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Mary C. Fabrizio
Virginia Institute of Marine Science

Troy D. Tuckey
Virginia Institute of Marine Science

Olivia M. Philips
Virginia Institute of Marine Science

Brian K. Gallagher
Virginia Institute of Marine Science

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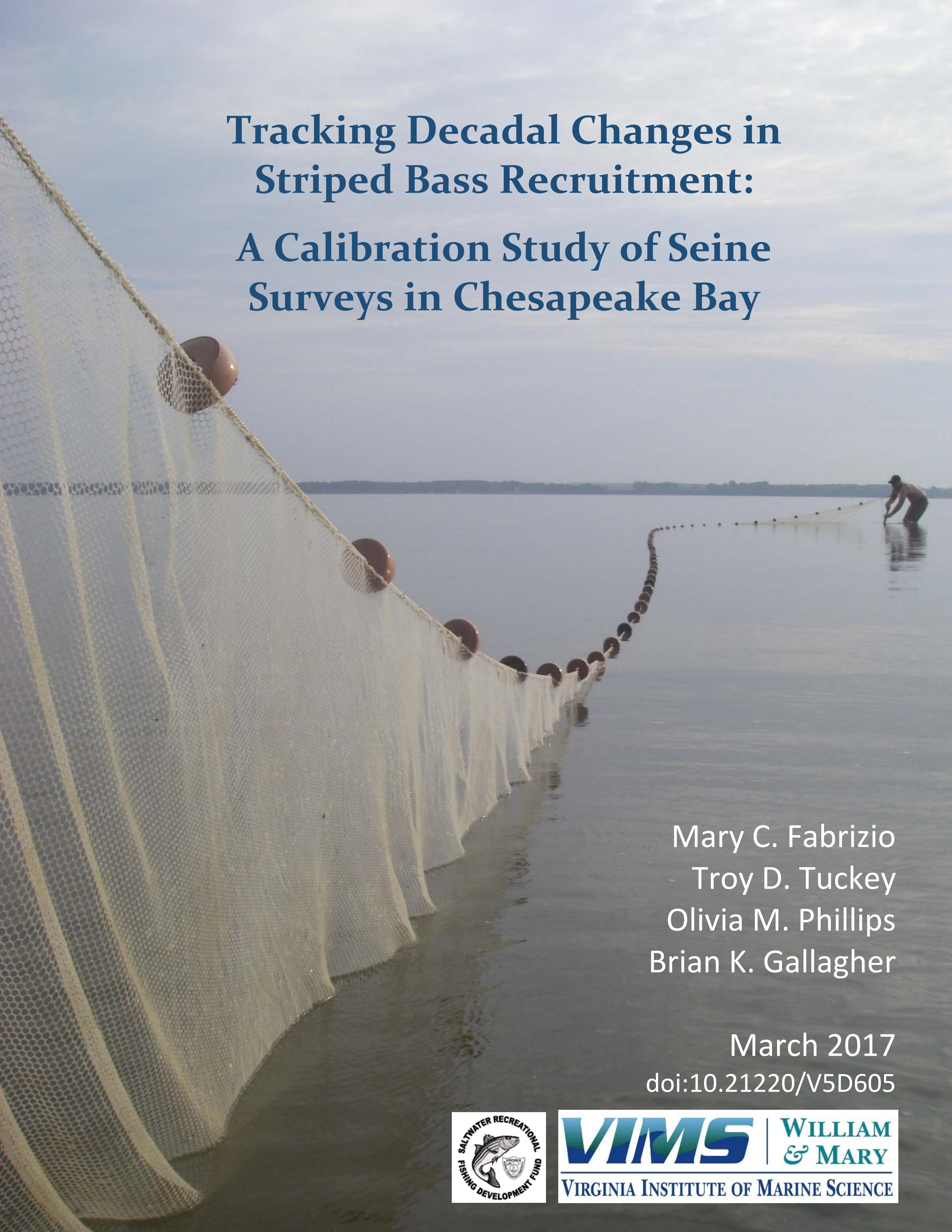

Tracking Decadal Changes in Striped Bass Recruitment:

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Mary C. Fabrizio
Troy D. Tuckey
Olivia M. Phillips
Brian K. Gallagher

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Executive Summary

In this study we estimated calibration factors necessary to maintain the long-term integrity of the juvenile striped bass surveys in the Chesapeake Bay region. These surveys provide annual indices of recruitment (estimated as juvenile fish abundance in summer) and are used by fisheries managers in Virginia and Maryland to inform adjustments of annual harvest limits for striped bass from the commercial and recreational fisheries in Chesapeake Bay. During the multi-decadal history of the survey, a potentially influential change occurred: VIMS deployed a net (the VA net) with a mesh material that differed from the standard net that MD DNR continued to deploy (the MD net). More recently, another change was necessitated when neither the standard net material nor the net material recently used by VIMS was available for construction of replacement nets. Hence, a net using new mesh material was constructed and experimentally deployed in 2015 (new net). Paired net hauls (n=144) were completed in Maryland and Virginia nursery areas during summer 2015 to permit estimation of calibration factors: 70 pairs with the VA-MD nets, 42 pairs with the MD-New nets, and 32 pairs with the VA-new nets. Not all paired hauls captured a given target species, however. Three sets of calibration factors were estimated from using beta-binomial models that accounted for differences in capture efficiencies and variation in the relative capture success of the nets. We considered the effects of several environmental covariates (e.g., temperature, salinity, and turbidity) as well as deployment characteristics (e.g., bottom type, calendar day, and maximum net extension) on the relative efficiency of nets and on the variation in the probability of capture among paired hauls.

The VA and MD nets performed similarly for juvenile striped bass and juvenile white perch, and thus we do not recommend adjustments of the historical time series of recruitment indices. The Virginia time series is internally consistent through time until 2015: indices calculated from 1967 to 1998 (when VIMS used the MD net) are consistent with indices calculated from 1998 to 2015 (when VIMS used the VA net) and no adjustment is necessary. Further, there is no evidence to suggest that the Virginia and Maryland time series are not directly comparable from 1967 to 2015. Although we do not recommend application of a calibration factor for the MD-VA nets, we note that for a given paired haul, net efficiencies may differ (failure to detect a difference does not imply that a difference does not exist). Overall, and on average across the wide range of environmental conditions and two deployment techniques used in this study, the efficiency of the two nets was similar. We strongly recommend maintenance of standardized deployment techniques as currently used by MD DNR and VIMS.

For juvenile striped bass, our modeling results with the MD and VA nets suggest that sampling in the earlier summer reduces the variation in the probability of capture among hauls, and that sampling when temperatures exceed 24°C reduces the difference in relative efficiencies of the MD and VA nets. Based on these findings, we suggest that the comparability of the Virginia and Maryland seine surveys may be enhanced by estimating recruitment from catches in July and August, or by considering catches restricted by fish size (efficiency is less variable when fish are smaller). We also noted that variation in the relative efficiencies of the VA and MD nets was lower when samples were collected during the early summer (late June). The potential for less variation in relative efficiency of the nets in late June has implications for the design and

analysis of the seine survey as the climate continues to warm and striped bass spawning occurs earlier in the year; in this situation, juvenile fish will become vulnerable to the gear earlier in the year. In recent years, VIMS has initiated sampling earlier in the summer (late June versus early July) to reflect the availability of small striped bass to the gear. It is during this early summer period that we noted that variation in the efficiencies of the MD and VA nets appeared to decline, thus, the performance of the two nets appeared to be more similar during times when smaller fish were available to the gear. We also note that temperatures above 24°C reduce differences in the relative catch efficiency of the two nets. Thus, sampling in the earlier part of the summer, after temperatures reach 24°C appears to be a reasonable strategy for standardizing seine surveys of juvenile striped bass abundance in the Chesapeake Bay region. Further investigations could be useful in determining the source of the variation in relative net efficiencies during late summer (late August-September) and consideration of the time period used to estimate recruitment indices for Maryland and Virginia may be warranted.

For both juvenile striped bass and juvenile white perch, we found significantly greater efficiency of the new net relative to the VA net. For a given net pair, estimated calibration factors for juvenile striped bass and juvenile white perch, were not significantly different. This is not surprising because as juveniles, these congeners occupy similar inshore habitats during summer and exhibit similar seasonal movements and prey preferences (Setzler-Hamilton 1980, 1991).

Given the similar efficiencies of the MD and VA nets, and the greater efficiency of the new net relative to the VA net, we expected that the new net would also be relatively more efficient than the MD net in capturing juvenile striped bass and juvenile white perch. However, we found the opposite. For both species, the MD net exhibited a greater efficiency than the new net. Possible explanations include small sample sizes for the MD-new pair comparisons (25 pairs for juvenile striped bass and 29 pairs for juvenile white perch), insufficient habitat representation (mud and gravel habitats may have been underrepresented in the comparisons), and insufficient range of net extensions realized in this paired-net comparison. Another possibility is that the calibration factor for the MD-VA pairs was significantly different from one, although our data did not support this. If so, then the MD net may have been more efficient than the VA net, with relative efficiencies ranging from MD net with the highest efficiency, the new net with intermediate efficiency, and the VA net with the lowest efficiency. Because our sample size for the MD-VA comparisons was somewhat large (n=50 pairs), we suspect that small sample sizes of the VA-new and MD-new comparisons contributed to the discrepancy. Thus, we recommend additional sampling with the new and VA nets in 2017 and re-estimation of calibration factors for this net pair.

Introduction

In the Chesapeake Bay, the annual abundance of juvenile striped bass (*Morone saxatilis*) is estimated using beach-seine surveys in tidal freshwater reaches and brackish habitats of the bay and its major tributaries (Figure 1). These surveys are conducted by scientists at the Virginia Institute of Marine Science (VIMS) and the Maryland Department of Natural Resources (MD DNR) during summer when young-of-the-year (YOY) striped bass are readily available to beach seines. The Striped Bass Fisheries Management Plan requires states with striped bass spawning and nursery grounds to maintain a monitoring program of annual juvenile production. Surveys have been ongoing since 1954 in MD and 1967 in VA, with a hiatus in the VA time series from the mid- to late-1970s. Using abundance estimates derived from seine catches, a recruitment index for each jurisdiction is provided to fisheries managers for use in stock assessments and to guide the adjustment of quotas for striped bass for the subsequent fishing year.

