

Abstract

Tuomikoski, Jack Esa. Effects of age-1 striped bass predation on juvenile fishes in western Albemarle Sound. (Under the supervision of Jeffrey A. Buckel and Joseph E. Hightower)

Historically, adult river herring (*Alosa pseudoharengus*, *Alosa aestivalis*) and American shad (*Alosa sapidissima*) fisheries were economically important in Albemarle Sound. Stocks of these species are currently in decline while stock estimates for striped bass (*Morone saxatilis*) have increased 10-fold for the Albemarle Sound-Roanoke River stock since the early 1990s. The primary goal of this study was to quantify the diet, prey selectivity and the predatory impact of age-1 striped bass on juvenile river herring and American shad in 2002 and 2003. Similar estimates were produced for juvenile yellow perch (*Perca flavescens*), a species with an expanding fishery. Striped bass and prey samples were obtained from 443 beach seine and 171 purse seine hauls from May through October in 2002 and 2003. Age-1 striped bass were primarily piscivorous from May onward in both years. *Alosa* spp. were a small component of age-1 striped bass diet in summer months but dominated diet in early fall months. Age-1 striped bass fed randomly with respect to *Alosa* spp. abundance during the summer and selected for them during early fall months. During summer 2003, selectivity for yellow perch decreased with concomitant decreases in importance as a prey item. Field estimates of consumption rates ranged from 3 to 8 % body weight per day while bioenergetics model estimates of consumption ranged from 4 to 12 % in 2002 and 3 to 10% in 2003. Age-1 striped bass density, diet, prey sizes eaten, and consumption rates were used to calculate loss rates due to predation and were compared with total loss rates from catch curves. There was interannual variation in the effects of predation. Age-1 striped bass predation had a marked effect on juvenile American shad densities in 2002 but had little influence on their numbers in 2003. Conversely, age-1 striped

bass predation explained none of the loss in juvenile yellow perch in 2002 but accounted for nearly all of the loss in 2003. Thus, predation by striped bass may explain at least some of the variability in year class strength for these species. In most cases, age-1 striped bass predation did not have a strong influence on juvenile alewife numbers. Juvenile blueback herring were preyed on but the relative predatory impact could not be determined because of apparent emigration into the study area. To better understand striped bass impacts on *Alosa* spp., future work should address movement of juvenile *Alosa* spp into and out of Albemarle Sound estuary.

**Effects of age-1 striped bass predation
on juvenile fishes in western Albemarle Sound**

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Effects of age-1 striped bass predation on juvenile fishes in western Albemarle Sound

1.1 INTRODUCTION

For over 100 years, fisheries biologists have studied the variability of fish stocks and the causes thereof (Sinclair 1988). Biotic and abiotic factors have been examined in egg, larval and juvenile stages (Leggett and DeBlois 1994). Egg and larval stages exhibit dramatic mortality rates over short periods and have been studied extensively. However, small changes in mortality rates during the juvenile stage of fishes can have large effects on the magnitude of recruitment because of the longer duration of this stage (Sissenwine 1984).

Predation can be a major source of mortality of prey fishes in many ecosystems (Bailey 1994, Christensen 1996, Bax 1998). These predator-prey interactions have received considerable attention in freshwater ecosystems (Tonn et al. 1992, Yule and Luecke 1993) but have been studied far less in coastal estuaries (Buckel et al. 1999) despite the importance of predation in regulating abundance of estuarine and marine species. Research identifying predator-prey relationships and quantifying the effects of these relationships will be vital to future directions in ecosystem based management of our fisheries (May et al. 1979, Hilden 1988, Latour et al. 2003).

Historically, river herring (alewife *Alosa pseudoharengus* and blueback herring *Alosa aestivalis*) and American shad (*Alosa sapidissima*) fisheries were economically important in coastal North Carolina, including the Albemarle Sound area (Hightower 1996). These North Carolina fisheries along with those of other East Coast states have declined dramatically, probably due to overfishing and loss of habitat (Crecco and Gibson 1990, Rulifson 1994). In 1996, it was estimated that the Albemarle Sound river herring fishery could experience a 10-fold increase in value to \$1,000,000/year if the population could be rebuilt to the level supporting the

average 1880-1970 catches (Hightower 1996). Unfortunately, the juvenile abundance index for Albemarle Sound blueback herring has been at low numbers since the mid 1980s (Figure 1a). Recruitment will have to significantly improve before the river herring stock can recover (Carmicheal 1999).

One factor that could be affecting abundance of river herring stocks coastwide is predation by striped bass. The U.S. east coast striped bass (*Morone saxatilis*) population may currently be at record levels after a moratorium in the 1980s (Richards and Rago 1999, Hartman and Margraf 2003). Within Albemarle Sound, the striped bass stock has experienced a marked increase; the numbers of age-4+ striped bass have increased by an order of magnitude since the early 1990s (Figure 1b; Grist 2004). The demands of this increased predator biomass on prey populations has recently been studied in some systems (Hartman 2003, Overton 2003, Uphoff 2003) but has not been quantified in Albemarle Sound.

Striped bass and juvenile *Alosa* spp. are known to interact in Albemarle Sound. A historical diet study (Manooch 1973) and our 2001 pilot study (results in Rudershausen et al., in press) found *Alosa* spp. in age-1 striped bass diets in the western portion of the sound. This part of the sound is the region of highest abundance for juvenile *Alosa* spp., based on NC Division of Marine Fisheries beach seine survey data (N.C.D.M.F., unpublished). Because of their higher abundance and higher weight specific consumption rate as compared to older fish, young striped bass should have the greatest impact on *Alosa* spp. Studies in other systems have shown that younger striped bass dominate the population-level consumption of biomass (Hartman and Brandt 1995c, Cyterski et al. 2002, Overton 2003). Another factor that would likely reduce the impact of predation by older striped bass in Albemarle Sound is that summer temperatures tend

to be well above optimal for age 2+ striped bass (Haeseker et al. 1996). For these reasons, this study primarily focused on the impact of age-1 striped bass on juvenile *Alosa* spp.

There is an expanding commercial fishery for yellow perch (*Perca flavescens*) in North Carolina and the North Carolina Department of Marine Fisheries is currently working on a fishery management plan for this species (N.C.D.M.F. 2004). Because of the interest in management of this species, and its occurrence as a common diet item in 2003, yellow perch was included in this study.

The three objectives of this study were to: (1) quantify the diet of age-1 striped bass; (2) calculate selectivity patterns of age-1 striped bass for dominant prey groups; and (3) determine the magnitude of predation by comparing predation rates and total loss rates of prey fishes. Additionally, predation (numbers eaten) was compared to available numbers of prey when total loss rates could not be estimated.

1.2 METHODS

1.2a STUDY AREA

Albemarle Sound is a submerged river bottom oligohaline estuary (Bowden and Hobbie 1977). The western end of Albemarle Sound (Figure 2) is approximately 135 kilometers from Oregon Inlet, the nearest source of saltwater. This portion of the sound is fed freshwater from the Chowan and Roanoke rivers; salinity is inversely related to river flow and weak stratification events are disrupted by high wind events (Bowden and Hobbie 1977). There is little tidal influence on water levels, whereas easterly winds can cause water levels to rise 0.3 to 0.6 meters (Heath 1983).

The study area generally consists of two different depth zones. Shoals are zero to 4 meters deep and extend up to 1400 meters between beach and channel areas. Channel areas have a relatively uniform depth of about 6 meters. The area sampled in western Albemarle Sound was about 32 kilometers in length with a maximum width of 13 kilometers (see insert in Figure 2).

1.2b FIELD SAMPLING

Predators and prey were sampled using two gear types. Shoal and channel areas were sampled using a beach and purse seine, respectively. During 2002 and 2003, both shoal and channel areas were sampled roughly biweekly from May through August and once every 3 weeks during September and October. Sampling was not performed during much of September 2003 because of safety issues caused by floating debris associated with Hurricane Isabel. Sampling during 2002 was both exploratory as well as functional and some sites were not visited on every occasion. Temperature, salinity and dissolved oxygen concentration were recorded at the surface during each beach seine trip and at the surface and bottom during each purse seine trip.

Shoal areas were sampled during the day using a 61 x 3 m beach seine (6.4 mm bar mesh wings and 4.8 mm bar mesh bag) set by boat. The horizontal area surrounded by a beach seine set was about 500 m². Beach seines of this type have been effective in quantifying and capturing age-0 fishes in other river systems (McBride et al. 1995, Buckel et al. 1999, DeLong et al. 2001). Each biweekly beach seine trip consisted of one seine haul at a minimum of 18 stations in 2002 and 18 fixed stations in 2003.

Channel areas were sampled at night with a purse seine set via a single boat and hauled in by hand. The circumference of the purse seine was 76 m and depth was 6.1 m (7.6 mm bar mesh).

Schooling behavior of fish is reduced at night and nighttime purse seining can reduce variance in catches (Tishchler et al. 2000). The horizontal area surrounded by a circular set was 462 m². Purse seines of this type have been effective in capturing pelagic juvenile fish in other studies (Hunter et al. 1966, Murphy and Clutter 1972, Evans and Johannes 1988, Tishchler et al. 2000) and shown to give similar density estimates of fish as horizontal acoustic methods (Yule 2000). The fishing depth of the purse seine was greater than the depth of the water so it fished the entire water column. The bottom of the purse seine was always muddy and catches often included benthic fishes (e.g. southern flounder, *Paralichthys lethostigma*) and brackish-water mollusks (e.g. *Rangia* spp.). A set of purse seine samples consisted of one seine haul at a minimum of 7 stations in 2002 and 12 fixed stations in 2003. Only 4 sites were sampled during 11-17 Aug 2002 and 10 sites 1-6 June 2003 because of adverse weather conditions.

During 2002, biweekly beach and purse seining was exploratory as well as functional whereas 2003 sampling was conducted at fixed sites throughout that year. Analyses of 2002 data are based on adjusted estimates of catch per unit effort (CPUE) using only those sites visited in both years (referred to as CPUE hereafter). Analyses for 2003 use an unadjusted CPUE. Density estimates for age-1 striped bass and prey needed for predation mortality calculations (see section 1.2.e) were calculated using the area estimates described above, assuming 100% capture efficiency.

Additional striped bass were collected throughout the sampling area via angling, boat-electrofishing, experimental gill nets, and otter trawl to supplement predator diet and growth information. Gill nets were soaked for an hour or less to prevent regurgitation of stomach contents and minimize digestion (Sutton et al. 2004). Experimental gill net bar mesh sizes were

13, 25, 38, 51, 64, and 76 mm. Age-1 striped bass samples from N.C.D.M.F. otter trawl survey catches within the sampling area were included in our study. Samples were also used from 24-hour sampling trips (see section 1.2.e).

All striped bass were preserved in 10% formalin for later diet analysis except for large catches (>25) which were subsampled (n=15-20). *Alosa* spp. were preserved in ethanol; large catches were volumetrically subsampled first. Other fishes were measured (total length $\pm$ 1 mm), enumerated and returned to the sound. During 2003, subsamples of age-1 striped bass and potential prey fishes were frozen in ice for later determination of seasonal energy content.

1.2c DIET FOR AGE-1 STRIPED BASS

Yearling striped bass ages were verified through examination of modal length-frequency diagrams and whole sagittae of a subsample of sizes. Whole preserved striped bass were blotted dry, weighed and measured (total length $\pm$ 1 mm). Stomach contents were identified to the lowest possible taxon, enumerated, blotted dry and weighed (0.001 g); total length ($\pm$ 1 mm) of prey items was measured when possible. Jaw morphology and scale type aided in identification of more digested fish. Peritoneum color and mandible shape were used in identification of *Alosa* spp. to species level. Atlantic Menhaden (*Brevoortia tyrannus*) were often identified by their distinctly shaped gizzard.

Striped bass diets were quantified by percent frequency and percent weight of occurrence. Percent weight was calculated using only organic, identifiable food items. Mean and variance estimates for percent frequency and weight diet indices were calculated with cluster sampling estimators (see Buckel et al. (1999) for a complete description). Using this method, each

collection (e.g. an individual seine haul, individual gillnet set, etc.) provided a cluster of non-independent fish.

Piscivorous fishes may consume fish prey in a net in which both are collected. Because this may bias stomach content analyses, the relative state of digestion of stomach content items was recorded. There was no evidence of net feeding in this study as all prey items showed signs of digestion.

1.2d FEEDING SELECTIVITY FOR AGE-1 STRIPED BASS

Prey-type selectivity of striped bass was determined by comparing the proportional contribution of individual fish species in striped bass diets with the proportional abundance of that prey species in the environment. The proportional abundance of prey in shoal and channel areas was separately measured by beach seine and purse seine collections, respectively. Prey taxa used for selectivity calculations were determined by selecting the dominant potential prey from each collection method. Manooch (1973) found that striped bass had consumed prey fishes up to 62% of their body length. Based on Manooch's work and the inspection of stomach items in this study, selectivity analysis included only those potential prey specimens whose total length was < 70% of the monthly average total length of age-1 striped bass.

Feeding selectivity for age-1 striped bass was estimated using Chesson's (1978) index:

$$\alpha_i = \frac{r_i / p_i}{\sum_{j=1}^m r_j / p_j} \quad i = 1, \dots, m$$

where,

α_i = selectivity for prey type i from a given predator collection

r_i = relative abundance of prey type i in age-1 striped bass diets

p_i = relative abundance of prey type i in seine samples (purse or beach)

m = the number of dominant prey types available

Chesson's index allows for selection to be compared temporally where prey abundances may change between dates (Chesson 1983). This index assumes that the catchability is equal for all prey types captured by a particular gear and that the prey abundance is large compared to prey consumed by a predator (Chesson 1978). The expected value of α_i when feeding is random (proportional to prey abundance) is $\alpha_i = m^{-1}$. Values where $\alpha_i > m^{-1}$ and $\alpha_i < m^{-1}$ indicate selection for and against a particular prey type, respectively. The values for m were 8, 4, 7 and 4 for the 2002 beach seine, 2002 purse seine, 2003 beach seine and 2003 purse seine, respectively. Relative abundance of prey type i (p_i) was computed from samples taken within 10 days of a striped bass sample. Predator samples (r_i) were compared with beach seine and purse seine estimates of p_i separately. Values of α_i were only computed on dates where at least two age-1 striped bass were captured. On days where more than one estimate of α_i was available, the standard error was calculated for the mean α_i value on that day. Further, this approach assumes that different prey types are identifiable at equal time points during digestion.

Because they represent a relatively small portion of the diet in most months, alosine species were grouped. During 2003, fewer age-1 striped bass were captured than in 2002 and selectivity values during October and May were not calculated. Yellow perch and silversides were not present in the purse seine prey field and selectivity values were not calculated.

1.2e CONSUMPTION RATES FOR AGE-1 STRIPED BASS

The daily ration of age-1 striped bass (g/g/day) was estimated from field 24-hour collections and using a bioenergetics model. Bioenergetics models have been developed for many fish species and are often used to predict consumption or growth (Whitledge et al. 2003). The field method provided point estimates that were used to validate or “ground-truth” predictions from the bioenergetics model.

This study employed the Kitchell et al. (1977) version of the mass-balanced bioenergetics models. These models follow the principle of the first law of thermodynamics: mass and energy must be conserved. The equation below represents the balanced energy budget used in the model where consumption (C) = metabolic losses + wastes + energy gain. Each element is expressed in joules while fitting daily consumption to observed growth. Consumption (C) is then converted back to a rate of grams of prey per gram of predator per day.

$$C = \underbrace{(R + A + Sda)}_{\text{Maintenance}} + \underbrace{(F + U)}_{\text{Wastes}} + \underbrace{(\Delta B)}_{\text{Energy gain}}$$

where,

ΔB = somatic growth in grams

F = egestion

U = excretion

R = resting metabolism

A = active metabolism

Sda = specific dynamic action

The model was programmed into Matlab (Matlab 2002) and run with the physiological parameters for age-1 striped bass (Hartman and Brandt 1995b) for all simulations. Consumption rates were estimated from 5/09/02 to 10/31/02 and from 5/13/03 to 10/31/03.

The input requirements for the model include water temperature, predator diet, growth of the predator and energy content of both predator and prey. Two separate temp loggers were placed 1 meter below the surface in the channel and shoal area during 2002. During 2003, temp loggers were similarly placed but temperature measurements were unrecoverable from the shoal temp logger. However, shoal area temperatures were recorded during beach seine collections. A daily temperature value (Figure 3) was taken as the mean of all possible measurements within the study (e.g. mean surface and bottom purse seine, mean beach seine, channel and shoal temp loggers). During early 2002, temperature information was only available on certain dates (05/09, 05/23, 05/30, 06/03, and 06/13). Daily temperatures between these dates were estimated with linear interpolation.

Diet information for age-1 striped bass collected during the 2002 (n=411) and 2003 (n=267) field seasons was used for inputs for the model (Table 1). Information on diet percentage by weight was grouped by month with the model interpolating between mid-points of each month (e.g. 15 Jun to 15 Jul). Using cluster estimators, the sum of food item estimates for an individual month may not add up to 100 %. So, for input to the model, monthly cluster estimators of identifiable animal food items by weight were normalized to 100 %. Starting dates for the May diet values in each of the two years are 5/09/02 and 5/13/03. During each year, September and

October diet values were grouped into one category and represent diet from September 15 onward.

Energy content of striped bass and prey were estimated from relationships between percent dry weight and whole body energy content (Table 2). In the laboratory, the specimens were thawed, patted dry, weighed (0.001 g) and dried at 70 C until weights were stable to determine percent dry weight. Percent dry weight is often linked to whole body energy content by establishing a mathematical relationship between the two where energy content is verified via other methods (e.g. bomb calorimetry). This approach has been used in other systems (Rippeto 1993, Rand et al. 1994, Hartman and Brandt 1995c, Lantry 1997) and often is a linear relationship between percent dry weight and joules/gram of fish (Hartman and Brandt 1995a). The slope of this model for juvenile fish is often less than slopes for these relationships determined for adult fish (Mark Wuenschel, N.O.A.A., pers. com.). Most of the prey fish were juveniles so care was taken to use models from data sets that included or were exclusively for juvenile fish. The relationships used for striped bass and prey fishes were from Hartman and Brandt (1995b) with the exception of yellow perch, silversides, *Menidia* spp., and Atlantic menhaden (Table 2). The age-0 Atlantic menhaden model was from Rippeto (1993) and the age-0 yellow perch model was established with data from Lantry (1997) and Kelso (1970) and the silverside model from data provided by Eric Shultz (University of Connecticut, pers com.). Energy content values for invertebrate prey were from the published literature (Table 3). Daily energy content values used in the model were estimated by interpolating between dates with measurements (Table 4).

Age-1 striped bass showed little ontogenetic shift in energy content in the Chesapeake Bay, only varying by 59 joules per gram from May through October (Hartman and Brandt 1995c) and also varied little in our study (although sample sizes were small). For these reasons, the energy content of age-1 striped bass in Albemarle Sound was based on pooled samples from all months (Table 5).

Observed growth of the predator over a period of interest is used to predict the consumption level that took place in the field. A logistic growth curve (Williams et al. 2001) was fit to the weight collected by date:

$$W_{SB} = \frac{\beta}{(1 + k * e^{-\lambda * t})}$$

where,

β, k, λ = model parameters

t = Julian date

This was fit for each field season with the SAS nlin procedure (SAS 2001). Each year's growth curve was used to generate weights of an average fish in grams (W_{SB}) at date for each field season (Figure 4).

When predicting consumption with a bioenergetics model, it is assumed that daily variations in feeding are accounted for in the amount of observed growth over a period of time. The model predicts the proportion of maximum feeding (p-value) that must have taken place over this period to result in observed growth. Input weights for the model were taken from the growth

curve in 14-day increments; short time periods such as this allow the most accurate model predictions of consumption (Rice and Cochran 1984).

The field method of estimating daily ration requires an estimate of stomach fullness over a 24-hour period at regular intervals. This also requires an estimate of gastric evacuation rate at temperatures similar to field conditions. Age-1 striped bass were collected in areas of known concentration at 4-hour intervals on 6/11/02, 7/11/02, 7/10/03, 8/5/03 and 9/8/03. Striped bass were collected with the 61-meter beach seine in 2002. During 2003, experimental gill nets and boat electrofishing were employed because of low striped bass catches in beach seines.

The Eggers (Eggers 1977) model was used to estimate consumption (C) in grams of prey per gram of predator per day where:

$$C = 24 * \bar{S} * G_e$$

where,

$\bar{S}$ = mean stomach fullness (g / g) of timepoint estimates over a 24-hour period

G_e = instantaneous rate of gastric evacuation

The instantaneous gastric evacuation rate, referred to hereafter as gastric evacuation rate (G_e), was estimated by fitting an exponential model to decreasing stomach fullness with the SAS nlin procedure (SAS 2001). The equation used for regression was:

$$S_t = S_0 * e^{-G_e * t}$$

where,

S_t = mean stomach fullness (g / g) at time t

S_0 = mean stomach fullness (g / g) at the starting timepoint of the regression

t = time in hours

Feeding is assumed to be zero over periods where the gastric evacuation rate is estimated from the loss in stomach contents. The gastric evacuation rate in 2002 was estimated from 16:00 on 07/11/02 to 08:00 on 07/12/02 and in 2003 from 08:00 on 07/10/03 to 16:00 on 07/10/03.

Changes in the rate of gastric evacuation are linked with water temperature (He and Wurtsbaugh 1993). The daily mean temperature on the two 2002 collections varied by less than 0.5 degrees C and varied by less than 1 degree for the two successful 24-hour collections in 2003. Therefore, each year's G_e estimate was used for both ration computations within that year. Standard errors for field estimates of consumption rates (σ_c) were computed via the delta method (Williams et al. 2001) where the standard error is computed as:

$$\sigma_C = 24 * (\bar{S}^2 * \sigma_{G_e}^2 + G_e^2 * \sigma_{\bar{S}}^2)^{0.5}$$

where,

$\sigma_{\bar{S}}$ = standard error of timepoint estimates of mean stomach fullness over 24-hours

σ_{G_e} = standard error of the gastric evacuation rate

1.2f PREY LOSS RATES DUE TO PREDATION

Prey loss rates due to predation were calculated separately for either purse seine (channel area) or beach seine (shoal area) samples. Calculations were performed at estimated mean values. Standard errors were estimated using the delta method (Williams et al. 2001). The bioenergetics model does not provide a standard error for consumption rate estimates; this

parameter was used as a multiplier. The calculations were performed as follows: first, the biomass of the predator (B_{SB}) in grams within the area of a seine haul on a given date was calculated:

$$B_{SB} = D_{SB} * W_{SB}$$

where,

D_{SB} = density of age-1 striped bass (individuals / seine haul)

W_{SB} = predicted weight of striped bass from growth curve (grams / individual)

Then biomass of prey fish eaten (B_{PREY}) in grams at day is calculated:

$$B_{PREY} = B_{SB} * C * P_{PREY}$$

where,

C = consumption rate (g/g/day) of age-1 striped bass from bioenergetics model

P_{PREY} = % of particular prey in diet by weight from non-normalized cluster estimators

For individual *Alosa* spp., the estimates of the effects of age-1 striped bass predation effects are conservative (biased low) because we had no way of assigning unidentified *Alosa* spp. to species specific P_{PREY} categories.

To estimate the weight of a particular species eaten at date, linear relationships of length eaten vs. date and length weight regressions were combined. For relationships of total length eaten at date, the sizes of prey in the stomachs of striped bass were measured directly when possible. Some specimens of *Alosa* spp. were partially digested and length was estimated from measurements of other characters. These meristic relationships were established with ethanol-preserved *Alosa* spp. that were rehydrated and measured (Table 6). Because the numbers of each *Alosa* spp. measured in the diet were small, data from both years for each species were

combined. For yellow perch, direct measurements of prey length eaten were sufficient to establish a linear relationship in 2003 (Table 7). Length weight regressions for *Alosa* spp. were from rehydrated beach and purse seine fish that were patted dry, weighed and measured. Yellow perch length weight regressions were from frozen fish that were thawed, patted dry, weighed and measured (Table 8).

An estimate of the weight of a particular species eaten at date (W_{prey}) was:

$$W_{\text{prey}} = \alpha * (b + m * t)^\beta$$

where,

α = intercept of that year's length to weight regression of prey species

β = exponent of that year's length to weight regression of prey species

b = intercept of linear regression relating length of prey species in diet to Julian date

m = slope of linear regression relating length of prey species in diet to Julian date

t = Julian date

The numbers of individual prey items eaten in shoal or channel areas were calculated between beach seine or purse seine dates respectively. This was done by summing the numbers of individuals eaten (I_{prey}) between seining dates:

$$I_{\text{PREY}} = \left(\sum_{\text{period of interest}} B_{\text{PREY}} / W_{\text{PREY}} \right)$$

The numbers of individuals eaten was also summed for ± 1 S.E. of the previous calculations.

The estimate of the instantaneous loss rate of a particular prey type due to predation (M_{PRED}) was then:

$$M_{\text{PRED}} = (I_{\text{PREY}} / D_{\text{PREY}}) / \text{number of days}$$

where,

D_{PREY} = geometric mean density of prey during the period of interest

The daily loss rate due to predation was calculated as $1 - e^{-M_{\text{pred}}}$. The numbers eaten and prey densities used to calculate M_{PRED} were gear specific.

