reporting mechanisms to ensure that annual effort and landings information by life stage are provided by harvesters or dealers, and a submission of an annual compliance report that details current state regulations, results of the mandated young-of-year survey, and current fishery dependent and/or independent data. The Plan also strongly encourages member states to collect biological data from representative eel subsamples to include sex ratio, age structure, length and weight information from both fishery dependent and fishery independent surveys. Through this study’s funding, requirements set forth by both the Chesapeake Bay and ASMFC American eel fishery management plans were exceeded. Maryland’s extensive biological sampling and harvest information have proven critical for stock assessments and management of American eels within the state and along the Atlantic coast.

Fish populations and fisheries can be quite dynamic, so fishery management plans (FMP) must be reevaluated and updated to effectively manage stocks. Through time, changes occur in species abundance, habitat, the fishery, economics, and society. Consequently, management goals and objectives may change as well. As new data are collected, research gaps filled and stock assessments completed, the FMP's are modified accordingly. Changes to the American eel ISFMP are based on the scientific information provided by the ASMFC AETC, as well as input from public hearings and the ASMFC American eel Advisory Panel. The Project Leader for this study is Maryland Department of Natural Resources' representative on the AETC (current Vice-Chair) and is a member of the American Eel Stock Assessment Sub-Committee (AESASC). Through these committees project personnel actively participated in the development and review of the coastwide stock assessment completed in 2005, the development of Addendums I and II and implementation of Addendum I to the American eel ISFMP.

Developments to Interstate Management of American eel over study period (2004-2008)

Annual activities

- Staff prepared the annual Compliance Report to ASMFC that detailing current regulations, results of the mandated young-of-year survey, and current fishery dependent and/or independent monitoring.
- Research needs listed in the American eel ISFMP were updated. The AETC prioritized existing needs and provided recommendations for additional needs.

July 1, 2003 – December 31, 2003

- Staff attended an ASMFC sponsored American eel young-of-the-year (YOY) survey workshop on December 10, 2003. All member states presented individual status reports concerning their YOY surveys. Sampling protocol for these surveys, data reporting, and annual compliance report changes were reviewed. Improvements in sampling techniques and data analysis were also discussed.

January 1, 2004-December 31, 2004

- A draft Public Information Document (PID) was created to explore current issues related to American eel management and potential changes to the ISFMP through an amendment or an addendum. The AETC recommended the amendment/addendum to include changes in the management programs for the recreational and commercial fisheries, an evaluation of non-fishing sources of mortality, and a review of the Plan's current monitoring requirements.
- The ASMFC American Eel Management Board (AEMB) recommended the US Fish and Wildlife Service (USFWS) and National Marine Fisheries Commission (NMFS) consider the American eel in the Lake Ontario/St. Lawrence River as a candidate for listing as a Distinct Population Segment under the Endangered Species Act (ESA). The AEMB also requested USFWS and NMFS to consider the entire coastwide American eel stock as a candidate for listing under the ESA.

January 1, 2005 – June 30, 2005

- Staff participated in an AESASC conference call on 14 March. A list of potential data holders was established and guidelines were developed for the coastal American eel stock assessment. A subsequent data holders meeting was conducted in Baltimore on May 24th-26th. Project staff attended and presented Maryland's fishery independent and dependent survey information, statewide eel landings, and analysis of relevant data for the upcoming American eel stock assessment. All state representatives and other invited data holders made similar presentations.

  On 17 June, staff participated in a second eel AESASC conference call. The committee discussed data issues and assigned tasks to individual members for various portions of the stock assessment document. The SASC decided on the next date for a conference call to discuss the direction of the preliminary analysis and progress on the assignments.
- Staff hosted a public hearing on May 16 to receive public input concerning the draft PID.

July1, 2005 – December 31, 2005

- Staff attended an AESASC Assessment Workshop in Jamestown, RI from August 23rd – 26th. Each sub-committee member presented and discussed specific analysis and corresponding write-ups that were assigned. Staff duties included review and development of the life history section of the stock assessment document, the compilation and development of a coastwide catch per-unit-effort (CPUE) index based on the commercial American eel pot fishery and the development of a yellow eel abundance index which included Maryland Biological Stream Survey (MBSS) data to be utilized as part of a coastwide fishery independent yellow eel index.

  Staff attended an AETC meeting in Baltimore, Maryland on October 26th and 27th to assist in the review and editing of the preliminary coastwide stock assessment document.

  On 11 November, staff participated in an AESASC conference call to discuss additional eel data not reviewed at the assessment workshop and the possible inclusion of this information as an appendix to the main body of the stock assessment document.
- The ASMFC AEMB initiated Addendum I to the ISFMP to establish a mandatory catch and effort monitoring program for American eel.
- On 6 July USFWS and NMFS announced a formal status review for American eel under ESA.

January 1, 2006 – June 30, 2006

- In February, the coastwide stock assessment was presented to the ASMFC AEMB.
- Staff participated in an AESASC conference call on 7 April to review the recommendations from the peer review panel concerning the American Eel Stock Assessment. The AESASC decided to address these recommendations on both a short and long term time scale.

  Staff attended an AESASC meeting in Providence, RI on June 19th and 20th. The committee assigned members short-term tasks and additional analysis.
- Staff hosted a public hearing 24 January to receive public comment on the proposed Addendum I to the ISFMP. Based on recommendations from the AETC and public input, the AEMB approved Addendum I which established a mandatory trip level catch and effort monitoring program for American eel.

- In April, staff prepared and submitted Maryland's implementation proposal regarding Addendum I, which was subsequently accepted by the AETC. Implementation was scheduled to begin January 1, 2007.

<u>July 1, 2006 – December 31, 2006</u>

- Staff attended the AESASC August 30th -September 1st meeting in Raleigh, NC that addressed the recommendations from the peer review panel concerning the American Eel Stock Assessment. The AESASC developed an additional document that updated data sets through 2005, explored possible development strategies for management reference points, and provided additional data analyses (e.g., General Linear Model).
  Staff attended an AETC meeting in Providence, RI from September 18th – 20th. The updated American Eel Stock Assessment document presented by the AESASC was discussed and edited by the AETC. The finalized document was then presented to the AEMB. In addition, the AETC reviewed state annual compliance reports and discussed the development of a young-of-year sampling workshop and fish passage workshop.
- The AEMB initiated the development of Draft Addendum II to the ISFMP with the goal of protecting silver eel out-migration as a priority.

<u>January 1, 2007 – June 30, 2007</u>

- Staff participated in an AETC conference call on 3 March to review Draft Addendum II. The Plan Development Team (PDT) formulated a draft that proposed a number of possible management options to facilitate an increase in the number of adult American eels that are able to out-migrate to the ocean and spawn. The AETC developed consensus comments on the proposed options. On June 26th-27th staff attended a SASC meeting in Raleigh, North Carolina. The AESASC investigated the use of an egg-per-recruit model that would demonstrate the relative effect of varying maximum size limits to egg production at different rates of instantaneous fishing mortality.
- In February, the USFWS announced the completion of the Status Review of American eel under the ESA. The report concluded that listing American eel as an endangered or threatened species was not warranted.

<u>July 1, 2007 – December 31, 2007</u>

- Staff attended the AESASC meeting in Raleigh, NC from June 26th- 27th. The AESASC reviewed the proposed management options in Draft Addendum II. The AESASC decided they were in favor of the use of size limits rather than gear restrictions and seasonal closures to enhance the escapement and resultant abundance of silver eels to the spawning stock. The AESASC believed the <u>S</u>equential <u>L</u>ife-table and <u>Y</u>ield-per-recruit <u>M</u>odel for the American <u>E</u>el (SLYME) could be an effective tool to evaluate the effects of different size limits on various population parameters, such as spawning escapement and egg production.
  Staff participated in an AETC conference call on 6 August that commented on the proposed approach by the SASC to management options developed in Draft Addendum II. The AETC voted in favor of using the SLYME model to evaluate the effects of maximum size limits on egg production.
  The Study Leader attended an AESASC meeting in Raleigh, NC from September 17th-18th to review the SLYME model structure, model assumptions, available data for model parameters, and to develop a list of caveats for model application to management options.

- Staff participated in an AETC/AESASC meeting on 26 March to develop consensus comments on the proposed options pertaining to Draft Addendum II. The AESASC presented an egg-per-recruit model to the AETC. The AETC agreed by consensus that an increase in egg production from exploited areas of 100% would likely produce a significant increase in actual egg abundance. The SLYME model predicted this increase in egg abundance would occur at a 19-inch maximum size limit. The AETC also indicated that a 19-inch maximum size limit would decrease harvest in some states by 40-50%.

  On 6 May the AEMB reviewed recommendations from the AETC pertaining to Addendum II. The AEMB tasked the AESASC to investigate the use of a slot limit as a potential management measure by modeling the results through the current egg-per-recruit model. They wanted to see if the relative increase in egg production achieved by using a 19" maximum size limit could be achieved by varying minimum size limits while increasing maximum size limits.

<u>Job 4</u>: Refine Stock Assessment Models.

INTRODUCTION

The primary objective of Job 4 was to estimate input parameters necessary to develop American eel yield-per-recruit (YPR) and eggs-per-recruit (EPR) models for sampled Maryland Chesapeake Bay tidal tributaries. Estimated current mortality rates for the selected tributaries will be compared to target and limit (threshold) biological reference points (BRP) for each model.

METHODS

Growth comparisons for American eel were made between all sampled Maryland Chesapeake Bay tributaries (fishery dependent and independent) during the study period (2004-2008). Sampled fishery dependent areas included Fishing Bay, Nanticoke, Choptank, Patuxent, and Sassafras rivers. Sampled fishery independent areas included the Sassafras River. Refer to Jobs 1 and 2 for detailed sampling methodology. Linear regression of ages common to all rivers was used to determine differences in eel growth among rivers and years within the same river. Systems without significant differences ($P>0.05$) in both the slope and y-intercept among common ages were pooled. Separate YPR and EPR models were developed and parameters for each model estimated separately, if significant differences in growth were determined.

I. Model Structure

The Sequential Life-table and Yield-per-recruit Model for the American Eel (SLYME) was used to evaluate current levels of fishing mortality for Maryland Chesapeake Bay tributaries in relation to target and limit BRP's. This model was initially developed by Dr. David Cairns (DFO Canada) for the August 2000 meeting of the International Council for the Exploration of the Sea (ICES) Working Group on Eels. The original deterministic version was modified by the ASMFC AESASC in 2008 during the development of Addendum II to the ISFMP for American eel. The model was used to investigate the effects of different harvest maximum size limits on female spawner escapement and egg production.

The model used in this study describes relative yield to the fishery, relative spawner biomass, and relative egg production given estimates of growth, mortality, and emigration from the age at entry in Maryland's Chesapeake Bay to egg deposition in the Sargasso Sea. An arbitrary initial cohort of 1,000,000 female age 0 eels was utilized in the model and run through age 14. The model calculated the number of American eels remaining in each age class following mortality (harvest and natural) and emigration (ASMFC report 2008).

The data inputs required in the model include a length-weight relationship, age-length relationship, estimate of natural mortality, partial recruitment vectors (PR) to the commercial fishery, emigration schedule, and a length-fecundity relationship. Important assumptions of the model include constant recruitment each year, a discrete yellow eel life stage (without immigration and emigration), year-round fishing for resident eels concurrent with natural mortality, and growth and mortality processes are density-independent.

The length-weight relationship was described using the allometric equation: $W = aL^b$ (W = weight (g), L = length (mm) and a and b are model parameters). Model parameters were fit using Excel Solver.

The age-length relationship was described by the von Bertalanffy (VB) ($Length=L_\infty(1-e^{-K(t-t_0)})$) growth function with model parameters t_0 set at -1.0 and L_∞, K, fit using Excel Solver.

Natural mortality (M) was described as a function of weight based on a modified version of Lorenzen's (1996) equation: $M_t = \gamma 3.00 W_t^{-0.288}$ where γ is an adjustment factor and W_t is weight at age t. The exponent value (-0.288) is considered fairly stable (McGurk 1996), but the coefficient value (3.00) may vary (D. Cairns, DFO Canada, pers. comm.).

The partial recruitment vectors (PR) represent the proportion of each age class vulnerable to the fishing gear. PR was estimated from Maryland harvest data as the fraction of eels that were 30 cm or greater at each age. Given current Maryland eel pot mesh regulations, this gear does not effectively harvest eels less than 30 cm (Weeder and Uphoff 2003).

Since silver eel metamorphosis and emigration are based more on length than age (Helfman et al 1987, De Leo and Gatto, 1996), emigration was modeled as a function of length through the logistic equation: $P_{mat}, L = 1/1+e^{(-alpha * (L - L_{50}))}$. P_{mat} is probability of being mature at length (L) and L_{50} is the length at 50% mature. Alpha and L_{50} were fit using Excel Solver.