In the early 1980s, when the Atlantic coast population of striped bass experienced a significant decline, juvenile striped bass surveys in Virginia and Maryland were standardized to improve comparability and to permit estimation of a baywide index for the species. Along with the implementation of consistent sampling protocols, the seine net was standardized (size, construction, and net material) to further ensure constant and equal catchability of YOY striped bass. Since the early 1980s, both the Virginia and Maryland crews used a 100' (30.5m) long, 4' (1.22m) deep, 1/4" (0.64cm) mesh minnow seine. Due to repeated use, seine nets were periodically replaced with nets manufactured to the same specifications. In late 2014, scientists in Virginia learned that the net material used in past years (1/4" knotless oval mesh) was no longer available. Thus, Virginia needed to replace nets in 2015 (and in subsequent years) with a different net material. When informed of the lack of net material for building replacement nets, scientists at VIMS contacted scientists at the MD DNR to discuss options for future net purchases. Further discussions revealed that, in fact, VIMS scientists had switched to a ¼" knotless oval mesh material in 1999 and were no longer using the standard ¼" knotted mesh used by scientists in Maryland since the late 1960s (Table 1). Scientists in Maryland continued using the ¼" knotted mesh material because in the late 1990s, when warned about the shortage of net material, MD DNR purchased a large supply of the material. This stockpile allowed MD DNR to construct multiple nets thereby ensuring gear consistency with their past surveys. Currently, Maryland scientists estimate having enough nets to complete surveys for the next several years, up to 2018.

Although mesh size is not a concern – all materials are described as ¼" mesh – mesh geometry varies significantly among materials used to construct nets. The standard knotted mesh (used by Maryland DNR) forms a rhombus-shaped opening, whereas the opening in the knotless material (used by VIMS) is oval. The netting used to construct the 'new net' is similar to the knotted mesh net because the opening is shaped like a rhombus, but the material is significantly thinner and lighter in color. It is unknown how these aspects affect net performance and relative catch efficiency. For example, a thinner mesh is less massive and easier to deploy, potentially improving catch efficiency. Another possibility is that a net constructed with the lighter mesh may not be detected by fishes as readily as a net made from the darker-colored, knotted mesh, and thus the lighter net may have a higher catch efficiency than the knotted-mesh net. Finally, a lighter, thinner mesh may be more likely to tear or snag on underwater debris thereby allowing fish to escape. In addition, the MD net was constructed with a heavier lead line than the VA net, which may influence catch efficiency. These differences and changes in survey gear necessitated a calibration study to develop conversion factors to ensure continuity of the striped bass recruitment index from the long-term survey. Three nets are involved in the calibration: the MD net, the VA net, and the new net.

Our objective was to estimate calibration factors for the MD net and the new net. These calibration factors (or relative catch efficiencies) were estimated relative to the VA net, which forms the basis of the long-term recruitment time series for striped bass in Virginia. We used two approaches to estimate relative catch efficiency. The first approach involved a block-net experiment with known numbers of striped bass; in this approach, an area is blocked off using a block net, fish are introduced into the area and allowed to acclimate, and a seine haul is completed within the blocked area. The ratio of the number of fish captured by the seine to the total number of fish introduced into the blocked area represents the catch efficiency of the seine net. For the second approach, we used conventional paired hauls at seine survey sites in striped bass nursery areas throughout the Chesapeake Bay region. Paired hauls can be used to estimate the relative catch efficiency of each net using statistical methods based on the binomial distribution and developed for paired gear deployments (e.g., Miller et al. 2010; Cadigan and Dowden 2010; Cadigan and Bataineh 2012; Miller 2013). Because site characteristics (such as bottom type and slope of the beach), and environmental conditions (such as salinity and temperature) may affect gear efficiency, and may alter the availability and vulnerability of fish to capture, we measured multiple features at each sample site and used this information to identify sources of variation among seine-net catches.

Methods

All field and laboratory procedures were conducted according to a protocol approved by the Institutional Animal Care & Use Committee at The College of William & Mary (IACUC 2015-05-14-10413-mcfabr).

Block-net Study

In June 2015, we obtained 7,000 juvenile striped bass from the King & Queen Fish Hatchery in Stevensville, Virginia, and held them in eight recirculating aquaria in the VIMS Seawater Research Lab until they were required for the block-net experiment. Fish were fed daily with ground pelleted feed, and aquaria and filters were cleaned every other day to maintain water quality. The block-net experiment took place on the VIMS beach along the York River in early July 2015. We deployed the block net within a shallow area deemed suitable for sampling by beach seines, and introduced 25, 100, or 300 hatchery-raised striped bass into the block-net area. After fish were allowed to acclimate (15 mins), we hauled one of seine nets within the blocked area and counted the number of fish captured. After numerous trials with the block net, we abandoned the experiment because catch efficiency appeared to reflect the size of the blocked area and not the characteristics of the seine nets. We found that striped bass aggregated near the perimeter of the blocked-in area and, as a result, were unavailable to the seines. When we decreased the area encompassed by the block net, we captured all or almost all of the fish released into the block-net enclosure. We were unsuccessful at finding a suitable size for the blocked area that would allow the deployment of the seine and permit the fish to behave naturally. We either captured very few fish or we captured nearly all of the fish, the outcome depending on the size of the enclosed area. With a large enclosed area, we could not capture fish that aggregated along the wall of the block net because these fish were not available to our beach seine (we documented this with video cameras attached to the block net and to the brail of the seine). Use of a smaller enclosed area allowed us to capture all of the fish because fish were likely chased away from the edge of the block net and into the path of the seine. In a previous experiment with wild-captured striped bass and with the same block-net methodology, we were successful at capturing a portion of the striped bass that had been released within the enclosed area. (We opted to not use wild-captured fish for this study because of amount of time required to capture sufficient numbers of wild fish in good condition to conduct a single block-net trial.) Our difficulties with the use of hatchery fish in the block-net experiment is believed to be due to differences in behavior of wild and hatchery striped bass. We hypothesize that hatchery-reared striped bass were accustomed to containment and may have used the 'wall' of the block net as a refuge in response to disturbance (i.e., hauling of a seine net within the blocked area). We therefore abandoned the block-net experiment and focused instead on the paired beach-seine hauls for development of calibration factors.

Paired Hauls

Previously, we identified 22 seine survey sites in the James, Rappahannock, and York rivers with suitable beaches for simultaneously deploying two beach seines (side by side; Figure 2). We sampled six additional sites (three in the James River, two in the York River, and one in the Rappahannock River) to increase sample sizes for pairwise comparisons of the three net types; in this manner, 28 unique sites were sampled in Virginia waters (Table 2).

We began side-by-side paired seine hauls in Virginia on 29 June 2015 and continued until 26 August 2015; this period corresponded directly with the standard VIMS Striped Bass Seine Survey sampling period. Because we did not wish to compromise the integrity of the Striped Bass Seine Survey (the calibration study and the Striped Bass Seine Survey occurred simultaneously), the VA net always sampled the 'historic' beach and the other net (MD or new) sampled the adjacent beach. It should be noted that net types were randomized with respect to the tidal current at the site: the position of the second net with respect to the VA net was determined by tidal flow at the site (up-current vs. down-current). At each site, the down-current beach was sampled first, and the up-current beach was sampled one minute later; this sampling order avoided disturbance of fish communities at adjacent, down-current beaches.

At about the same time, scientists in MD deployed VA and MD nets in consecutive hauls between 21 July and 10 September 2015 at four of the historic Maryland Seine Survey sites and at seven additional sites in the upper bay, Kent Narrows, and the Chester River (11 unique sites were sampled in Maryland; Table 2). As before, this period corresponded with the standard Maryland Seine Survey sampling period. Because MD DNR did not have sufficient staff to execute simultaneous hauls, scientists performed consecutive hauls at a site with a 30-min delay between hauls. The order of deployment of nets was randomized so that the MD net was fished first at some sites but the VA net was fished first at other sites. All hauls were completed using standard seine survey deployments and protocols described by VIMS (Davis et al. 2015) and MD DNR (http://dnr2.maryland.gov/fisheries/Pages/striped-bass/juvenile-index.aspx). Together, MD DNR and VIMS crews completed 144 paired hauls with multiple nets: 70 pairs with the VA-MD nets, 42 pairs with the MD-New nets, and 32 pairs with the VA-new nets. We note, however, that not all paired hauls captured a given target species (Table 3).

Sample Processing

Fish were identified to species, counted, and measured to the nearest mm; all YOY striped bass were counted and measured. When large catches (>25 individuals of a species other than striped bass) were encountered, all fish were counted, but a subset of only 25 fish were measured for length. VIMS scientists measured fork length (FL, mm), whereas MD DNR scientists reported total length (TL, mm) for striped bass and other species. We converted TL of striped bass to FL using the following linear model, applicable to YOY fish between 41 and 223 mm TL:

$$FL = 0.2842 + 0.9269*TL.$$

The overall model was significant (F=287,905; $P<0.05$) and explained 99.9% of the variation in FL. For white perch, we used the following conversion:

$$FL = 0.954*TL$$

reported in FishBase and taken from Pauly (1978).

For striped bass, we used monthly length thresholds to identify YOY individuals. Maryland DNR scientists also verified YOY status of striped bass and white perch by scale aging of fish captured in Maryland. Only YOY catches for **striped bass, white perch, Atlantic croaker, spot, Atlantic menhaden, American shad, alewife, and blueback herring** were considered in further analyses because seine surveys target this life stage. Catches of other major species – **Atlantic silversides, inland silversides, spottail shiner, and banded killifish** – were not sorted by life stage, as all ages of these fishes are equally vulnerable to seines. Although we captured additional, less numerous species, we do not report on those here because they were not captured with sufficient frequency to warrant consideration.

Potential Sources of Variation Among Paired Hauls

Environmental conditions, deployment characteristics, time (sample date), mean size of fish captured, and differences in techniques were used to explore sources of variation in relative efficiency of the nets. Environmental conditions included water temperature, salinity, dissolved oxygen (DO), Secchi depth, turbidity, tide stage (flood, high slack, ebb, low slack), and bottom type (sand, gravel, mud). Temperature, salinity, and DO were measured with a handheld YSI instrument; turbidity was measured with a YSI EXO2 Multiparameter Sonde. Mean environmental conditions and deployment characteristics at sites sampled in Maryland and Virginia were compared using simple ANOVAs implemented in SAS with the GLM procedure.