Prey loss rates were calculated over the same time period that catch curve loss rates were calculated (see section 1.2g). Prey and total loss rates were compared for American shad within the beach seine during both years, yellow perch in the beach seine in 2003, alewife in the beach seine in 2003, and alewife in the purse seine in both years.

1.2g PREY TOTAL LOSS RATES AND PREDATORY IMPACT

Catch curve analysis was used to estimate total loss rates where the instantaneous total loss rate of prey items (Z) is computed as the slope of decreasing $\ln(\text{CPUE})$ over time (Ricker 1975). Catch curve analysis was performed separately for beach seine (shoal area) and purse seine (channel area) density estimates through time. The criterion that had to be met for this method to be used was that the fish densities had an ascending and descending limb. This method assumes that the total loss occurs at a constant rate and that this loss can be attributed solely to mortality. To discount a bias associated with the immigration of younger/smaller fish into the sampling area, catch curves were fit at times when the monthly length frequency distribution was consecutively unimodal.

Catch curve estimates of total loss assume that immigration and emigration are negligible. To reduce the bias associated with emigration out of the study area, loss rates were estimated over times where fish movement was assumed to be low. Juvenile *Alosa* spp. typically migrate out of their primary nursery habitat during late summer or early fall (Bozeman and Van Den Avyle 1989). Cues to fall migrations likely include a variety of factors: decreasing length of day,

falling water temperature, increased rainfall, rising water levels, and increased flow rates (Leggett 1976, Marcy 1976, O'Leary and Kynard 1986, Bozeman and Van Den Avyle 1989, Stokesbury and Dadswell 1989, Winslow and Rawls 1992). Because several of these cues were associated with declines in water temperature, water temperature was used as an indicator of fall emigration.

Water temperatures that have been reported to cue mass fall emigrations of juvenile *Alosa* spp. in other east coast estuaries range from 18°C to 23°C (Leggett 1976, Marcy 1976, O'Leary and Kynard 1986). The highest temperature reported to cue the beginning of emigration out of nursery areas was by Marcy (1976), who stated that emigration may begin at 23-26°C. To minimize the error in total loss estimates introduced through emigration, a 26°C temperature criteria was used to terminate catch curve analysis. Catch curve analysis was applied to data beginning at peak catch and terminating at the point preceding the first mean water temperature of 26°C after mid-July (Figure 3). Because less is known about seasonal use of the estuary by juvenile yellow perch, catch curve analysis was applied from the maximum point on the catch curve until the last date where the monthly length frequency distribution was unimodal.

Daily total loss rates were computed as $1 - e^{-Z}$. These were compared with daily loss rates due to predation (see section 1.2.f) over the same time interval to determine how important striped bass predation was to the apparent total loss rate of a particular prey fish.

Because data for blueback herring (all cases) and alewife (2002 beach seine) never met the criteria for catch curve analysis, an additional comparison was included to quantify the relative effects of striped bass predation on these fishes. Estimates of density of prey fishes (#'s / area) were compared to the numbers lost due to predation. Each estimate of density was from beach

seine or purse seine sampling dates. The numbers lost to predation were computed from the preceding to the following midpoint between sampling dates. The assumption here was that our estimates of density were valid across midpoint dates.

1.3 RESULTS

1.3a WATER QUALITY

During 2002, surface salinity, temperature and dissolved oxygen levels were similar in the shoal and channel areas but shoal temperature and dissolved oxygen levels (DO) showed more variability than surface measurements in channel areas (Table 9). Bottom channel temperatures (23.1 – 27.6 C) were slightly lower than at the surface (23.4 – 28.5 C). Bottom salinities (2.4 – 7.6 ‰) were up to twice the coinciding surface measurement (1.9 – 4.2 ‰). Also during these times, bottom DO (2.0 – 6.1 mg/Liter) was much lower than at the surface (7.0 – 7.8 mg/Liter) (Table 9).

During 2003, mean surface temperature and DO were similar in channel and shoal areas with more variability on the shoals (Table 9). The surface and bottom temperature in the channel were very similar and all salinity measurements in 2003 were low. The maximum salinity measurement taken was 1.8 ‰ and the monthly mean was always less than or equal to 0.1 ‰ for shoal and, channel surface and bottom. Channel bottom DO levels (4.2 – 6.1 mg/Liter) were slightly lower than surface measurements (4.8 – 7.3 mg/Liter) but never fell below 3.5 mg/Liter. The low monthly mean purse seine DO measurements in October (4.8 mg/Liter at surface, 4.4 mg/Liter at bottom) were a result of Hurricane Isabel.

1.3b THE FISH COMMUNITY

A total of 97,247 and 46,807 fish were captured with the beach seine in 2002 and 2003, respectively (Table 10). Most fishes captured were either juveniles or other small fishes (e.g. *Menidia* spp., *Fundulus* spp., *Notropis* spp.). The mean total length (TL) of captured fishes in the beach seine in 2002 was 79 mm (standard deviation, SD = 40; range 21-790) and 59 mm (SD = 32; range 20-600) in 2003. A total of 5,706 and 6,930 fish were captured in the purse seine in 2002 and 2003, respectively. The mean TL of fishes captured in the purse seine in 2002 was 74 mm (SD=34; range 37-1200) and 74 mm (SD=41; range 28-910) in 2003.

Beach seine catches in 2002 represented 33 genera from 23 families (Table 10). The top 5 genera by frequency of occurrence were *Menidia*, *Anchoa*, *Morone*, *Mugil* and *Leiostomus*. *Alosa* was the sixth most abundant genus at 5.4% of the total catch. Beach seine catches in 2003 were less diverse with 24 genera from 18 families represented. The top 5 genera were *Brevoortia*, *Alosa*, *Perca*, *Menidia* and *Morone*.

While a large percentage of beach seine catches were of non-pelagic genera (e.g. *Leiostomus*, *Micropogonias* and *Morone*), the purse seine catches were dominated by pelagic fishes (e.g. *Alosa* and *Brevoortia*). Purse seine catches were less diverse than beach seine catches in both years. Purse seine catches included 16 genera from 10 families in 2002 and 19 genera from 15 families in 2003 (Table 10). The family Clupeidae composed over 70% of the catch in each year. The top 2 genera by frequency of occurrence in both years were *Alosa* and *Brevoortia*, which together comprised 70% and 80% of the 2002 and 2003 catches, respectively.

1.3c YEARLY DISTRIBUTION OF PREDATOR AND PREY

The total number of blueback herring captured in both gears during both years (12,053) was much higher than alewife (4,001) or American shad (2,913) suggesting that blueback herring are

the most abundant of these three fishes in western Albemarle Sound (Table 11). Blueback herring were also the most abundant *Alosa* spp. captured with the purse seine in both years and the beach seine in 2003 (Table 11).

American shad CPUE in the beach seine were an order of magnitude higher than in the purse seine; shad were caught almost exclusively with the beach seine (Table 11). Blueback herring and alewife CPUE were higher in the purse seine compared to the beach seine but were within the same order of magnitude. Thus, American shad occupy shoal areas preferentially over channel areas while blueback herring and alewife occupy both.

Generally, temporal patterns in beach and purse seine CPUE for juvenile fish prey and striped bass were highly variable (Figures 5-9). American shad CPUE in the beach seine increased from near zero to a peak in late May-early June and then showed a decline during both field seasons (Figure 5a, 7a). Monthly length frequency distributions of shad collected with the beach seine showed a unimodal distribution throughout both field seasons (Figure 10a, b). Purse seine catches of shad were very low (Figure 6a, 8a) and no temporal trends were observed. Because of these low samples sizes, length frequency distributions were not compiled for shad collected in the purse seines.

Alewife CPUE did not show an ascending and descending limb in the beach seine in 2002 (Figure 5b). Mean beach seine CPUE of alewife in 2002 was low relative to 2003. During 2003, alewife beach seine catches did show an ascending and descending limb with a peak CPUE in May (Figure 7b) and a unimodal length distribution (Figure 11b). Purse seine catches of alewife were conducive to catch curve analysis in both years with ascending and descending limb (Figure 6b, Figure 8b) and unimodal length frequency distributions (Figure 12a, b).

Beach seine CPUE of blueback herring in 2002 was variable but generally showed an increasing trend through time (Figure 5c). This pattern was also observed in the beach seine in 2003 but the CPUE was dominated by extremely high catches during the week of 08/18/03 (383 fish per haul, Figure 7c). Catches of blueback herring in the purse seine were less variable than in the beach seine. An increasing trend of blueback herring CPUE was observed for 2002 and 2003 purse seine collections (Figure 6c, 8c). Catch curve analysis could not be applied to the 2002 beach seine alewife because of the large variation in catches through time (Figure 5b); additionally, length frequency distributions were not always unimodal (Figure 12). This may have been because our sample design could not accurately observe the lower population size of alewives in 2002. Although length frequencies were unimodal (Figure 13, 14), the 2002 and 2003 blueback herring catches generally increased through time (Figure 5c, 6c, 7c, 8c), so catch curve analysis was not valid.

Generally, all three clupeids were more abundant in shoal and channel areas in 2003 when compared with 2002 (Table 11). The mean(CPUE) for alewife and American shad in the beach seine increased by a factor of 2 in 2003. The mean(CPUE) of blueback herring increased by a factor of 40 in the beach seine in 2003. The 2003 mean(CPUE) of alewife in the purse seine was double the 2002 values. However, the mean(CPUE) of blueback in the purse seine was higher in 2002 than 2003.

Juvenile yellow perch primarily occupied shoal areas; no yellow perch were captured with the purse seine in 2002 and only a total of 9 were caught in 2003. Juvenile yellow perch were much less common in beach seine catches in 2002 than 2003; densities increased by a factor of 20 from 2002 to 2003 (Table 11). Beach seine catches showed an ascending and descending limb in

2002 and 2003 (Figure 5d & 7d); additionally, length frequency distributions were unimodal throughout summer months (Figure 15).

Age-1 striped bass occupied both shoal and channel areas but the beach seine mean(CPUE) was always higher than in the purse seine for both years (Table 11). Additionally, age-1 striped bass densities were much higher in shoal areas during 2002 than 2003 (0.67 and 0.09 mean(CPUE) respectively). Length frequency distributions for age-1 striped bass are presented in Figure 16.

1.3d DIET FOR AGE-1 STRIPED BASS

Striped bass consumed a variety of fishes in 2002 but Atlantic menhaden, bay anchovy, *Anchoa mitchilli*, and silversides were the dominant prey types by weight from May through August (Table 12a; Figure 17a). Atlantic menhaden decreased from being a major component of the diet by weight in May to not being present in September-October diet. *Alosa* spp. composed less than 25% of the biomass of diet items until September-October when they were over half of the diet by weight. Invertebrates comprised less than 9% of the diet by weight in most months of 2002; the September-October diet was about 15% invertebrates by weight (Table 12a; Figure 17a). Other fish consumed by age-1 striped bass in 2002 included Atlantic croaker, *Micropogonias undulatus*, bluefish, *Pomatomus saltatrix*, goby, Gobiidae, killifish, *Fundulus* spp. , mullet, *Mugil* sp., speckled trout, *Cynoscion nebulosus*, spottail shiner, *Notropis hudsonius*, age-0 striped bass, and white perch, *Morone americana* (Table 12a).

During 2003, striped bass were again primarily piscivorous. Invertebrates were about 4% of the diet by weight during May but less than one percent in all other months (Table 12b; Figure 17b). Yellow perch dominated the biomass of the diet during May (81% by weight) and

continued to be a primary component through August (Table 12b; Figure 17b). Atlantic menhaden increased by weight (from 6% to over half of the biomass of diet items) and frequency in the diet from May through August but were not present in September-October. *Alosa* spp. increased from 8 % of the diet by weight in May to being most of the diet biomass in September-October 2003 (Table 12b; Figure 17b). Silversides and bay anchovy were never a large component of the diet in 2003. Age-1 striped bass also consumed Atlantic croaker, killifish, spottail shiner, sunfishes, *Lepomis* spp., and white perch in 2003 (Table 12).

The primary *Alosa* spp. found in the diet changed between years. The percent biomass that American shad contributed to those *Alosa* spp. prey items identified to species decreased from 25 to 3% from 2002 to 2003. Alewives increased by weight from 10 to 34% and blueback herring decreased very little from 65 to 63% from 2002 to 2003.

1.3e FEEDING SELECTIVITY FOR AGE-1 STRIPED BASS

Most mean values of selectivity were not significantly different from random feeding. However, there is some biological importance in seasonal patterns of selectivity that were measured for age-1 striped bass. For both gears, selectivity values for Atlantic menhaden (mean and single estimates) trended towards selection in May through June-July and selection against in August and early fall of 2002 (Figure 18a, b). Striped bass selectivity values for *Alosa* spp. shifted from random feeding in early summer to selection for *Alosa* spp. after early August in both gears in 2002. Striped bass selection for silversides was variable (Figure 18a) throughout the 2002 season.

Using the 2003 beach seine data, yellow perch were selected over other species in May but selection for this species decreased over the course of the season (Figure 19a). Selection for

Atlantic menhaden (beach seine) increased throughout the summer in 2003 in a pattern opposite that of yellow perch (Figure 19a) while the 2003 beach seine selectivity values for *Alosa* spp. remained near random feeding most of the year (Figure 19a). For purse seine estimates, selection for Atlantic menhaden was high for most of the summer (Figure 19b) while selection for *Alosa* spp. was variable with periods where they were selected against (summer months) and periods they were selected for (Fall).

1.3f CONSUMPTION RATES FOR AGE-1 STRIPED BASS

The mean stomach fullness pattern for the June 2002, 24-hour collection was variable and generally low; all timepoint values were less than 0.015 g/g (Figure 20a). The July 2002 collection peaked at 16:00 and decreased during night (Figure 20b). This decrease in stomach fullness yielded a gastric evacuation rate estimate of 0.148.

Mean stomach fullness for the July 2003 collection was highest at both of the 08:00 timepoints and lowest values at 00:00 (Figure 21a). The decrease in stomach fullness throughout the day yielded a gastric evacuation estimate of 0.147 for July. Striped bass collected in August 2003 had peak stomach fullness at 20:00 and lowest stomach fullness at 12:00 (Figure 21b).

Daily mean stomach fullness (means of timepoint means) during a 24-hour collection in both years ranged from 0.007 to 0.021 g/g (Table 13). When combined with our estimates of gastric evacuation, the field estimates of consumption ranged from 0.025 to 0.078 g/g/day in 2002 and 2003 (Table 13). On 9/8/03, samples sizes of age-1 striped bass were too low ($n=18$) over the 24-hour collection and estimates of consumption rate were not possible.

Bioenergetics modeling provided daily estimates of consumption from May through October in both years. In 2002, daily consumption estimates (C , g/g/day) ranged from 0.04 to 0.12

g/g/day. Seasonally, consumption rates increased from May until mid July and then decreased through October (Figure 22a). Bioenergetics model estimates of consumption rates declined markedly for a short period around 08/02/02; this drop coincides with temperatures that approached 30 °C (Figure 22a). This is the near the upper thermal limit allowed in the temperature-based consumption function. Bioenergetics model estimates of consumption rates were within 2 standard errors of the July field estimate of consumption but markedly differed from the June field estimate of consumption rate (Figure 22a). Bioenergetics estimates of C ranged from 0.03 to 0.094 g/g/day in 2003 (Figure 22b). Seasonally, C estimates followed a similar pattern as 2002 where rates climbed to a maximum around mid-July and declined through October. When compared with field estimates in 2003, model estimates were within 2 standard errors of the July field estimate and matched well with the August field estimate (Figure 22b).

For each day, given all inputs, the model predicts a theoretical maximum consumption. The p-value is the percentage of this maximum consumption that must have occurred to explain the observed predator growth. P-value fits to growth for 2002 started at 0.78 and for 2003 at 0.76. P-value fits for each year increased to a maximum in July and decreased through October (Figure 23a, b). These values theoretically range from 0 to 1 but estimated values exceeded 1 briefly in both years at the apex of the seasonal pattern in p-value fits.

1.3g PREY LOSS RATES DUE TO PREDATION

In the shoal areas in 2002, mean loss rate due to predation for American shad was 4.17 % (0-11.3%) (Table 14a). Channel predation rates for alewife in the purse seine that year were much lower with a mean estimate of 0.28% per day (0-0.6%). Predation rates never exceeded 0.68% per day at any time during 2002 for Alewife.

Estimates of mean predation mortality of American shad in 2003 were never above 0.001 % per day at any time (Table 14b). Predation mortality rate estimates for alewife in both the shoal and channel areas were low in 2003; the mean shoal and channel predation rates were 0.12 % (0-0.36%) and 0.12% (0.02-0.23%), respectively (Table 14b).

There was no evidence of juvenile yellow perch consumption by age-1 striped bass in 2002. During 2003 on the shoal, the mean predation mortality rate for yellow perch was highest in May and June (~4% per day) and averaged 1.38 % per day (0.12-2.77%) for all time periods combined (Table 14b).

1.3h PREY TOTAL LOSS RATES AND PREDATORY IMPACT

Estimates of instantaneous mortality rates (Z ; d^{-1} ; Figure 24a-g) were converted into conditional mortality (loss) rates for American shad, alewife and yellow perch. The total loss rate in shoal areas for American shad in 2002 was 2.5 % per day and was 5.5 % per day for yellow perch (Figure 24a&f; Table 14a). Alewife in the channel area declined at a rate of ~5.0 % per day (Figure 24d; Table 14a).

American shad densities decreased only slightly over the course of the 2003 season (a loss rate of 0.15 % per day) in shoal areas (Figure 24b; Table 14b). In 2003, the alewife loss rate was 1.8 % per day in shoal areas whereas the channel area loss rate was much lower at 0.6% per day (Figure 24c&e; Table 14b). The total loss rate for yellow perch in shoal areas was 4.6% per day in 2003 (Figure 24g; Table 14b).

Predation by age-1 striped bass accounted for more than all of the apparent loss rates of American shad in shoal areas in 2002 (Table 14a). The Alewife predation loss rate was 6% of

the total loss rate in 2002. Age-1 striped bass predation did not account for any of the yellow perch loss rate in 2002.

Shoal area striped bass predation on American shad in 2003 was essentially zero while total loss rates were 0.15 % per day (Table 14b). In 2003, the predatory effect of striped bass on alewife was higher than in 2002 and accounted for 7% and 20% of total loss rates in the shoal and channel areas, respectively. The larger effects on alewife in 2003 were because of the lower total loss rates whereas the predation loss rate was similar between years. Predation on juvenile yellow perch accounted for 32% of their total loss rate in 2003 (Table 14b). However, most of the loss in numbers of juvenile yellow perch occurred from 5/26/03 to 6/10/03. The loss due to predation accounts for 107% of the total loss during this period (Table 14b).

Catch curves analysis was judged inappropriate for blueback herring for both gears and years, and alewife in the beach seine in 2002. In order to gain insight into predation effects in these cases, numbers eaten were compared to standing stock measures. Predation on alewife in the shoal area during 2002 was comparable in magnitude to the density available for predation (Figure 25) during several periods from May-August; the numbers of alewife eaten by age-1 striped bass in the shoal area dropped to zero during September and October.

A comparison of blueback herring density versus estimated numbers eaten by age-1 striped bass for 2002 suggests that predation mortality varies in importance through time for the shoal area and is relatively unimportant in the channel area (Figure 26). Estimated numbers of blueback herring juveniles eaten by age-1 striped bass in shoal areas increased gradually until July then dropped off quickly; this was followed by increases in number eaten beginning in late August which increased to very high levels in October (Figure 26a). The estimated numbers of

blueback herring eaten from May through July and in October exceeded the available density. During 2002, purse seine age-1 striped bass densities were low and the numbers of blueback herring lost due to predation was near zero and is minimal as compared to available density (Figure 26b).

In May and June 2003, the estimated numbers of blueback herring consumed in shoal areas were higher than available densities as in 2002 (Figure 27a). However, there was no fall peak in blueback herring consumption in 2003 (Figure 27a). The estimated numbers of blueback herring consumed using purse striped bass densities were higher or close in value to available densities during June and July; numbers eaten were very low from August 1 onward (Figure 27b).

1.4 DISCUSSION

1.4a YEARLY AND SEASONAL PREDATION PATTERNS

Many piscivores undergo an ontogenetic shift from invertebrate to fish prey during the first or second year of life (Mittelbach and Persson 1998). Yearling striped bass were piscivorous in May samples during both years of this study. In other east coast estuaries yearling striped bass did not shift to feeding primarily on fish until late June (Overton 2003), mid summer (Hartman and Brandt 1995d) or late summer (Buckel and McKown 2002). Manooch (1973) also found that age-1 striped bass were already piscivorous by late spring in Albemarle Sound.

Age-1 striped bass attain a larger size at a given date in Albemarle Sound than in more northern estuaries (Rudershausen et al., in press). This may enable Albemarle Sound yearling striped bass to be more effective piscivores at a given date than individuals from more northern populations; striped bass capture success on fish prey is inversely related to prey size-predator size ratio (Scharf et al. 2003). It is not known whether this larger size is due to a difference in

growth potential or environmental factors (e.g. temperature, food availability); Coutant (1985) suggested that higher first-year growth by striped bass in southern latitudes might be due to the longer growing season.

Age-1 striped bass had high selection values for soft-rayed fishes from the suborder clupeoidei. Similar to our findings, Manooch (1973) identified Atlantic menhaden, blueback herring, alewife and unidentified clupeids in the diet of age-1 striped bass in Albemarle Sound; however, this is the first documentation of American shad as a component of age-1 striped bass diet in this area. Soft-rayed fishes composed most of the biomass of the diet in all months for both years with the exception of early 2003 when yellow perch were a large portion of the diet. Despite the relatively early piscivorous behavior of age-1 striped bass and the inclusion of clupeoidei fishes as a major diet item throughout the season, *Alosa* spp. were never more than 20% of the diet by weight in May and June of either year. The diet and selectivity results were contrary to the expectation that *Alosa* spp. would be particularly vulnerable to predation shortly after metamorphosis from the larval stage (i.e. juveniles during May and early summer). Predation on early stages of *Alosa* spp. during these periods may be buffered by the high abundance of alternative prey types. During September and October in both years, age-1 striped bass had increased selection for *Alosa* spp. and they became the dominant prey during these months.

During 2002 and 2003, blueback herring comprised the majority of the fall alosine biomass in the diet of age-1 striped bass. Blueback herring spawn the latest of the three *Alosa* spp. (Schmidt et al. 1988) and were smaller in size late in the summer than American shad or Alewives. This would make them more vulnerable to predation than other *Alosa* spp.; additionally, densities of

alternative prey are decreasing at this time. Following August, estuarine water temperatures begin to drop and *Alosa* spp. along with other juvenile fish begin to emigrate out of primary nursery areas.

Densities of blueback herring sharply increased in September through October during both years. This suggests that blueback herring may have primarily occupied areas upstream of the study area and passed through the study area during their outmigration. This agrees with Schmidt et al. (1988) who found that juvenile blueback herring occupied areas farther upstream than American shad or alewives in the Hudson River. A combination of small PPR (see Table 15) and high density are likely the cause of striped bass selection for blueback herring during fall months.

Yellow perch were not a component of age-1 striped bass diets during 2002; this was probably due to this prey's low density and relatively large size (see Table 15). During 2003, the seasonal decreasing selection pattern for yellow perch mirrored the concurrent decrease of yellow perch in the diet of age-1 striped bass. Rudershausen et al. (in press) found that age-1 striped bass selected against spiny-rayed fishes such as Atlantic croaker. Age-1 striped bass selection against spiny-rayed fishes and the ontogeny of yellow perch spine development may partially explain the decreasing selection for yellow perch in 2003.

1.4b CONSUMPTION RATES

The rates of consumption rate for age-1 striped bass estimated here were similar between years in magnitude and pattern. In general, the bioenergetics model estimates were higher than field estimates. However, on three of four occasions, bioenergetics model estimates were within

two standard errors of the field estimates. Because both are estimates with their own assumptions, either or both could be incorrect.

These are the first field obtained estimates of age-1 striped bass consumption rate during summer months in an estuarine environment. With this approach, if feeding took place over periods where G_e was estimated, then G_e and the resulting consumption rate estimates would be biased low. This could explain the discrepancy between the two approaches. Unfortunately, there are no published estimates of age-1 striped bass gastric evacuation rates at similar temperatures. Field and laboratory measurements of gastric evacuation rates in striped bass at multiple temperatures are needed. During 2003, age-1 striped bass could not be obtained at the 00:00 (August) or the 04:00 (July and August) timepoints and this lack of information on stomach fullness may have also biased estimates of consumption rate.

Overton (2003) conducted a sensitivity analysis of annual bioenergetics model runs using Chesapeake Bay data and the physiological parameters for all ages of striped bass from Hartman and Brandt (1995a). He found that the model was very sensitive to prey energy densities, RB (slope of the allometric mass function for resting metabolism vs. weight) and RQ (approximation of the Q_{10} effect of temperature on resting metabolism). Bioenergetics models assume that laboratory measured physiological parameters for fish are valid in the wild; future comparisons between field studies and bioenergetics modeling of striped bass will help in determining the validity of the bioenergetics model.