Fecundity was modeled as an allometric function of length: $E_t = aL_t^b$ where E_t is the number of eggs per female, L_t is length at age t, and a and b are model parameters. Model parameters derived from a previous fecundity study in Maine (Barbin and McCleave 1997) were used as a surrogate since data were not available to model fecundity from Maryland eels. The number of eggs produced in each age class was calculated by multiplying the estimated fecundity-at-age by the number of female spawners. The total production of eggs summed over all age classes was divided by the initial number of recruits (1,000,000) to estimate eggs per recruit (EPR).

II. Biological Reference Points

Yield-per-recruit

A YPR curve was calculated by summing yield to the fishery (g) over all age classes divided by initial number of recruits (1,000,000) at a range of F from 0.0-1.15. Reference points derived from YPR analysis include F_{max} and $F_{0.1.}$ F_{max} is the fishing mortality rate that maximizes the YPR and occurs when the slope of the YPR function is zero (Hilborn and Waters 1992). $F_{0.1}$ occurs where the slope of the YPR function is 10% of the initial slope. It is essentially an arbitrary, conservative choice of F (Hilborn and Waters 1992). If the fishing mortality rate from sampled rivers exceeds F_{max}, then growth overfishing has occurred.

Eggs-per-recruit

Under conditions of no fishing mortality, 100% of a stock's spawning potential is realized. The reduction in spawning stock biomass per recruit, in this case EPR, can be reflected as a percentage of the maximum spawning potential (MSP) (Gabriel and Mace 1999). The EPR curve is calculated as the proportion of MSP at a range of F from 0.0-1.15. $F_{replacement}$ is the estimate of fishing mortality modeled from age 0-T_{max} that would enable the adult stock to replenish itself based on the spawner-recruit relationship. If there is a lack of data to determine a spawning recruitment relationship, as is the case with American eel, Goodyear (1989) suggested that a critical minimum of at least 20% of the MSP should be maintained. Mace and Sissenwine (1993) advocated $F_{20\%}$ ($MSP_{20\%}$) as a recruitment overfishing threshold for well-known stocks with average resilience and $F_{30\%}$ ($MSP_{30\%}$) as a recruitment overfishing threshold for less well-known stocks believed to have low resilience. If fishing mortality from sampled rivers exceeds $MSP_{20\%,}$ assumed to be $F_{replacement\ ,\ recruitment}$ overfishing has occurred.

RESULTS AND DISCUSSION

Based on statistically similar growth rates for comparable ages, data was pooled among years within the same system, except in the Sassafras River, where significant differences in growth existed between 2004 and 2006-2008. Significantly slower growth was apparent in eels from the Sassafras River from both 2004 and 2006-2008. Two growth groups were classified with slow growth (SG) represented by the Sassafras River (2006-2008) and fast growth (FG) represented by Fishing Bay, Nanticoke, Patuxent, and Choptank rivers.

Estimation of Input Parameters

The length-weight relationship for eels showed little difference between SG and FG. The best fit for parameters a and b ($W = aL^b$) was $4.5x10^{-7}$ and 3.2, respectively, for the SG and 2.1×10^{-6} and 3.0, respectively for the FG.

The age-length relationship described by the von Bertalanffy (VB) showed the pooled FG had exceptional growth at earlier ages, but reached an asymptote quickly at approximately age 6 (Figure 4-1). At this age, these eels were approximately 90 % of their predicted maximum length. The VB function for the SG showed that growth was nearly linear with respect to age. The predicted length for ages 0-6 was on average over 90mm less at age for the SG. The parameters K and L_∞ solved for in the VB for the SG and FG were 0.08 and 996.8 and 0.30 and 568.6, respectively.

Lorenzen's natural mortality equation: $M_t = \gamma 3.00 W_t^{-0.288}$ uses the weight at age predicted from the VB function and an adjustment factor (*y*) to establish a variable M at age. The adjustment factor used in this model (0.20) created an annual loss of approximately 0.15 for background or resident M for ages 0-14. Additional loss, typically included in M, in the form of emigration was modeled separately. Recent applications of the SLYME model to Canadian data used a similar adjustment factor of 0.164 (D. Cairns, pers. comm.). Predicted M for age 0 and age 1 SG eels (0.72 and 0.39) was considerably higher than the FG (0.36 and 0.22).

The estimation for PR vectors varied considerably based on the growth differences. Nearly 25% of the FG were recruited to the pot fishery at age 1 and nearly 70% at age 2. Partial recruitment for the SG did not occur until age 2 and they weren't 70% recruited to the pot fishery until age 4.

Oliveira (1999) and Oliveira and McCleave (2000) measured emigrating female silver eels in Rhode Island and Maine, respectively, and found the average length of female silver eels ranged between 50 and 55cm. In a Hudson River (unexploited) eel pot study all sites showed a decrease in abundance of eels between 50 and 55 cm, suggesting that eels in the Hudson River begin to emigrate when they reach this length (Secor et. al 2002). The mean size of female silver eels migrating from two southern Delaware streams was 571mm (Barber 2004) and 592 mm from a first order Maryland stream (K. Whiteford, pers. comm.). The proportion of eels at age

>= 570mm for each growth group was used as a proxy for their respective maturity schedules. A logistic curve was fit to this data to predict emigration at age. The FG had a predicted emigration rate for ages 4-8 that was on average more than twice as high as predicted for the SG (Figure 4-2). Since emigration is modeled as a function of length and as a result of the more linear growth reflected in the SG, the predicted emigration approaches 100% at age 14. As a result of the more asymptotic growth function in the FG, the predicted emigration rate asymptotes at approximately 65%.

Yield-per-recruit

The instantaneous fishing mortality rate (F) from the most recent year from each sampled tributary was used to compare with reference points derived from the YPR and EPR curves. The YPR curves derived from parameter inputs for the SG and FG were drastically different (Figure 4-3). The maximum YPR for the FG was estimated at more than three times the SG and occurred at a considerably higher F (0.52 vs. 0.39). Even F of 0.05 for the FG was estimated to produce more yield than F_{max} for the SG. Due to the slower growth and higher M at earlier ages, over 65% of the initial cohort for the SG is lost to natural mortality before the eels are partially recruited to the fishery at age 2. In the FG, only 30% of the initial cohort die of natural mortality before they are partially recruited to the fishery at age 1. The target reference point for $F_{0.1}$ was closer between the growth groups at 0.31(fast growth) and 0.26(slow growth).

The $F_{current}$ for the Sassafras River, the lone representative tributary for the SG, exceeded $F_{0.1}$ and slightly exceeded F_{max} at 0.46. Based on the reference points, growth overfishing appears to have occurred in the Sassafras River, yet YPR was over 99% of maximum yield at the current F.

For the FG, F_{max} (0.52) was greatly exceeded, indicating growth overfishing occurred in Fishing Bay ($F_{current}$=0.90) and the Choptank River ($F_{current}$=0.94). YPR was at 94% and 93% of maximum yield, respectively, for Fishing Bay and Choptank River. F could be reduced to 0.31

to produce the same YPR to the fishery. Growth overfishing did not occur in the other two tributaries (Nanticoke, Patuxent). $F_{current}$ for the Nanticoke River (0.38) was between $F_{0.1}$ and F_{max} and YPR was 98% of the maximum. $F_{current}$ for the Patuxent River (0.21) was well below $F_{0.1}$ (0.31) and had a YPR that was 82% of the maximum.

Eggs-per-Recruit

The EPR curves derived from parameter inputs for the SG and FG were nearly identical when EPR were expressed as a proportion of maximum spawning potential for F's from 0-1.15. However, when F = 0.0 ($MSP_{100\%}$), the FG was predicted to produce more than double EPR in actual numbers than the SG. The same amount of EPR would be produced from the SG with F = 0.0 as the FG with F = 0.65. The reference points derived from the EPR curve for $MSP_{20\%}$ and $MSP_{30\%}$ were similar for both the SG ($F_{20\%}$=0.29 and $F_{30\%}$=0.21) and FG ($F_{20\%}$=0.31 and $F_{30\%}$=0.23) (Figures 4-4, 4-5).

The $F_{current}$ for the Sassafras River (0.46) exceeded $F_{20\%}$ (0.29) and would result in a 9.0% MSP (Figure 4-4). Both Fishing Bay (F=0.90) and Choptank River (F=0.94) greatly exceeded the limit reference point of $F_{20\%}$ (0.31) and would result in an EPR indicating 1.8 and 1.6% of MSP (Figure 4-5). The $F_{current}$ for the other two FG systems, Nanticoke and Patuxent rivers, indicated much higher relative EPR. The $F_{current}$ for the Nanticoke River (0.38) was slightly higher than $F_{MSP20\%}$ (0.31) and would result in EPR indicating 14.4% of MSP. The $F_{current}$ for the Patuxent River (0.21) was below reference points $F_{MSP20\%}$ and $F_{MSP30\%}$ and would result in an EPR indicating 32.6% of MSP. Based on these reference points, recruitment overfishing has occurred in 4 of the 5 tributaries sampled during the study period. Calculated F's in the respective tributaries that exceeded the BRP's indicate growth and/or recruitment overfishing only as a result of maintaining that F over the life of the cohort (14 years). Of the sampled areas, only the Patuxent River would allow enough female spawners to replenish its own stock.

Although $F_{current}$ from most of the sampled tributaries would indicate there are not enough spawners to replenish themselves, aggregate commercial eel pot CPUE in Maryland has continued to increase over the last 10 years. This may indicate a possible increase in overall eel abundance, despite high levels of F in many tributaries. The relative contribution of spawner biomass coming from unexploited areas (non tidal freshwater and unfished estuarine areas in Maryland) as well as unexploited areas throughout the species range is unknown. Given the American eel is panmictic (one spawning population and passive drift of leptocephali), the number of recruits entering a certain river in a given year should not be related to the number of spawning eel that left that specific river in previous years, but rather related to the total number of eels from all geographic areas that spawned successfully (ICES 2001). Until a stock-recruit (SR) relationship is defined for American eel, the level of production needed to sustain adequate recruitment will remain unknown. Koslow (1992) suggests the concept of a simple deterministic SR relationship does not appear applicable to organisms with high fecundities because of the variability of M during the pre-recruit period.

The SLYME model did provide valuable insight to the effects of growth and mortality on YPR and EPR. The YPR for the FG was 2.7-3.9 times greater at respective fishing mortality rates than the SG. The EPR for the FG was 2.0-2.4 times greater at respective fishing mortality rates than the SG. The SG was represented only by the Sassafras River. This was the only river sampled in the upper Chesapeake Bay. The four systems comprising the FG were located in the lower-middle Chesapeake Bay. The Choptank River was the closest, approximately 75 miles south of the Sassafras River. The Sassafras River had a range of salinities from 0-5 ppt. Although eels from the other tributaries were occasionally fished from salinities < 5 ppt, salinities at the river mouths ranged from 15-18 ppt. Inter-annual movement and prior development in nearby higher salinity and more productive areas could potentially enhance the growth of those eels that are still captured in lower salinities. This would support previous studies that concluded significantly faster growth in brackish water eels than eels from freshwater (Helfman 1987; Secor 2002). As predicted from the emigration schedule used in the model, rapid growth apparently mandates rapid maturation (Vladykov and Liew 1982). Helfman (1987) concluded estuarine eels matured faster and were younger than eels sampled from freshwater. According to Trippel (1995) compensatory response based on density-dependent mechanisms would enable faster growth and earlier maturation in heavily exploited fisheries. Although this most likely plays a large role growth and maturation, high fishing mortalities (1.07-1.13) were calculated in the Sassafras River (slow growth) from previous studies (1998-2000 and 2004). The assumed reduced densities as a result of heavy exploitation appeared to have little effect on the Sassafras River's eel growth. In addition, two of the rivers included in the FG had relatively low F's (0.21 and 0.38) and potentially higher eel densities, yet growth rates remained high. Differences in habitat, food availability, food quality, and potentially metabolism (estuarine eels are more sedentary) coupled with density-dependent mechanisms may explain the growth differences between sampled estaurine and freshwater eels. In a comparison of fresh and brackish water locations within the same large estuary (Hudson River), brackish water locations supported higher growth and subsequent higher eel production than freshwater locations, suggesting that brackish water areas could support a higher fishing mortality level than freshwater areas. The lower productivity, and the later age at maturity in eels in freshwater habitats suggests that fisheries would have much larger impacts (Secor et. al 2002) The results indicated from the SLYME model on Maryland Chesapeake Bay eels support this hypothesis.

Overall, assumptions made in developing the SLYME model, most notably that recruitment is constant each year and growth and mortality processes are density-independent, must be considered and results interpreted with caution. Consideration for future work should include the following to provide additional insight to American eel population dynamics:

separate model runs based exploited vs. unexploited areas and based on growth, model both males and females, and stochastic model runs.