In general, water temperatures in nursery areas increase from late June to July, and decrease from August to September (Davis et al. 2015). Temperature may affect availability of striped bass to the gear; for example, juvenile fish may use deeper, cooler areas of the river when water temperatures in shallow areas exceed metabolic optima, and thus may not be available to the seine. Although juvenile striped bass are found in a wide range of salinities, we included salinity as a possible factor that may affect availability of fish to the seine. DO concentrations in shallow waters are typically greater than 4 mg O_2/l (Davis et al. 2015), and as such, are unlikely to affect availability or vulnerability of fish to the seine; however, we included this covariate in the models because fish may exhibit preferences for higher DO conditions. Secchi depth and turbidity may affect catch efficiency because fish may not detect the presence of the net in turbid conditions and thus, may be vulnerable to capture as turbidity increases. Turbidity was not measured at all sites, and was included in calibration models for the VA-New and MD-New net pairs only. Tide stage affects the amount of habitat available for seining, with fishes expected to be less aggregated in shallow waters during high tides; flood and ebb currents may also affect how the net fishes. Bottom type can affect seine efficiency, particularly if mud bottoms are encountered; mud effectively increases the time required for deployment and this increased time may provide fish with opportunities for escapement.

We considered the mean observed length of YOY striped bass as a potential source of variation in net catches because larger fish may be less vulnerable to capture. We measured the maximum offshore distance that each net was hauled (net extension) because this characteristic was found to affect detectability of juvenile fishes by beach seines (Williams and Fabrizio 2011). Time was recorded as calendar day (e.g., June 29 = calendar day 180); we expect fish in late summer to be larger and more capable of escaping the seine. Other temporal metrics included the biweekly period (round) used by the VIMS Seine Survey to delineate sampling intervals, rank order of sample date, month (June, July, August, or September), and period (four discrete and non-overlapping time blocks: 29 Jun – 8 Jul, 20 Jul – 30 Jul, 5 Aug - 19 Aug, and 25 Aug – 14 Sep). Based on preliminary investigations, we retained calendar day as our temporal metric because this factor explained most of the variation in catches from among the time variables considered.

Finally, the technique employed by the field crews (side-by-side vs. consecutive hauls) was considered a source of variation because catches from side-by-side hauls may be more similar than catches from hauls deployed consecutively. Based on decades of seine survey observations in Virginia, the second haul at a particular site typically captures significantly less fish on average than the first haul. This is thought to be due to disturbance, even though 30 minutes are allowed to lapse between the first and second haul at a given beach. We note that in this study, technique (side-by-side vs. consecutive hauls) is confounded with jurisdiction (Maryland vs. Virginia) because a single technique was executed in each jurisdiction.

Calibration Model

Prior to model building, all environmental conditions (e.g., temperature, salinity, mean fish size, etc.) and deployment characteristics (maximum extension of the MD net, maximum extension of the VA net, technique, and calendar day) were examined for collinearity using tolerance statistics using the GLM procedure in SAS. Day was collinear with the environmental factors, and mean size was collinear with jurisdiction (MD vs. VA). None of the factors of interest exhibited collinearity (all tolerances exceeded 0.1). Nevertheless, to remove collinearity, we standardized all continuous factors (temperature, salinity, DO, turbidity, Secchi depth, maximum extension of the MD net, maximum extension of the VA net, calendar day, and mean fish size) to facilitate model fitting and parameter estimation (Morel and Neerchal 2012).

We used a binomial approach to estimate species-specific calibration factors, which represent the relative catch in one net conditional on the total catch across the pair of nets. To do this, the data were analyzed as the catch of a particular species in net A relative to the total catch for that species in a given pair (catch in net A + catch in net B). We also wished to consider random effects due to environmental and site characteristics that may have affected catches. In these analyses, the paired hauls represent the sampling units, and models were constructed from only those pairs in which a particular species was observed in at least one net. Thus, some pairs included hauls with zero catches of a particular species in one, but not both, nets.

Four model formulations were considered to describe the catch data from the paired hauls: (1) the binomial model, (2) the beta-binomial model, (3) the random-clumped binomial model, and (4) a generalized overdispersed mixed model (GLOMM), the beta-binomial GLOMM, that accounted for additional variation associated with the individual paired hauls.

The **binomial model** assumes paired hauls are identical and the outcomes (probability of capture) are independent (Liggett and Delwiche 2005). Further, the number of pairs containing a particular species follows a binomial distribution conditional on the random probability of success, π (either the species is present or absent in the catch). The binomial model assumes that the only source of variation is from the samples (total number of fish captured), but in practice, gear deployments are also a source of variation because deployments vary with site characteristics (e.g., bottom type) or technique (e.g., side-by-side vs. consecutive hauls). Such variation may lead to varying outcome probabilities among pairs (Liggett & Delwiche 2005). If deployments result in additional variation among pairs, then the binomial distribution may not account for the extra variation. Thus, the binomial model may fail to capture the additional variation inherent in such data and may not be a reasonable model for these data.

The **beta-binomial model** also assumes that the number of pairs containing a particular species follows a binomial distribution conditional on the random probability of success (π), but incorporates additional variation by assuming that π varies among pairs and follows a beta distribution. Thus, each pair has its own probability of success, π (Nelson et al. 2004), and the variance due to differences between deployments is explained by the beta distribution. Relative to the binomial distribution, this additional variation is termed 'overdispersion' and is estimated by the parameter ρ in the beta-binomial model. Here, ρ^2 is an estimate of the intracluster correlation (correlation between two trials) and provides a measure of the strength of similarity of responses among pairs (Morel and Neerchal 2012). In addition, the linear effect of covariates such as salinity and temperature on π and ρ can also be examined and models can be fit that allow for different probabilities of success and different degrees of overdispersion (Morel and Neerchal 2012).

A **random-clumped binomial model** is used to model data from a mixture of two binomials and is identical to the beta-binomial when the number of trials (the number of paired hauls) is two. When the number of trials is greater than two (as in this study), such models may be used to describe outcomes that are clumped into two groups due to factors not explicitly considered in the model. As before, two parameters are estimated with random-clumped binomial models: π and ρ, along with parameters describing covariate effects. In the random-clumped binomial model, the response (capture of fish) of any paired-haul in the group is the same with probability ρ (Morel and Neerchal 2012). Further, the responses observed among hauls in one group are similar (correlated), but the responses observed among the remaining hauls that are clustered in the second group are independent Bernouilli responses (capture or non-capture of a fish).

The **beta-binomial GLOMM model** may also be used to capture the inherent lack of fit in the data relative to the simple binomial model; GLOMM models capture the heterogeneity among pairs by incorporating one or more random effects associated with each pair (Morel and Neerchal 2012). With the beta-binomial GLOMM, the probability of success (π) varies by paired hauls and the individual pairs are treated as a random effect; this random effect represents the deviations of the pair's response from the average among all pairs. The GLOMM model thus allows incorporation of an additional random effect, which the simple beta-binomial does not (Morel and Neerchal 2012). As before, we considered covariate effects due to environmental conditions and deployment characteristics on the estimates of ρ and π.

Each of these model formulations was fit to the data from three pairs of nets (MD-VA nets, VA-New nets, and MD-New nets), and calibration factors were estimated as π/(1-π) (Miller 2013). In cases where the calibration factor varied with covariates, a mean calibration factor, $\bar{\pi}$, was calculated for a given net pair. To estimate the variance of the calibration factor, we considered applying the delta method of variance estimation for a ratio:

$$Var(calibration\ factor) = \frac{1}{(1-\hat{\pi})^2} * Var(\hat{\pi})$$

but this method, which is based on a first-order Taylor series expansion, requires large sample sizes (Patterson et al. 2001), and the absence of significant variation among the data (Cooch and White 2016). Because our samples sizes were small ($\leq$ 50), the delta method of variance estimation was likely to produce confidence intervals (CI) that are narrower than the nominal intervals. Instead, we estimated the 95% CI for the calibration factor using a nonparametric bootstrap approach implemented in SAS using the procedure SURVEYSELECT. The nonparametric bootstrap eliminates the need to make assumptions about the distribution of the observations and uses resampling of the original observations to estimate the empirical distribution function of the parameter of interest, in this case, π or ρ (Patterson et al. 2001). We used simple random sampling with replacement to select 10,000 bootstrap replicates from the original observations for each net pair and species; where applicable, sampling was stratified by technique (side-by-side or consecutive hauls) so that the proportion of bootstrapped replicates represented by each technique remained constant. The selected calibration model was then fit to the 10,000 replicate data sets, providing 10,000 estimates of π (or $\bar{\pi}$) and ρ (or $\bar{\rho}$). The 95% CI for $\hat{\pi}$ or $\hat{\rho}$ was obtained using the upper 97.5th and lower 2.5th percentiles of the resulting distribution, i.e., using Efron's (1979) percentile method.

We considered salinity, temperature, DO, Secchi depth, tidal stage, technique, maximum net extension, bottom type, time, and mean fish length as explanatory factors in the models; DO and Secchi depth were not considered for the models for the MD-VA net pairs only because MD DNR did not collect information on these conditions. Covariates were considered singly and in concert (up to three covariates) for their effects on π and ρ. The simple binomial model contained fixed covariate effects for π and can be written as:

$$N_{xAi} \sim \text{Binomial}(\pi_x, N_{x(A+B)i})$$

where N_{xAi} is the number of juvenile striped bass in net A of paired-haul *i* and covariate level *x*, π_x is the probability of capture of striped bass in net A for covariate level *x*, and $N_{(A+B)i}$ is the number of juvenile striped bass captured in both nets (net A + net B) of paired-haul *i* and covariate level *x* (Morel and Neerchal 2012). The beta-binomial model containing fixed covariate effects for π and ρ is:

$$N_{xAi} \sim \text{Beta-binomial}(\pi_x, \rho_x; N_{x(A+B)i})$$

where N_{xAi}, π_x, and $N_{x(A+B)i}$ are as before and ρ_x is the overdispersion parameter that accounts for possible variation among pairs of tows for covariate level *x*. Similarly, the random-clumped binomial model containing fixed covariate effects for π and ρ is:

$$N_{xAi} \sim \text{Random-clumped}(\pi_x, \rho_x; N_{x(A+B)i})$$

The GLOMM containing fixed covariate effects for π and ρ, as well as the random effect due to individual pairs is:

$$N_{xAi}|u \sim \text{Beta-binomial}(\pi_x, \rho_x; N_{x(A+B)i}|u)$$

where $N_{xAi}|u$ is the number of juvenile striped bass in net A of paired-haul *i* and covariate level *x* conditional on the random effect (*u*) of paired hauls, and $N_{x(A+B)i}|u$ is the number of juvenile striped bass captured in both nets (net A + net B) of paired-haul *i* and covariate level *x* conditional on the random effect (*u*) of paired hauls.