When comparing bioenergetics model and field estimates of consumption rate, Rice and Cochran (1984) found that their field estimates for largemouth bass followed the same general pattern as their bioenergetics estimates but did not always correspond closely. However, because

growth inputs to bioenergetics models integrate variable feeding rates over time, Rice and Cochran (1984) concluded that bioenergetics estimates of cumulative consumption may be better than predictions based solely on field estimates of consumption. Given that we cannot determine which of the consumption rate estimates is best with the data at hand and the fact that bioenergetics models give daily estimates of consumption rate throughout the summer, we chose to use the bioenergetics model for estimating the effect of age-1 striped bass on prey fishes.

The seasonal p-value fits for each year exceeded one (i.e. 100% of maximum consumption) during periods where seasonal temperatures peaked. Since the p-value is the proportion of maximum feeding that has taken place given the amount of growth in the predator (Kitchell et al. 1977), the periods of p-values greater than one and near one could be the result of a predator maximizing its growth potential; in Albemarle Sound this may be due to abundance of prey. Similar to our study, Hartman and Brandt (1995c) found that age-1 striped bass in Chesapeake Bay were prey limited until June but had adequate prey and optimized their growth potential (e.g. p-values at or near 1) until about September when they began to be prey limited again.

The physiological temperature limits within the model reduce maximum consumption by 2% at 28 C and reduce consumption markedly as temperatures approach and surpass 30 C. A dramatic example of this physiological limit on consumption was seen in the marked decrease in consumption estimates in early August 2002. Mean daily temperatures used in the bioenergetics model were above 28 C on 20% and 16% of bioenergetics model days from May through October during 2002 and 2003 respectively. Higher temperatures also increase the maintenance costs of respiration (i.e. resting respiration increases exponentially with temperature) within the model. Juvenile striped bass in Florida have reduced growth during summer months because of

temperature limitations (Coutant 1985). North Carolina is in the southern portion of the range for this cool-water species (Coutant 1985) and as such, summer temperatures may be near the upper thermal range for a few days each season. However, the temperatures used in the bioenergetics model are mean values and it's possible that age-1 striped bass move to cooler refuge areas during high temperature days.

1.4c THE EFFECTS OF AGE-1 STRIPED BASS PREDATION ON PREY FISHES

Age-1 striped bass have been found to interact strongly with clupeid and engraulid fishes in other systems. For example, age-1 striped bass were a large contributor to annual consumption of clupeid fishes in Smith Mountain Lake (Cyterski et al. 2002). Hartman and Brandt (1995c) modeled age-1 striped bass consumption using a hypothetical predator population in Chesapeake Bay and found a strong annual predatory link with clupeid and engraulid fishes. Similarly, Hartman (2003) found that predatory demand of striped bass on clupeids either at a coast-wide spatial scale (U.S. east coast and Atlantic menhaden) or estuarine scale (Hudson River and *Alosa* spp.) was exceedingly high. The studies above described impacts at coarse temporal scales (i.e., years); the predatory impacts in this study were determined at finer temporal scales to determine if age-1 striped bass are a significant source of daily mortality during the potentially critical early juvenile stage.

The estimate of juvenile American shad total loss rate in 2002 (2.45 % per day) is similar to otolith-derived loss rates for juvenile American shad estimated in other east coast estuaries. Loss rates for juvenile American shad ranged from 1.5 – 2.2 % per day in the Connecticut River (Crecco and Savoy 1987) and mean loss rate of shad was 1.7% per day in the Hudson River (Limburg 1996). Daily loss rate estimates for other juvenile fishes are similar; a daily rate of

1.2% has been estimated for juvenile winter flounder, *Pseudopleuronectes americanus*, 2.9% for juvenile largemouth bass, *Micropterus salmoides*, and 1.5% for juvenile striped bass (Crecco et al. 1983). During 2002, age-1 striped bass were more abundant in shoal areas than in 2003 and striped bass predation could account for all of the total loss in American shad. In 2003, age-1 striped bass were far less abundant in shoal areas and the estimate of the predation loss rate was zero. This is surprising because American shad were more abundant in 2003 than in 2002. These results support the total loss rate estimate for American shad in 2003, which was nearly zero.

Direct impacts of predators on prey require that predator and prey overlap in time and space and that prey are available for capture during that time (Bax 1998). In Albemarle Sound, American shad appear to occupy shoal areas almost exclusively. This finding is in agreement with American shad spatial distributions in the Hudson River (Schmidt et al. 1988, Limburg 1996). Thus, the impact of age-1 striped bass on American shad will be primarily limited to shoal habitats and will be dependent on their overlap in this area.

Predator prey interactions can be influenced by hypoxic bottom waters as a result of changes in predator and prey overlap (Keister et al. 2000). Although this sampling design was not focused on age-1 striped bass movement, there is evidence to suggest that yearly changes in hypoxic bottom waters in channel areas may contribute to yearling striped bass use of shoal areas and thus their impact on fishes occupying the shoal areas. Juvenile striped bass avoid dissolved oxygen concentrations of 3.8-4.0 mg/Liter (Meldrim et al. 1974) while adults become physiologically stressed when levels approach the vicinity of 3.0 mg/Liter (Coutant 1985). During 2002, several saline stratification events led to hypoxic bottom waters (<3.0 mg/Liter) in channel

areas while during 2003 the channel area was consistently well-mixed. Additionally, during summer 2002, dead striped bass (age 2+) were often observed floating at the surface while during 2003 this was rare (J.E. Tuomikoski, personal observation). Striped bass may have used the shoal habitat as a refuge from hypoxic waters in 2002 leading to elevated predation on American shad.

Yearling striped bass predation appeared to have relatively little impact on juvenile alewives. Total loss rates were much lower in 2003 than 2002 whereas predation loss rates remained about the same between years. Although, predation estimates by age-1 striped bass were a larger percentage of the total estimates loss in 2003 most of the total loss rate in both years is unaccounted for. Estimates of numbers eaten on the shoal in 2002 are comparable in magnitude to estimates of numbers available for predation but a comparison of loss rates was not possible that year on the shoal. Sources of loss other than age-1 striped bass would include birds, older striped bass or other fish predators in this system. Rudershausen et al. (in press) found that older striped bass, captured concurrent with this study, contained very few *Alosa* spp. Other fish predators in this system include southern flounder and white perch but neither of these predators is as abundant as age-1 striped bass. Little is known of avian predators in the system although cormorants and gulls were commonly seen within the study area. Avian predators are known to be positively size selective and it is possible that the larger body size of alewife makes them more vulnerable to avian predators.

When comparing estimates of numbers of bluebacks eaten in shoal areas to available densities in 2002, the numbers of blueback eaten in May/June and in September/October exceeded apparent available densities. This non-intuitive result may be a result of blueback herring

immigrating into the sampling area (e.g. a continual input or throughput of prey) resulting in density estimates that are much lower than the actual numbers available for predation. The low density of age-1 striped bass in the channel areas in 2002 (as determined from the purse seine) may mean that this habitat is a refuge from predation by age-1 striped bass for much of the year. During early summer 2003, both beach seine and purse seine estimates of predation are at levels that exceed the available density of bluebacks. Although blueback herring were found in the diet of striped bass during late summer/early fall 2003, we did not collect any striped bass in our shoal or channel seines; thus, estimates of predation during this time period for these two areas are zero. This is obviously an erroneous result; the true estimate for predation on blueback herring in 2003 (and for all prey not solely associated with the shoal habitats) would require estimates of age-1 striped bass densities throughout the Albemarle Sound.

Yellow perch were not a prey of age-1 striped bass during 2002 so estimates of striped bass predation mortality were zero while the total loss rate was 5.5%. The observed declines in yellow perch abundance during 2002 could be due to the same array of factors as for alewife. However, the absolute loss in numbers of yellow perch in 2002 was not great. Densities of yellow perch in 2002 decreased from 5.7 to 0.2 fish per beach seine haul during June and July. During 2003, yellow perch abundance declined substantially. Densities of yellow perch decreased from 145 to 2 fish per beach seine haul and yearling striped bass predation accounted for over 32 % of the total mortality. Most importantly, the majority of this loss occurred between 5/26/03 and 6/10/03 when predation loss accounted for 107 percent of the total loss. During 2003, yearling striped bass predation reduced the densities of yellow perch in the western sound by more than one order of magnitude.

There appears potential for large interannual differences in the influence of age-1 striped bass on juvenile American shad and yellow perch mortality rates. In the Connecticut River it has been suggested that the year-class strength of American shad is established prior to the juvenile stage and that juvenile indices of abundance provide adequate qualitative predictors of adult recruitment (Crecco et al. 1983, Crecco and Savoy 1984). However, the variable predatory impact between years in this study points to the importance of mortality during the juvenile stage. This finding has implications for the timing of surveys used in developing juvenile abundance indices. Early (June) beach seine sampling of juvenile American shad (in 2002) or yellow perch (in 2003) would differ markedly from late summer collections. Future work should determine if mid- to late-summer collections of these juveniles most accurately predict future recruitment.

Estimates of error around estimates of mean predation impact were large. Improvements on the present study would include reducing the error associated with predator population estimates through other techniques (e.g., tagging studies) or greatly increasing the sample size. In some cases, the prey of interest was not a common prey type and the estimate of sizes of prey species eaten vs. date could be improved through an increased sample size.

1.4d MANAGEMENT IMPLICATIONS AND FUTURE WORK

Understanding predation effects between resurgent predator populations and prey fishes at low populations will be vital to future management of our fish stocks (Link 2002). Interannual differences in predation mortality might lead to interannual variability in recruitment. The finding of a strong direct influence by age-1 striped bass on juvenile American shad numbers will be useful to management agencies charged with decisions in American shad stocking and

those setting striped bass harvest limits. The fact that the magnitude of this interaction can differ markedly between years may be particularly useful. Future management decisions concerning yellow perch will similarly benefit from this work.

This work suggests that areas occupied by age-1 striped bass might be related to water quality; moreover, the change in areas utilized might have influenced striped bass impacts on American shad juveniles. Future study of age-1 striped bass movement in Albemarle Sound is warranted to determine the importance of water quality on predator and prey overlap.

During this study, the focus was on the post-metamorphic/early juvenile stage of *Alosa* spp during summer. However, for *Alosa* spp. and blueback herring especially, emigration during fall months could represent a significant source of mortality from striped bass predation. During these months the temperatures are dropping which may allow older striped bass cohorts to begin feeding during juvenile fish emigration. Future work studying predatory impacts during this dynamic time in the sound would present its own challenges but may provide additional information on how to best manage our fisheries stocks.

There has been increased interest in using ecosystem-based approaches in management of marine fish stocks (Beamish and Mahnken 1999). This study contributes to that goal by providing diet, selectivity, and consumption rate information that are critical components of ecosystem models (Hilden 1988; Christensen and Walters 2004). The information produced in this study regarding age-1 striped bass diet should be valuable given that species abundance has changed markedly since the study by Manooch (1973). Although this study provides the first steps toward any future ecosystem-based management approaches in Albemarle Sound, it also

points out the complexity of estuarine predator-prey interactions which will make population modeling difficult.

Table 1. Diet inputs for bioenergetics model for (a) 2002 and (b) 2003. Percent weight taken from monthly cluster estimators of each animal food item normalized to 100%. The “other fish” category in 2002 includes bluefish, mullet, and speckled trout. See table 10 for scientific names of fishes.

(a) 2002 diet inputs for bioenergetics model.

	5/9/02	6/15/02	7/15/02	8/15/02	9/15/02 to 10/31/02
<i>Alosa</i> spp.	0	0	0	0	3.31
American Shad	3.26	0.71	20.39	0	0
Alewife	0	1.65	3.01	26.10	0
Anchovies	10.05	9.16	18.84	0	11.80
Blueback Herring	0	1.32	0	0	58.91
Atlantic croaker	12.81	0	2.08	0	0
Killifish	0	0.99	0	32.53	0
Goby	0	6.67	0	8.71	0
Atlantic menhaden	66.42	43.31	4.49	14.15	0
Silversides	0	13.03	31.35	17.22	10.68
Spottail Shiner	0	5.90	2.00	0	0
Striped Bass	0	0	1.71	0	0
Other Fish	0	12.29	0.88	0	0
White perch	0	0	7.01	0	0
Copepod/Isopod	0.06	0.07	0	0	0.32
Decapod	0	2.75	8.10	0	14.67
Amphipods	7.41	2.15	0.13	0	0
Insect	0	0	0	0	0
Bivalves	0	0	0	1.29	0.31

(b) 2003 diet inputs for bioenergetics model.

	5/13/03	6/15/03	7/15/03	8/15/03	9/15/03 to 10/31/03
<i>Alosa</i> spp.	0	5.42	9.49	6.59	53.13
American Shad	0	0	0	2.90	0
Alewife	8.33	0	1.26	12.81	5.58
Anchoa sp.	0	0	0	0	5.58
Blueback Herring	0	9.18	1.48	6.59	8.35
Atlantic croaker	0	1.98	0	0	0
Killifish	0	6.79	0	0	0
Sunfishes	0	0	0.70	0	19.82
Atlantic menhaden	6.42	24.81	71.42	60.98	0
Spottail Shiner	0	2.58	0.42	1.95	7.54
White Perch	0	0	2.50	2.66	0
Yellow Perch	80.91	49.24	11.77	5.51	0
Decapod	4.34	0	0	0	0
insect	0	0	0.95	0	0

Table 2. Regressions relating whole body energy content (EC) in joules per gram of wet weight and percent dry weight (DW) for prey fishes; (*) notes regressions established during this study. See table 10 for scientific names of fishes.

Species	Equation	Reference	r ²
Age-0 Atlantic menhaden	EC = 1046.53 e ^{0.0605(DW)}	Rippetoe (1993) thesis	0.92
Age-0 Yellow Perch *	EC = 186.7 + 200.2 (DW)	Data from Lantry (1997) and Kelso (1973)	0.90
Bay Anchovy	EC = 691 + 156.3 (DW)	Hartman and Brandt (1995b)	0.77
Age-1 Striped Bass	EC = - 1460 + 313.9 (DW)	Hartman and Brandt (1995b)	0.93
Age-0 Alewife	EC = -2414 + 387 (DW)	Hartman and Brandt (1995b)	0.93
White Perch?	EC = -1932 + 293.8 (DW)	Hartman and Brandt (1995b)	0.99
General	EC = -3419 + 375 (DW)	Hartman and Brandt (1995b)	0.95
Silversides *	EC = -902.26 + 222.63 (DW)	Data from Eric Shultz (pers. com.)	0.59
Cyprinidae	EC = -981 + 251.1 (DW)	Hartman and Brandt (1995b)	0.86

Table 3. Invertebrate whole body energy values in joules per gram of wet weight used for prey in the bioenergetics model.

Prey Item	Energy Content	Reference
Amphipods	4972	Thayer et. al.(1972); Steimle and Terranova (1985)
Decapods	5030	Thayer et. al.(1972); Steimle and Terranova (1985)
Bivalvia	3027	Steimle and Terranova (1985)
Insects	3234	Cummins and Wuychuck (1971), cited by Hanson et. al. (1997); Driver et. al. (1974)
Copepod/Isopod	2792	Schindler et. al. (1971), cited by Hanson et. al. (1997)

Table 4. Seasonal whole body energy content of fish prey items in joules per gram of wet weight for western Albemarle Sound. Gray boxes represent days without data. Linear interpolation between measurements yielded daily energy content values. The first and last measurements were extrapolated out to the first and last model days where necessary. Fishes were sampled from May through October of 2003. See table 10 for scientific names of fishes.

	Julian Day																	
	156	161	176	183	189	197	203	211	218	225	232	238	247	274	280	296	301	n
Alewife			4036	4791	4613	5163	4086	4996		4637	4508		5788	4893	4453			91
American Shad			3622		4171		4562		4721		5237		5992		4344		4832	111
Blueback Herring			2967	3799		3106		4700	4049	4992	5185	5474		4926	4016	3427	4448	136
Silversides		2942	2902		2977		2963		2957		1778		3168		2192		1843	110
Atlantic Menhaden	3361	3408	3233	3730		3591		3655		3538						3532		100
White Perch			2767				3985	3493	4502			3801		4281	4408	4370	4208	76
Killifish			5036		4206		5186		4767		5131							64
Yellow Perch			4347		4606		4599		4851		5066				4422	4463		94
Spottail Shiner			4633		2924		3222		3681		3571		3743		3322	3776		90

Table 5. Whole body energy content of age-1 striped bass in joules per gram of wet weight for western Albemarle Sound. Age-1 striped bass were sampled from June through October of 2003.

	Jul (n=1)	Aug (n=8)	Sep (n=7)	Oct (n=1)	MEAN
Striped Bass	6555	6265	7117	6206	6229

Table 6. Linear regressions of meristic characters of *Alosa* spp. where total length (TL) was regressed against caudal peduncle (CP), body depth (BD) and eye orbit diameter (EO); all measurements in millimeters.

Species	Sizes (TL)	n	Equation	r ²
American Shad	32 – 83	62	TL = 10.84 (CP) + 7.98	0.97
			TL = 3.89 (BD) + 10.10	0.99
			TL = 16.40 (EO) – 6.16	0.95
Blueback Herring	32 – 68	91	TL = 12.34 (CP) + 2.60	0.92
			TL = 4.43 (BD) + 5.87	0.94
Alewife	37 – 99	86	TL = 11.37 (CP) + 1.36	0.96
			TL = 3.62 (BD) + 7.55	0.97

Table 7. Linear regressions of prey fish sizes eaten by age-1 striped bass vs. date (2002 and 2003 combined for *Alosa* spp.). All prey lengths in millimeters of total length (TL); JULIAN is 3 digit Julian date.

Species	n	Equation	r ²
Blueback Herring	31	TL = 4.10 + 0.21 * (JULIAN)	0.29
American Shad	12	TL = 14.75 + 0.25 * (JULIAN)	0.26
Alewife	13	TL = 5.11 + 0.29 * (JULIAN)	0.51
Yellow Perch	24	TL = -53.82 + 0.60 * (JULIAN)	0.91

Table 8. Regressions relating total length in mm (TL) and wet weight in grams (W) of prey fishes; equations of the form $W = \alpha * TL^\beta$.

Species	Sizes (TL)	n	α	β	r ²
2002 – American Shad	29-102	1423	3.68×10^{-6}	3.15	0.97
2002 – Alewife	28-103	1201	5.39×10^{-6}	3.09	0.96
2002 – Blueback Herring	28-88	2744	15×10^{-6}	2.82	0.94
2003 – American Shad	19-112	1738	5.24×10^{-6}	3.05	0.97
2003 – Alewife	20-104	2824	6.36×10^{-6}	3.03	0.98
2003 – Blueback Herring	22-78	3960	18×10^{-6}	2.71	0.95
2003 – Yellow Perch	47-98	94	22×10^{-6}	2.82	0.92

Table 9. Mean monthly temperature (temp, ° C), salinity (ppt, ‰), and dissolved oxygen (DO, mg/Liter) for the 2002 and 2003 beach seine (BS) and purse seine stations (PS). No data = nd; range is the range of values measured within that year.

Year / Month/ Range	BS Temp	BS Salinity	BS DO	PS Surface Temp	PS Surface Salinity	PS Surface DO	PS Bottom Temp	PS Bottom Salinity	PS Bottom DO
2002									
May	22.3 (0.4)	2.7 (0.2)	9.2 (0.3)	23.6 (0.1)	2.0 (0.3)	7.3 (0.2)	23.1 (0.0)	2.4 (0.7)	6.1 (0.2)
June	28.1 (0.2)	2.5 (0.1)	6.2 (0.2)	25.9 (0.1)	1.9 (0.3)	7.4 (0.2)	24.7 (0.0)	4.4 (0.1)	2.0 (0.8)
July	30.1 (0.3)	3.1 (0.1)	7.3 (0.2)	28.5 (0.2)	3.1 (0.2)	7.5 (0.1)	26.9 (0.2)	4.9 (0.3)	3.1 (0.5)
Aug.	28.8 (0.4)	3.7 (0.2)	7.5 (0.1)	27.3 (0.1)	4.3 (0.3)	6.5 (0.1)	27.6 (0.6)	4.8 (0.3)	4.1 (0.8)
Sep.	23.9 (0.2)	4.9 (0.3)	7.2 (0.1)	25.5 (0.1)	4.2 (0.1)	7.8 (0.1)	24.8 (0.1)	7.6 (0.4)	3.6 (0.1)
Oct.	20.6 (0.3)	4.5 (0.3)	7.6 (0.1)	23.4 (0.1)	4.2 (0.2)	7.0 (0.1)	nd	nd	nd
Range	18.1 - 35.1	0.7 - 8.3	4.8 - 12.4	23.2 - 30.3	1.1 - 5.4	5.7 - 9.4	23.1 - 30.0	1.7 - 8.4	0.03 - 7.5
2003									
May	22.4 (0.3)	0.1 (0.0)	7.6 (0.1)	nd	nd	nd	nd	nd	nd
June	28.0 (0.8)	0.0 (0.0)	8.5 (0.8)	25.5 (0.2)	0.1 (0.0)	7.3 (0.1)	25.3 (0.2)	0.1 (0.0)	6.1 (0.3)
July	29.6 (0.2)	0.0 (0.0)	7.8 (0.2)	27.4 (0.2)	0.1 (0.0)	6.8 (0.1)	27.1 (0.2)	0.1 (0.0)	4.2 (0.2)
Aug.	29.0 (0.2)	0.0 (0.0)	7.1 (0.2)	27.8 (0.1)	0.1 (0.0)	6.7 (0.1)	27.1 (0.1)	0.1 (0.0)	5.2 (0.2)
Sep.	29.8 (0.2)	0.1 (0.0)	6.6 (0.1)	nd	nd	nd	nd	nd	nd
Oct.	19.7 (0.4)	0.2 (0.1)	7.3 (0.2)	19.3 (0.5)	0.1 (0.0)	4.8 (0.6)	19.2 (0.5)	0.1 (0.0)	4.4 (0.6)
Range	15.5 - 34.3	0.0 - 1.8	3.9 - 11.0	16.5 - 29.2	0.0 - 0.4	0.3 - 9.0	16.5 - 28.9	0.0 - 0.4	0.6 - 9.0

Table 10. Relative abundance of teleost fish captured at beach and purse seine stations in 2002 and 2003. Abundance expressed as percentage of all teleost fish captured by one gear within a particular year. Totals are numbers of fish captured by one gear within a year.

Family	Scientific Name	Common Name	Beach Seine		Purse	Seine
			2002	2003	2002	2003
Achiridae	<i>Trinectes maculatus</i>	Hogchoker	0.03	0.11		0.36
Anguillidae	<i>Anguilla rostrata</i>	American Eel	0.03	0.04		0.09
Atherinopsidae	<i>Menidia</i> spp.	Silversides	34.16	8.32	0.63	0.03
Belonidae	No ID to species	Needlefish	0.70	0.18	0.02	0.01
Bothidae	<i>Paralichthys lethostigma</i>	Southern Flounder	0.02	0.12	0.04	0.39
Catostimidae	No ID to species	Sucker	0.01	0.04		0.01
Centrarchidae	<i>Lepomis</i> spp.	Other Sunfish	0.03	0.15		
	<i>Micropterus salmoides</i>	Largemouth Bass	0.05	0.03		
Clupeidae	<i>Alosa</i> spp.	<i>Alosa</i> species	5.38	26.74	43.08	42.60
	<i>Brevoortia tyrannus</i>	Atlantic Menhaden	1.56	35.16	27.81	37.85
	<i>Dorosoma cepedianum</i>	Gizzard Shad	0.01	0.01	0.07	0.10
Cyprinidae	<i>Cyprinus carpio carpio</i>	Common Carp	0.01	0.01		
	<i>Notemigonus crysoleucus</i>	Golden Shiner	< 0.01	0.02		
	<i>Notropis Hudsonius</i>	Spottail Shiner	1.73	4.85		0.04
Cyprinodontidae	<i>Fundulus</i> spp.	Killifish	1.26	2.45		
Elopidae	<i>Elops saurus</i>	Ladyfish	0.02			
Engraulidae	<i>Anchoa</i> spp.	Anchovies	28.21	3.80	21.36	0.46
Esocidae	<i>Esox</i> spp.	Pickrel		< 0.01		
Gerreidae	No ID to species	Mojarra	0.05			
Gobiidae	No ID to species	Goby	< 0.01			0.01
Ictaluridae	No ID to species	Catfish	0.06	0.47	0.12	4.05
Lepisosteidae	<i>Lepisosteus</i> spp.	Gars		< 0.01	0.02	0.14
Moronidae	<i>Morone</i> spp.	Striped Bass / White Perch	7.71	6.58	0.26	10.20
Mugilidae	<i>Mugil</i> spp.	Mulletts	7.25	0.35		
Percidae	<i>Perca flavescens</i>	Yellow perch	0.55	9.74		0.13
Pomatomidae	<i>Pomatomus saltatrix</i>	Bluefish	0.02		0.05	
Scianidae	<i>Bairdiella chrysoura</i>	Silver Perch	0.01		0.12	
	<i>Cynoscion</i> spp.	Weakfish / Speckled Trout	0.01		0.04	0.01
	<i>Leiostomus xanthurus</i>	Spot	6.64	0.51	1.35	0.03
	<i>Micropogonias undulatus</i>	Atlantic croaker	4.42	0.31	5.03	3.35
	<i>Pogonias cromis</i>	Black Drum	0.01			
	<i>Scianops ocellatus</i>	Red Drum	< 0.01			
	<i>Lagodon rhomboides</i>	Pinfish	0.05			
Sparidae						
Syngnathidae	No ID to species	Pipefishes	0.04			
TOTAL			97,247	46,807	5,706	6,930

Table 11. Catches of juvenile *Alosa* spp., juvenile yellow perch, and age-1 striped bass captured during both years by (a) beach seine and (b) purse seine (non-24-hour collections). Catches expressed as total numbers (TOTAL) , and mean catch per unit effort (mean(CPUE)). Standard error of CPUE in parentheses. The areas swept by the beach seine and purse seine are roughly 500 m² and 462 m² respectively.