Figure 4-1: American eel age-length relationship described by von Bertalanffy growth equation ($Length=L_{\infty}(1-e^{-K(t-t_0)})$) for Maryland Chesapeake Bay 'slow' and 'fast' growth areas.

'Slow' = Sassafras 2006-2008: L_{∞}=997 mm, K=0.08, T_o= -1.00

'Fast' = Nanticoke, Patuxent, Choptank, Fishing Bay 2004-2008: L_{∞}=568 mm, K=0.30, T_o= -1.00

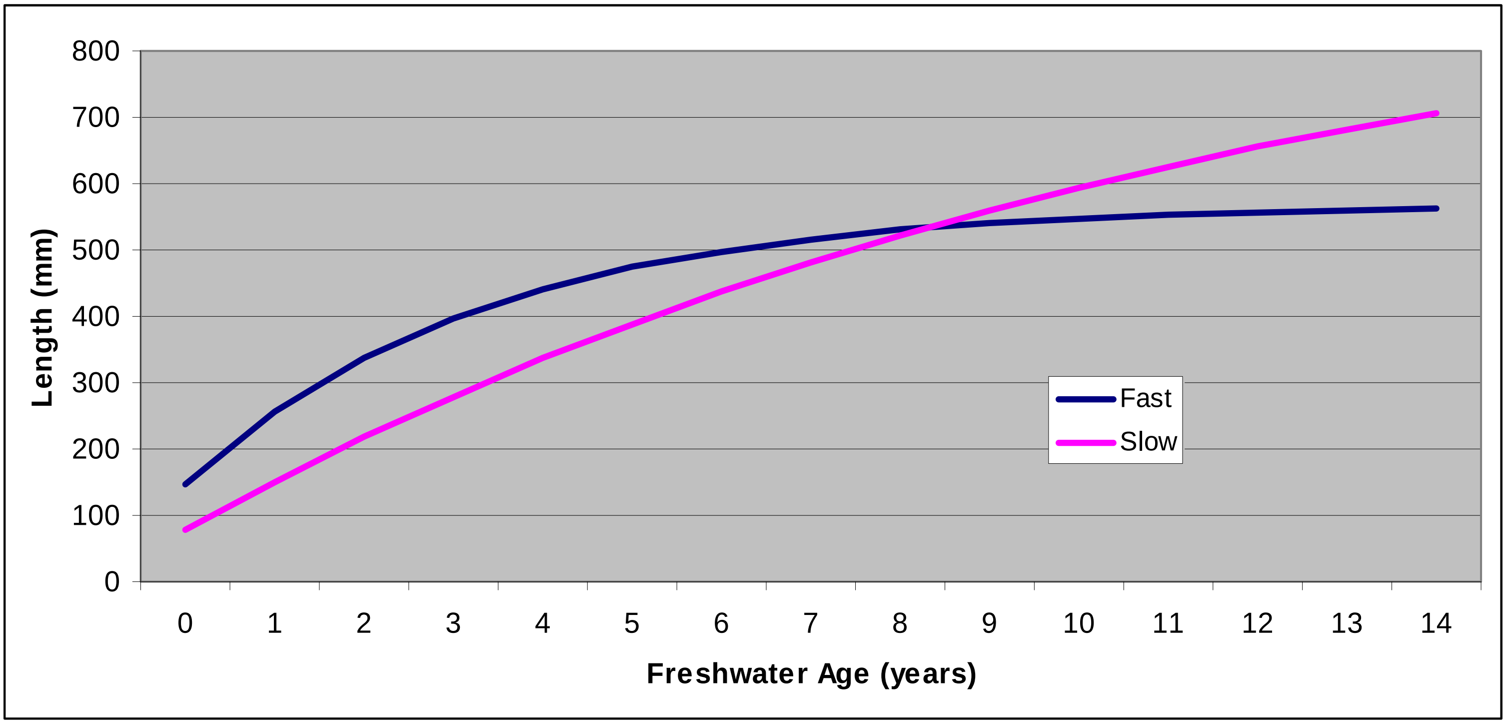


Figure 4-2: Predicted emigration rate at age for American eels from Maryland Chesapeake Bay 'slow' and 'fast' growth areas.

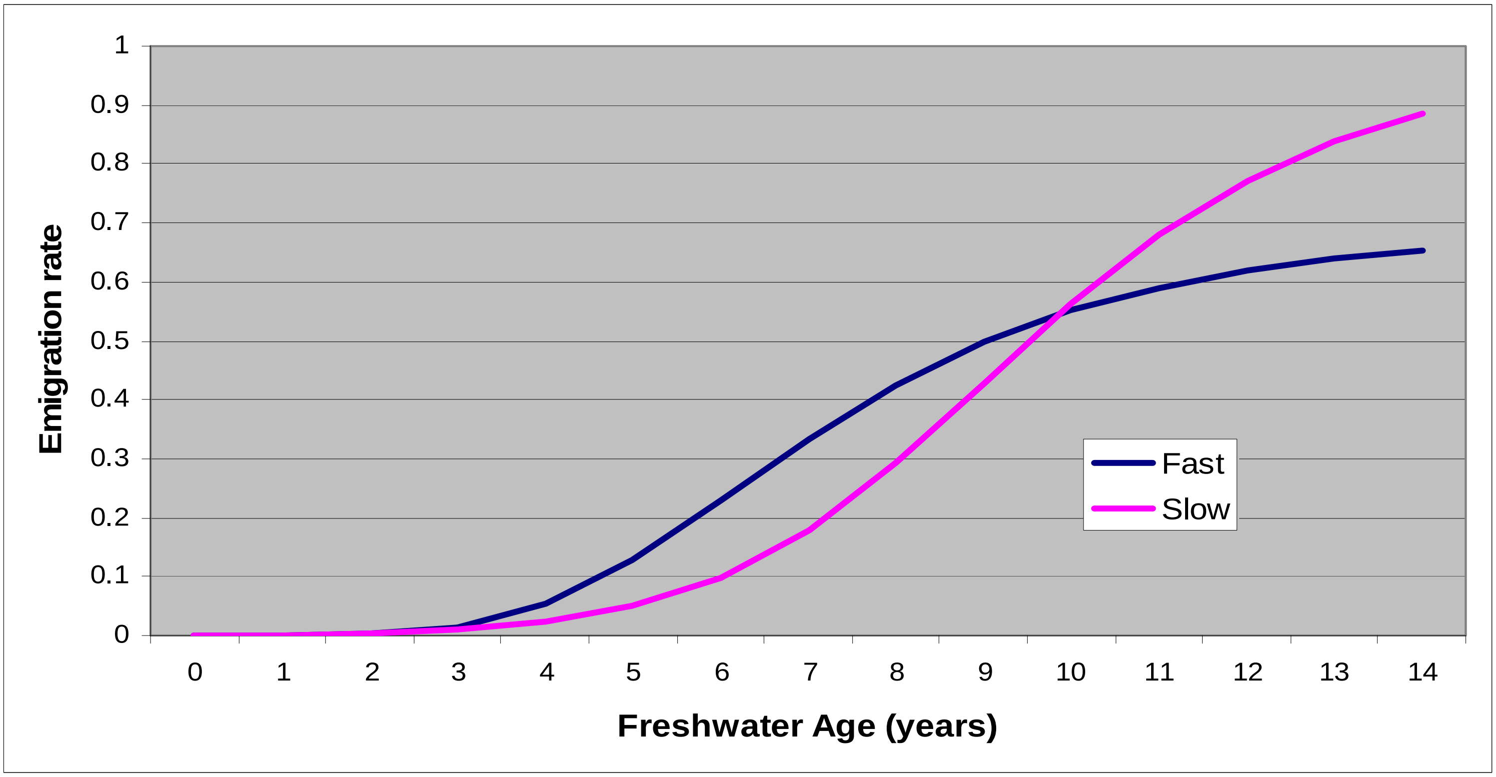


Figure 4-3: Yield-per-Recruit (YPR) and Biological Reference Points (BRP) for Maryland Chesapeake Bay 'slow' and 'fast' growth areas including current fishing mortality (F) from sampled tributaries in respective growth groups.

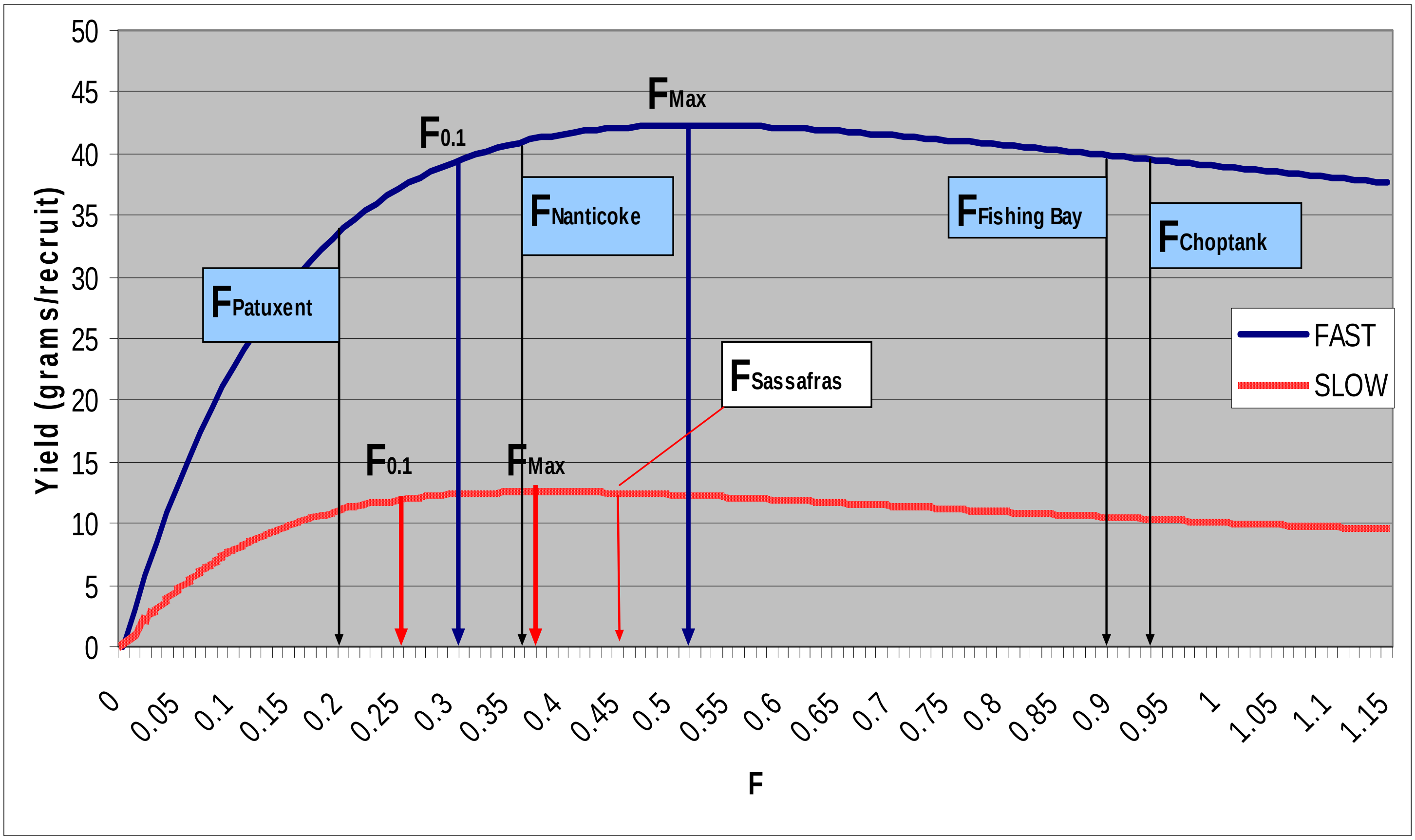


Figure 4-4: Proportion maximum spawning potential (MSP) and Biological Reference Points for Maryland Chesapeake Bay slow growth group and current instantaneous fishing mortality rates for the Sassafras River.