The beta-binomial, random-clumped binomial, and the GLOMM models use two link functions to describe the data: one link fits π, the probability of success, and the other link fits ρ, the overdispersion parameter (Morel & Neerchal 2012). For example, in the beta-binomial, the link function for the probability of capture of striped bass in Net A is:

$$\ln(\pi/(1-\pi)) = \beta_0 + \beta_1 X_1 + \beta_2 X_2$$

where the β's are model parameters, and X_1 and X_2 are covariates. Similarly, the link function for the overdispersion parameter is:

$$\ln(\rho/(1-\rho)) = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2$$

where the α's are model parameters and X_1 and X_2 are covariates (Morel and Neerchal 2012). The four model formulations were implemented in SAS v. 9.4 using the GLIMMIX procedure for the simple binomial model (Schabenberger SUGI 30), the NLMIXED procedure as described by Morel and Neerchal (2012) for the beta-binomial and random-clumped binomial models, and the NLMIXED procedure modified from the description in Nelson et al. (2006) for the beta-binomial GLOMM model. The NLMIXED implementation of the GLOMM model used numerically integrated marginal likelihoods and assumed that the random effect due to paired hauls was normally distributed.

Our model-building strategy was to identify factors (environmental conditions and deployment characteristics) accounting for variation in π and ρ using the beta-binomial model as the base model. We did not consider more than three main effects to describe variation in π or ρ, and based on preliminary model runs, it was evident that interactions were not useful in further explaining variation. Given the number of factors considered, we built 71 possible models for each species and type of seine-net comparison using the beta-binomial formulation (71 x 3 net-pair comparisons = 213 models per species). Akaike's information criterion corrected for small sample sizes (AIC_c) was used for model selection and for identification of the suite of factors important in explaining variation in π and ρ. To determine if simpler or more complex formulations were warranted, we used the suite of factors from the 'best' beta-binomial model to fit three additional models – the simple binomial model, the random-clumped binomial model, and the beta-binomial GLOMM model. We note that the simple binomial model does not include a ρ parameter, so only the factors affecting π were considered. Based on the results from the four model formulations, we selected the model that provided the best description (i.e., the model with the lowest AIC_c) and estimated the calibration factor using the estimate of π from the selected model (calibration factor = $\pi/(1-\pi)$). In some cases, AIC_c values were equivalent among two model formulations, so we selected the simplest model (e.g., we selected the beta-binomial model if both this model and the beta-binomial GLOMM yielded the same AIC_c value). When π (or ρ) varied with covariate effects, we calculated a mean of the estimated π's (or ρ's).

Results

Calibration Factors for Juvenile Striped Bass

MD vs VA Net – Juvenile Striped Bass

Of the 70 paired hauls (trials) completed with the MD and VA nets, 65 contained juvenile striped bass in at least one of the hauls, but only 50 paired hauls contained juvenile striped bass in both nets (22 completed by MD DNR and 28 completed by VIMS). We used catches from the 50 pairs to estimate the calibration factor because we found that the addition of the 15 pairs containing a single zero haul did not significantly change the estimate of π (the difference in the point estimates was 0.72% for the MD-VA nets). **Henceforth for all net pairs and species, we provide results using paired hauls for which the target species was captured in both nets (i.e., we do not consider paired hauls for which a single net encountered the target species).**

In Virginia, we completed 14 trials with the VA net in the up-current position and 12 trials with the VA net in the down-current position (two trials, one in the James River, the other in the Rappahannock River, failed to record position of nets), thus, the position of the nets was well randomized. In Maryland, the VA net was hauled first in 7 trials, and second in 15 trials; the VA net was twice as likely to be hauled second and thus, for the Maryland trials, we expect catch rates to be lower for the VA net relative to the MD net.

Most of the trials with the VA and MD nets occurred in sandy habitats: this was the most common bottom type encountered (35 trials), followed by mud (10 trials) and gravel (5 trials). Mud sites were predominantly sampled in Virginia, with only a single mud site sampled in Maryland waters (Patuxent River); gravel occurred at three sites in Virginia (James River) and two sites in Maryland (Northeast River and the head of Chesapeake Bay). As expected, maximum net-extension of the MD net varied significantly among bottom types (F=11.76, P<0.05), with greater net extensions realized in sandy habitats ($\text{mean}_{\text{sand}}$=91.2 ft, 95% CI: 84.1 – 98.3 ft; $\text{mean}_{\text{gravel}}$=68.2 ft, 95% CI: 49.5 – 87.0 ft; mean_{mud}=56.8 ft, 95% CI: 43.6 – 70.1 ft). The same was true of the VA net (F=10.00, P<0.05; $\text{mean}_{\text{sand}}$=90.0 ft, 95% CI: 82.4 – 97.6 ft; $\text{mean}_{\text{gravel}}$=68.2 ft, 95% CI: 48.1 – 88.4 ft; mean_{mud}=55.8 ft, 95% CI: 41.6 – 70.1 ft).

Tidal stage during the calibration experiment varied, but most (50%) paired hauls were completed during an ebb tide, with an additional 34% completed at flood tide. Only a few paired hauls occurred during low slack (12%) or high slack (4%) tide. The standard protocol for the Seine Survey in Virginia dictates that sites are sampled at low (slack) tide, but it is not possible to sample all sites in a particular subestuary at precisely the same tidal condition. In Virginia, during the 1990-2016 surveys, most hauls were completed during the late ebb tide; sites were also sampled at low tide as the tide began to flood (early flood). These two stages (late ebb and early flood) were the most commonly encountered conditions for the Juvenile Striped Bass Seine Survey in Virginia, representing about 94% of hauls since 1990 (Figure 3), and representing 84% of paired hauls completed for this calibration study. Thus, our calibration hauls occurred during similar tidal stage as the historical Seine Survey in Virginia and represents tidal conditions typically encountered.

Environmental conditions at sites in Virginia and Maryland varied. On average, catches from Maryland sites were obtained in conditions that were significantly more saline (F=24.91, P<0.05; mean_{MD}= 8.2 psu, 95% CI: 6.5 to 9.9 psu; mean_{VA}=2.5 psu, 95% CI: 1.0 to 4.0 psu) but cooler than those obtained from Virginia sites (F=36.76, P<0.05; mean_{MD}=26.1°C, 95% CI: 25.4 – 26.8°C; mean_{VA}=28.8°C, 95% CI: 28.2 – 29.4°C). In this study, salinity ranged between 0 and 18.8 psu, and temperatures ranged between 22.5 and 31.8°C. In addition, temperatures declined during summer in Maryland, but increased slightly during deployments in Virginia (Figure 4); this was because Maryland trials began later in the summer than those in Virginia. Dissolved oxygen concentration and Secchi depth were measured at 35 of the sites, and neither of these conditions differed significantly among sites sampled in Maryland and Virginia (F_{DO}=2.37, P=0.13; F_{Secchi}=2.32, P=0.14).

Crews in Maryland were able to obtain significantly greater mean maximum extension of the MD net than crews in Virginia (F=5.90, P<0.05; mean extension by MD DNR crew = 91.2 ft, 95% CI: 81.0 to 101.5 ft; mean extension by VIMS crew = 74.8 ft, 95% CI: 65.7 – 83.8 ft). The same was true for the VA net (F=6.73, P<0.05; mean extension by MD DNR crew=91.2 ft, 95% CI: 80.6 – 100 ft; mean extension by VIMS crew=73.0, 95% CI: 63.6 – 82.4). For a given pair of hauls, all 22 pairs completed in Maryland exhibited the same value for maximum extension of the MD and VA nets; the mean difference in maximum extension of the two nets deployed by the VIMS crews was 1.79 (SE=1.156) ft. This is consistent with the techniques used: in Maryland, both nets fished the same beach at a given site and thus, both nets were extended to the same maximum distance offshore, whereas in Virginia, nets were fished side-by-side where bathymetry may have varied slightly. A mean maximum-net-extension difference of less than 2 ft (which represents 2% of the maximum net extension possible) is not likely to be meaningful operationally and thus, side-by-side hauls in VA were considered comparable.

The mean size of striped bass was significantly greater in Maryland than in Virginia (F=96.95, P<0.05; mean_{MD} = 103.3 mm FL, 95% CI: 95.8 – 110.8 mm; mean_{VA} = 54.4 mm FL, 95% CI: 47.7 – 61.0 mm). This difference likely reflects the later sampling by MD DNR and the rapid growth of juvenile striped bass that occurs in late summer (Figure 5).

Using the preliminary beta-binomial model, we identified two covariates – month and temperature – that contributed to variation in the catch efficiency of the VA and MD nets (Table 4). We examined multiple covariates (technique, net extension, month, calendar day, bottom type, temperature, salinity, tidal stage, and mean fish length) singly and in various combinations, up to three covariate effects on π or ρ. Many of the beta-binomial models considered yielded AIC_c values within 0 to 2 units of the model with the lowest AIC_c, implying that multiple covariates may account for the variation in catch rates of the nets, or that we were unable to clearly resolve covariate effects. Although models within 0 to 2 AICc units are considered to have substantial support (Burnham and Anderson 2002), we did not use model averaging (Burnham and Anderson 2002) to estimate covariate effects because of the potentially large number of models with plausible covariate effects and because preliminary estimates of π were similar among competing models.

We fit four model formulations to the observations of paired deployments of the MD and VA nets using temperature to account for variation in capture efficiency of the nets and month to account for overdispersion; the best-fitting model to the data was the beta-binomial model (Table 5). In this model, the probability of capture of juvenile striped bass by the VA net relative to the MD net (π) depended on temperature (Table 6) such that as temperature increased, the probability of capture in the VA net (relative to the MD net) decreased. Although the effect of temperature was not strictly significant (P=0.09), the data suggested that temperature may be an important determinant of relative capture probabilities for juvenile striped bass during summer. For temperatures observed in summer 2015 (22.5 to 31.9 °C), the 95% CI for estimates of π included 0.5 (Figure 6), suggesting that a calibration factor was not necessary. That is, the null hypothesis that the nets exhibited equal relative catch efficiencies could not be rejected. Over the range of temperatures sampled in 2015, the average π was 0.5340 (95% CI: 0.4664 – 0.6034), and the corresponding calibration factor was 1.1459 (95% CI: 0.8741 – 1.5214; Table 7).