(a) Beach seine prey and predator catches

Year / Gear/ Species	TOTAL	mean(CPUE)
2002 - Beach Seine		
American Shad	873	4.98 (1.46)
Alewife	528	3.03 (1.02)
Blueback Herring	292	1.65 (0.71)
Yellow Perch	207	1.21 (0.57)
Striped Bass	149	0.67 (0.21)
2003 – Beach Seine		
American Shad	1904	9.62 (2.39)
Alewife	1860	9.39 (4.52)
Blueback Herring	8497	42.92 (32.58)
Yellow Perch	4500	22.73 (12.67)
Striped Bass	18	0.09 (0.06)

(b) Purse seine prey and predator catches

Year / Gear / Species	TOTAL	mean(CPUE)
2002 – Purse Seine		
American Shad	30	0.59 (0.15)
Alewife	310	6.43 (3.13)
Blueback Herring	1704	29.14 (6.92)
Yellow Perch	0	n/a
Striped Bass	2	0.03 (0.02)
2003 – Purse Seine		
American Shad	106	0.98 (0.23)
Alewife	1303	12.09 (2.49)
Blueback Herring	1560	14.45 (6.72)
Yellow Perch	9	0.09 (0.02)
Striped Bass	6	0.06 (0.02)

Table 12. Mean stomach contents ($\pm$ S.E.) of age-1 striped bass for (a) 2002 and (b) 2003. The percent frequency (F) of stomachs (with food) containing a prey type and the percent contribution of identifiable organic prey to diet by weight (W) are shown for each month. Standard error computed with cluster estimators.

(a) 2002

Prey Type	May		Jun		Jul		Aug		Sep/Oct	
	F	W	F	W	F	W	F	W	F	W
Fish										
Alosa sp.									8.70(4.60)	3.00(1.60)
Alewife			0.45(0.44)	1.49(1.48)	0.68(0.52)	2.73(2.07)	2.33(2.13)	12.14(11.08)		
American shad	2.50(1.92)	2.88(2.20)	0.45(0.44)	0.64(0.63)	6.85(1.57)	18.50(3.30)				
Blueback herring			0.45(0.40)	1.20(1.10)					34.80(8.37)	53.40(1.20)
Anchovy	7.50(5.76)	8.88(6.80)	3.59(1.49)	8.30(4.12)	5.48(1.93)	13.36(6.07)			6.45(5.56)	7.47(6.39)
Bay anchovy					3.42(1.40)	3.73(1.73)			3.23(3.90)	3.23(3.90)
Atlantic croaker	2.50(1.92)	11.32(8.67)			2.05(1.44)	1.89(1.26)				
Atlantic menhaden	27.50(5.53)	58.70(12.64)	4.04(1.20)	39.23(18.38)	2.05(1.17)	4.07(2.66)	4.65(4.22)	6.58(6.29)		
Bluefish					0.68(0.64)	0.42(0.39)				
Goby			0.90(0.61)	6.04(4.14)			2.33(2.77)	4.05(4.82)		
Killifish			0.45(0.45)	0.90(0.90)			6.98(4.92)	15.13(13.41)		
Mullet			1.79(0.80)	11.13(5.47)						
Silverside			5.38(2.24)	11.80(5.04)	14.38(2.54)	28.44(4.05)	6.98(4.47)	8.01(6.48)	3.23(3.70)	9.68(11.08)
Speckled trout					0.68(0.64)	0.38(0.36)				
Spottail shiner			0.90(0.60)	5.34(3.74)	1.37(1.29)	1.81(1.70)				
Striped bass					0.68(0.70)	1.55(1.59)				
Unidentified fish	22.50(6.33)		20.2(4.61)		21.92(2.19)		32.56(7.74)		22.58(4.72)	
White perch					3.42(1.91)	6.36(3.20)				
Invertebrates										
Amphipods	2.50(2.11)	6.55(5.52)	1.35(1.32)	1.95(1.91)	0.68(0.52)	0.12(0.08)				
Ants			0.45(0.41)	0.002(0.002)						
Bivalves							2.33(2.77)	0.60(0.71)	3.23(1.72)	0.28(0.15)
Copepods	2.50(1.92)	0.05(0.04)							3.23(1.72)	0.02(0.01)
Coral							2.33(1.81)			
Isopods			0.45(0.41)	0.06(0.06)					3.23(3.90)	0.27(0.33)
Xanthid crabs					3.42(1.74)	3.24(1.65)			3.23(1.71)	6.85(3.63)
Mysids			1.35(0.65)	2.49(1.05)	2.05(2.07)	4.11(4.14)			3.23(3.80)	6.45(7.60)
Unid. crustaceans			0.90(0.67)		0.68(0.70)					
Unid. insects					0.68(0.52)					
Other										
Metal			0.45(0.41)							
Sand	5.00(3.84)		7.62(2.55)		5.48(2.54)		6.98(5.43)			
Stone					0.68(0.70)					
Unidentified	15.00(6.77)		5.83(1.57)		7.53(2.27)		20.93(8.66)		6.45(3.32)	
Vegetation	5.00(4.22)	0.14(0.12)	4.04(1.04)	2.26(1.56)	6.16(3.75)	0.74(0.31)	4.65(3.62)	37.21(28.84)	3.23(3.49)	0.10(0.10)
No. age-1 striped bass	40		179		121		40		31	
No. that contain prey	33		118		94		28		23	
Mean TL (mm) (S.D.)	168.5 (23.2)		172.2 (24.0)		180.1 (26.4)		209.3 (39.1)		255.2 (28.4)	
TL range (mm)	121-240		130-257		136-256		116-274		166-294	

(b) 2003

Prey Type	May		Jun		Jul		Aug		Sep/Oct	
	F	W	F	W	F	W	F	W	F	W
Fish										
Alosa sp.			8.16(5.30)	5.60(3.90)	10.08(3.50)	8.80(2.60)	7.55(3.06)	6.07(2.60)	8.82(5.56)	27.99(15.00)
Alewife	8.33(15.28)	8.33(15.28)			0.84(0.70)	1.17(0.98)	5.66(2.50)	11.80(5.60)	2.94(3.26)	2.94(3.15)
American shad							1.89(1.84)	2.67(2.60)		
Blueback herring			12.20(7.46)	9.48(6.20)	3.36(2.02)	1.37(1.01)	7.55(3.06)	6.07(2.60)	5.88(5.36)	4.40(3.80)
Atlantic croaker			2.04(2.28)	2.04(2.28)						
Atlantic menhaden	8.33(1.39)	6.42(1.07)	28.57(12.92)	25.62(10.35)	37.82(3.78)	66.20(5.80)	45.28(8.50)	56.16(8.01)		
Bay anchovy									2.94(3.26)	2.94(3.15)
Killifish			4.08(2.22)	7.01(3.53)						
Spottail shiner			4.08(4.41)	2.66(2.87)	0.46(0.37)	0.39(0.30)	3.77(1.85)	1.80(2.10)	2.94(2.89)	3.97(3.73)
Sunfish					0.84(0.89)	0.65(0.68)			2.94(2.89)	10.44(9.81)
Unidentified fish	16.67(13.89)		26.53(5.74)		14.29(3.01)		16.98(6.00)		20.59(8.12)	
White perch					1.68(0.78)	2.32(1.81)	3.77(4.12)	2.45(2.67)		
Yellow perch	83.33(13.89)	80.92(13.49)	32.65(10.49)	50.85(13.06)	5.88(0.22)	10.91(0.59)	5.66(3.97)	5.07(4.62)		
Invertebrates										
Grass shrimps	33.33(5.56)	4.34(0.72)								
Roundworms					0.84(0.70)	0.04(0.03)				
Unid. insects					0.84(0.90)	0.84(0.90)				
Other										
Unidentified					0.84(0.83)		3.77(2.28)		14.71(7.49)	
Vegetation			4.08(3.23)	0.30(0.26)	2.52(1.60)	0.09(0.07)	3.77(2.87)	0.37(0.28)	2.94(2.89)	0.29(0.27)
No. age-1 striped bass	12		49		118		54		34	
No. that contain prey	12		37		77		47		17	
Mean TL (mm) (S.D.)	173.7 (8.9)		198.5 (29.9)		230.5 (21.5)		242.2 (24.3)		261.3 (23.4)	
TL range (mm)	162-185		124-262		188-280		198-296		221-303	

Table 13. Results from field estimates of consumption. The instantaneous rate of gastric evacuation (G_e) was estimated over periods where feeding was assumed to be zero. Temperature (Temp.) is the daily mean in °C at each date. Mean stomach fullness (S) is the mean of each time point's mean fullness over a 24-hour period in grams of prey per gram of predator. Daily ration is expressed in grams of prey per gram of predator per day. Standard errors are in parentheses; standard error of daily ration was computed with the delta method.

Day	G_e	S.E.	Temp.	S	S.E.	Daily Ration	S.E.	n
06/11/02	n/a	n/a	25.8	0.007	0.002	0.025	0.008	98
07/11/02	0.148	0.018	26.1	0.022	0.006	0.078	0.023	127
07/10/03	0.147	0.008	28.8	0.015	0.005	0.054	0.017	36
08/05/03	n/a	n/a	28.1	0.021	0.005	0.075	0.018	44

Table 14. Effects of predation for (a) 2002 and (b) 2003. Geometric mean prey density per haul (Geomean), number of days for interval, numbers of prey consumed, M_{pred} and predation mortality ($1-e^{-M_{pred}}$). Predation mortality estimates bound by ± 1 S.E. of numbers of prey consumed. Percentage total loss per day is averaged for whole period. Total losses are from catch curve analysis. Percent of total losses is predation loss percentage divided by total loss percentage. The areas swept by the beach seine and purse seine are roughly 500 m² and 462 m² respectively.

a) 2002

Area	Species	From	To	Geomean	No. Days	No. Prey Consumed ($\pm$ S.E.)	$M_{pred}(\pm$ S.E.)	Predation Mortality (%*day ⁻¹) ($\pm$ S.E.)	Total Losses From Catch Curves (%*day ⁻¹)	% of Total Losses ($\pm$ S.E.)
Shoal	AS	5/23/02	6/3/02	15.8	12	0.87 (0-2.65)	0.005 (0-0.01)	0.46 (0-1.39)	2.45	19 (0-57)
		6/3/02	6/13/02	6.6	11	0.45 (0-1.34)	0.01 (0-0.02)	0.61 (0-1.81)		25 (0-74)
		6/13/02	6/24/02	5.2	12	2.91 (0-8.39)	0.05 (0-0.13)	4.55 (0-12.53)		186 (0-512)
		6/24/02	7/8/02	4.8	15	6.83 (0-19.51)	0.1 (0-0.27)	9.11 (0-23.89)		372 (0-975)
		7/8/02	7/23/02	3.7	16	2.6 (0-7.5)	0.04 (0-0.13)	4.32 (0-11.96)		177 (0-488)
		7/23/02	7/31/02	1.6	9	0.87 (0-2.52)	0.06 (0-0.18)	5.93 (0-16.27)		242 (0-664)
		7/31/02	8/8/02	1.1	9	0.81 (0-2.32)	0.08 (0-0.24)	7.98 (0-21.27)		326 (0-868)
		8/8/02	8/22/02	2.5	15	0.49 (0-1.4)	0.01 (0-0.04)	1.28 (0-3.62)		52 (0-148)
							Mean	4.17 (0-11.3)		170 (0-461)
Channel	AW	6/19/02	7/1/02	24.2	13	0	0	0	4.93	0
		7/1/02	7/15/02	7.2	15	0.11 (0-0.25)	0.001 (0-0.002)	0.1 (0-0.23)		2 (0-5)
		7/15/02	7/29/02	3.7	15	0.38 (0-0.78)	0.007 (0-0.01)	0.68 (0.01-1.4)		14 (0.15-28)
		7/29/02	8/12/02	2.8	15	0.27 (0-0.61)	0.006 (0-0.01)	0.62 (0-1.42)		13 (0-29)
		8/12/02	8/28/02	1.2	17	0	0	0		0
							Mean	0.28 (0-0.6)		6 (0.03-12)

b) 2003

Area	Species	From	To	Geomean	No. Days	No. Prey Consumed ($\pm$ S.E.)	Mpred($\pm$ S.E.)	Predation Mortality (%*day ⁻¹) ($\pm$ S.E.)	Total Losses From Catch Curves (%*day ⁻¹)	% of Total Losses ($\pm$ S.E.)
Shoal	AS	6/10/03	6/24/03	12.1	15	0	0	0	0.15	0
		6/24/03	7/8/03	9.1	15	0	0	0		0
		7/8/03	7/21/03	12.8	14	0.001 (0-0.003)	< 0.001	0.001 (0-0.002)		0.352 (0-1)
		7/21/03	8/4/03	11.1	15	0	0	0		0
		8/4/03	8/18/03	14.9	15	0	0	0		0
		8/18/03	9/4/03	14.3	18	0	0	0		0
							Mean	0		0
Shoal	AW	5/26/03	6/10/03	16.9	16	1.91 (0-5.8)	0.007 (0-0.02)	0.7 (0-2.12)	1.75	40 (0-121)
		6/10/03	6/24/03	8.3	15	0.08 (0-0.24)	0.001 (0-0.002)	0.07 (0-0.19)		4 (0-11)
		6/24/03	7/8/03	5.8	15	0.02 (0-0.05)	<0.001 (0-0.001)	0.03 (0-0.06)		1 (0-3)
		7/8/03	7/21/03	5.8	14	0.03 (0-0.07)	<0.001 (0-0.001)	0.04 (0-0.09)		2 (0-5)
		7/21/03	8/4/03	4.8	15	0	0	0		0
		8/4/03	8/18/03	3.3	15	0	0	0		0
		8/18/03	9/4/03	5.3	18	0	0	0		0
							Mean	0.12 (0-0.36)		7 (0-20)
Shoal	YP	5/26/03	6/10/03	57.2	16	46.26 (3.6-89.48)	0.051 (0.004-0.1)	4.93 (0.39-9.32)	4.61	107 (9-202)
		6/10/03	6/24/03	17.1	15	8.23 (0.72-15.74)	0.032 (0.003-0.061)	3.16 (0.28-5.96)		69 (6-129)
		6/24/03	7/8/03	15.2	15	0.57 (0-1.23)	< 0.001 (0-0.005)	0.25 (0-0.54)		5 (0-12)
		7/8/03	7/21/03	11.9	14	0.27 (0-0.58)	< 0.001 (0-0.003)	0.16 (0-0.35)		4 (0-7)
		7/21/03	8/4/03	3.4	15	0	0	0		0
		8/4/03	8/18/03	1.9	15	0	0	0		0
							Mean	1.46 (0.12-2.77)		32 (3-60)
Channel	AW	6/30/03	7/14/03	16.2	15	0.05 (0-0.11)	0	0.02 (0-0.04)	0.61	3 (0-7)
		7/14/03	7/28/03	13.5	15	0.44 (0.1-.78)	0.002 (0-0.004)	0.22 (0.05-0.39)		36 (8-63)
		7/28/03	8/11/03	12.8	15	0.52 (0.09-0.94)	< 0.001 (0-0.005)	0.27 (0.05-0.49)		44 (8-80)
		8/11/03	8/25/03	12.7	15	0	< 0.001 (0-0)	0		0 (0-0)
							Mean	0.12 (0.02-0.23)		20 (4-37)

Table 15. Mean total length (TL) of American shad (AS), alewife (AW), blueback herring (BH) and age-1 striped bass (SB) captured with all gear types by month. Monthly mean prey to monthly mean predator size ratio included (PPR). September and October are grouped together for each year. SE is standard error.

YEAR / FISH	MAY			JUN			JUL			AUG			SEP / OCT		
	TL	SE	PPR	TL	SE	PPR	TL	SE	PPR	TL	SE	PPR	TL	SE	PPR
2002															
AS	41	4.6	0.24	54	6.7	0.31	67	7.7	0.37	73	7.6	0.35	84	8.9	0.33
AW	45	7.7	0.27	56	6.2	0.33	73	9.3	0.41	75	8.4	0.36	83	6.2	0.33
BH	n/a	n/a	n/a	44	5.1	0.26	59	4.6	0.33	60	4.9	0.29	71	5.3	0.28
YP	n/a	n/a	n/a	56	9.1	0.33	75	7.4	0.42	83	10.4	0.40	92	10.2	0.36
SB	168	23.2		172	23.7		180	26.4		206	38.7		254	28.2	
2003															
AS	29	3.7	0.17	40	6.4	0.20	60	10.3	0.26	70	9.1	0.29	80	7.7	0.31
AW	34	4.8	0.20	51	11.4	0.26	64	9.7	0.28	74	9.3	0.31	82	7.4	0.31
BH	31	3.0	0.18	32	6.8	0.16	42	7.2	0.18	47	6.8	0.20	61	6.2	0.23
YP	34	4.3	0.20	47	8.5	0.24	66	8.5	0.29	83	10.9	0.34	97	14.3	0.37
SB	174	8.9		198	30.0		230	17.6		241	23.4		262	23.8	

Figure 1. Recent changes in abundance of blueback herring and age 4+ striped bass: (a) juvenile abundance index of blueback herring in Albemarle Sound; provided by Elizabeth City Division of Marine Fisheries and (b) Albemarle Sound-Roanoke River striped bass stock; data from recent stock assessment (Grist 2004).

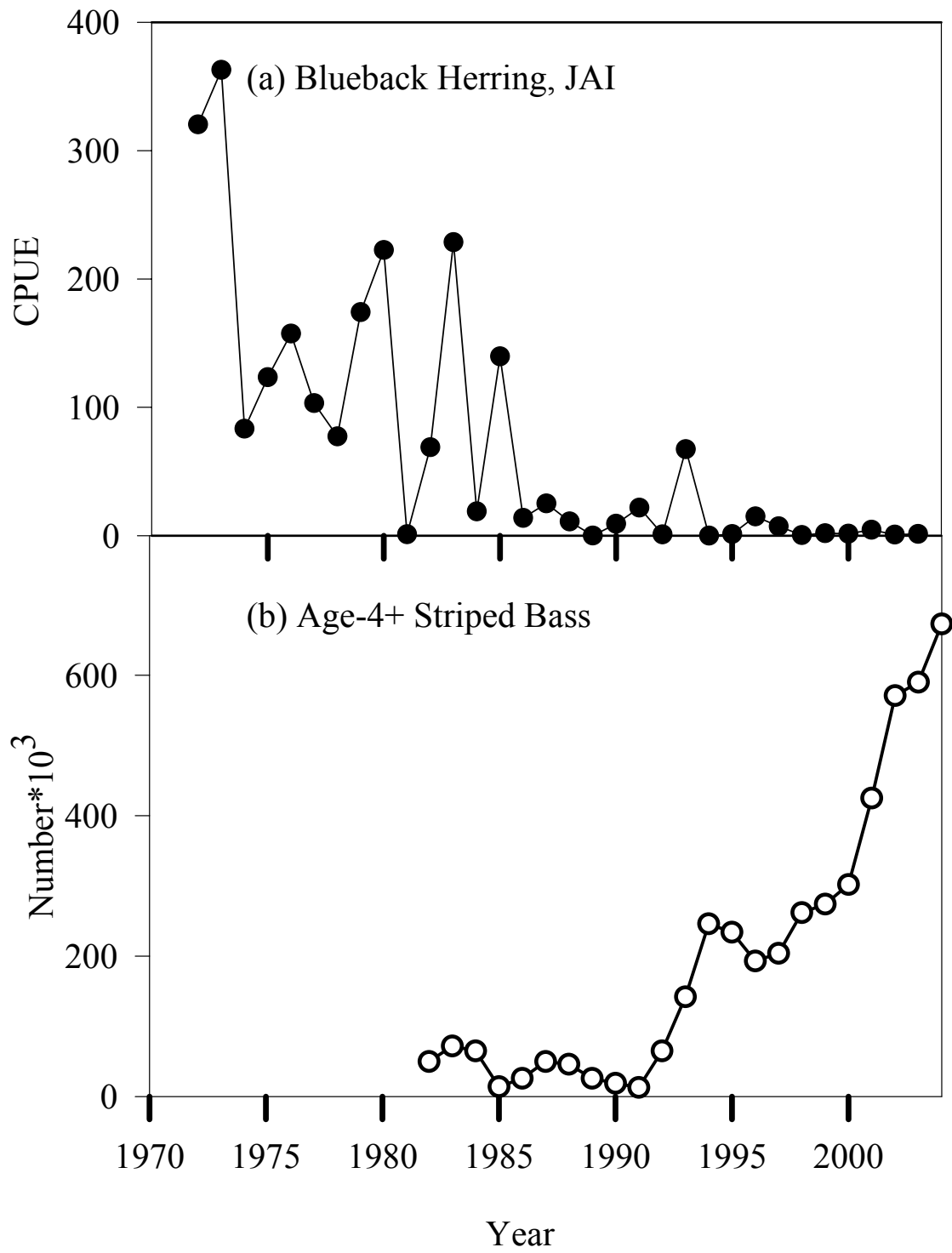


Figure 2. Map of Albemarle Sound, NC with the sampling area outlined in dashed box. Lower right insert shows beach seine and purse seine sites. Lower left insert shows Albemarle Sound location on the east coast.

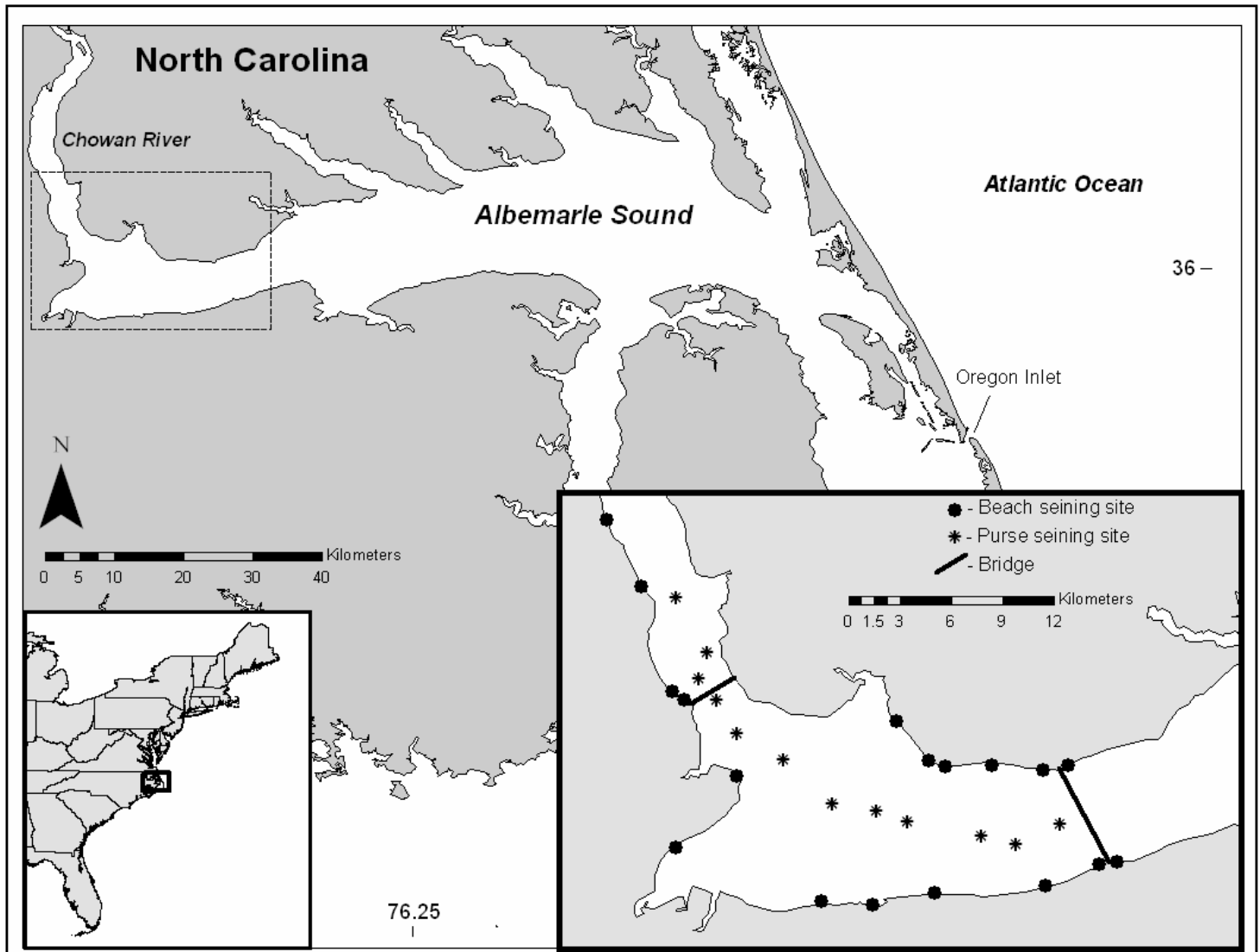


Figure 3. Mean temperature ($^{\circ}\text{C}$) plotted vs. date used in striped bass bioenergetics model for (a) 2002 and (b) 2003. The top and bottom panels include vertical lines on 8/28/02 and 9/07/03 that denote the first late summer mean temperature of 26°C .