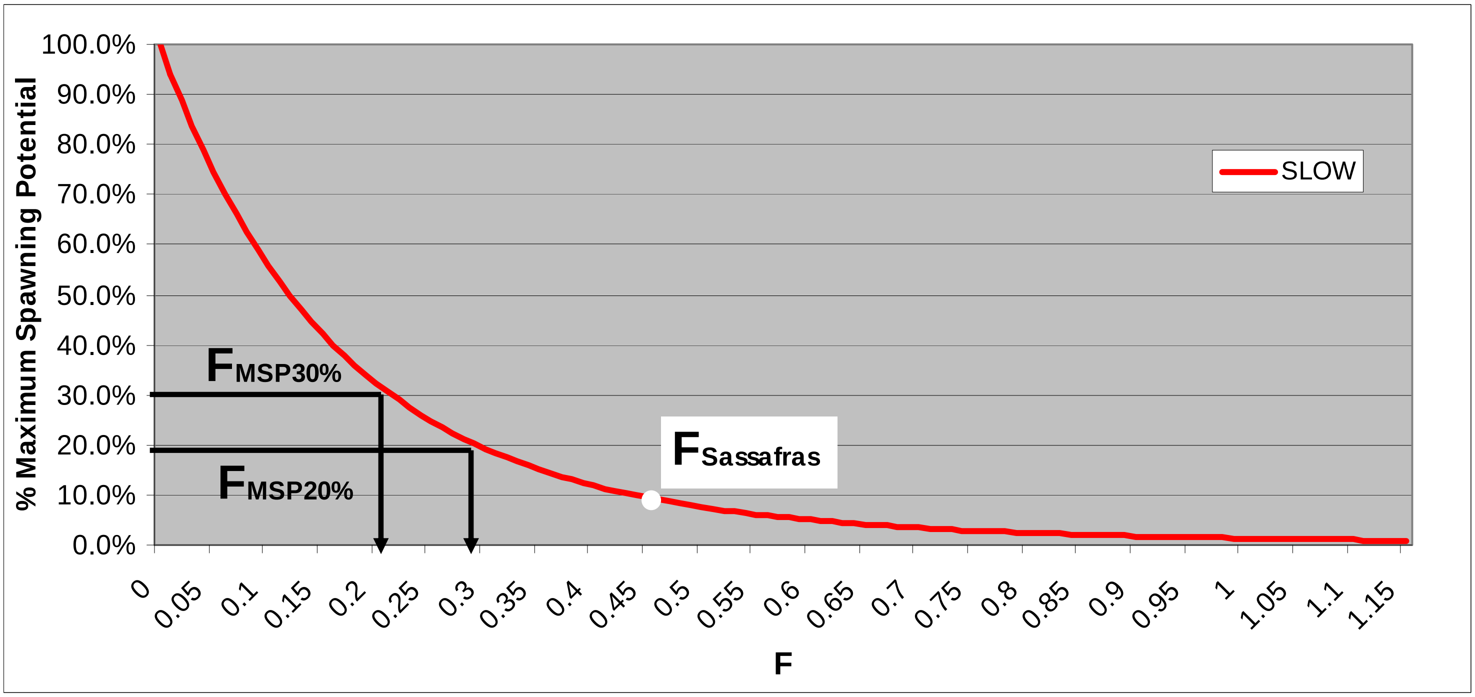
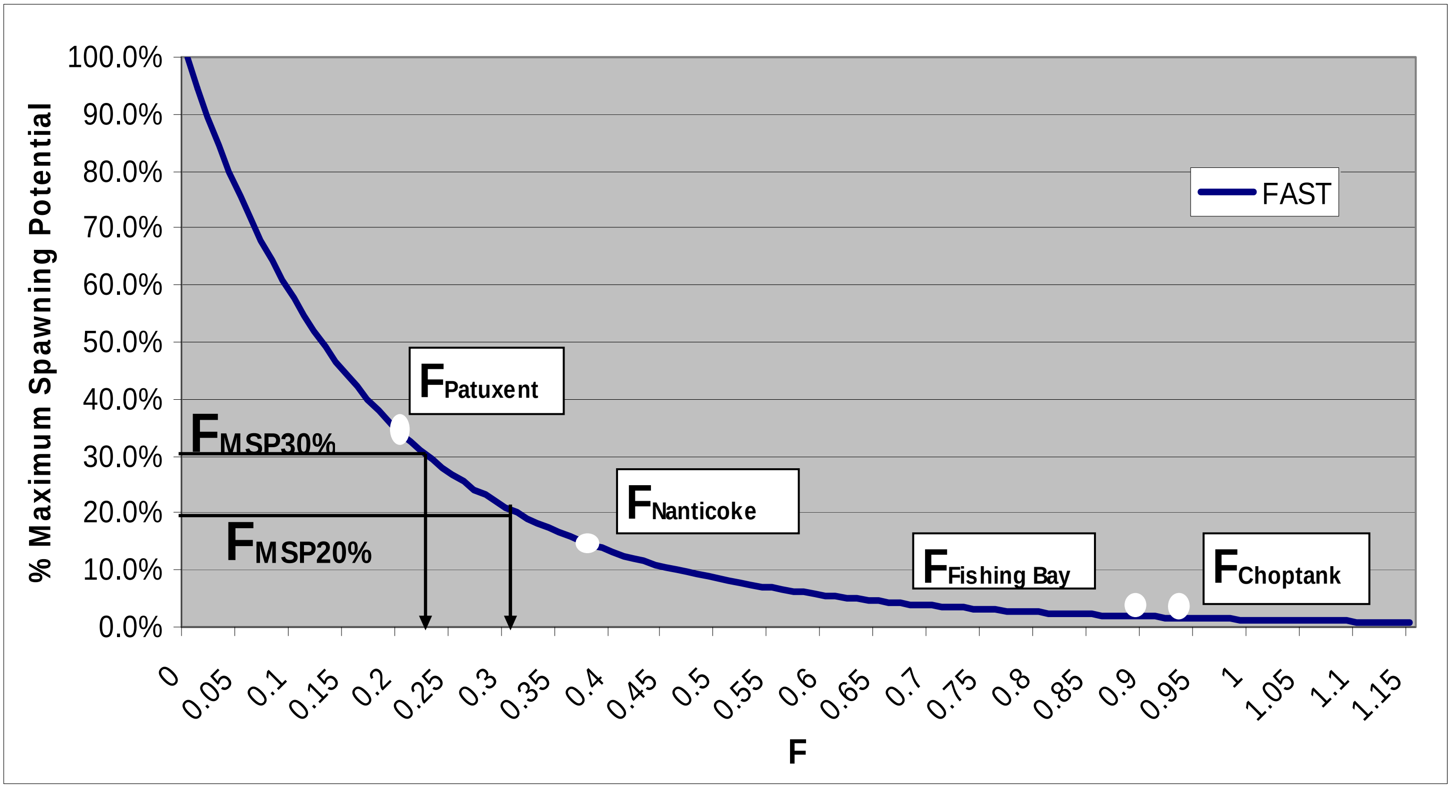


Figure 4-5: Proportion maximum spawning potential (MSP) and Biological Reference Points for Maryland Chesapeake Bay fast growth group and current instantaneous fishing mortality rates for individual tributaries.



Job 5: Assess American eel recruitment to Maryland's Coastal Bays.

INTRODUCTION

In April 2000, the Atlantic States Marine Fisheries Commission (ASMFC) completed their Interstate Fishery Management Plan (ISFMP) for American eel. The ISFMP requires each state to conduct an annual American eel young-of-year (YOY) relative abundance survey (ASMFC 2000). The goal of the YOY survey is to provide a 'qualitative appraisal of the annual recruitment of American eel to the U.S. Atlantic coast' (ASMFC 2000). In addition to documenting trends in annual relative abundance, this survey may provide an early indicator of future adult stock recruitment.

METHODS

The Maryland YOY survey followed protocol provided by ASMFC (2001) and utilized methods that met or exceeded ISFMP requirements. The ASMFC protocol required, at a minimum, to sample one site four days per week for six weeks. As stated in the ISFMP, the timing of the survey should coincide with the peak onshore migration of the YOY. The Irish elver ramp, the Sheldon trap, and elver fyke nets were the recommended and most commonly used gear types to effectively sample YOY. States were allowed to choose what gear was most suitable to the habitat and geography within their jurisdiction. Site location would be dictated by the catchability of YOY and site/gear logistics, but Coastal bay streams were the preferred locations. These areas are more preferable to Chesapeake Bay streams as they were closer to the continental shelf and catches would be less impacted by YOY dispersal and mortality.

I. Field Operations

Sampling Gear

Maryland selected the Irish elver trap as its gear of preference for the YOY study. This is a passive gear that fishes continuously, weather permitting. In order to deploy this sampling gear at the chosen site location, the standard design of the trap was modified. The trap was normally set on land, with the substrate extending into the water, however, due to stream bank morphology, the trap utilized in Maryland was placed in the water. Styrofoam was attached to the bottom of the trap to provide flotation. The trap was tethered to nearby vegetation in case of floods, and was accessed by wading. These modifications have been used for all nine years of the study, did not alter trap operation, and were consistent with ASMFC protocol.

Trap dimensions were approximately 35 cm (14 inches) wide x 110 cm (44 inches) long x 17 cm (7 inches) high (Figure 5-1). It was constructed of marine plywood and consisted of a ramp of low slope covered with plastic erosion control material (Enkamat®) inside a narrow box. The ramp runs ¾ the length of the trap and ends in a small well at the top of the ramp. Water was gravity-fed into the trap from a freshwater source above a small blockage through a 1.5" rubber hose. Water slightly overfilled the well and ran down the ramp, attracting the YOY eels. The YOY eels climb up the rough ramp, fall into the well, and are subsequently flushed into a fine mesh bag through a 1.5" hose attached to the well.

Sample Area

The YOY survey was conducted at Turville Creek, a first order stream and tributary to the Isle of Wight Bay, in Maryland's coastal bay watershed (Figure 5-2). The specific trap location was 6.6 river miles from the Atlantic Ocean and approximately 70 miles from the Continental Shelf. The trap was placed just downstream of a multiple stepped, notched fish passage structure (maximum height 45.7 cm (18 in)). The freshwater input through the dam structure directly into a mesohaline environment (salinity = 5-18 parts per thousand) provided a strong freshwater signal attractive to incoming YOY. This coupled with increased densities of YOY due to the blockage made this site attractive for sampling.

Sampling Protocol

Once the mesh bag was removed from the trap, the YOY catch was recovered and enumerated. The Maryland Fisheries Service considered YOY to include transparent glass eels and elvers (pigmented YOY eels) less than 85 mm long. When catches of YOY were small (<30ml), each specimen was measured for total length (TL) to the nearest millimeter and weight recorded to the nearest one hundredth of a milligram. Larger catches were volumetrically measured with a graduated cylinder and then released above the obstruction. Subsamples of at least 60 specimens were taken at least once a week. Since the volumetric measurements taken on the subsamples had actual counts, larger catches (>30ml) were extrapolated into total counts. Estimated total number of YOY captured per day = total ml of YOY * number YOY/ml calculated from the subsample. These subsamples also provided length, weight, and pigmentation stage data. Pigmentation stage was assigned using a scale 1 through 7 (Haro and Krueger 1988).

Other ancillary data collected daily included date/time of sampling, water temperature (ºC), salinity (‰), water level, and qualitative judgment on gear performance (1-4; good, fair, poor, void). Water velocity for each sampling day was recorded based on the nearest stream where a USGS water gauging station was located (Birch Branch). This tributary was located approximately 3 miles from site location, but reflective of local precipitation and watershed response. Moon phase was recorded as % moon illumination (0-100%) from the moon phase calendar for Berlin, Maryland from the Old Farmer's Almanac.

II. Data Compilation

Relative Abundance

The actual or estimated counts of YOY were used to compute catch per unit of effort (CPUE). CPUE is reflected as the total number of YOY captured / number of hours the trap fished. Both geometric mean (GM) and arithmetic mean (AM) CPUE were calculated to create indices of relative abundance. The GM was calculated with 95% confidence intervals (CI's) as antilog ($\log_e(x+1)$ mean ± 2 standard errors), where x is number of YOY caught by hour (CPUE). One was added to all of the catches because the log of 0 does not exist (Ricker 1975). The $\log_e$ transformation stabilizes the variance of the catches (Richards 1992) and normalizes the catch distribution. The GM is not as sensitive to an extremely large sample value as would be the AM. The GM is almost always lower than the AM (Ricker 1975). The AM was calculated with 95 % CI's by the mean CPUE ± 2 standard errors.

Because of slight annual variations in survey dates, only comparable periods were used in calculating the indices of relative abundance. Sampling days in which the gear was qualitatively given a rating of 4 (void) were excluded from the data analysis.

Abiotic Factors

Ancillary data collected in the survey was analyzed to determine what patterns or relationships, if any, existed between each variable and YOY catch. Scatter plots were developed with YOY catch per hour over the nine year sampling effort with each of the following variables: water temperature (ºC), salinity (‰), water level (inches), water velocity (cfs), and % moon illumination (0-100%). Distributions were normalized through data transformations when necessary. Pearson Product Moment Correlation analysis was used to test for the strength of the linear relationship of the independent variables and $\log_e$ (CPUE). These factors were considered significant at $P \leq 0.05$. A Best Subsets Regression method was used to help determine which independent variables would be the best predictors of $\log_e$ (CPUE) in a multiple regression model. This method examines all of the models created from all possible combination of predictor variables.