Although both nets fished similarly, we noted that at cooler temperatures (<24°C), the efficiency of the VA net relative to the MD net was lower than at warmer temperatures. This may have resulted from differences in temperature during sampling: cooler temperatures were encountered in Maryland than in Virginia. However, we were unable to identify a possible mechanism related to temperature that would result in differential catches. Instead, we hypothesize that the lower efficiency of the VA net relative to the MD net was associated with differences in deployment techniques. A greater proportion of MD DNR deployments were such that the VA net was fished after the MD net (15 out of 22 pairs, or 68.2% were completed with the VA net hauled after the MD net), which likely decreased the encounter rate of fish with the VA net. As a result, lower catches would be expected from the second haul (i.e., the VA net haul) for these deployments. The frequency distribution of the estimates of π indicated that the consecutive pair approach used in Maryland yielded slightly higher values of π than the side-by-side approach used in Virginia (Figure 7). Higher values of π signify that the VA net was less efficient than the MD net during consecutive hauls on the same beach.

Although estimates of π appeared to increase with observed mean fish length (Figure 8A), this relationship may simply reflect the fact that on average, fish tended to be larger in collections made by the MD DNR than by VIMS. MD DNR sampled later in the summer than VIMS. When the relationship is examined for each deployment technique separately, the effect of fish length on π appears minor or non-existent (Figure 8B). We expect our recommendation to forego calibration of the VA net catches relative to the MD net catches to apply only to fish represented by the range of fish sizes observed in 2015 (i.e., age-0 fish from 40 to 150 mm FL).

The overdispersion, ρ, among the pair-specific capture probabilities was estimated from the beta-binomial model; these probabilities were distributed as a beta distribution and the variance of that distribution (ρ) was best explained by month (Table 6). The parameter estimate for month was positive and significant (Table 6) suggesting that as the summer progressed, so did the variation in π among pairs of hauls. That is, the distribution of the individual π's became more variable later in summer (Figure 9A).

Reflecting the changing environmental conditions and the growth of striped bass, the variation in π between paired hauls (i.e., ρ) also decreased with increasing water temperature and increased with mean fish size (Figure 9B and C). Estimates of ρ were lowest early in the summer, when temperatures were slightly warmer and juvenile fish were relatively smaller. This suggests that relative net efficiency is less variable when striped bass are small and perhaps easier to capture, but that as fish grow, the variance in the catch efficiency among-paired-hauls increases.

Estimates of ρ tended to be slightly lower using side-by-side hauls (technique used by VIMS in Virginia) than using consecutive hauls (technique used by MD DNR in Maryland; Figure 10A). This is consistent with expectations that side-by-side hauls are less likely to sample disturbed fish communities than consecutive hauls on the same beach. However, this result may also be explained by the fact that paired hauls in Maryland started later in the summer and continued into September, whereas paired hauls in Virginia started in June and ended in late August. Hauls completed at slack tide (either high or low slack) were more consistent in terms of inter-haul variation (estimates of ρ more similar) than hauls completed at flood or ebb tide (Figure 10B). We hypothesize that the variation in ρ observed among tidal stages may be related to current strength, but we have no estimates of current strength at the time of sampling, nor is this information available for our sampling sites.

Together, our results from the beta-binomial model fit to the paired data from the MD-VA nets imply that sampling in the earlier part of the summer reduces the variation in the probability of capture among hauls (month effect on ρ), and that sampling when temperatures exceed 24°C reduces the difference in relative efficiencies of the MD and VA nets (temperature effect on π). Although we noted differences in the weight of the lead line of the two nets (the MD net had a heavier lead line than the VA net), our results do not support the expectation that the MD net was more effective at capturing fish due to its enhanced ability to maintain bottom contact. The MD mesh material was also heavier than the VA mesh material and may have decreased the efficiency with which the net was deployed relative to the VA net. Overall, both nets fished similarly. Thus, we do not recommend application of a calibration factor for catches made in Virginia with the MD net, thus the Virginia time series is internally consistent through time until 2015. That is, indices calculated from 1967 to 1998 (when VIMS used the MD net) are consistent with indices calculated from 1998 to 2015 (when VIMS used the VA net) and no adjustment is necessary. Further, there is no evidence to suggest that the Virginia and Maryland time series are not directly comparable from 1967 to 2015.

VA vs New Net – Juvenile Striped Bass

Of the 32 paired hauls completed with the VA and new nets, 28 contained juvenile striped bass in at least 1 net. All of these paired hauls were completed in Virginia nursery areas by VIMS between 29 July and 21 August 2015; sites sampled included those in the James, York, and the Rappahannock rivers (Table 3). Of these, only 21 pairs (10 in the James River, 4 in the York River, and 7 in the Rappahannock River) yielded juvenile striped bass in both hauls and thus, were used to estimate the calibration factor. Between 29 July and 20 August 2015, the VA net was deployed in the up-current position 55% of the time, whereas the new net was deployed in the up-current position 45% of the time, thus achieving an acceptable distribution of randomized positions relative to the tidal current. Water temperatures during sampling with the VA-new net pairs ranged between 28.2 and 31.5 °C; salinity varied between 0 and 5.1 psu. Water temperature and salinity increased slightly from late July to late August, reflecting environmental conditions on the nursery grounds in Virginia.

Most of the trials with the VA and new nets occurred in sandy habitats: this was the most common bottom type encountered (11 trials), followed by mud (7 trials) and gravel (3 trials). For a given pair, the maximum extension of the two nets was identical. Contrary to expectations, we found no significant effect of bottom type on the mean maximum extension of either net (*F*=0.56, *P*=0.58); this is likely due to the small number of samples in at least two of the habitats (mud, gravel). Mean extension of either net in sandy habitats was 82.5 ft (95% CI: 65.9 – 99.2 ft); in gravel habitats, the mean extension was 68.0 ft (95% CI: 20.1 – 100 ft); and in mud habitats, the mean extension was 70.9 ft (95% CI: 40.3 – 100 ft). Thus, we were unable to detect differences in net extensions realized among habitats sampled with the VA and new nets.

The mean size of juvenile striped bass captured in the VA net increased through time (Figure 11) and also appeared to exhibit differences among the subestuaries sampled such that fish from the Rappahannock River were slightly larger than those from the James River; the York River sites yielded the smallest juvenile striped bass observed in these paired hauls. We further examined these results using a one-way ANCOVA with time as the covariate and river as an explanatory factor. The interaction of time and river was not significant (*F*=0.19, *P*=0.83), implying that linear increases in mean fish size through time were similar among the rivers. Mean lengths of juvenile striped bass were significantly greater in the Rappahannock (mean=59.1 mm FL, 95% CI: 52.6 – 65.7 mm) and James (mean=56.3 mm FL, 95% CI: 51.1 – 61.6 mm) rivers than in the York River (mean= 44.1 mm FL, 95% CI: 35.0 – 53.3 mm; *F*=3.78, *P*=0.04). Although present in VA net catches from the Rappahannock and James rivers, fish greater than 57 mm FL were absent from York River samples (Rappahannock River range: 41 – 80 mm FL, James River range: 41 – 92 mm FL; York River range: 33 – 57 mm FL). Time was only marginally significant in explaining the variation in mean size among fish from these rivers (*F*=2.85, *P*=0.11). With only 21 pairs of observations and a short time span, we were not surprised that time was not a significant effect, however, the significantly smaller mean size of fish from the York River is noteworthy.

Using the preliminary beta-binomial model, temperature was the only factor from among those considered that contributed to variation in the catch efficiency of the VA and new nets (Table 8). Catch efficiency of the two nets was modeled as a constant and the overdispersion parameter (ρ) was modeled as function of temperature. Using this construct, we fit three other model formulations to the catches from the paired hauls with the VA and new nets and selected the random-clumped binomial model as the best fitting model from among the four formulations considered (Tables 9 and 10). The probability of capture of juvenile striped bass by the VA net relative to the new net (π) was constant and significantly less than 0.5 ($\hat{\pi}$ = 0.3410, 95% CI: 0.2878 - 0.4537; Table 7). Thus, the efficiency of the VA net was lower than that of the new net. The corresponding calibration factor was 0.5175 (95% CI: 0.4041 –

0.8305), implying that the new net captured about twice the number of juvenile striped bass as the VA net (new net catches should be adjusted by multiplying by 0.5175).

The distribution of ρ was skewed such that the most frequently observed values of ρ were very small and near zero (Figure 12), leading to selection of the random-clumped model as a best descriptor of the overdispersion in these catches. Further, the magnitude of ρ decreased with increasing water temperature and was constant and near-zero at temperatures above 30°C (Figure 13). These results imply that catch efficiency of the new net and the VA nets exhibited the greatest variation when sampling occurred at temperatures below 30°C, and that the efficiency of the VA and new nets exhibited very little variation among paired hauls when sampling occurred at high temperatures (>30°C). We do not believe this effect is associated with fish size because we observed near-zero values of ρ across all sizes of fish encountered (Figure 14). We hypothesize that the low variation among estimates of efficiency at high temperatures may be associated with physiological constraints on the escape response of juvenile striped bass. The range of optimal temperatures for juvenile striped bass from riverine environments is 14 to 21°C, although fish will tolerate temperatures between 10 and 27°C, and may be found in waters up to 35°C (Greene et al. 2009). We have observed juvenile striped bass in Virginia nursery areas where temperatures exceeded 30°C, however, fish at these temperatures may experience metabolic stress and may be less capable of detecting and avoiding the VA net.

MD vs New Net – Juvenile Striped Bass

Of the 42 paired hauls completed with the MD and new nets, 33 contained juvenile striped bass in at least 1 net. Paired hauls were completed by VIMS between 24 July and 26 August 2015; sites were sampled in the James, York, and Rappahannock rivers (Table 3). Of these, only 25 pairs contained juvenile striped bass in both hauls (16 sites in the James River, 6 sites in the Rappahannock River, and 3 sites in the York River); these 25 pairs were used to estimate the calibration factor and spanned the period 24 July to 26 August 2015. A smaller proportion (37.5%) of the pairs containing striped bass in both hauls were deployed with the MD net in the up-current position, and most hauls were completed during an ebb tide (23 of the 25 pairs, or 92%); the remaining 8% were completed during flood tide.