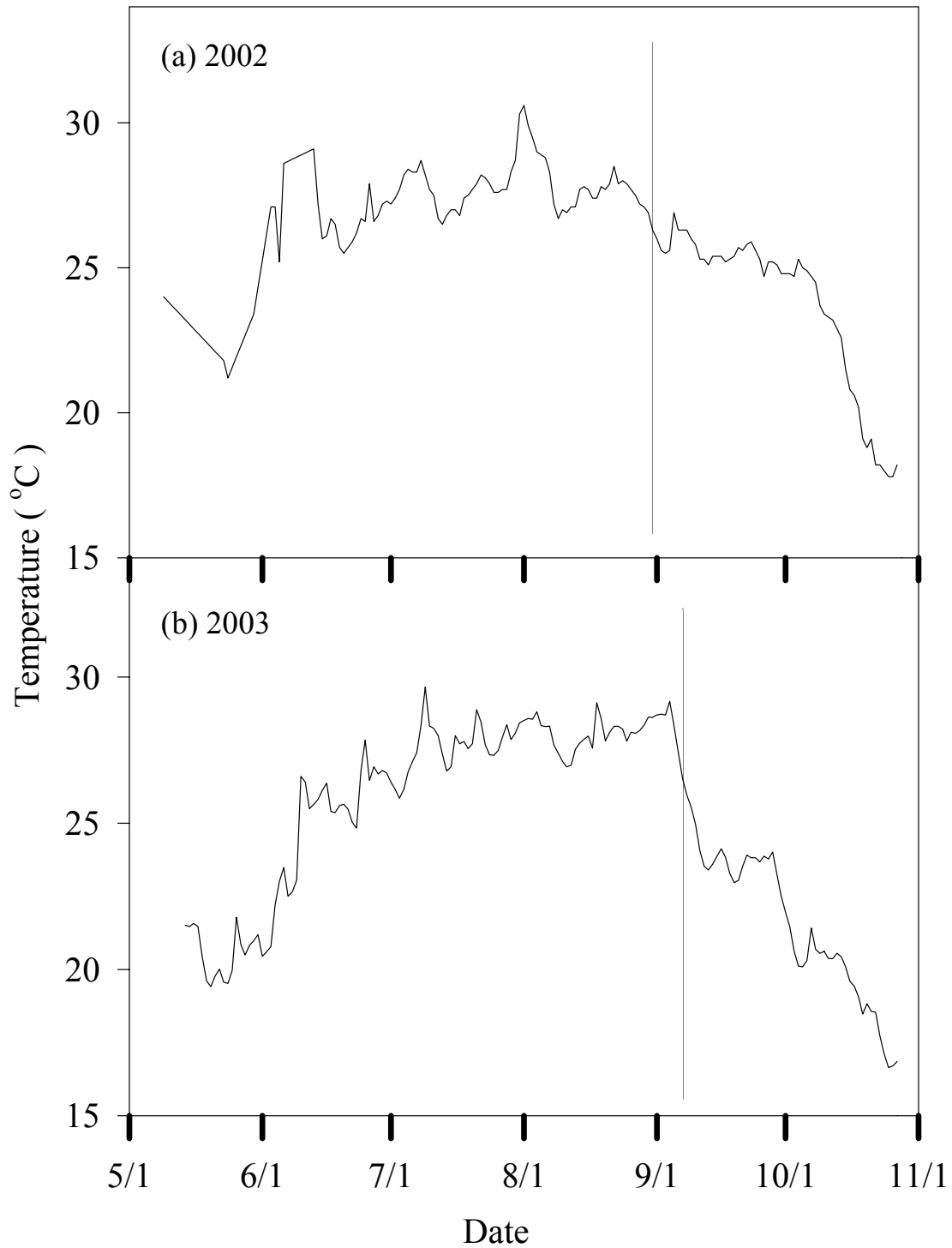


Figure 4. Logistic growth curve fit to age-1 striped bass weight vs. date for (a) 2002 and (b) 2003. All weights in grams. Fish captured via beach seine, boat electrofishing, angling, otter trawl, purse seine and experimental gill nets shown as open circles, open squares, open triangles, filled triangles, filled squares and filled circles respectively. Solid line is predicted mean from logistic model. Dashed lines represent ± 1 S.E. from mean predicted value.

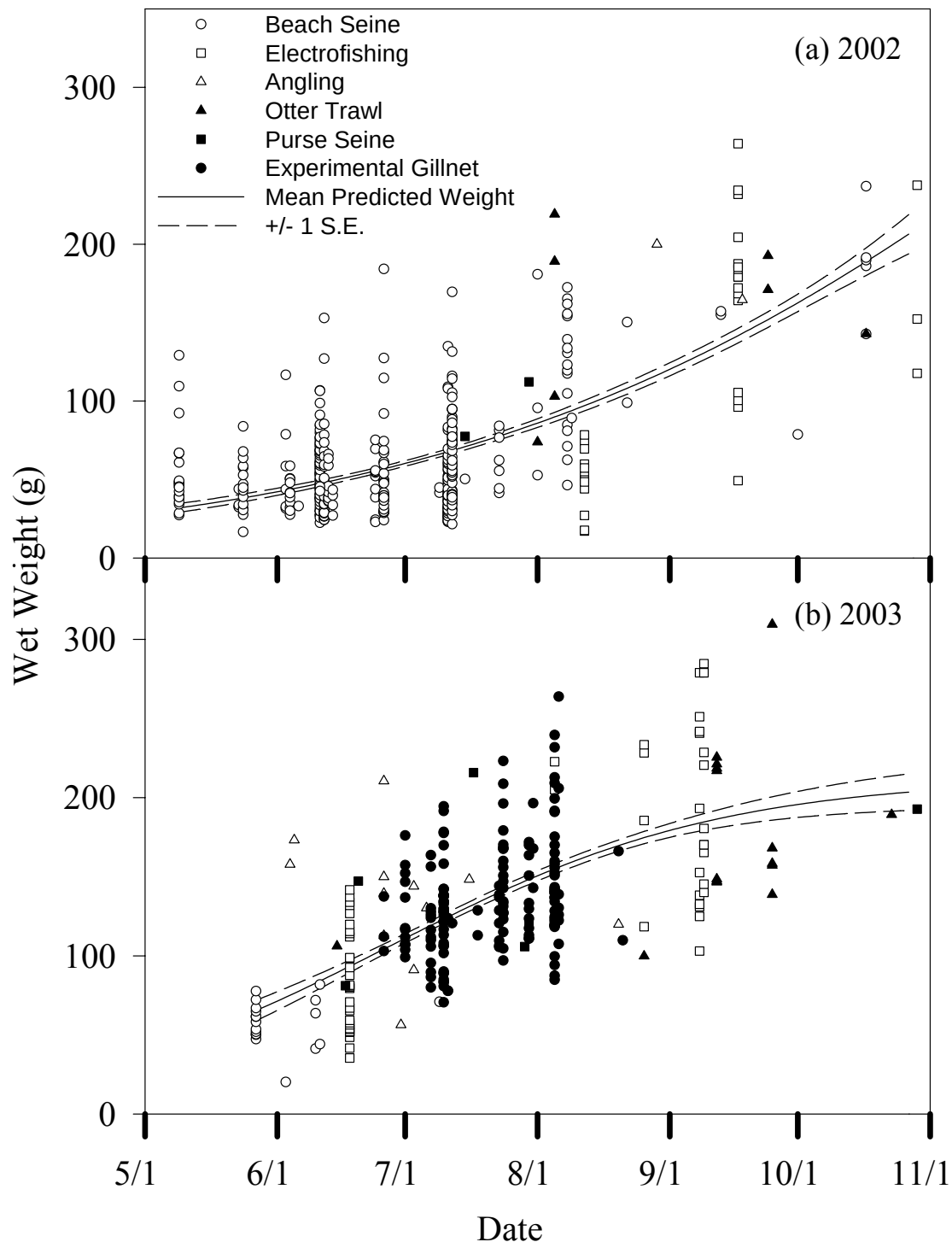


Figure 5. Beach seine CPUE vs. date in 2002 for juvenile (a) American shad [AS], (b) alewife [AW], (c) blueback herring[BH], and (d) yellow perch [YP].

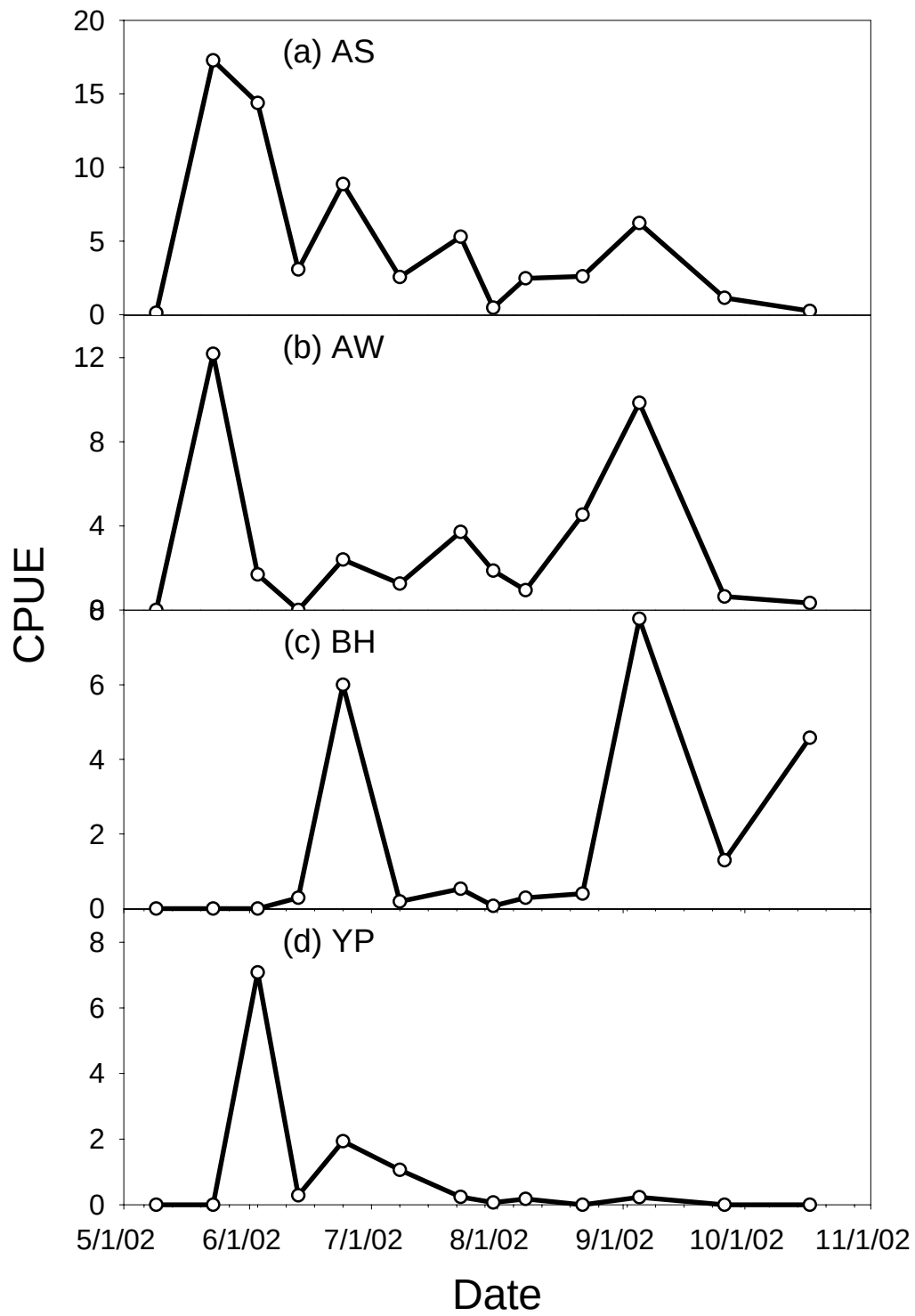


Figure 6. Purse seine CPUE and adjusted (CPUE) vs. date in 2002 for juvenile (a) American shad [AS], (b) alewife [AW], and (c) blueback herring [BH].

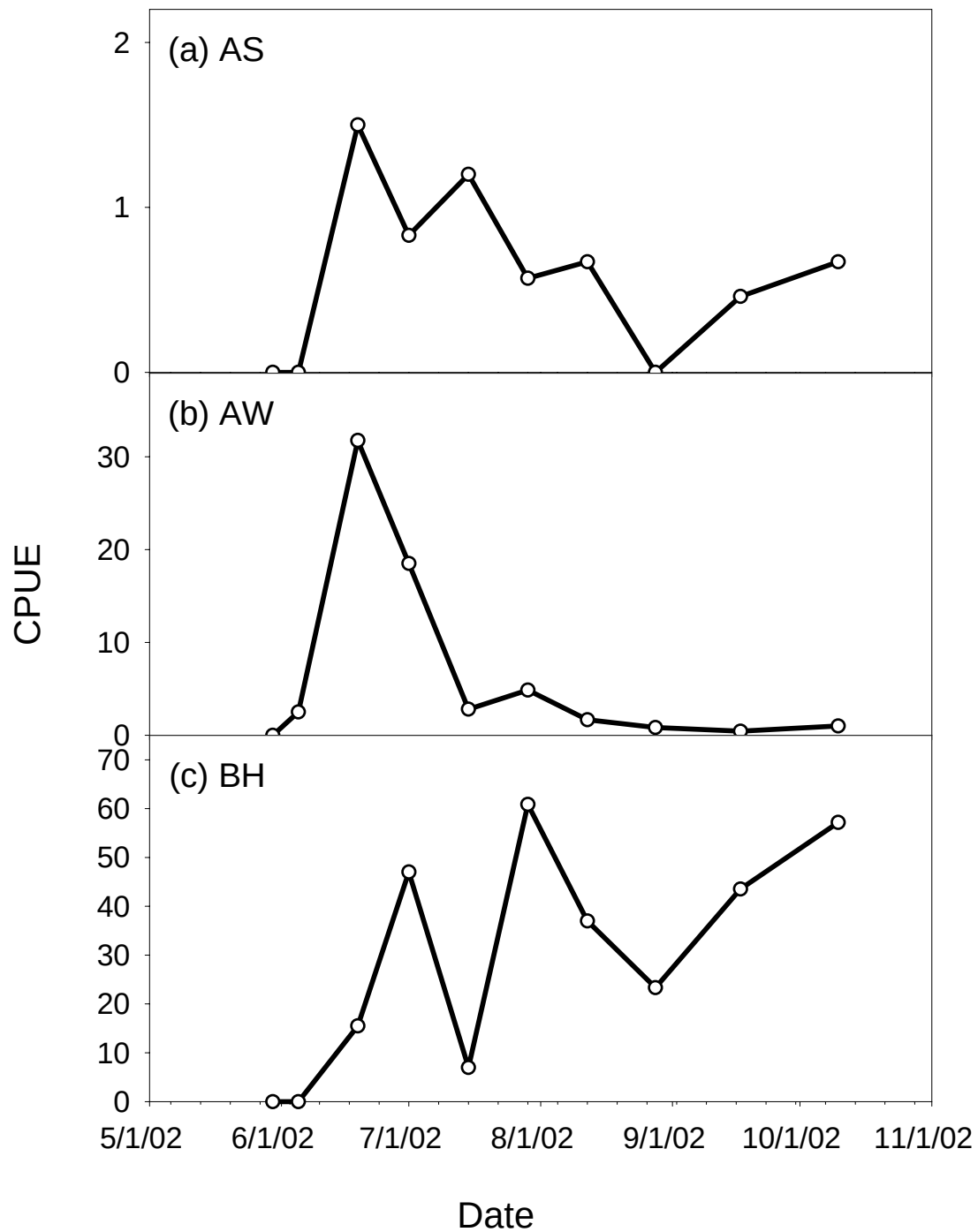


Figure 7. Beach seine CPUE vs. date in 2003 for juvenile (a) American shad [AS], (b) alewife [AW], (c) blueback herring [BH], and (d) yellow perch [YP].

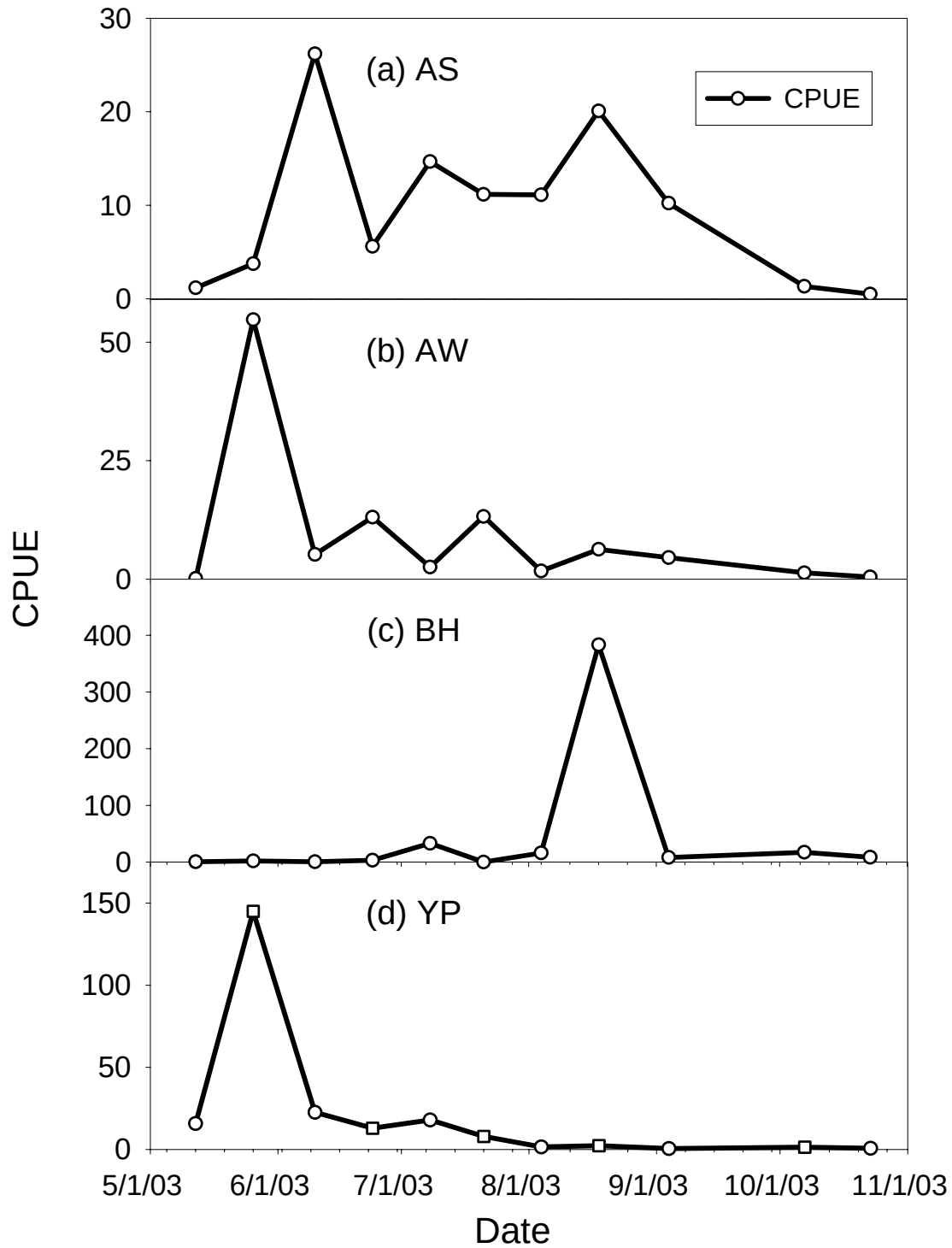


Figure 8. Purse seine CPUE vs. date in 2003 for juvenile (a) American shad [AS], (b) alewife [AW], and (c) blueback herring [BH].

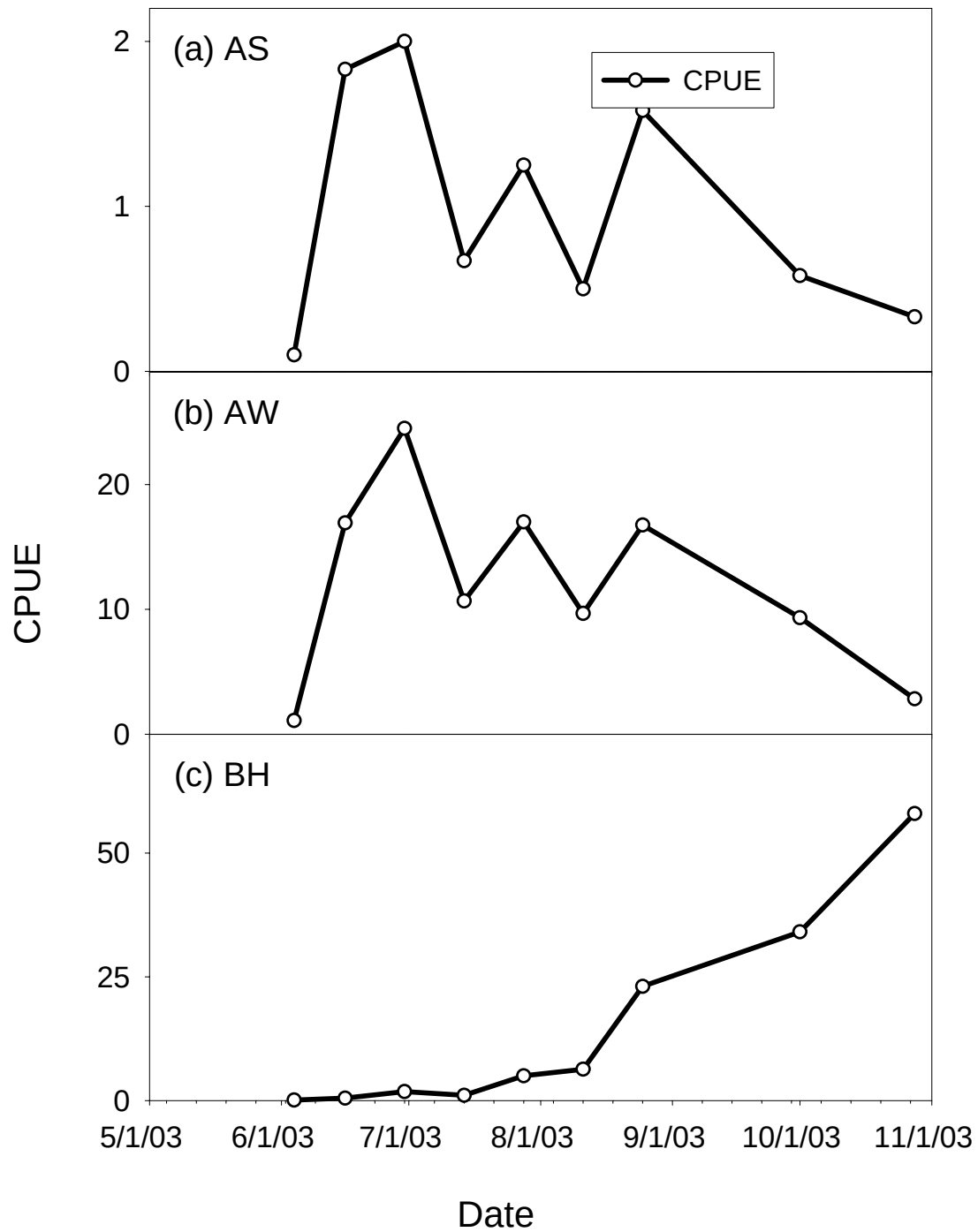


Figure 9. Catch per unit effort of age-1 striped bass for (a) 2002 beach seine, (b) 2002 purse seine, (c) 2003 beach seine, and (d) 2003 purse seine. The areas swept by the beach seine and purse seine are roughly 500 m² and 462 m² respectively.