RESULTS AND DISCUSSION

Since 2000, the sample period has been periodically modified to include peak onshore migration of YOY eels. The sampling period has started as early as 9 March and commenced as late as 9 June, but has averaged 8 weeks in length and 34 sampling days over the 9 year period. A total of 840,386 American eel YOY were collected over the nine year sampling period at Turville Creek. Peak one sample catches of YOY occurred as early as 10 March and as late as 20 April and have represented from 11-40 % of total annual YOY catches (Figure 5-3). In most years the peak in catches occurs for less than a week. In both 2007 and 2008 peak catches occurred 1-2 weeks earlier than the previous 7 years. In 2007, the largest catch occurred on the first sampling day. As a result, 2008 sampling began a week earlier with the two largest catches occurring in the first three sampling days. The 2007 and 2008 results may indicate a shift in the timing of peak onshore migration of YOY to the Turville Creek sampling location. Abiotic factors such as water temperature, moon phase, and water discharge may have played a role in this shift.

Relative Abundance

The annual time series high AM CPUE was 217.2 YOY/hr. in 2007 (Figure5-4). The AM CPUE was below the time series average of 110.7 YOY/hr. four out of the last 5 years. The annual time series high GM CPUE was 106.2 YOY/hr in 2001 while the time series average GM CPUE was 51.65 YOY/hr (Figure 5-5). The largest difference between the AM and GM indices occurred in 2007. In 2007, one sample comprised approximately 40 % of the total annual sample and was the largest catch in the nine year study period. As a result of this sample’s large influence on the AM, 2007 produced the highest value for the AM index compared to the 4th highest for the GM index.

A one-way analysis of variance (ANOVA) performed on the $\log_e$-transformed catch values indicated significant differences among annual means (ANOVA: $P<0.001$). A Tukey pairwise multiple comparison test found the 2002 $\log_e$-transformed mean to be significantly smaller than all years except 2005 and 2006 (Tukey: $P<0.05$). The highest $\log_e$-transformed mean occurred in 2001 and was found to be significantly higher for 2002, 2005, and 2006

(Tukey: P<0.05). A slight non significant negative trend was indicated by the linear regression of the GM CPUE index of relative abundance (Linear regression: P=0.21).

Length-Weight

A total of 6,920 YOY American eels were measured and weighed over the nine year time series. The mean length and weight of YOY, determined from weekly subsamples and over comparable sampling periods, was compared from 2000-2008. Annual mean length and weight ranged from 53.7-57.9 mm and 0.094-0.165 g, respectively throughout the 9 year sampling period (Table 5-1). Slight, but significant increases occurred in both mean length and weight over the time series (Linear regression: P<0.005). Mean length and weights were calculated by sampling week to note changes in size for YOY eels within the spring sampling period. Slight decreases in both mean length and weight were noted for the comparable 6 week periods (Figure 5-6). This decrease in size is most likely attributable to the morphological body change that occurs from early stage glass eels to early stage pigmented elvers. Early stage glass eels can still resemble the Leptocephalus stage in which the body is longer and laterally compressed. As the YOY eels become pigmented their bodies become shorter and more cylindrical in shape. The end of the survey period in early May is before the significant growth in pigmented elvers.

A one-way analysis of variance (ANOVA) indicated significant differences among annual mean YOY lengths and weights (Kruskal-Wallis ANOVA: P<0.001). Dunn's pairwise multiple comparison test indicated 2007 mean lengths were significantly larger than mean lengths from each of the other 8 years and 2008 mean weights were significantly higher than all years except 2003 and 2007 (Dunn: P< 0.05)

Pigmentation

Beginning in spring 2007, pigmentation stage was classified by the seven stages as described by Haro (1988). Stage 1 is considered a glass eel lacking pigmentation while stage 7 is considered a fully pigmented YOY eel. Mean weekly pigmentation calculated from 2007 and 2008 subsamples varied between stages 2.9-5.9. In 2007 and 2008 mean pigmentation stage progressed from 2.5 to 4.6 over the 8 week sampling period from the middle of March to early May.

Abiotic Factors

Scatter plot analysis did not indicate any clear pattern between catch and water temperature(ºC), salinity(‰), water level(inches), water velocity(cfs), and % moon illumination(0-100%). The Pearson Product Moment Correlation indicated salinity as the only independent variable analyzed to be significantly correlated to YOY catch (Pearson: P= 0.01). However, this negative correlation was weak as indicated by an R = -0.21. A marginal positive correlation was noted for YOY catch and water discharge, yet the relationship was very weak (Pearson: R = 0.12, P = 0.07). Although moon phase was not significantly correlated with catch, the highest YOY catch occurred during the new moon (% moon illumination < 5%) 6 out of 9 sampling years (Figure 5-3). The Best Subsets Regression indicated that salinity alone provided the best predictive value, although poor itself ($r^{2 =}$ 0.046), as any and all combinations of the independent variables. The increase in catch of YOY eels as salinity decreased may be site specific for this location. Salinity at this site is highly sensitive to fresh water discharge. The freshwater signal, which attracts YOY eels, increases substantially with the increase in discharge levels. Although a positive relationship existed between water discharge and YOY catch, a threshold level of approximately 20 cubic feet per second appeared to exist at this site. Above this level of discharge, a negative impact on the upstream migration of YOY eels occurred and catches declined.

Future Study Considerations

- Peak catches have occurred earlier in the sample period in recent years. Correlation analysis indicated a positive relationship between catch and discharge and negative relationship with catch and salinity and temperature. Based on these relationships higher catches could be expected earlier in the sampling period. In addition, peak catches have occurred 67% of the time during the new moon phase. For these reasons, YOY sampling should continue to be revised to an earlier start date in March and must incorporate the new moon phase to ensure that peak migration periods of YOY eels are effectively sampled.

- Develop a yellow eel CPUE relative abundance index through an eel pot survey in the same system as the YOY survey. This would allow a stock-recruitment relationship to be investigated.
- Attempt to acquire data describing oceanographic conditions, such as water temperature, measures of Gulf Stream strength, North Atlantic Oscillation Index, etc that may affect the timing of the out-migration and spawning of adult American eels as well as larval development and continental transport. These independent variables may play a significant role in predicting recruitment strength of YOY American eels.

Figure 5-1: Modified Irish elver trap used for Maryland YOY eel survey, 2000-2008.

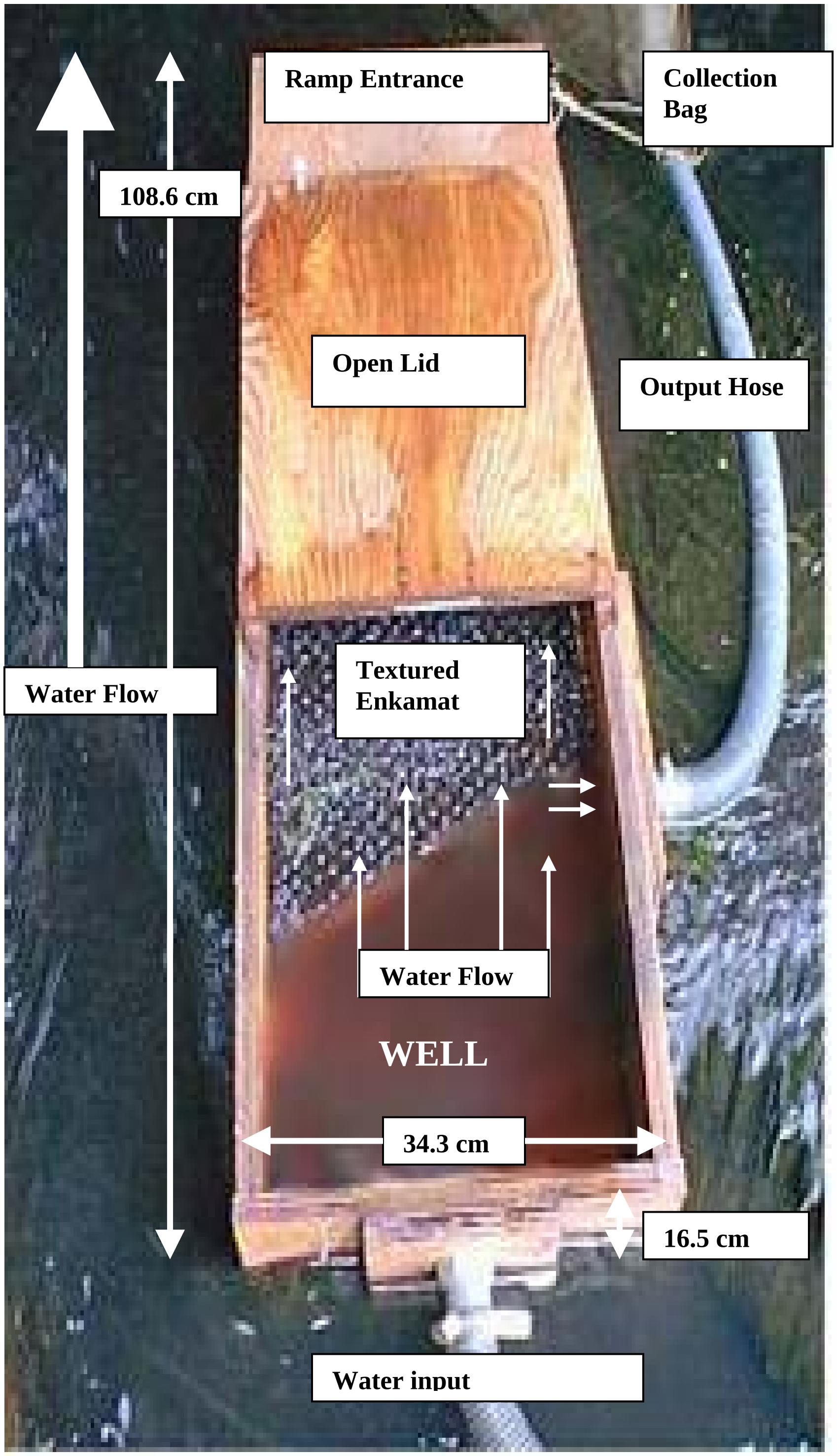


Figure 5-2: Maryland YOY eel survey location, Turville Creek, 2000-2008.