Most (76%) of the habitats sampled with the MD and new nets were sand; mud (12%) and gravel (12%) habitats were sampled in the James River only. Maximum extensions of the MD and new nets were identical for a given pair. The mean maximum net extension in gravel habitats was significantly lower than that in mud or sand, which did not differ (F=4.70, P=0.02; $\text{mean}_{\text{gravel}}$= 56.7 ft, 95% CI: 34.7 – 78.6 ft; mean_{mud}=96.7 ft, 95% CI: 74.7 – 100 ft; $\text{mean}_{\text{sand}}$=89.6 ft, 95% CI: 80.9 – 98.3 ft).

Water temperatures in the habitats sampled during the deployment of the MD and new net pairs ranged between 26 and 31.2°C and declined significantly through time (F=6.43, P=0.02; Figure 15). However, no linear change in salinity was detected as the season progressed (F=0.80, P=0.38); salinity at the 25 sites ranged between 0.1 and 20.3 psu.

The mean size of juvenile striped bass captured in the MD net increased through time (Figure 16) and also appeared to exhibit differences among systems such that the mean size of fish in the York River was slightly larger than that of fish in the Rappahannock River; the James River sites yielded the smallest juvenile striped bass observed in these paired hauls. Fish ranged in size from 37 to 119 mm FL (James River), 42 to 116 mm FL (Rappahannock River), and 51 to 126 mm FL (York River). We further examined these observations with a one-way ANCOVA using time as the covariate and river as an explanatory factor. Because the interaction of time and river was not significant (F=1.76, P=0.20), we examined the main effects of river and time; both factors were significant (F_{river}=6.94, P<0.01; F_{time}=12.35, P<0.01). The mean lengths of juvenile striped bass were significantly greater in the York River (mean=73.8 mm FL, 95% CI: 65.0 – 82.6 mm) than in the James River (mean=57.3 mm FL, 95% CI: 53.5 – 61.1 mm) based on a multiple comparison test of least-square means using the Tukey-Kramer adjustment (t=-3.575, P<0.01). The mean size of fish from York River, however, was not significantly different from the mean size observed in the Rappahannock River (mean=63.5 mm FL, 95% CI: 57.3 – 69.6 mm). Unlike our observations from the VA-new net pairs, here we noted a significantly smaller mean size of fish in the James River, suggesting that fish size varies among sites within a river and that these means from a subset of sites in each river may not fully represent the size structure of juvenile striped bass in these subestuaries.

Using the preliminary beta-binomial model, the variation in the catch efficiency of the MD and new nets (π) was best described by bottom type and maximum net extension (Table 11). In this model, the overdispersion parameter (ρ) was best modeled as a constant. Using this construct, we fit three other model formulations to the catches from the paired hauls with the MD and new nets and selected the beta-binomial model as the best description of the data from among the four formulations considered (Tables 12 and 13). The probability of capture of juvenile striped bass by the MD net relative to the new net (π) varied with bottom type and net extension, and was significantly greater than 0.5 ($\hat{\pi}$ = 0.6490, 95% CI: 0.5634- 0.7324; Table 7). Thus, the efficiency of the MD net was greater than that of the new net. The corresponding calibration factor was 1.8490 (95% CI: 1.2904 – 2.7369), implying that the new net captured about half the number of juvenile striped bass as the MD net (new net catches should be adjusted by multiplying by 1.8490).

The distribution of π varied with bottom type such that values of π greater than 0.5 were observed at sandy sites and values of π near 0.5 were observed at muddy sites (Figure 17); this suggests that the MD net was more efficient in sand than the new net, whereas the net efficiency was similar in mud. Further, the magnitude of π decreased with increasing maximum net extension, regardless of bottom type (Figure 18). These results imply that catches of the new net and the MD nets exhibited the greatest differences when sampling occurred at sites where the full length of the nets could not be deployed offshore, and this was particularly true at sandy sites. Alternatively, the heavier lead line of the MD net may have better enabled the net to remain on the bottom when the net was not fully extended (i.e., at sandy sites), relative to the new net. We found no environmental or deployment effects on ρ, which was modeled as a constant in the calibration model. We hypothesize that the constant value of the overdispersion parameter reflects the low sample size, and not necessarily the lack of environmental or deployment effects on the variation in the probability of observing juvenile striped bass in the nets.

Calibration Factors for Juvenile White Perch

The paired hauls that captured juvenile white perch were conducted in environments similar to those in which juvenile striped bass were captured, and in the interest of brevity, we do not present summaries of capture conditions here. We note that turbidity was recorded by VIMS, so this covariate was considered in calibration models for white perch.

MD vs VA Net – Juvenile White Perch

The preliminary beta-binomial model fit to the catch data from 49 paired hauls indicated that the variation in the catch efficiency of the MD and VA nets (π) was best described by maximum net extension, and the overdispersion parameter (ρ) was best modeled as a function of salinity, although the effect of salinity was not strictly significant ($P = 0.10$). Using these covariates, we fit three additional model formulations to the catches from the paired hauls with the MD and VA nets and selected the beta-binomial model as the best description of the data from among the four formulations considered (Tables 14 and 15). On average, and over the values of net extensions achieved in this study, the probability of capture of juvenile white perch by the MD net relative to the VA net (π) was not significantly different from 0.5 (mean $\hat{\pi} = 0.4615$, 95% CI: 0.4072- 0.5236; Table 7). Thus, the efficiencies of the two nets were similar. The corresponding calibration factor was 0.8570 (VA net catches are adjusted by multiplying by 0.8570), but this was not significantly different from 1.0 (95% CI: 0.6869 – 1.0991).

VA vs New Net – Juvenile White Perch

The preliminary beta-binomial model fit to the catch data from 27 paired hauls indicated that the variation in the catch efficiency of the VA and new nets (π) was best described by maximum net extension, and the overdispersion parameter (ρ) was best modeled as a function of water temperature and DO concentrations. Although the effect of DO on ρ was not significant ($P = 0.09$), we retained this covariate in the model because the data suggested that DO differentially affected the catches of the VA and new nets. Using these covariates, we fit three additional model formulations to the catches from the paired hauls with the VA and new nets and selected the beta-binomial model as the best description of the data from among the four formulations considered (Tables 16 and 17). On average, and over the values of net extensions achieved in this study, the probability of capture of juvenile white perch by the VA net relative to the new net (π) was significantly lower than 0.5 (mean $\hat{\pi} = 0.3953$, 95% CI: 0.3159 - 0.4627; Table 7). Thus, the efficiency of the VA net was lower than that of the new net. The corresponding calibration factor was 0.6537 (new net catches should be adjusted by multiplying by 0.6537); the 95% CI for the calibration factor was 0.4618 – 0.8612.

MD vs New Net – Juvenile White Perch

For this comparison, we used catch data from 29 paired hauls of the MD and new nets. The preliminary beta-binomial model indicated that the variation in the catch efficiency of the MD and new nets (π) was best described by turbidity, and the overdispersion parameter (ρ) was best modeled as a function of DO concentrations. Although the effect of DO on ρ was not significant (*P* = 0.07), we retained this covariate because the data suggested that DO differentially affected the catches of the MD and new nets. Using these covariates, we fit three additional model formulations to the catches from the paired hauls with the MD and new nets and selected the beta-binomial model as the best description of the data from among the four formulations considered (Tables 18 and 19). Although the AIC_c for the beta-binomial GLOMM model was 0.1 units less than that of the beta-binomial model (and therefore, technically, had the lowest AIC_c), we selected the simpler beta-binomial model because the bootstrap estimate of the variance of π could not be obtained using the GLOMM formulation (models applied to many of the replicate bootstrap samples failed to converge and halted execution). On average, and over the values of turbidity observed in this study, the probability of capture of juvenile white perch by the MD net relative to the new net (π) was significantly greater than 0.5 (mean $\hat{\pi}$ = 0.6620, 95% CI: 0.5367 - 0.7231; Table 7). Thus, the efficiency of the MD net was greater than that of the new net for juvenile white perch. The corresponding calibration factor was 1.9586 (new net catches should be adjusted by multiplying by 1.9586); the 95% CI for the calibration factor was 1.1584 – 2.6114.

Calibration Factors for Other species

Calibration factors for juvenile stages of Atlantic croaker, spot, Atlantic menhaden, American shad, alewife, and blueback herring were not possible to estimate because of the low number of paired hauls in which species were captured (Table 20). For example, we captured YOY American shad in only 7 paired hauls (n=12 hauls, including zero catches in the pair) of the VA and new net pairs. We captured no YOY alewife in paired hauls of the VA and new net; alewives were encountered in only 2 net hauls. We captured YOY Blueback herring in only 8 paired hauls (n=13 hauls, including zero catches in the pair) of the VA and new net pairs. We recommend using the catch data from the new net without calibration for juveniles of these species.

Similarly, calibration factors for Atlantic silverside, inland silverside, spottail shiner, and banded killifish were not possible to estimate because of the low number of paired hauls in which these species were captured. We recommend using the catch data from the new net without calibration for these species.

Discussion

Estimated Calibration Factors

In this study we estimated calibration factors necessary to maintain the long-term integrity of the juvenile striped bass surveys in the Chesapeake Bay region. Three sets of calibration factors were estimated from catches of paired net hauls analyzed with beta-binomial models that accounted for the variation in the capture success of the nets. Our study is the first report of relative catch efficiencies of multiple seine nets; we caution, however, that these results are specific to the tidal habitats that we sampled, and to the species and life stages that we targeted.

The VA and MD nets performed similarly for juvenile striped bass and juvenile white perch, and thus we do not recommend adjustments of the historical time series of recruitment indices. We do not recommend application of a calibration factor for catches made in Virginia with the MD net, thus the Virginia time series is internally consistent through time until 2015. That is, indices calculated from 1967 to 1998 (when VIMS used the MD net) are consistent with indices calculated from 1998 to 2015 (when VIMS used the VA net) and no adjustment is necessary. Further, there is no evidence to suggest that the Virginia and Maryland time series are not directly comparable from 1967 to 2015. Although we do not recommend application of a calibration factor for the MD-VA nets, we note that for a given paired haul, net efficiencies may differ (failure to detect a difference does not imply that a difference does not exist). Overall, and on average across the wide range of environmental conditions and two deployment techniques used in this study, the efficiency of the two nets was similar. We strongly recommend maintenance of standardized deployment techniques as currently used by MD DNR and VIMS.