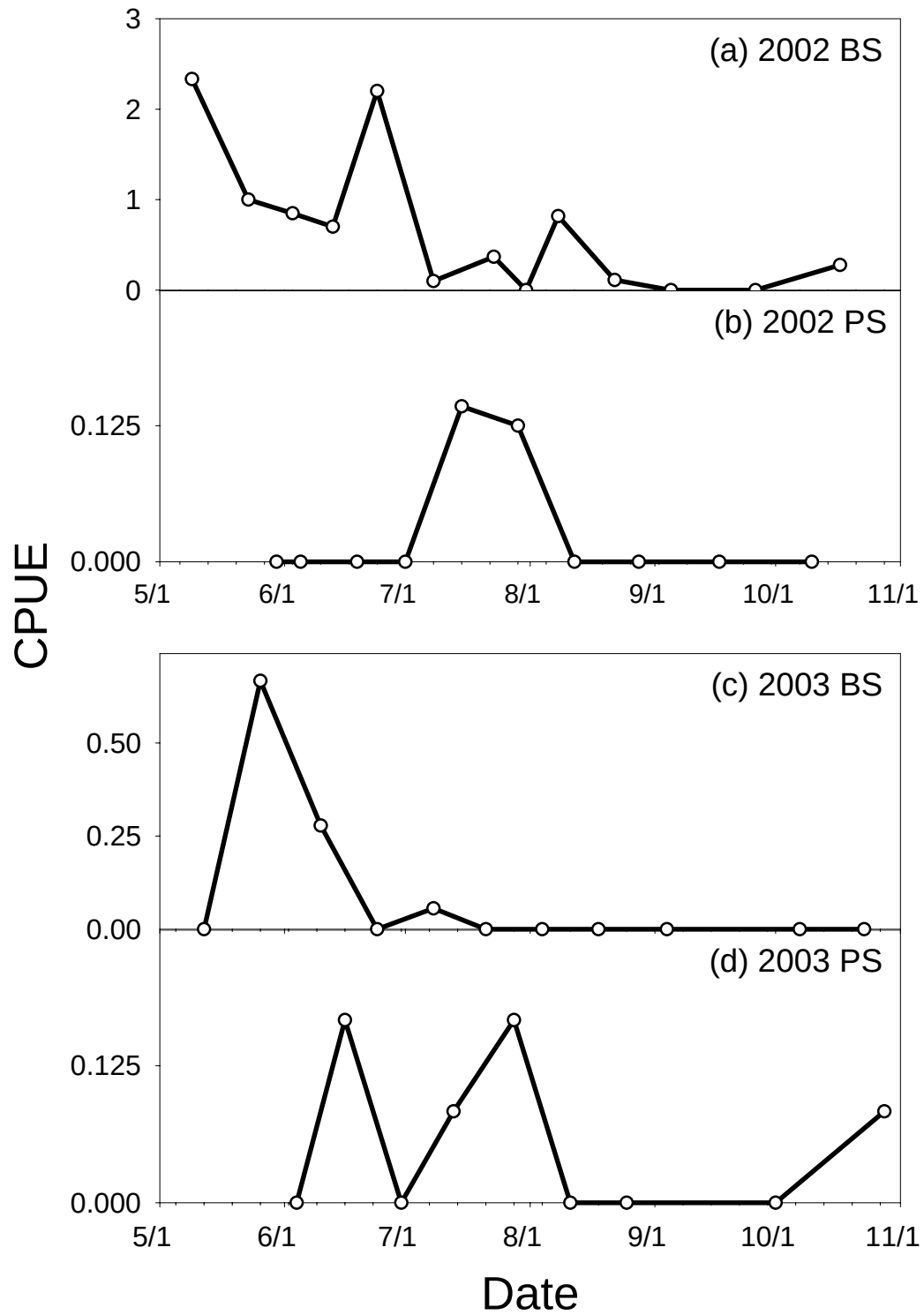


Figure 10. Length frequency distributions of juvenile American shad captured in 61 m beach seine for (a) 2002 and (b) 2003. Bins are 5 mm length bins. October catches (not shown) were 7 and 33 total shad for 2002 and 2003 respectively. Total lengths of a subsample or an entire catch were measured in millimeters. The linear approximation of the growth rate for 2002 and 2003 was 0.37 and 0.50 $\text{mm}\cdot\text{day}^{-1}$ respectively over dates preceding the final drop in water temperatures.

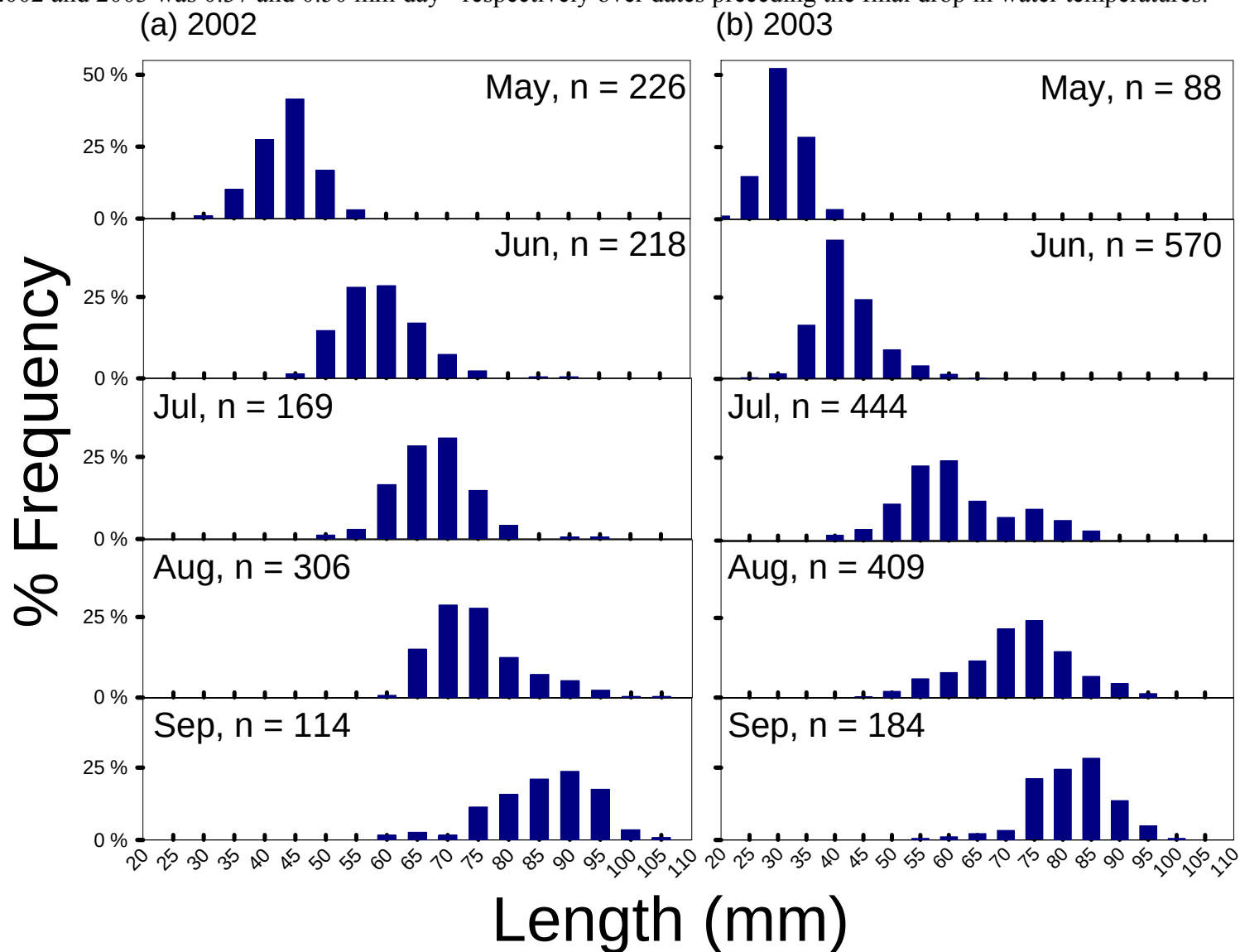


Figure 11. Length frequency distributions of juvenile alewife captured in 61 m beach seine for (a) 2002 and (b) 2003.

Bins are 5 mm length bins. October catches (not shown) were 4 and 32 total alewife for 2002 and 2003 respectively.

Total lengths of a subsample or an entire catch were measured in millimeters. The linear approximation of the growth rate for 2002 and 2003 was 0.36 and $0.49 \text{ mm} \cdot \text{day}^{-1}$ respectively over dates preceding the final drop in water temperatures.

(a) 2002

(b) 2003

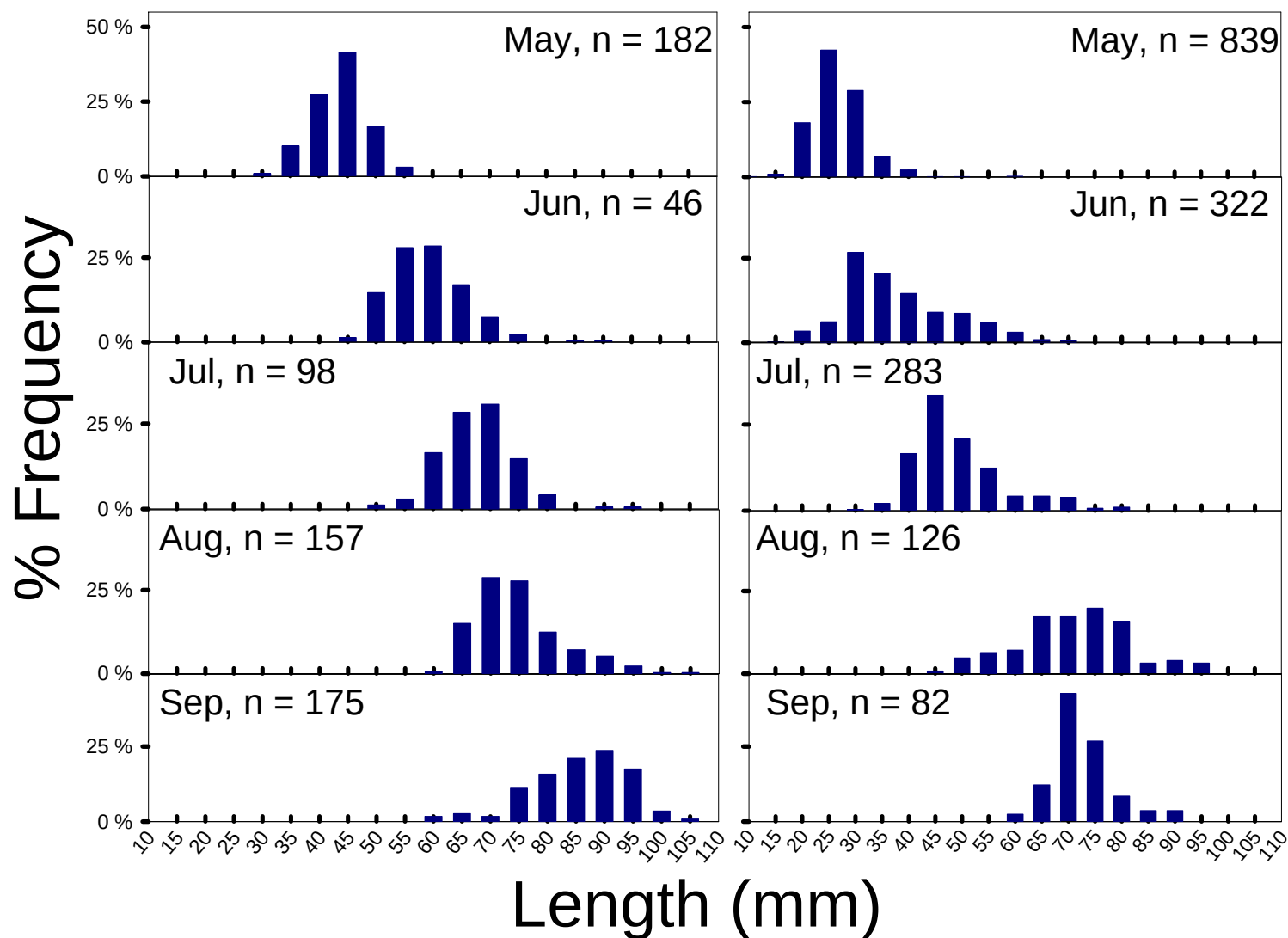


Figure 12. Length frequency distributions of juvenile alewife captured in 76 m purse seine for (a) 2002 and (b) 2003.

Bins are 5 mm length bins. Total lengths of a subsample or an entire catch were measured in millimeters. The linear approximation of the growth rate for 2002 and 2003 was 0.59 and $0.23 \text{ mm} \cdot \text{day}^{-1}$ respectively over dates preceding the final drop in water temperatures.

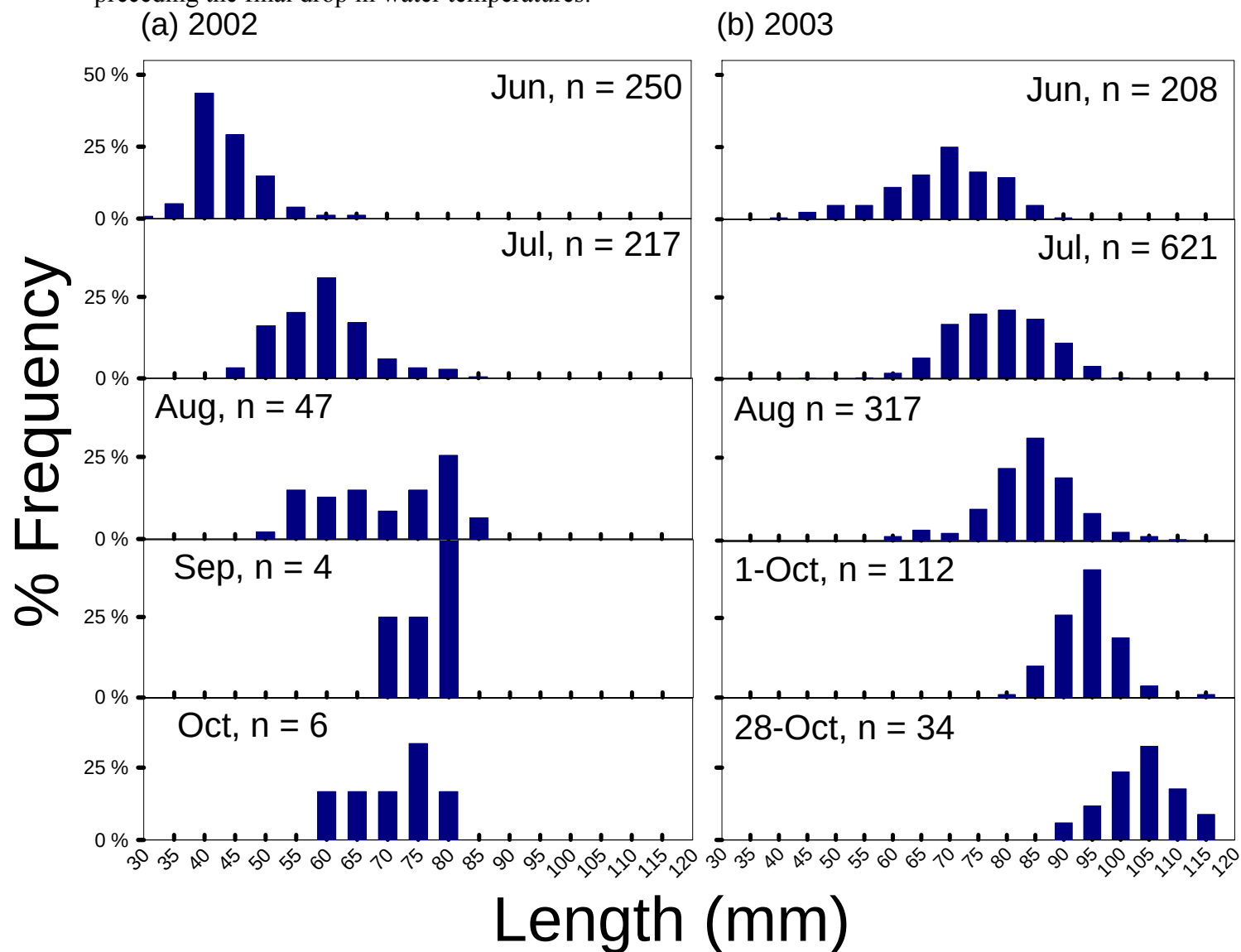


Figure 13. Length frequency distributions of juvenile blueback herring captured in 61 m beach seine for (a) 2002 and (b) 2003. Bins are 5 mm length bins. Total lengths of a subsample or an entire catch were measured in millimeters. The linear approximation of the growth rate for 2002 and 2003 was 0.27 and $0.19 \text{ mm} \cdot \text{day}^{-1}$ respectively over dates preceding the final drop in water temperatures.

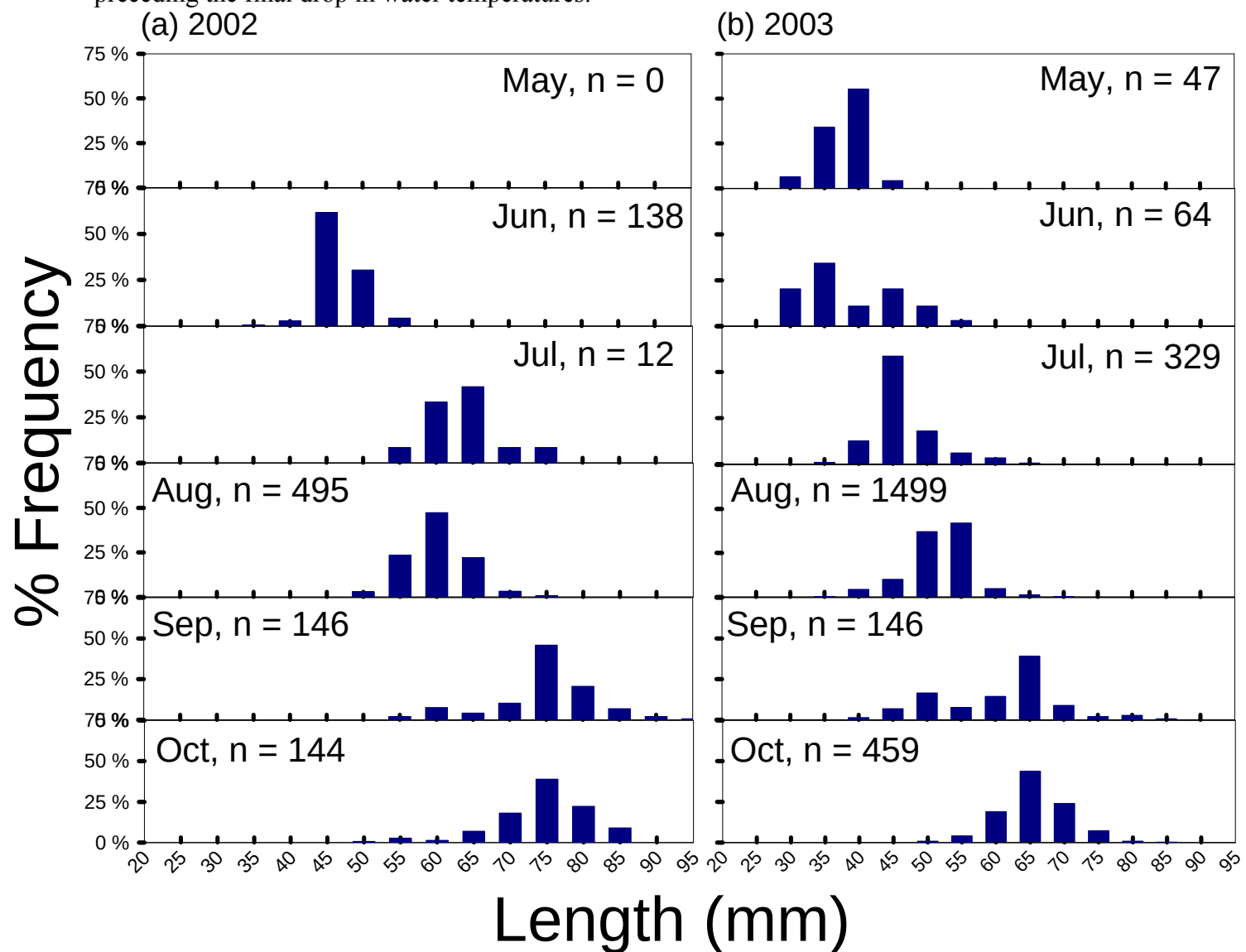


Figure 14. Length frequency distributions of juvenile blueback herring captured in 76 m purse seine for (a) 2002 and (b) 2003. Bins are 5 mm length bins. Total lengths of a subsample or an entire catch were measured in millimeters. The linear approximation of the growth rate for 2002 and 2003 was 0.20 and $0.30 \text{ mm} \cdot \text{day}^{-1}$ respectively over dates preceding the final drop in water temperatures.

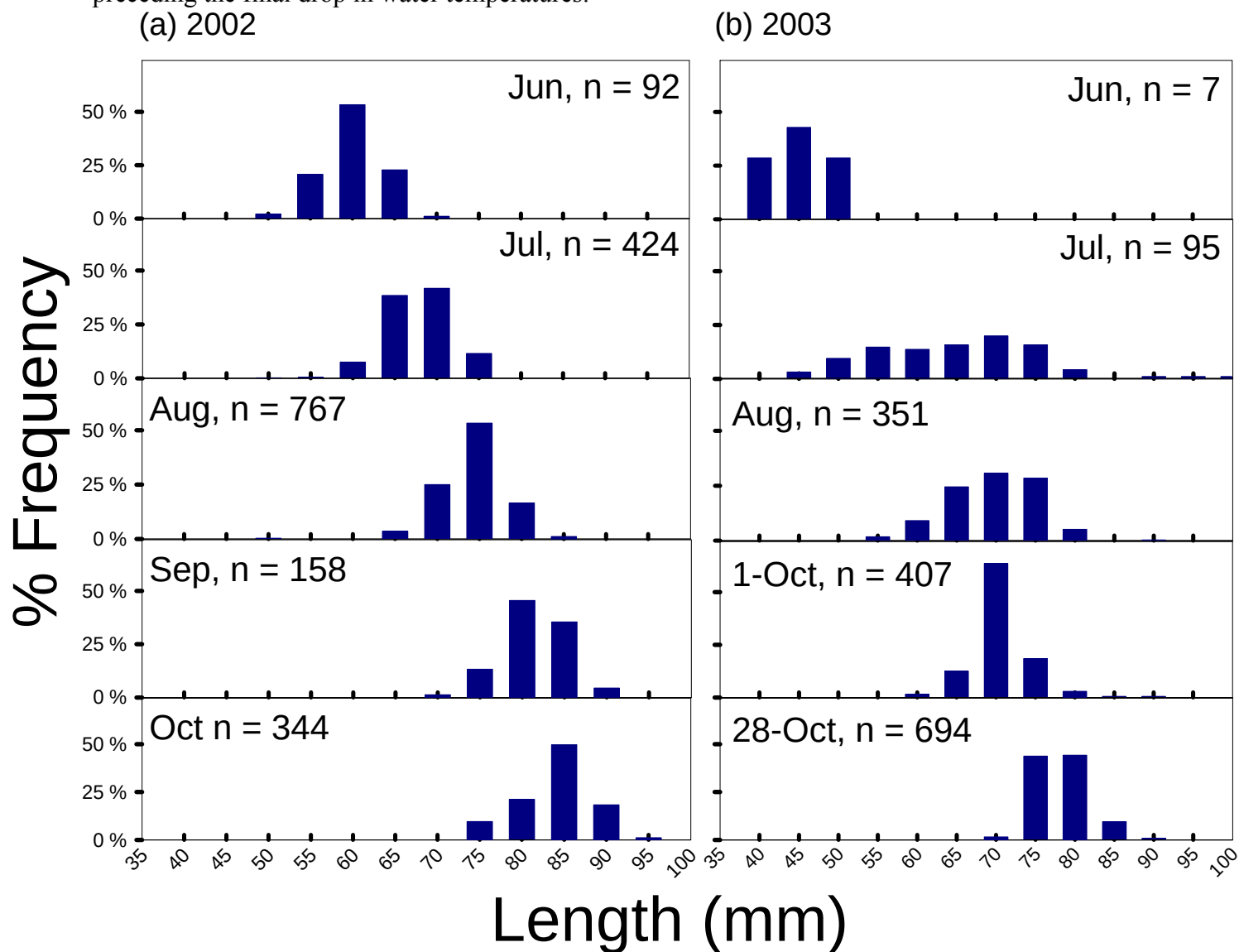


Figure 15. Length frequency distributions of juvenile yellow perch captured in 61 m beach seine for (a) 2002 and (b) 2003. Bins are 5 mm length bins. Total lengths of a subsample or an entire catch were measured in millimeters. The linear approximation of the growth rate for 2002 and 2003 was 0.55 and $0.60 \text{ mm} \cdot \text{day}^{-1}$ respectively over months with a unimodal length frequency distribution.