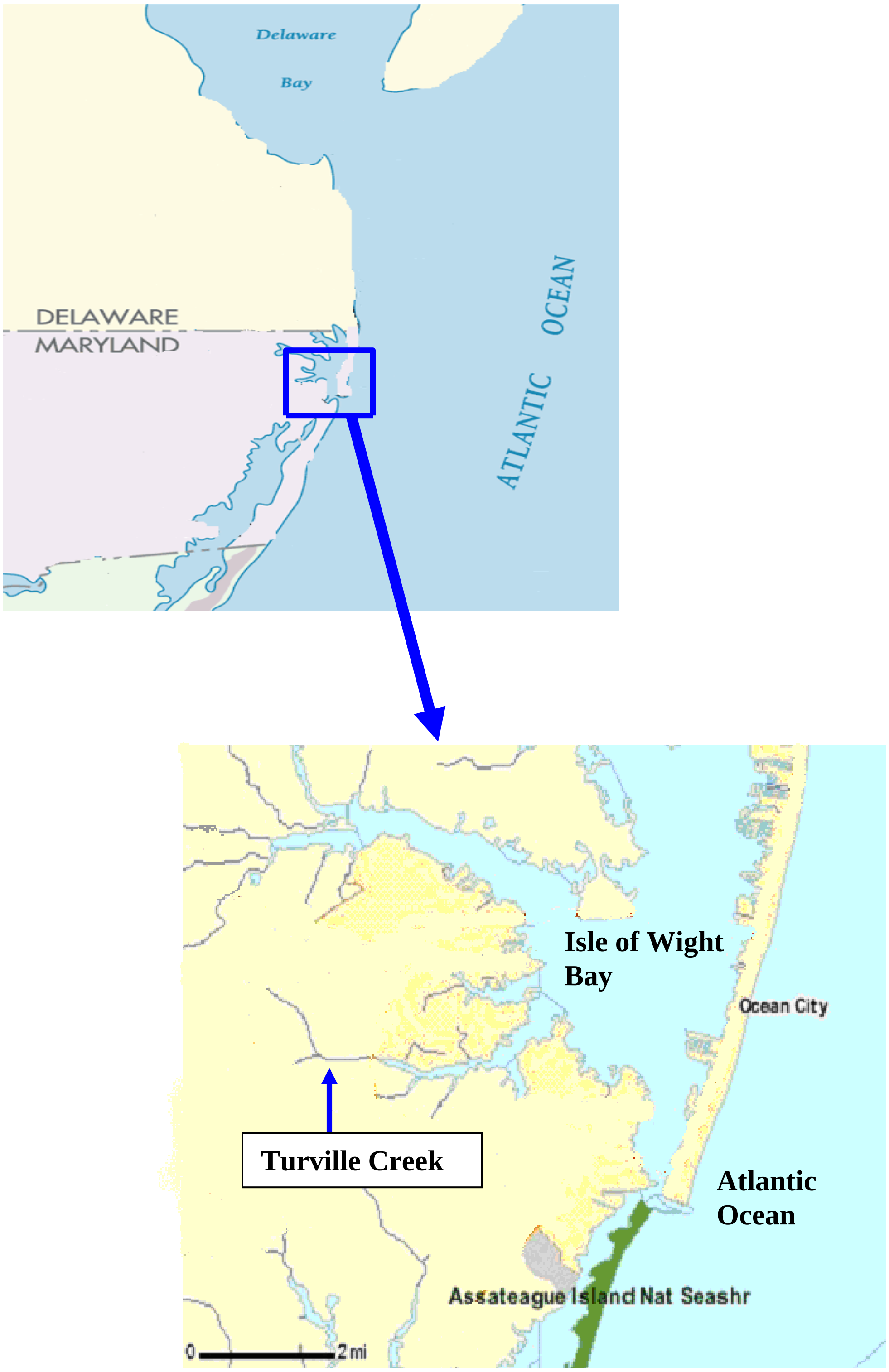
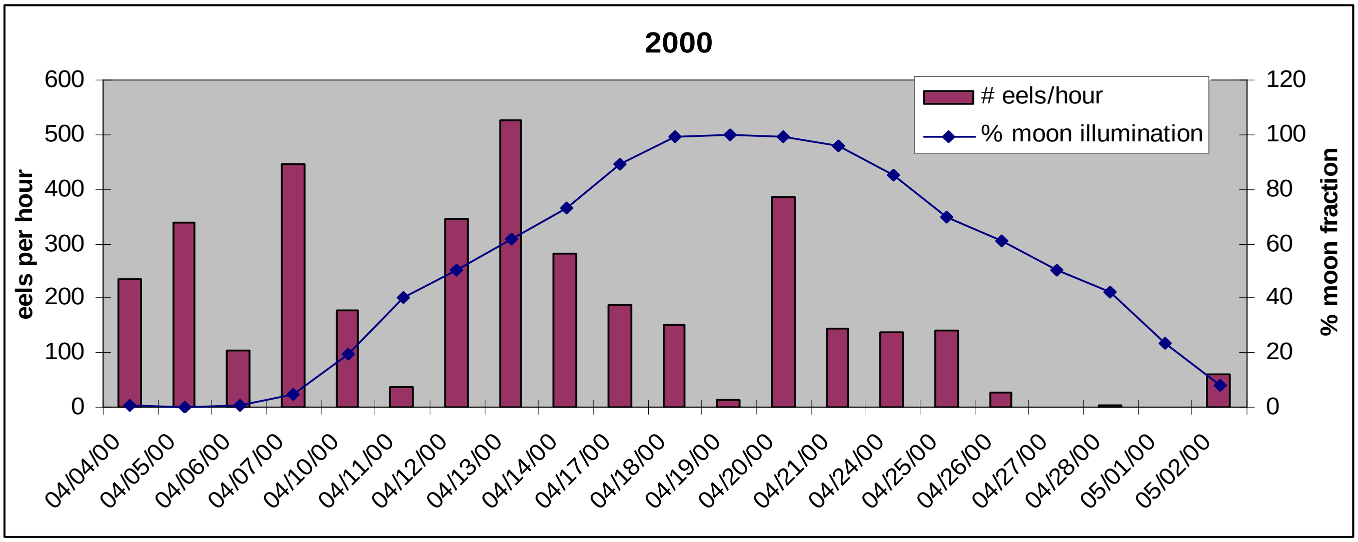
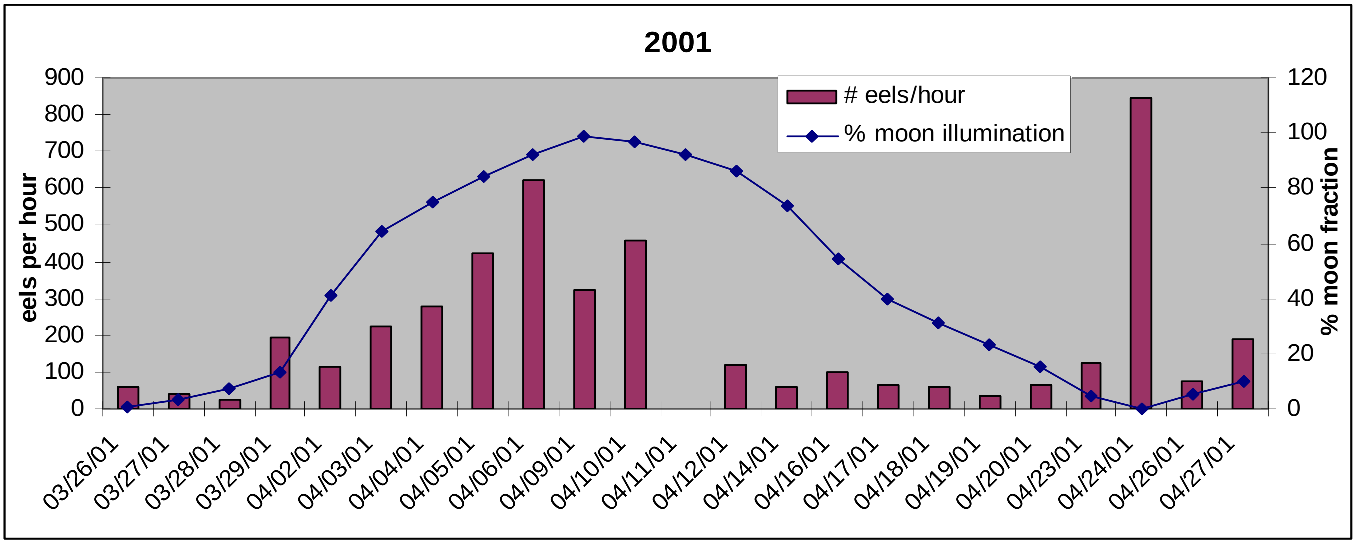
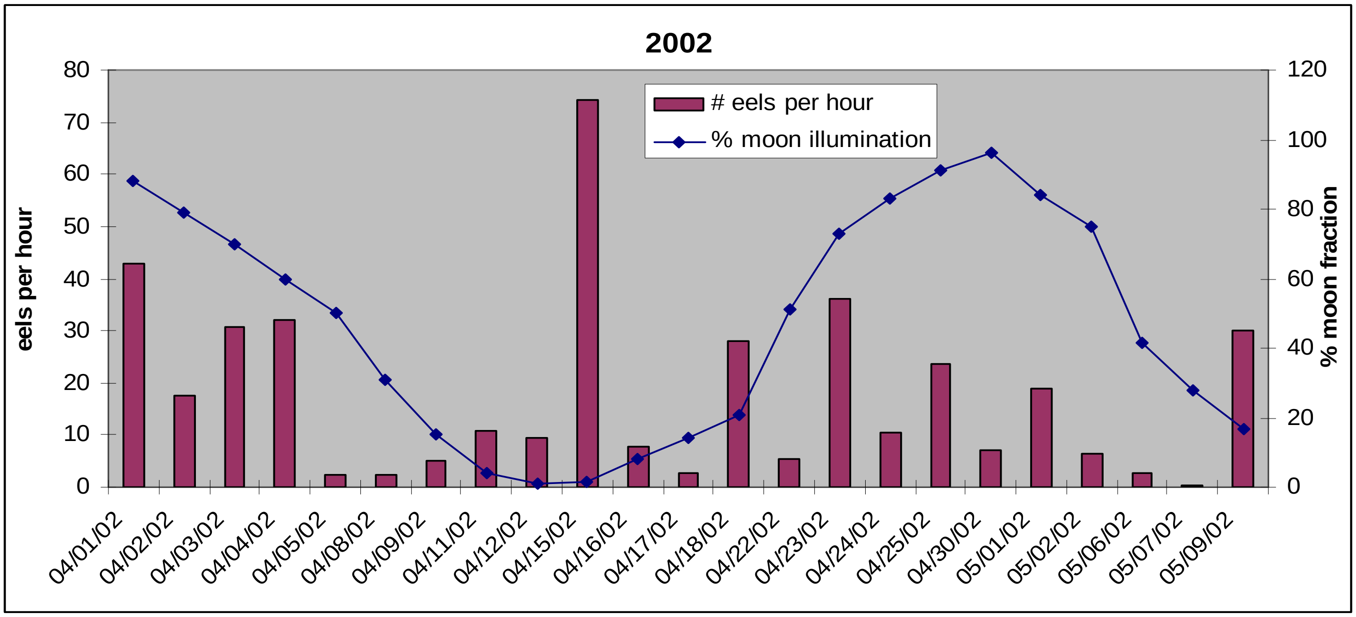
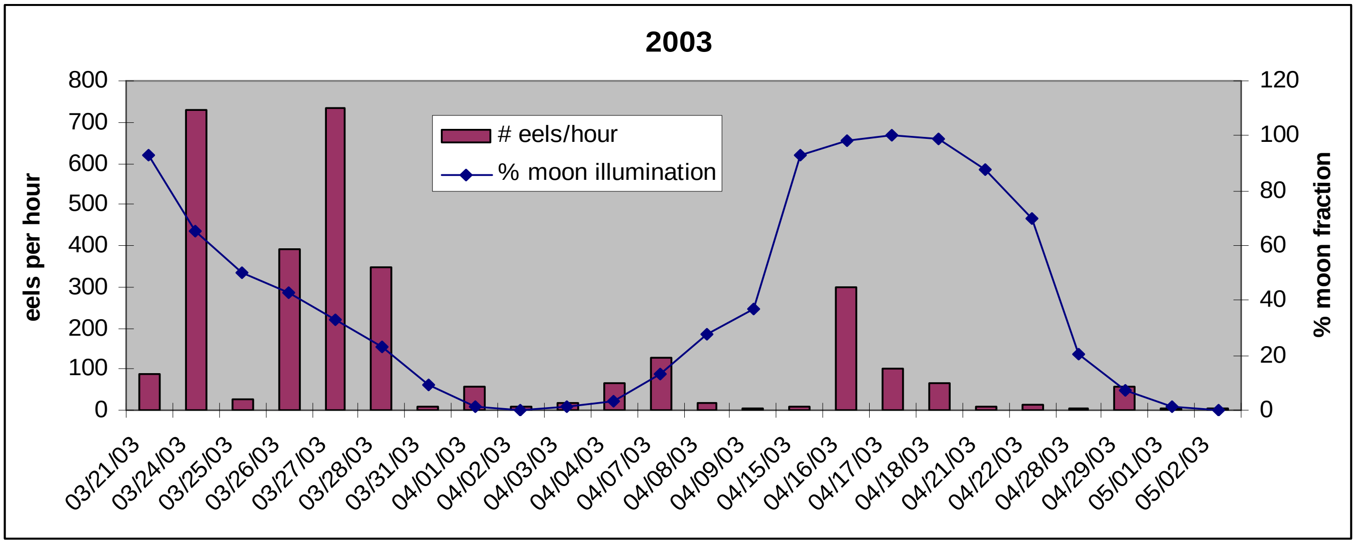


Figure 5-3: YOY eel cpue and moon phase (% moon illumination) by day, 2000-2008.