For juvenile striped bass, our modeling results with the MD and VA nets suggest that sampling in the earlier summer reduces the variation in the probability of capture among hauls (month effect on ρ), and that sampling when temperatures exceed 24°C reduces the difference in relative efficiencies of the MD and VA nets (temperature effect on π). In general, the seine surveys in VA have been conducted at temperatures exceeding 24°C, with less than 1.5% of hauls in June, July, and August occurring in waters < 24°C, and less than 29.7% of hauls in September occurring in waters < 24°C (Figure 19). We noted greater variation in paired net catches during September, suggesting that the comparability of the Virginia and Maryland surveys may be enhanced by estimating recruitment from catches in July and August or by considering catches restricted by fish size (efficiency is less variable when fish are smaller). We also noted that variation in the relative efficiencies of the VA and MD nets was lower when samples were collected during the early summer (late June). The potential for less variation in relative efficiency of the nets in late June has implications for the design and analysis of the seine survey as the climate continues to warm and striped bass spawning occurs earlier in the year; in this situation, juvenile fish will become vulnerable to the gear earlier in the year. In recent years, VIMS has initiated sampling earlier in the summer (late June versus early July) to reflect the availability of small striped bass to the gear. It is during this early summer period that we noted that variation in the efficiencies of the MD and VA nets appeared to decline, thus, the performance of the two nets appeared to be more similar during times when smaller fish were available to the gear. We also note that temperatures above 24°C reduce differences in the relative catch efficiency of the two nets. Thus, sampling in the earlier part of the summer, after temperatures reach 24°C appears to be a reasonable strategy for seine surveys of juvenile striped bass abundance in the Chesapeake Bay region. Further investigations could be useful in determining the source of the variation in relative net efficiencies during late summer (late August-September) and may warrant consideration of the time period used to estimate recruitment indices for Maryland and Virginia.

For both juvenile striped bass and juvenile white perch, we found significantly greater efficiency of the new net relative to the VA net. For juvenile striped bass, the variation in catch efficiencies declines at temperatures exceeding 30°C. Although juvenile striped bass are found at these temperatures in Chesapeake Bay nurseries, 27°C appears to be the upper limit of optimal thermal habitat for this life stage (Greene et al. 2009). We hypothesize that the variation in catch efficiency of the VA and new nets declines at temperatures greater than 30°C because fish may experience metabolic stress, which could affect their ability to detect the net, as well as their escape response.

For a given net pair, estimated calibration factors for juvenile striped bass and juvenile white perch, were not significantly different as determined by overlapping 95% CI for π. This is not surprising because as juveniles, these congeners occupy similar inshore habitats during summer and exhibit similar seasonal movements and prey preferences (Setzler-Hamilton 1980, 1991).

Given the similar efficiencies of the MD and VA nets, and the greater efficiency of the new net, we would have expected that the new net would also be more efficient than the MD net in capturing juvenile striped bass and juvenile white perch. However, we found the opposite. For both species, the MD net exhibited a greater efficiency than the new net. Possible explanations include small sample sizes for the MD-new pair comparisons (25 pairs for juvenile striped bass and 29 pairs for juvenile white perch), insufficient habitat representation (the MD net is more efficient in sand than the new net, but mud and gravel habitats may have been underrepresented in the comparisons), and insufficient range of net extensions realized in the comparisons (net extensions were significantly greater in sand than in gravel). Another explanation is that the calibration factor for the MD-VA pairs was significantly different from one, and that the MD net was significantly more efficient than the VA net (with relative efficiencies ranging from MD net with the highest efficiency, the new net with intermediate efficiency, and the VA net with the lowest efficiency). Because our sample size for the MD-VA comparisons was somewhat large (n=50 pairs), we suspect that small sample sizes of the VA-new and MD-new comparisons contributed to the discrepancy. Thus, we recommend additional sampling with the new and VA nets in 2017 and re-estimation of calibration factors for this net pair.

Other sources of variation that we did not measure may have also influenced the relative sampling efficiency of nets, and therefore, the estimated calibration factors. For example, beach seine deployment may vary among individual crew members as a result of differences in crew size, strength, and experience level. We did not record the identity of the crew members hauling each seine during each paired sample in this study, and thus, this information could not be included as a covariate in our calibration models. Future calibration work may benefit from exploration of crew member effects on sampling efficiency. However, we note that all crew members were trained in standardized hauling techniques, and we suspect that variation due to personnel was relatively small compared with the variation in fish distribution and catchability. Our analyses implicitly assumed that fishes were uniformly distributed throughout the deployment areas that we sampled. A non-uniform or patchy distribution of fish would result in greater overdispersion, which we could detect using the beta-binomial models applied here. However, patchy distributions and small sample sizes (e.g., less than 50 paired comparisons) are likely to bias estimates of the calibration factor. Independent information on fish distributions in shallow inshore habitats in Chesapeake Bay is not currently available, but may be obtained using sonar or acoustic camera technologies. Such information may provide useful insights into the effects of fish distribution and behavior on the catch efficiency of seine nets and other sampling gears.

Implications from Model Fitting

We investigated several model formulations that assumed an underlying binomial distribution in the probability of capture of fish in a given net (relative to the second net), but in no case was the simple binomial model supported by the data. We observed significant overdispersion in the data and modeled the extra-binomial variation directly using beta-binomial, random-clumped binomial, and beta-binomial GLOMM models. With these models, we identified multiple environmental conditions and deployment characteristics that contributed to overdispersion, ρ (the variation in the probability of capture among paired nets), and the probability of capture, π. Further, these effects varied by species (striped bass or white perch) and net pair. For example, for the MD-VA net comparisons, we selected month as the factor affecting ρ, but models within 0 - 2 AIC units of the 'best' models suggested factors such as tide, technique, maximum net extension, and bottom type may also explain overdispersion in the relative catch rates of these nets. Similarly, we selected temperature as the covariate affecting π, but other covariates were plausible. Although we recognize that sample sizes may have been limiting, the inability to identify a single overwhelmingly 'best' factor or covariate should not be misconstrued as a shortcoming of this study, but rather an indication that seine protocols must be standardized across multiple conditions and techniques. Use of a fixed-station sampling design can help to maintain temporal consistency across physical site conditions such as bottom type and bathymetry (which affects net extension). This has important implications for study design. For example, if a particular fixed site should be abandoned (due to alteration of the shoreline, growth of invasive milfoil, or construction of in-water structures such as piers or docks), a site with similar characteristics (bottom type, bathymetry, and salinity) should be used to replace the retired site. Consistency of techniques used (net type, net dimensions, deployment methods with regard to tide and current flow, and sample processing) also ensure comparability of results across time and space.

Many of the beta-binomial models considered yielded AIC_c values within 0 to 2 units of the model with the lowest AIC_c, implying that multiple factors or covariates may be considered reasonable descriptors of the variation in catch rates of the paired nets. Another interpretation is that sample sizes (number of paired hauls with the target species present) were too low to resolve the differential effects of environmental conditions and deployment characteristics. Nevertheless, the factors we identified through model selection seemed reasonable. We found temperature, maximum net extension, and bottom type affected π for juvenile striped bass, and maximum net extension and turbidity affected π for juvenile white perch. Overdispersion (ρ) was affected by month or was constant for juvenile striped bass; overdispersion was affected by salinity, temperature, and dissolved oxygen for juvenile white perch. In no case was technique (side-by-side vs consecutive haul), calendar day, tidal stage, or mean fish length selected from among the 'best' models describing π or ρ for juvenile striped bass or white perch.

Although we fit models to the paired hauls in which the target species was observed in at least one of the nets, we found that the addition of pairs containing zero hauls did not appreciably change our estimates of π. For example, addition of 15 MD-VA net pairs containing a single zero haul for juvenile striped bass changed the estimate of π by 0.72%. Thus, for model development, we considered only those pairs that captured fish in both nets. We also note that when sample sizes were low, the consideration of pairs containing one zero haul in the beta-binomial models resulted in higher uncertainty in the parameters of the factors affecting π or ρ (larger confidence intervals and less likely to detect a significant effect of the factor).

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Table 1. Chronology of seine nets (100’ x 4’) used by the Virginia and Maryland striped bass seine surveys in Chesapeake Bay; all meshes are ¼”.

	MD DNR	VIMS
1967 – 1998	Knotted rhomboid (MD net)	Knotted rhomboid (MD net)
1999 – 2015	Knotted rhomboid (MD net)	Knotless oval (VA net)
2016 -	Knotted rhomboid (MD net)	Knotless rhomboid (New net)

Table 2. Thirty-nine sites sampled by paired seine hauls during summer 2015 in MD and VA. N refers to the number of sites. Sites designated with numbers other than 1 and 2 refer to river miles; 'special site' indicates sites sampled for the calibration study that are not sampled during the standard seine surveys in MD or VA.

System	Area or river	N	Sites
Eastern Chesapeake Bay, MD	Kent Narrows	2	Beach 1 (special site) Beach 2 (special site)
Head of Chesapeake Bay, MD	Chesapeake Bay	4	Playground (special site) Volleyball beach (special site) The Point (special site) Tolchester
	Chester River	2	West Ferry Point (special site) East Ferry Point (special site)
	Northeast River	1	Carpenter Point
Patuxent River, MD	Patuxent River	2	Peterson Point Eagle Harbor
Rappahannock River, VA	Rappahannock River	8	12 21 37 40 (special site) 41 50 55 69
York River, VA	Mattaponi River	3	44 47 52
	Pamunkey River	3	36 42 45
	York River	2	1 (special site) 2 (special site)
James River, VA	James River	12	2 (special site) 3 (special site) 12 22 29 42 46 48 (special site) 51 56 62 68

Table 3. Number of hauls and unique sites sampled for each type of paired-net trial; 144 paired hauls were completed for this study in Maryland and Virginia in summer 2015. Not all pairs contained striped bass (or any given species).

Paired nets	**Number of hauls**	**Sites sampled**	**Number of unique sites**
MD-VA	30	MD	11
MD-VA	40	VA	25
VA-New	32	VA	21
MD-New	42	VA	15

Table 4. AIC$_c$ values for the preliminary beta-binomial models fit to striped bass catches from paired hauls with the MD and VA nets. Mean length refers to the mean size of fish captured by the VA net; net extension refers to the maximum distance offshore of the VA net; and constant indicates that no effects were modeled (intercept only model). Technique refers to the method used to deploy the pair of nets, either consecutive (used by Maryland DNR) or side-by-side (used by VIMS). For all models, standardized effects were used. The model with the minimum AIC$_c$ is highlighted with a shaded box.