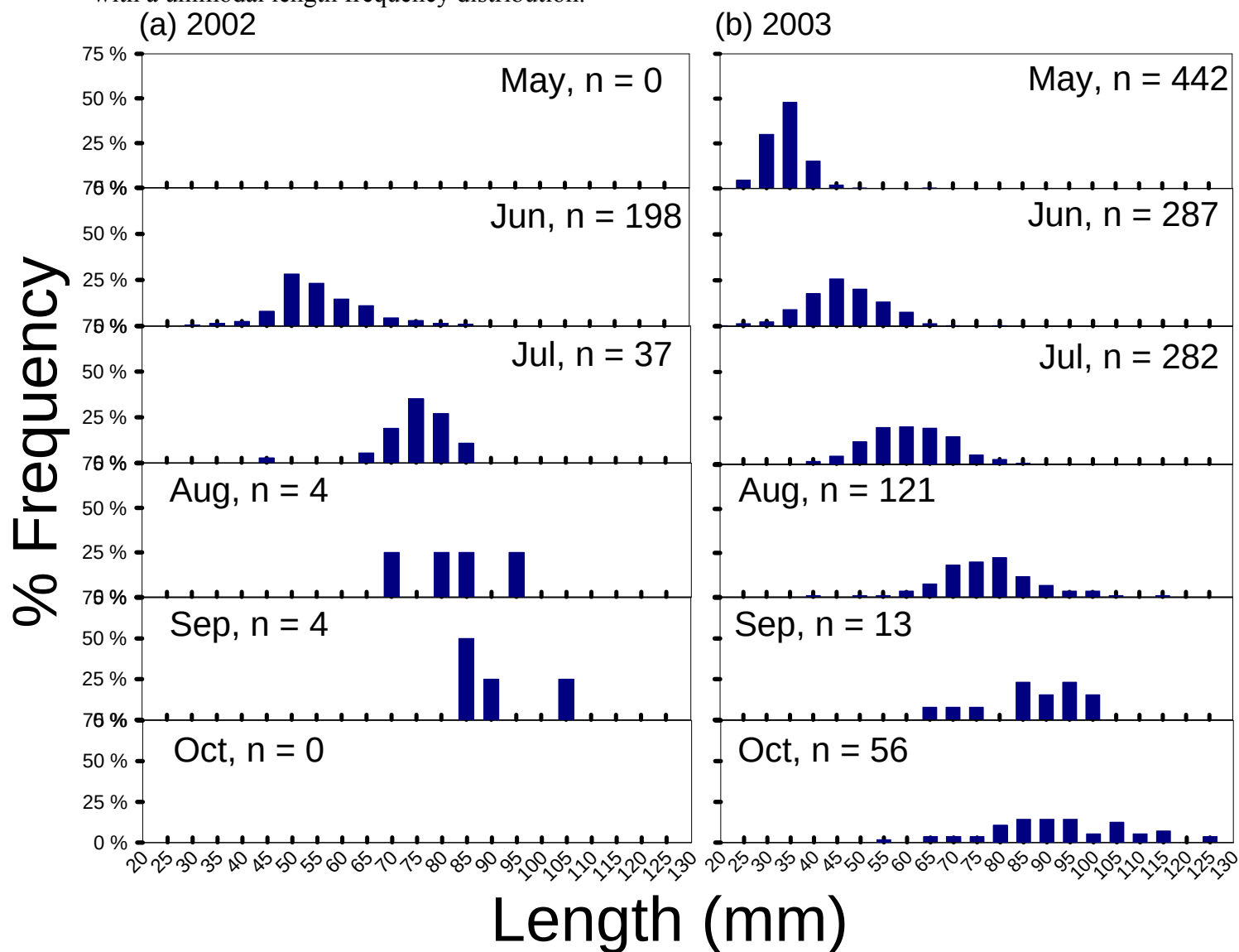


Figure 16. Length frequency distributions of age-1 striped bass captured with all gear types for (a) 2002 and (b) 2003. Bins are 10 mm length bins. Total lengths of a subsample or an entire catch were measured in millimeters.

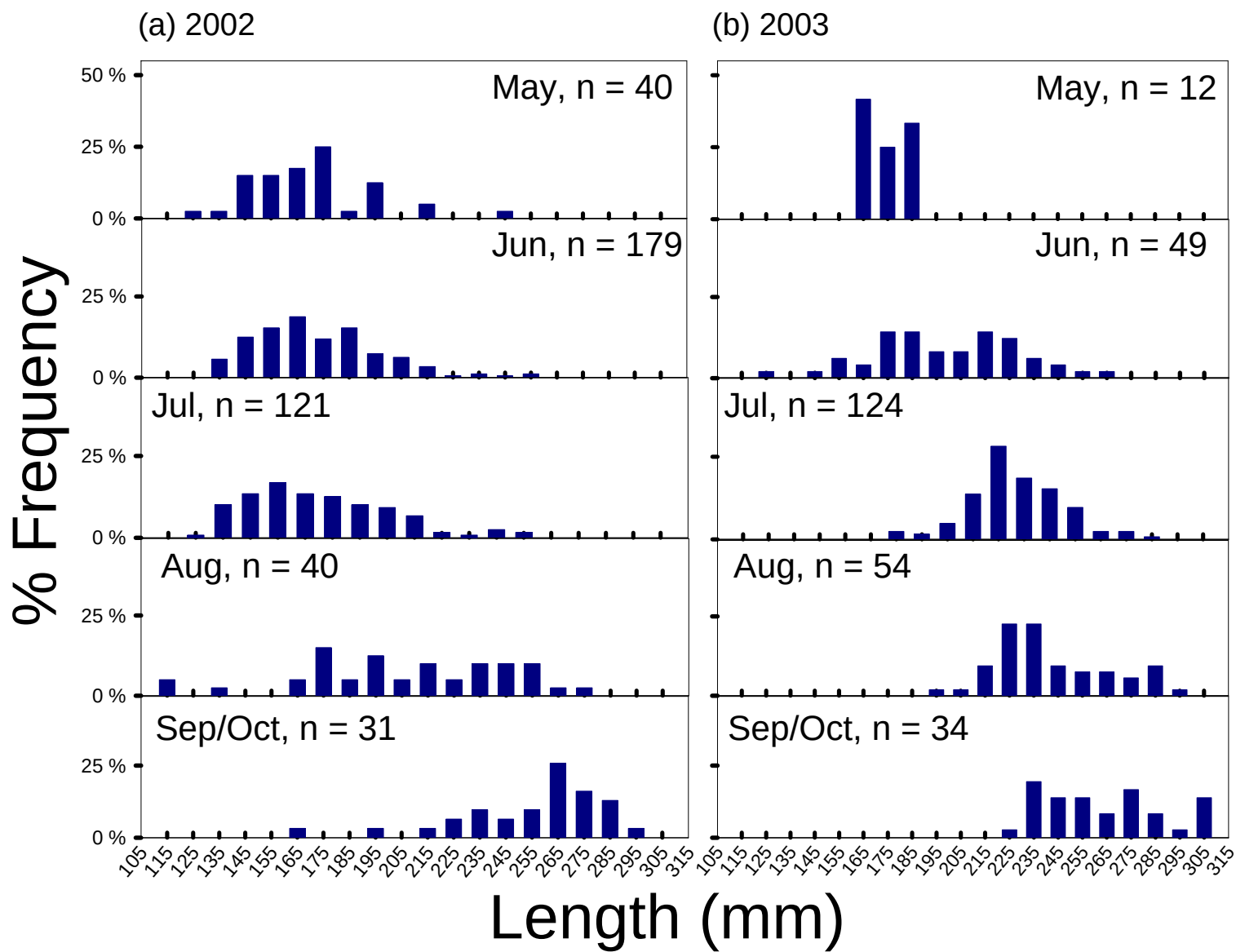


Figure 17. Percent frequency and weight of major animal food groups normalized to 100% for age-1 striped bass in (a) 2002 and (b) 2003. See table 12 for items in “other fish” category.

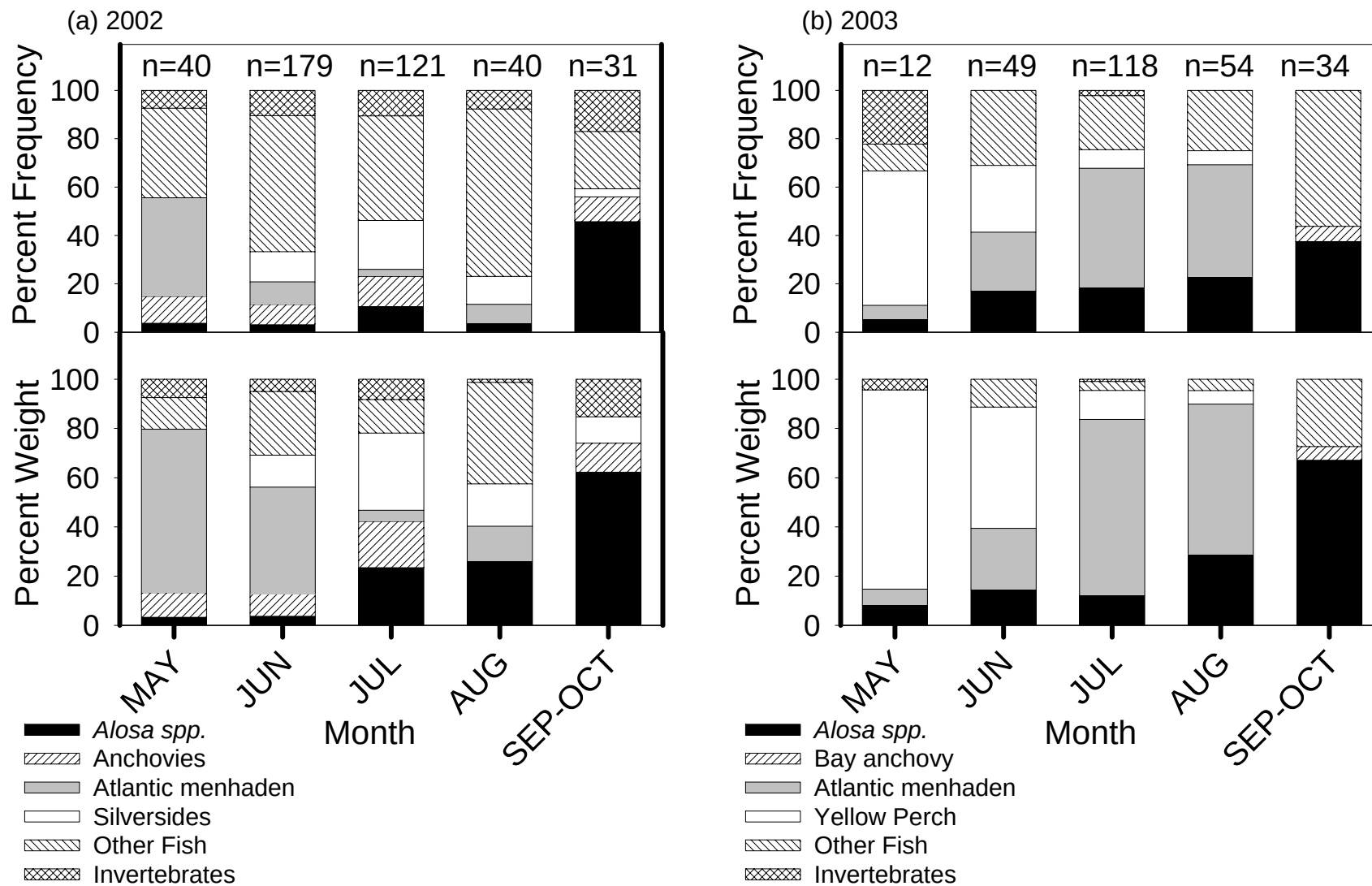


Figure 18. Mean selectivity ($\pm$ S.E.) vs. date for dominant prey groups of age-1 striped bass for (a) 2002 beach seine, (b) 2002 purse seine; random feeding (i.e. $1/(\text{number of food groups})$) shown as dashed line in each panel.

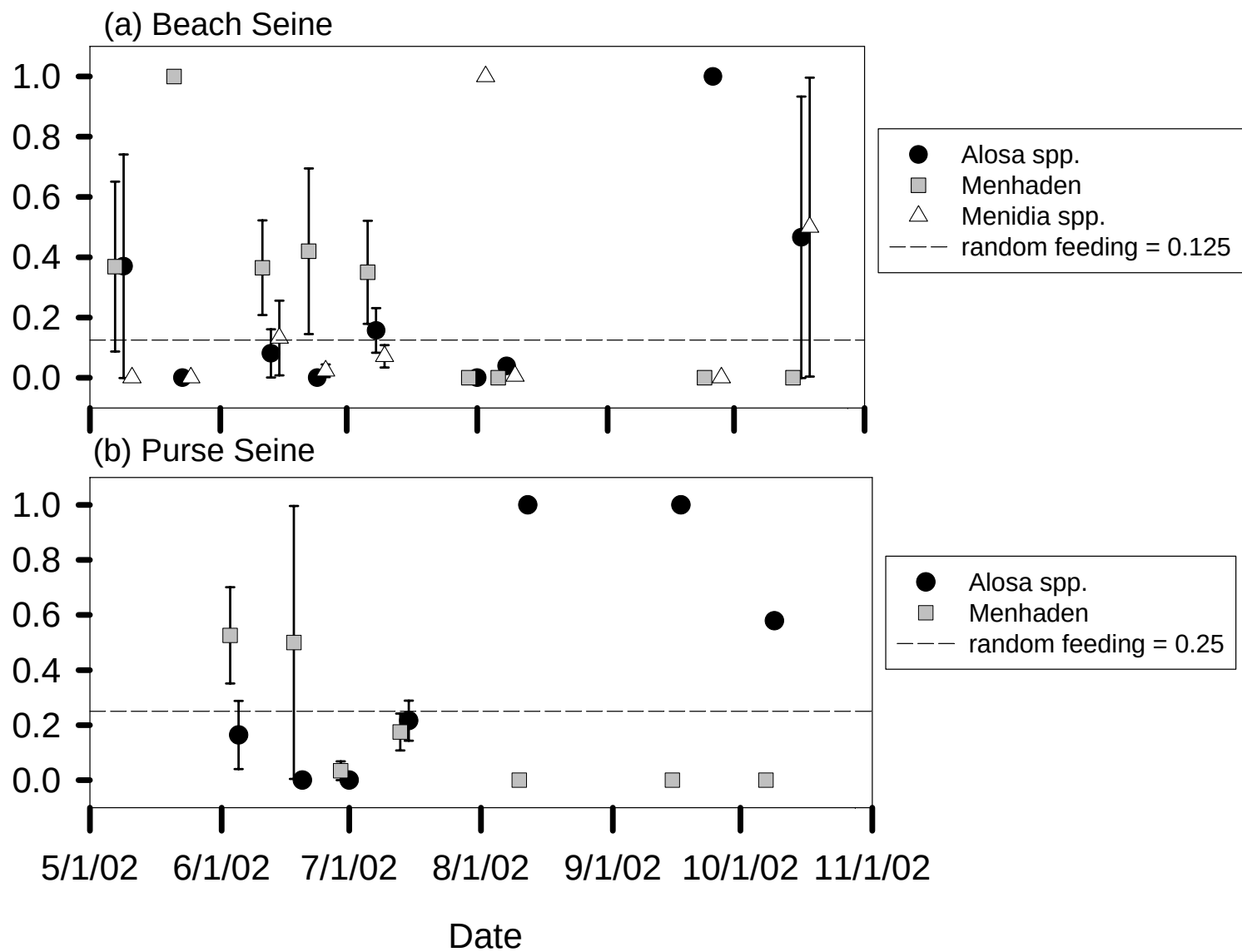


Figure 19. Mean selectivity ($\pm$ S. E.) vs. date for dominant prey groups of age-1 striped bass for (a) 2003 beach seine, (b) 2003 purse seine; random feeding (e.g. $1/(\text{number of food groups})$) shown as dashed line in each panel.

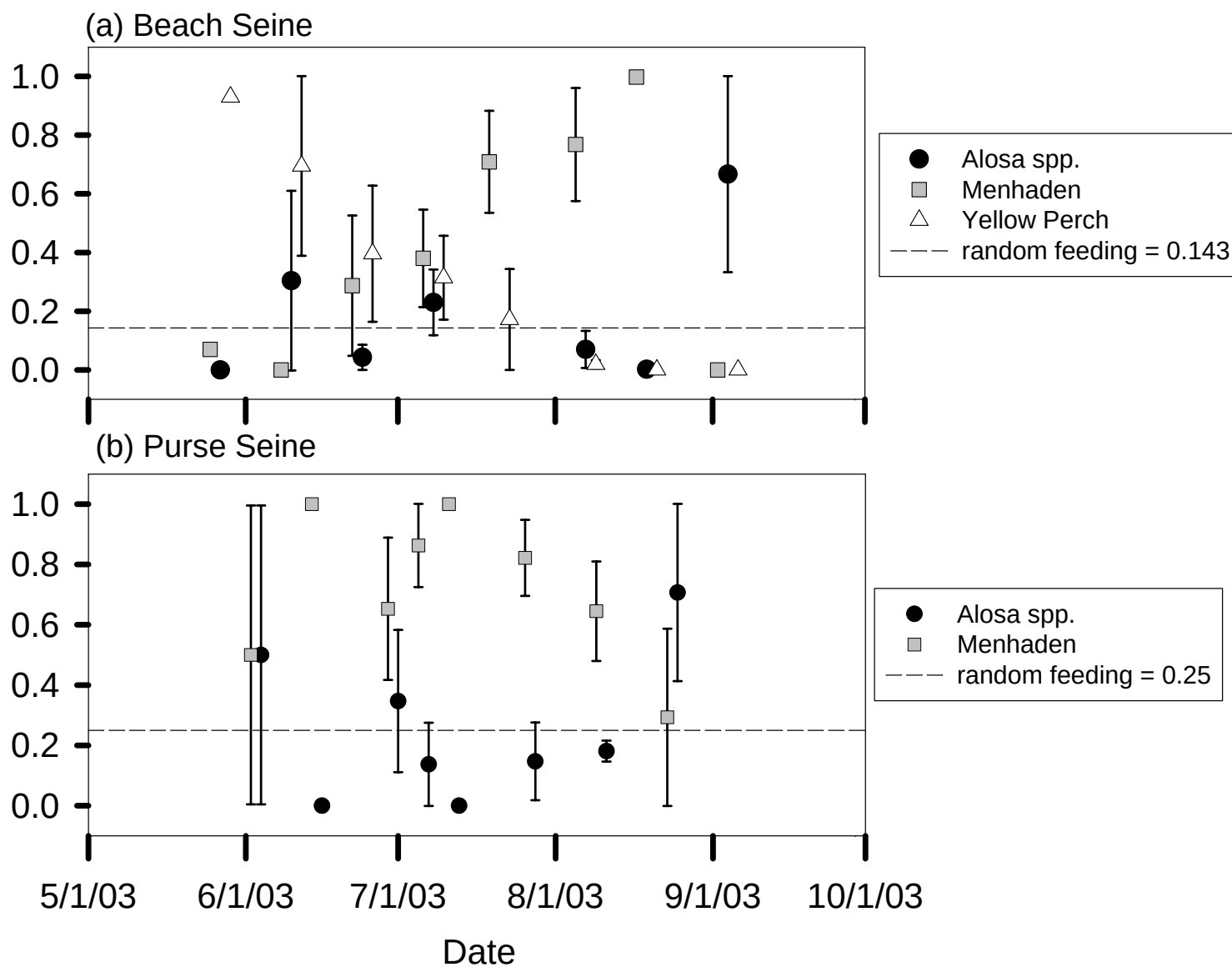


Figure 20. Mean gut-fullness values ($\pm$ S.E.) of age-1 striped versus time of capture during 24-hour collections in 2002 on (a) 06/11/02 – 06/12/02 and (b) 07/11/02 – 07/12/02. Sample size for each timepoint shown above S.E. bars. The time periods from sunset to sunrise are indicated by dark horizontal bars. Gray line in bottom panel represents fit of gastric evacuation equation.

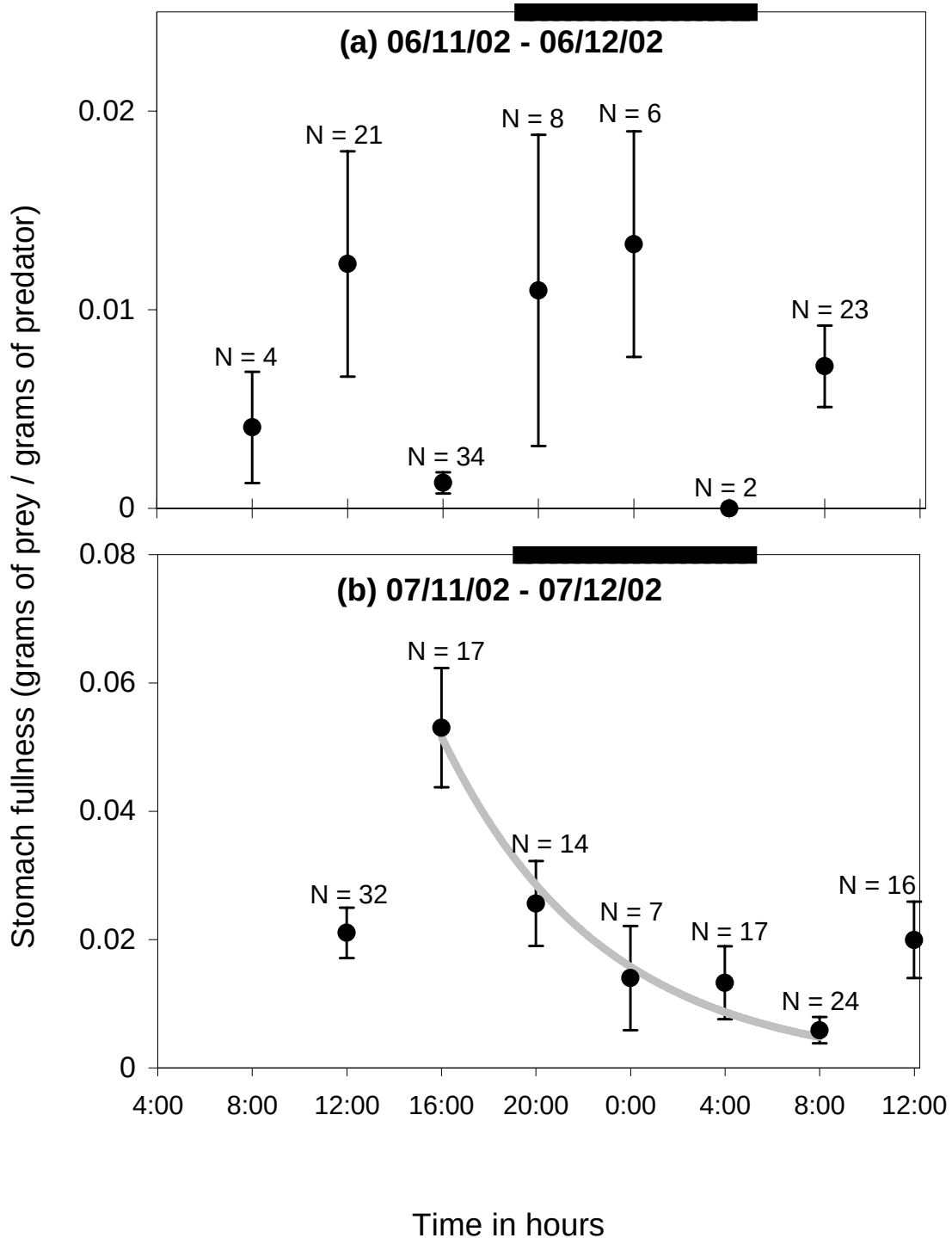


Figure 21. Mean gut-fullness values ($\pm$ S.E.) of age-1 striped versus time of capture during 24-hour collections in 2003 on (a) 07/10/03 – 07/11/03 and (b) 08/05/03 – 08/06/03. Sample size for each timepoint shown above S.E. bars. The time periods from sunset to sunrise are indicated by dark horizontal bars. Gray line in top panel represents fit of gastric evacuation equation. Open squares in top panel represent gut-fullness of individual purse seine captured fish in the month of July.