2003
eels per hour
% moon fraction
# eels/hour
% moon illumination
800
700
600
500
400
300
200
100
0
120
100
80
60
40
20
0
03/21/03
03/24/03
03/25/03
03/26/03
03/27/03
03/28/03
03/31/03
04/01/03
04/02/03
04/03/03
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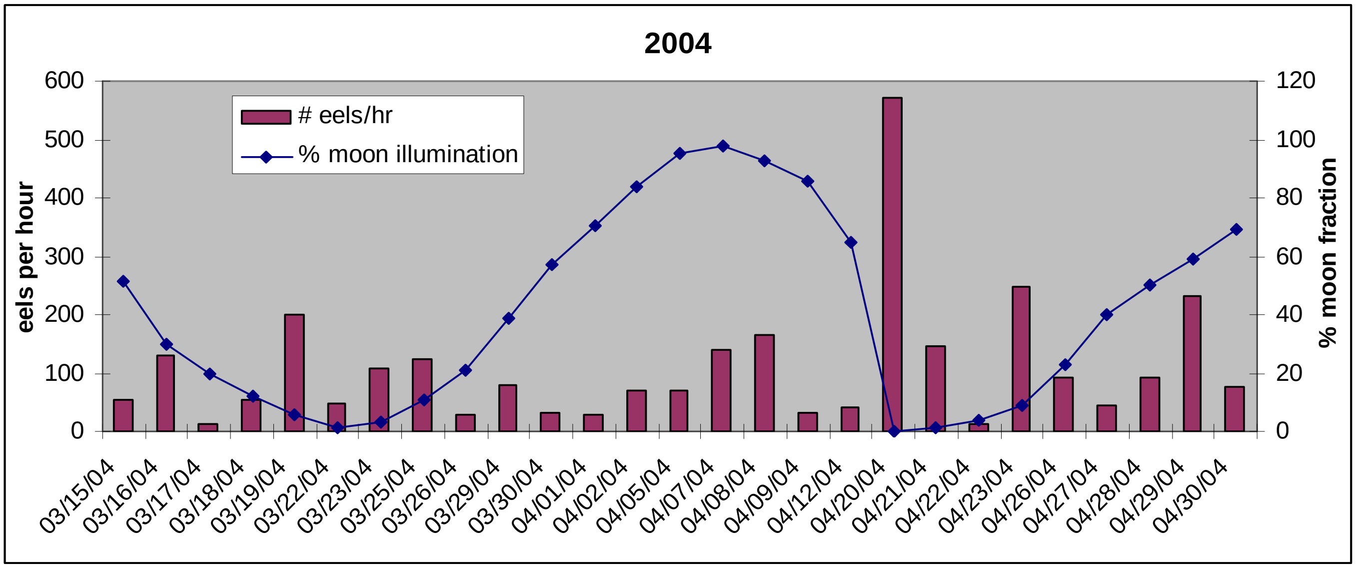
05/01/03
05/02/03


2004
eels per hour
% moon fraction
# eels/hr
% moon illumination
600
500
400
300
200
100
0
120
100
80
60
40
20
0
03/15/04
03/16/04
03/17/04
03/18/04
03/19/04
03/22/04
03/23/04
03/25/04
03/26/04
03/29/04
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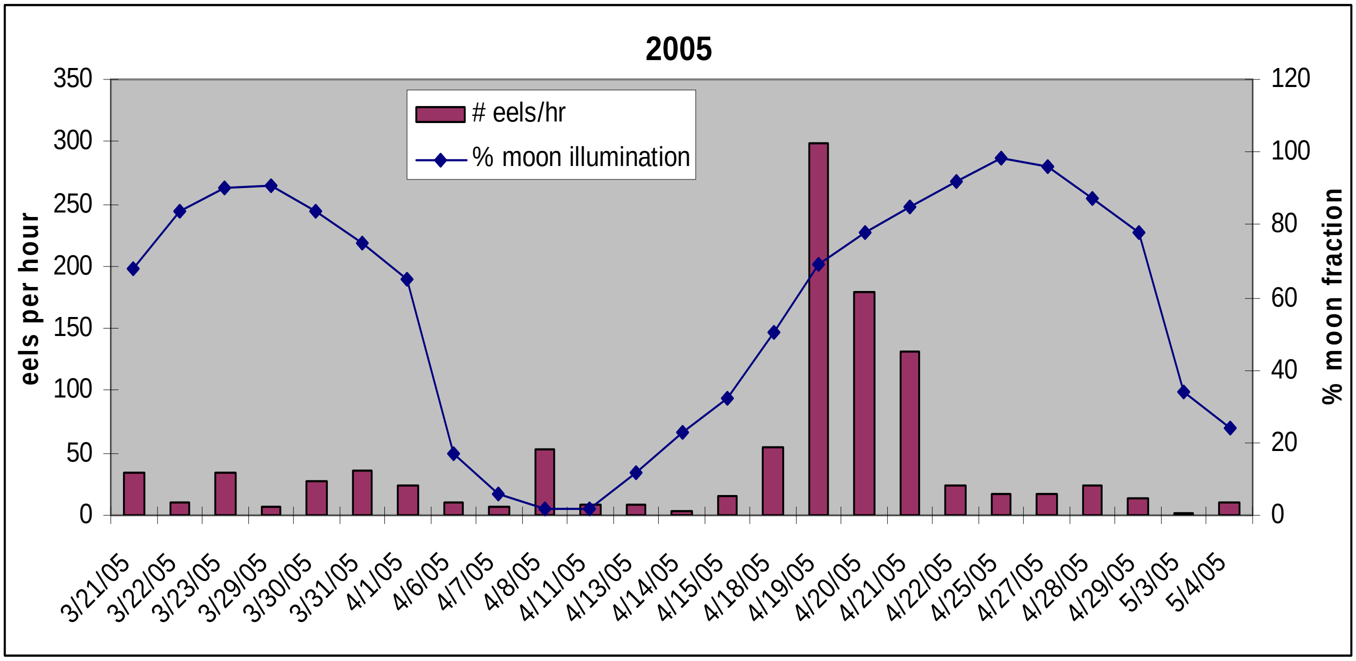
04/30/04


2005
eels per hour
% moon fraction
# eels/hr
% moon illumination
350
300
250
200
150
100
50
0
120
100
80
60
40
20
0
3/21/05
3/22/05
3/23/05
3/29/05
3/30/05
3/31/05
4/1/05
4/6/05
4/7/05
4/8/05
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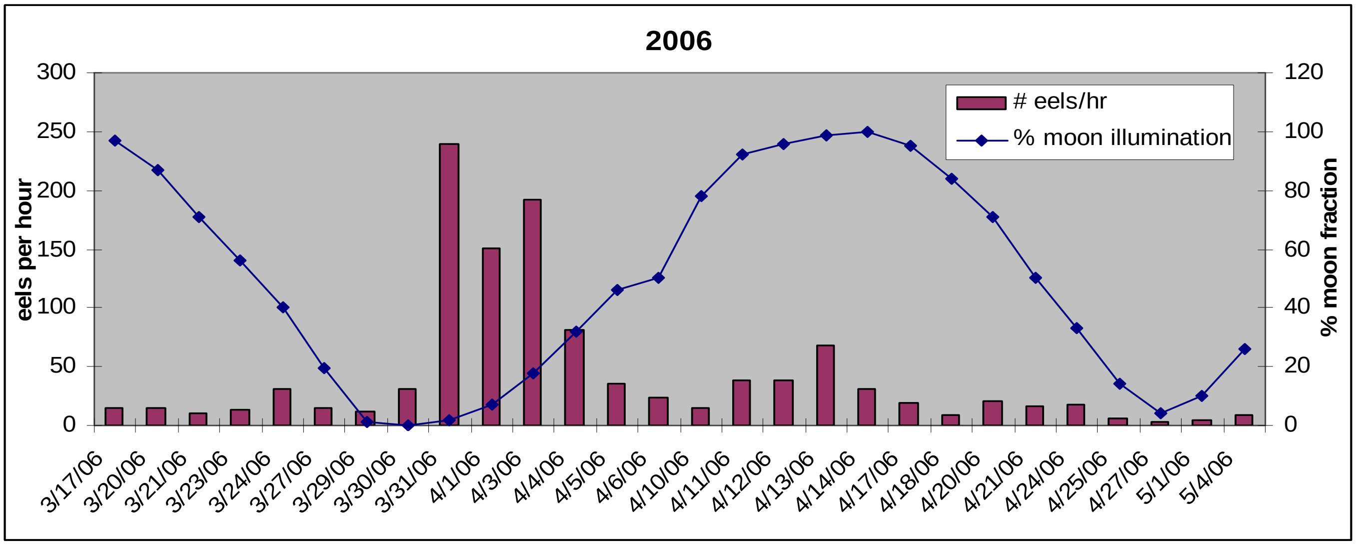
5/3/05
5/4/05


2006
eels per hour
% moon fraction
# eels/hr
% moon illumination
0
50
100
150
200
250
300
0
20
40
60
80
100
120
3/17/06
3/20/06
3/21/06
3/23/06
3/24/06
3/27/06
3/29/06
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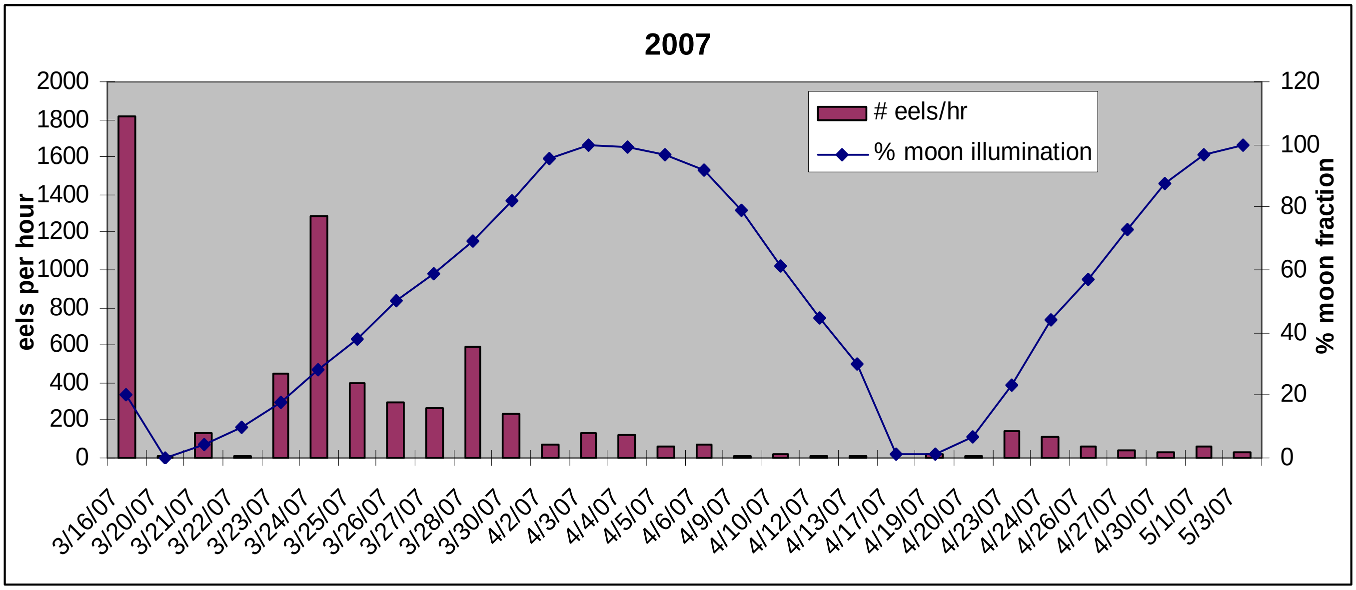
5/1/06
5/4/06


2007
eels per hour
% moon fraction
# eels/hr
% moon illumination
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
20
40
60
80
100
120
3/16/07
3/20/07
3/21/07
3/22/07
3/23/07
3/24/07
3/25/07
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4/30/07
5/1/07
5/3/07

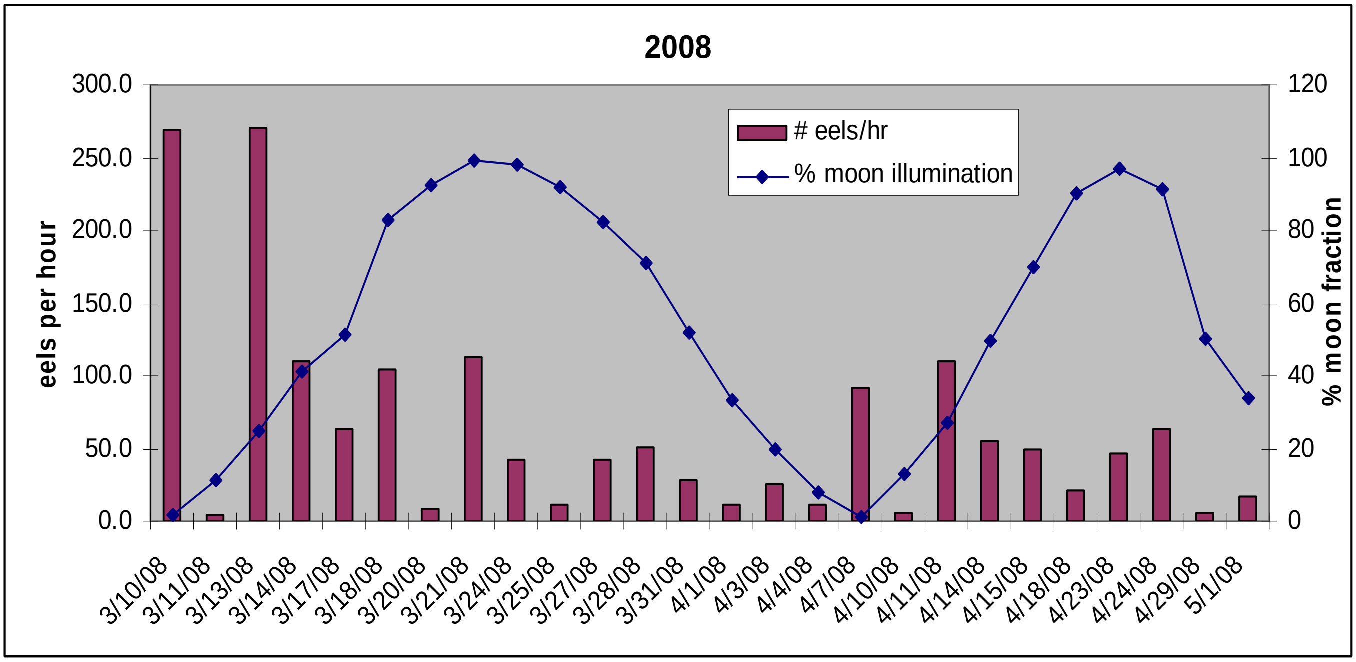
2008
eels per hour
% moon fraction
# eels/hr
% moon illumination
0.0
50.0
100.0
150.0
200.0
250.0
300.0
0
20
40
60
80
100
120
3/10/08
3/11/08
3/13/08
3/14/08
3/17/08
3/18/08
3/20/08
3/21/08
3/24/08
3/25/08
3/27/08
3/28/08
3/31/08
4/1/08
4/3/08
4/4/08
4/7/08
4/10/08
4/11/08
4/14/08
4/15/08
4/18/08
4/23/08
4/24/08
4/29/08
5/1/08

Figure 5-4: **Maryland American eel YOY arithmetic CPUE index with 95% confidence intervals, 2000-2008.**

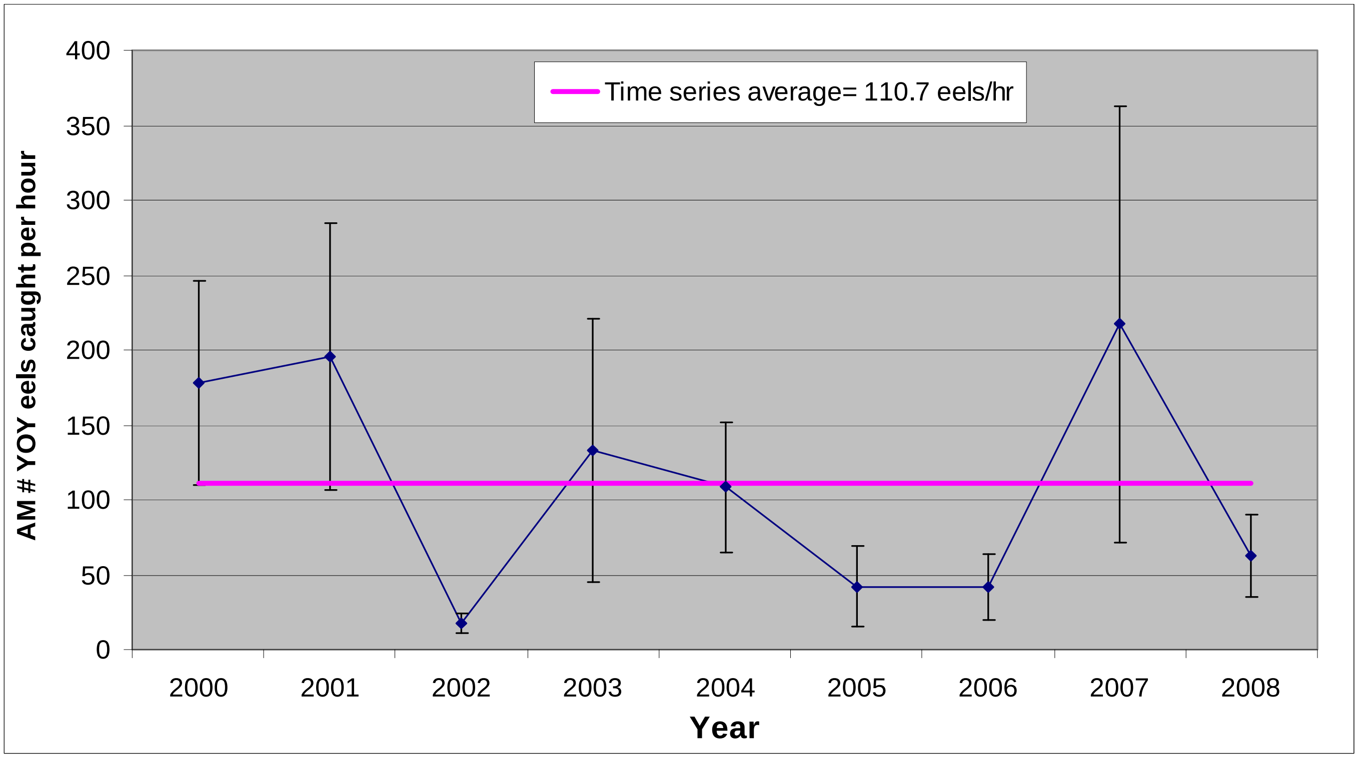

Figure 5-5: Maryland American eel geometric mean CPUE index with 95% confidence intervals, 2000-2008.

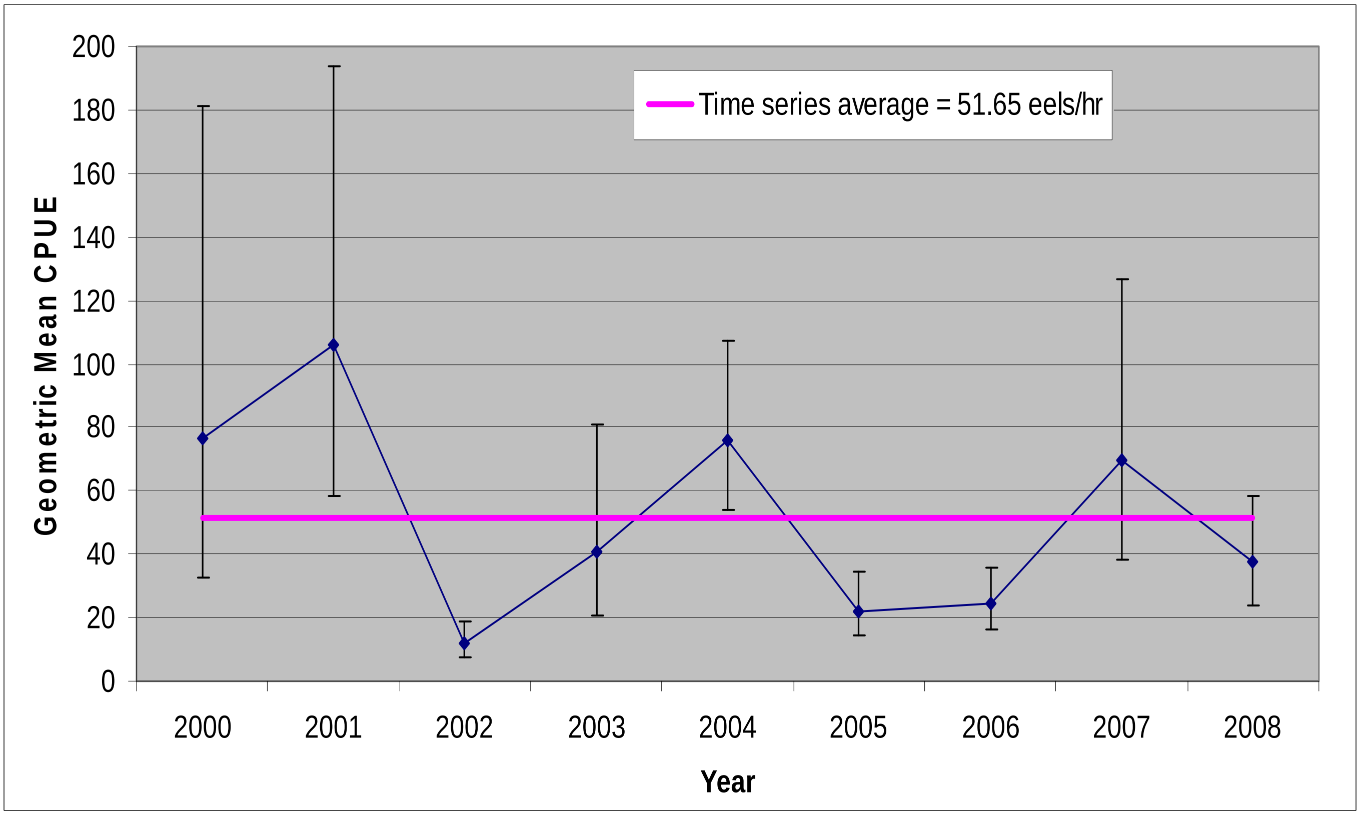

Figure 5-6: Mean YOY eel length and weight over comparable sampling weeks, aggregate 2000-2008.

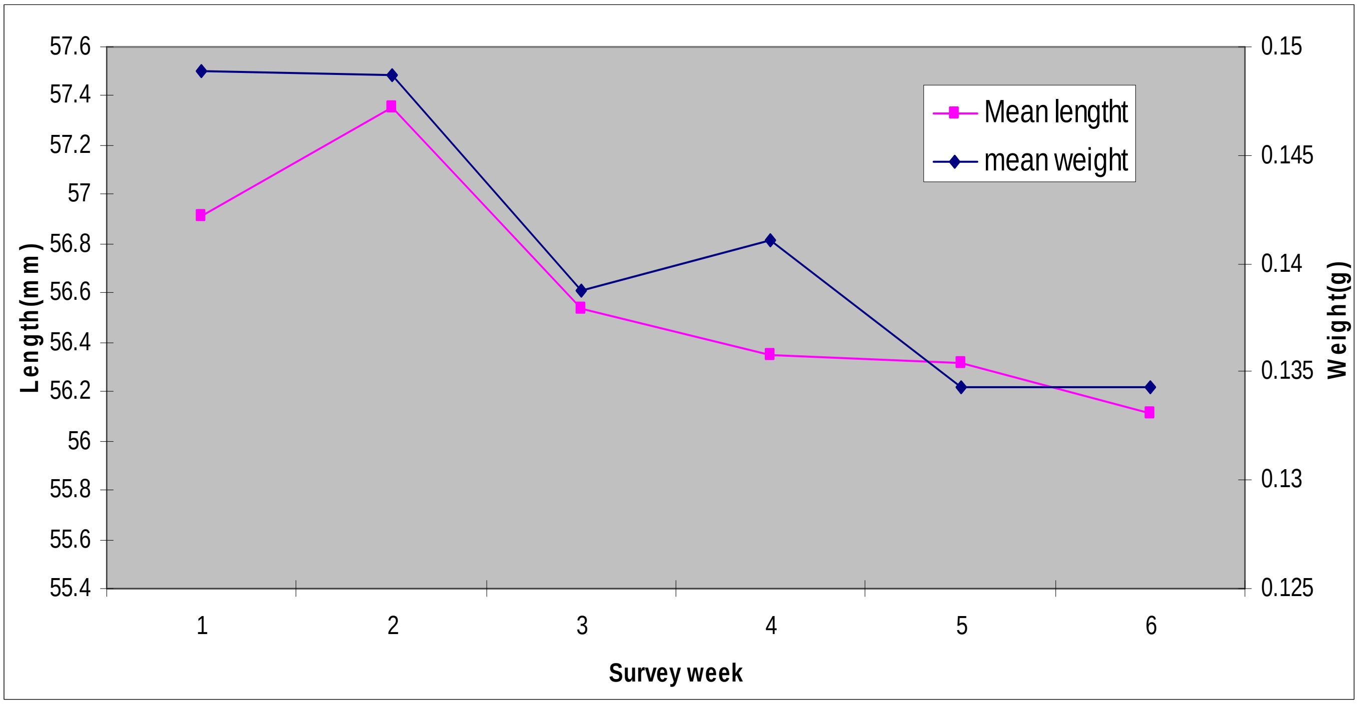

Table 5-1: Annual mean length and weight of YOY eels with 95% confidence intervals, 2000-2008.

Sample Year	N	Mean length(mm)	95% CI(±)	Mean weight(g)	95% CI(±)
2000	600	55.85	0.25	0.114	0.003
2001	660	56.75	0.24	0.124	0.002
2002	2169	53.73	0.13	0.094	0.001
2003	430	57.03	0.35	0.161	0.004
2004	313	57.33	0.42	0.151	0.005
2005	423	56.85	0.30	0.136	0.003
2006	360	55.10	0.31	0.126	0.003
2007	420	57.89	0.30	0.157	0.003
2008	420	57.05	0.30	0.165	0.003

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