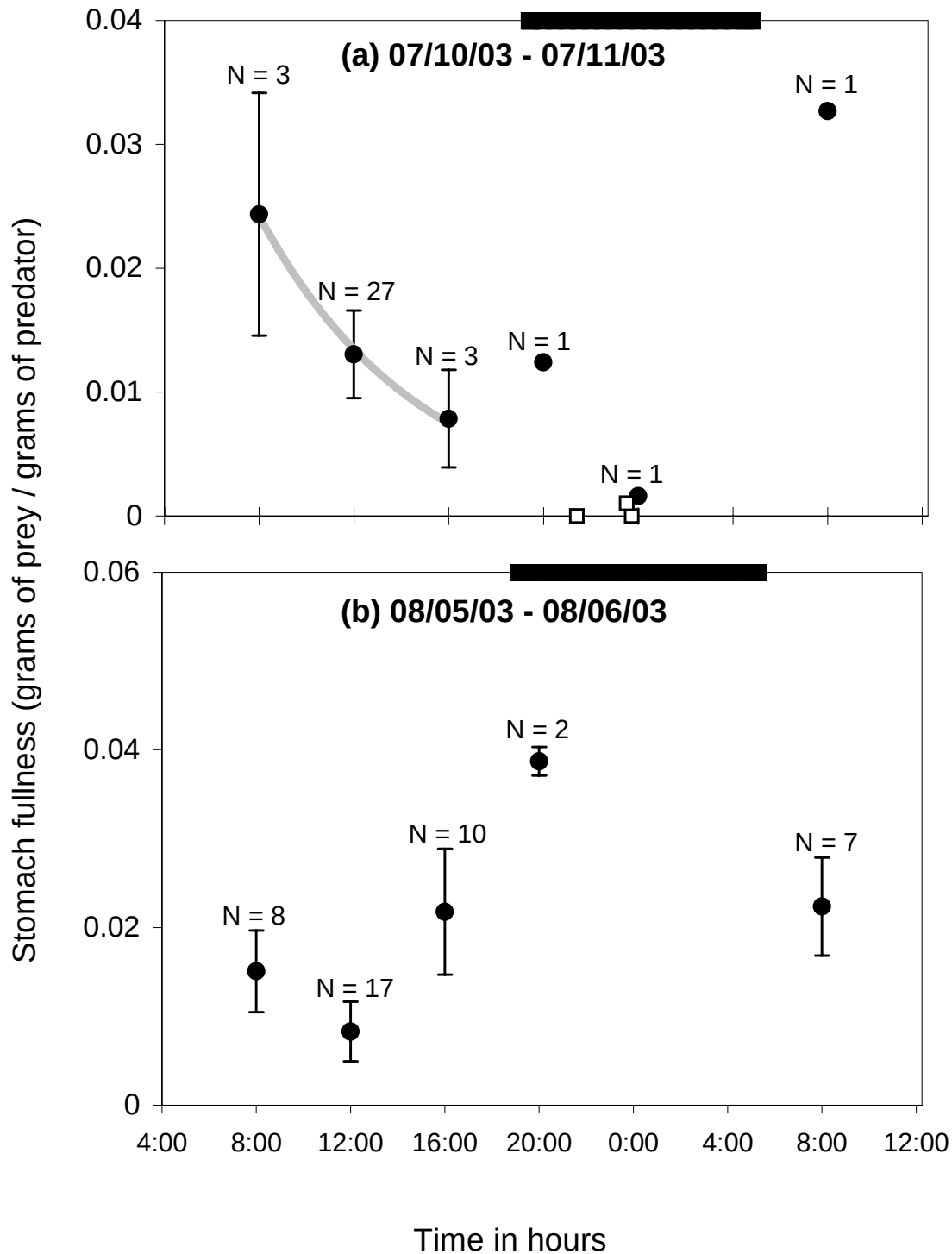


Figure 22. Estimates of consumption rates g/g/day vs. date for age-1 striped bass in western Albemarle Sound in (a) 2002 and (b) 2003. Daily bioenergetics model estimates displayed in a solid line. Field estimates of consumption with $\pm$ one standard error are plotted as open circles.

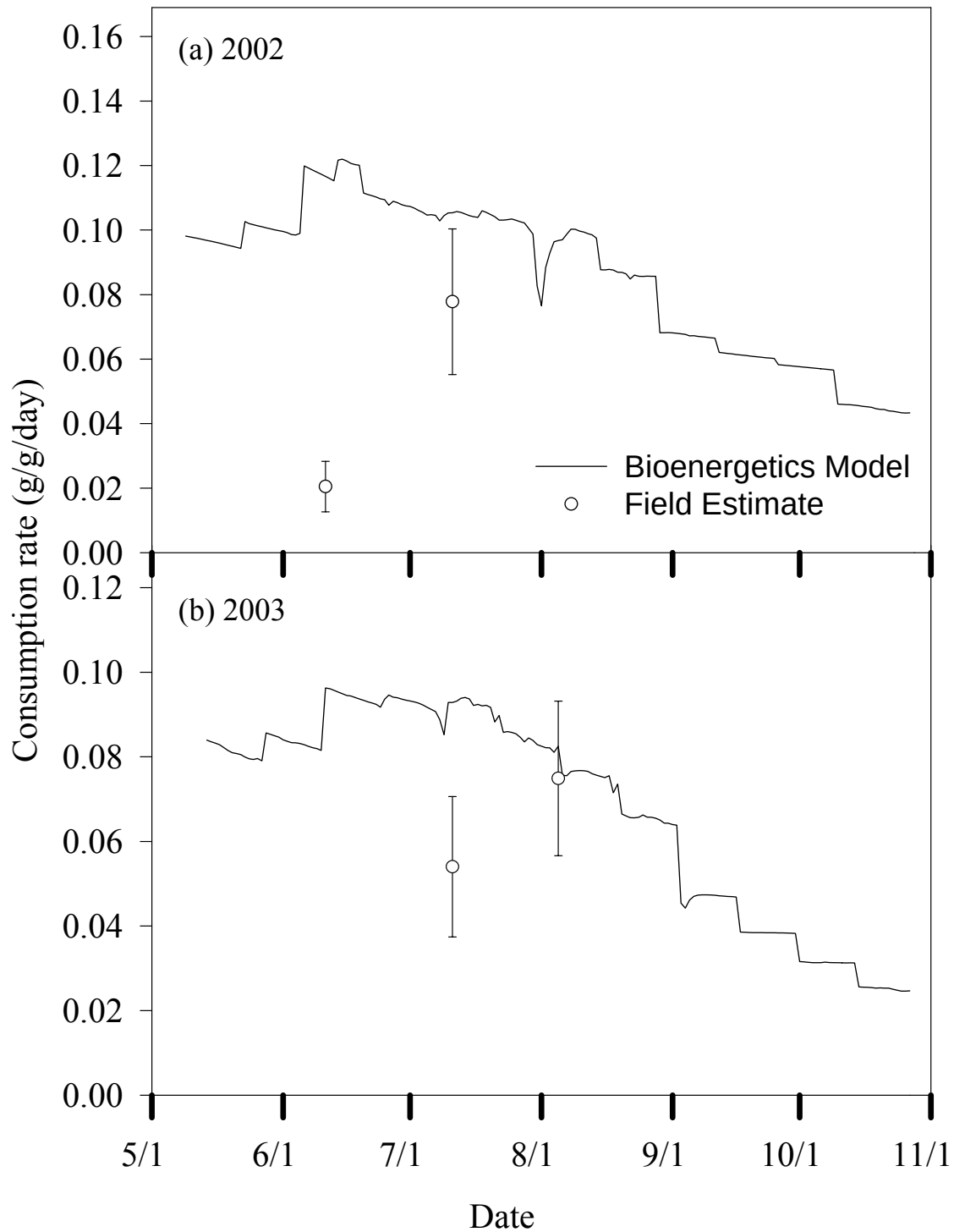


Figure 23. P-value fits for the bioenergetics model plotted vs. date for (a) 2002 and (b) 2003. P-values are the proportion of maximum theoretical consumption at day. P-values were fit to age-1 striped bass growth in 14-day increments.

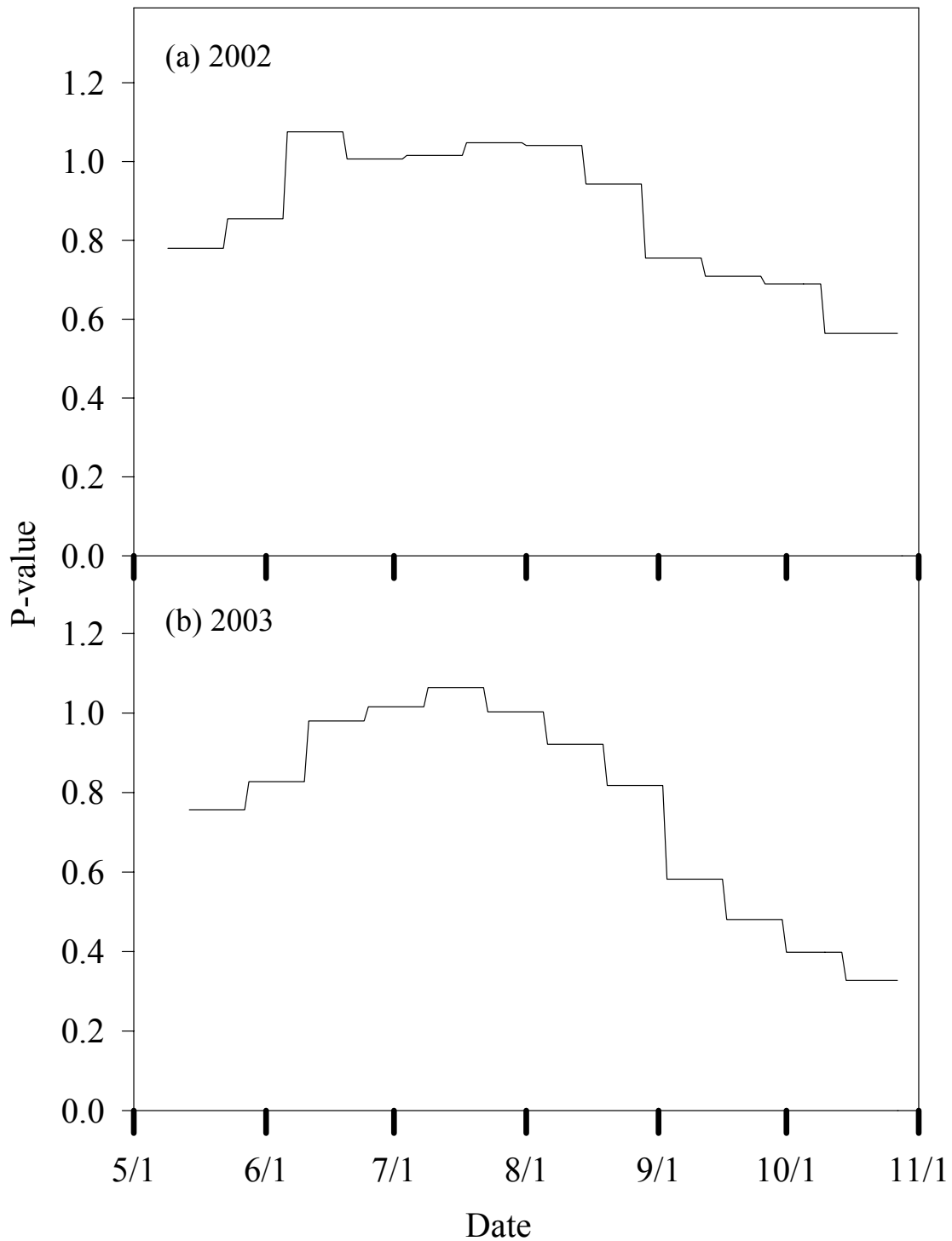


Figure 24. Regressions for catch curve analysis for American shad (AS) in beach seine (BS) in both years (a, b); alewife (AW) in the beach seine (BS) in 2003 and purse seine (PS) in both years (c, d, e) and yellow perch (YP) in the beach seine in both years (f, g).

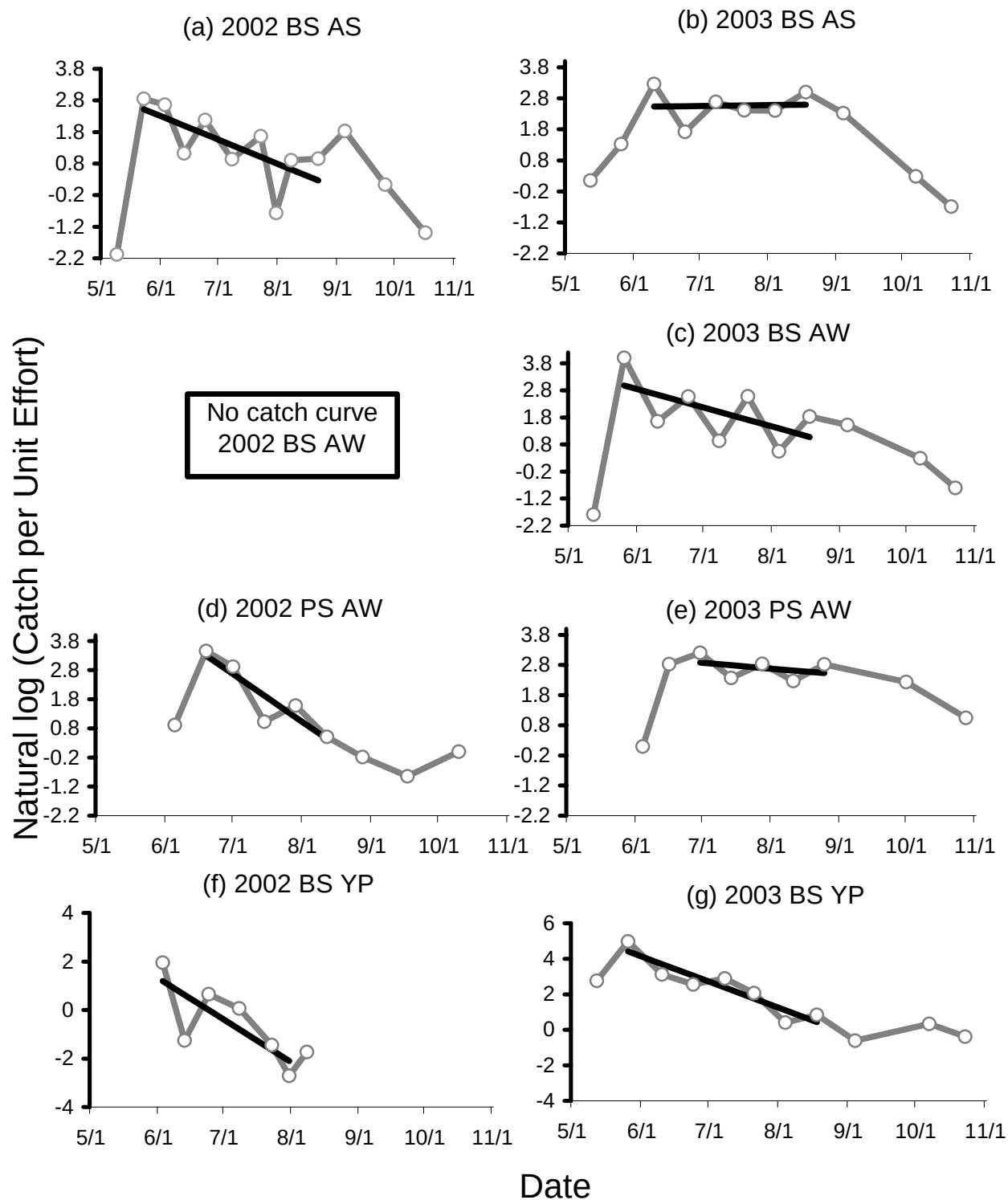


Figure 25. Numbers lost due to predation and available density for alewife in the 2002 beach seine. The area swept by the beach seine is roughly 500 m².

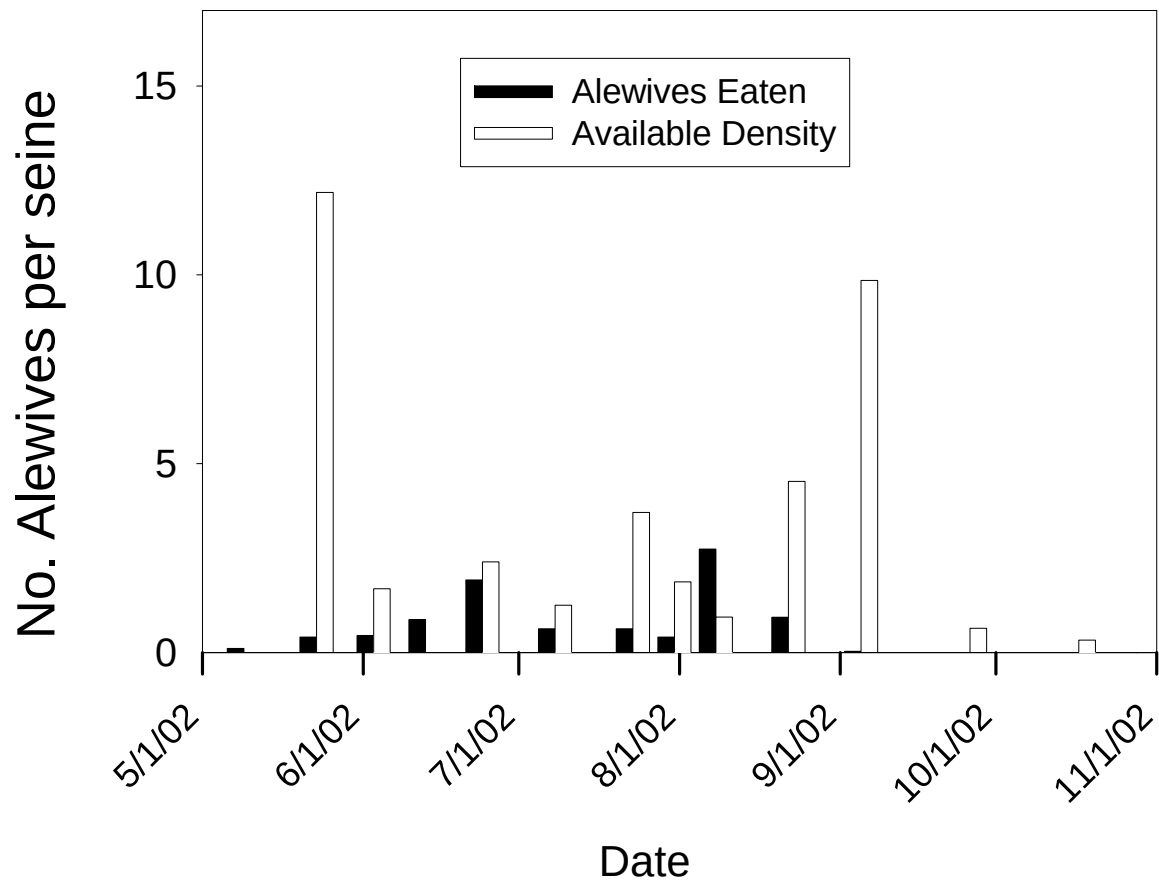


Figure 26. Numbers lost due to predation, and available density for blueback herring in (a) the 2002 beach seine, and (b) the 2002 purse seine. The areas swept by the beach seine and purse seine are roughly 500 m² and 462 m² respectively.

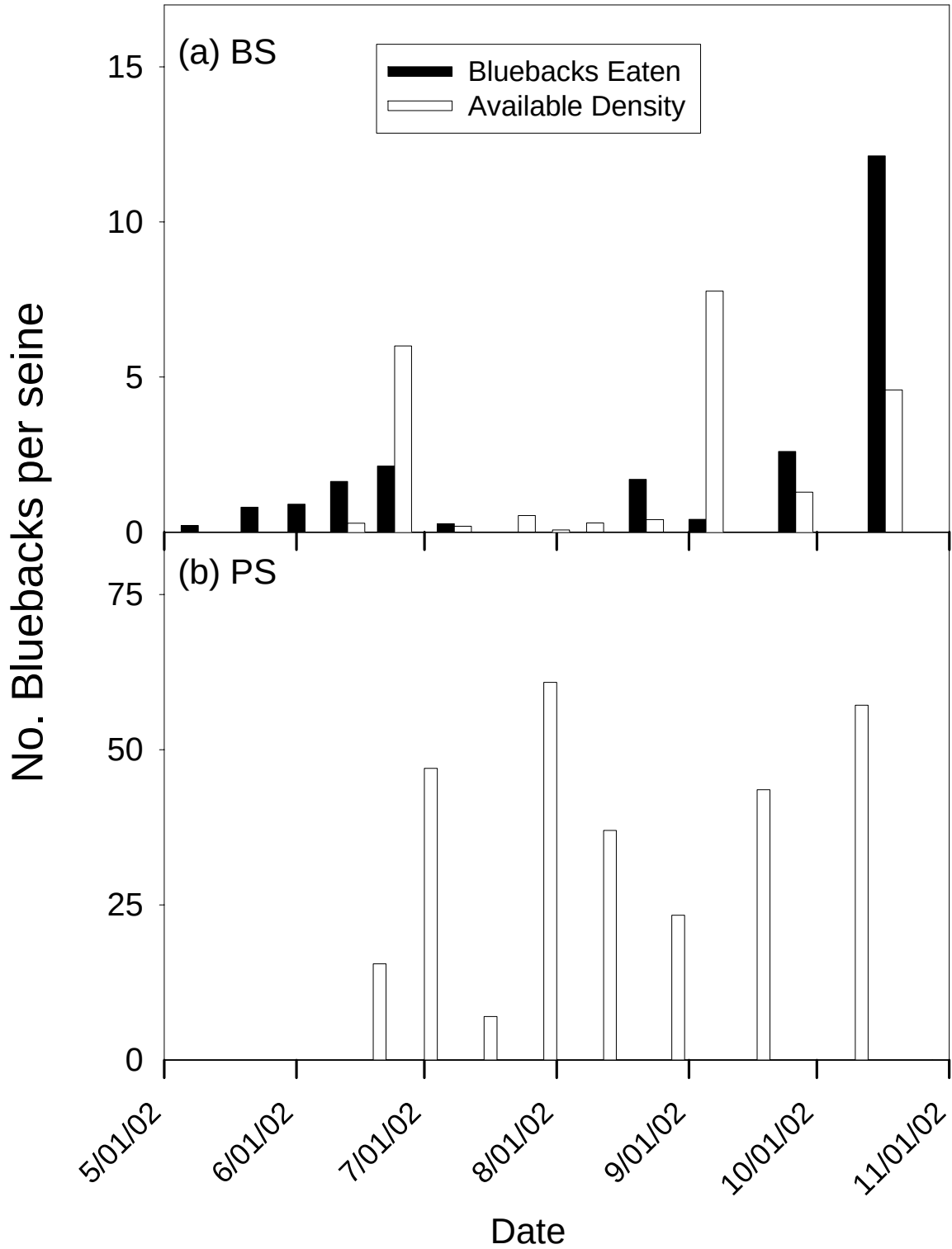
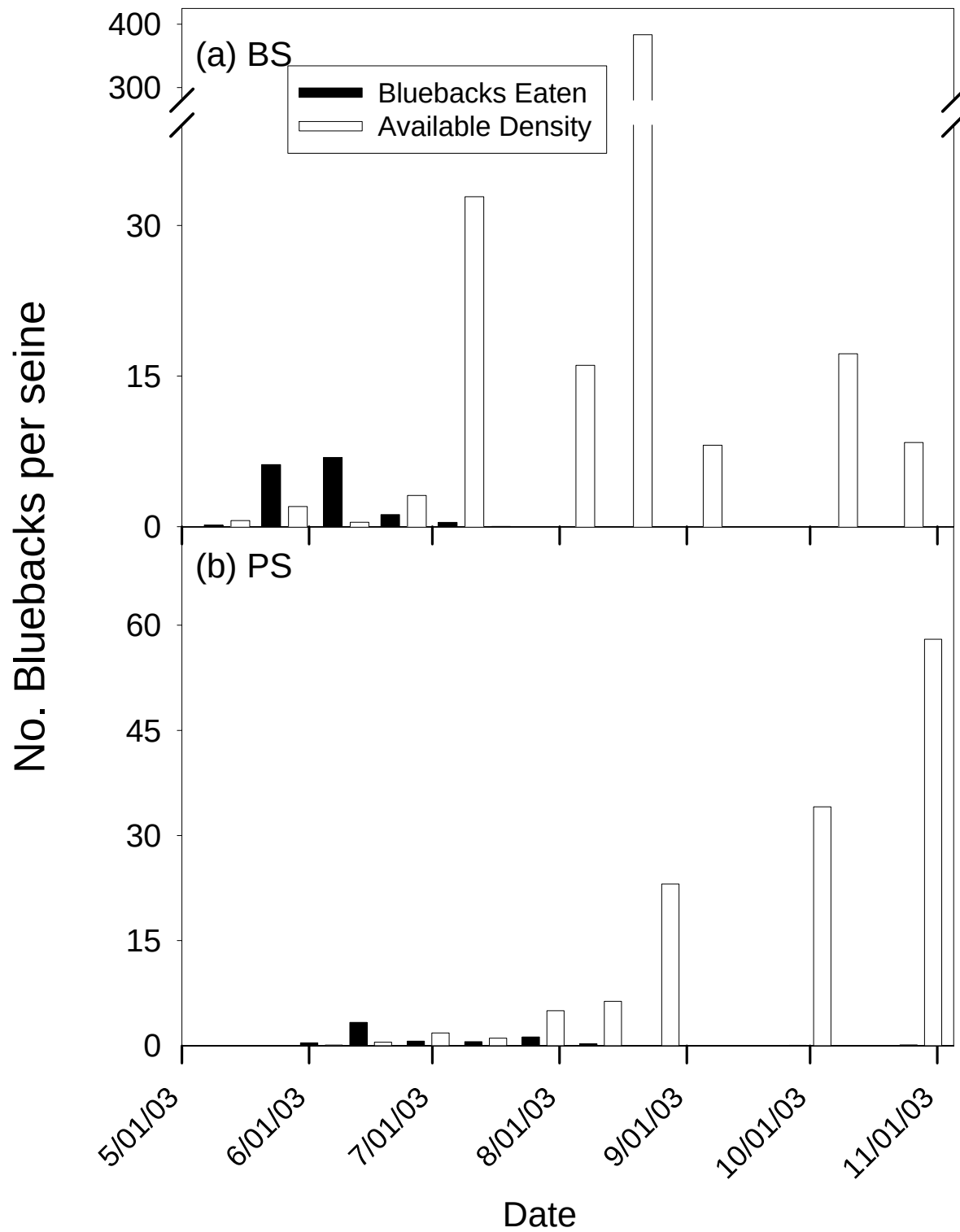


Figure 27. Numbers lost due to predation, available density and adjusted available density for blueback herring in (a) the 2003 beach seine, and (b) the 2003 purse seine. The areas swept by the beach seine and purse seine are roughly 500 m² and 462 m² respectively.



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