Effects on π	**Effects on ρ**	**AIC$_c$**
Technique, net extension, bottom type	(constant)	280.4
Technique, net extension, bottom type	Temperature	282.9
Technique, net extension, bottom type	Bottom type	280.4
Technique, net extension, bottom type	Technique	280.2
Technique, net extension, bottom type	Month	277.1
Technique, net extension, bottom type	Salinity	278.6
Technique, net extension, bottom type	Calendar day	278.7
Technique, net extension, bottom type	Net extension	282.7
Technique, net extension, bottom type	Mean length	280.8
Technique, net extension, bottom type	Tide	282.9
Technique, net extension, bottom type	Tide, temperature	285.5
Technique, net extension, bottom type	Tide, salinity	281.2
Technique, net extension, bottom type	Salinity, bottom type	281.1
Technique, net extension, bottom type	Salinity, technique	281.3
Technique, net extension, bottom type	Salinity, temperature	281.1
Technique, net extension, bottom type	Calendar day, tide	281.4
Technique, net extension, bottom type	Calendar day, bottom type	281.0
Technique, net extension, bottom type	Calendar day, technique	281.4
Technique, net extension, bottom type	Calendar day, temperature	280.4
Technique, net extension	Month	274.5
Technique, bottom type	Month	275.4
Technique, temperature	Month	273.2
Technique, tide	Month	272.8
Technique, mean length	Month	273.2
Net extension, bottom type	Month	275.9

Net extension, temperature	Month	272.1
Net extension, tide	Month	273.7
Net extension, mean length	Month	275.9
Bottom type, temperature	Month	273.2
Bottom type, tide	Month	273.9
Bottom type, mean length	Month	276.3
Tide, temperature	Month	272.0
Tide, mean length	Month	273.9
Tide	Month	271.4
Temperature	Month	270.8
Technique	Month	273.0
Net extension	Month	273.5
Bottom type	Month	273.8
Mean length	Month	273.8
[constant]	Month	271.4
Technique, net extension	Salinity	276.1
Technique, bottom type	Salinity	276.8
Technique, temperature	Salinity	275.6
Technique, tide	Salinity	273.9
Technique, mean length	Salinity	274.9
Net extension, bottom type	Salinity	276.5
Net extension, temperature	Salinity	274.6
Net extension, tide	Salinity	273.5
Net extension, mean length	Salinity	276.5
Bottom type, temperature	Salinity	275.4
Bottom type, tide	Salinity	273.8
Bottom type, mean length	Salinity	276.9
Tide, temperature	Salinity	273.7
Tide, mean length	Salinity	273.8
Temperature	Salinity	273.4
Tide	Salinity	271.6
Technique	Salinity	274.6
Net extension	Salinity	274.0
Bottom type	Salinity	274.5
Mean length	Salinity	274.5

[constant]	Salinity	272.3
Tide	[constant]	274.8
Technique, net extension	Calendar day	276.1
Technique, bottom type	Calendar day	277.2
Technique, temperature	Calendar day	275.5
Technique, tide	Calendar day	274.5
Technique, mean length	Calendar day	275.0
Net extension, bottom type	Calendar day	277.6
Net extension, temperature	Calendar day	274.0
Net extension, tide	Calendar day	274.9
Net extension, mean length	Calendar day	277.5
Bottom type, temperature	Calendar day	275.1
Bottom type, tide	Calendar day	275.3
Bottom type, mean length	Calendar day	278.0
Tide, temperature	Calendar day	274.0
Temperature	Calendar day	273.1
Tide	Calendar day	272.9
Technique	Calendar day	275.0
Net extension	Calendar day	275.1
Bottom type	Calendar day	275.6
[constant]	Calendar day	273.3

Table 5. AIC$_c$ values for calibration models fit to striped bass catches from paired hauls with the MD and VA nets. The beta-binomial GLOMM is the generalized linear overdispersed mixed model using the beta-binomial distribution for the response. In these models, temperature was not standardized. Both the beta-binomial and the beta-binomial GLOMM had the same minimum AIC$_c$,; we selected the simpler beta-binomial model (denoted with a shaded box).

Model	**AIC$_c$**	**Effects on π**	**Effects on ρ**
Binomial	564.70	Temperature	--
Beta-binomial	270.8	Temperature	Month
Random-clumped binomial	306.1	Temperature	Month
Beta-binomial GLOMM	270.8	Temperature	Month

Table 6. Parameter estimates from the beta-binomial model fit to the striped bass catches from paired hauls with the MD and VA nets. SE is standard error; df is degrees of freedom. The *t*-statistic is used to test the null hypothesis that the estimate of the effect or intercept is not different from zero. *P* is the probability of observing a larger absolute value of *t* under the null hypothesis. Lower and upper refer to the lower and upper 95% confidence intervals of the estimated parameters.

Parameter	**Effect**	**Estimate**	**SE**	**DF**	***t***	***P***	**Lower**	**Upper**
π	Intercept	0.1391	0.1422	50	0.98	0.3328	-0.1466	0.4248
	Temperature	-0.2582	0.1498	50	-1.72	0.0909	-0.5590	0.0426
ρ	Intercept	-3.6785	1.5505	50	-2.37	0.0216	-6.7928	-0.5642
	Month	0.4628	0.2042	50	2.27	0.0278	0.0527	0.8729

Table 7. Estimates of π and ρ for the seine calibration study for striped bass and white perch. Values in **bold** are means for π or ρ that were not estimated as constants (i.e., significant covariate effects present). N is the number of paired hauls in which the species was present in both nets; CI is confidence interval estimated by a nonparametric bootstrap; CF is calibration factor.

Species	Net pair	N	π	95% CI for π	ρ	Calibration factor	95% CI for CF
Striped bass	MD-VA	50	**0.5340**	0.4664-0.6034	**0.4429**	1.1459	0.8741-1.5214
	VA-New	21	0.3410	0.2878-0.4537	**0.1737**	0.5175	0.4041-0.8305
	MD-New	25	**0.6490**	0.5634-0.7324	0.3037	1.8490	1.2904-2.7369
White perch	MD-VA	49	**0.4615**	0.4072-0.5236	**0.3574**	0.8570	0.6869-1.0991
	VA-New	27	**0.3953**	0.3159-0.4627	**0.3241**	0.6537	0.4618-0.8612
	MD-New	29	**0.6620**	0.5367-0.7231	**0.3777**	1.9586	1.1584-2.6114

Table 8. AIC$_c$ values for preliminary beta-binomial models fit to striped bass catches from paired hauls with the VA and new nets. Mean length refers to the mean size of fish captured by the VA net; net extension refers to the maximum distance offshore of the VA net; and constant indicates that no effects were modeled (intercept only model). For all models, standardized effects were used; if the algorithm could not optimize the fit of the model, no AIC$_c$ value is given. The model with the minimum AIC$_c$ is highlighted with a shaded box.

Effects on π	**Effects on ρ**	**AIC$_c$**
Net extension, bottom type, month	(constant)	98.2
Net extension, bottom type, month	Temperature	99.4
Net extension, bottom type, month	Bottom type	101.2
Net extension, bottom type, month	Month	103.6
Net extension, bottom type, month	Salinity	101.5
Net extension, bottom type, month	Calendar day	100.4
Net extension, bottom type, month	Net extension	102.1
Net extension, bottom type, month	Mean length	102.0
Net extension, bottom type, month	Tide	--
Net extension, bottom type, month	Tide, temperature	104.0
Bottom type	Temperature	96.5
Month	Temperature	97.9
Mean length	Temperature	96.1
Bottom type, month	Temperature	95.8
Bottom type, mean length	Temperature	95.5
Salinity, bottom type	Temperature	96.5
Salinity, month	Temperature	97.9
Salinity, net extension	Temperature	98.0
Salinity, mean length	Temperature	96.3
Temperature, month	Temperature	97.3
Temperature, net extension	Temperature	97.7
Temperature, bottom type	Temperature	96.4
Temperature, salinity	Temperature	97.5
Temperature, mean length	Temperature	96.4
Calendar date, salinity	Temperature	98.0
Calendar date, net extension	Temperature	98.0

Calendar date, bottom type	Temperature	96.4
Calendar date, mean length	Temperature	96.3
Tide, bottom type	Temperature	93.9
Tide, net extension	Temperature	96.5
Tide, salinity	Temperature	96.4
Tide, month	Temperature	96.4
Tide, temperature	Temperature	96.1
Tide, mean length	Temperature	95.3
Tide	Temperature	93.0
Bottom type	Temperature	93.0
Net extension	Temperature	94.5
Month	Temperature	94.4
Salinity	Temperature	94.5
Temperature	Temperature	94.2
Mean length	Temperature	93.0
Calendar date	Temperature	94.5
[constant]	Temperature	91.4
[constant]	Salinity	94.0
[constant]	Bottom type	94.5
[constant]	Mean length	96.6
[constant]	Tide	95.8
[constant]	Calendar date	96.3
[constant]	Net extension	96.3
[constant]	Month	95.8
[constant]	[constant]	93.9
Tide, bottom type	[constant]	93.7
Tide, net extension	[constant]	99.3
Tide, salinity	[constant]	98.9
Tide, month	[constant]	99.3
Tide, temperature	[constant]	95.9
Tide, mean length	[constant]	98.3
Calendar date, salinity	[constant]	99.3
Calendar date, net extension	[constant]	99.7
Calendar date, bottom type	[constant]	95.2
Calendar date, mean length	[constant]	98.5

Temperature, month	[constant]	96.1
Temperature, net extension	[constant]	96.7
Temperature, bottom type	[constant]	94.1
Temperature, salinity	[constant]	96.7
Temperature, mean length	[constant]	96.5
Salinity, bottom type	[constant]	95.4
Salinity, month	[constant]	99.3
Salinity, net extension	[constant]	99.3
Salinity, mean length	[constant]	98.5
Bottom type, month	[constant]	95.0
Bottom type, mean length	[constant]	94.8
Net extension, bottom type	[constant]	95.4
Net extension, month	[constant]	99.7
Net extension, mean length	[constant]	98.7
Salinity	[constant]	94.0
Tide	[constant]	96.2
Month	[constant]	96.6
Temperature	[constant]	93.6
Mean length	[constant]	96.5
Net extension	[constant]	96.6
Bottom type	[constant]	92.4
Calendar date	[constant]	96.6

Table 9. AIC_c values for calibration models fit to striped bass catches from paired hauls with the VA and new nets. The beta-binomial GLOMM is the generalized linear overdispersed mixed model using the beta-binomial distribution for the response. Constant indicates that an intercept only model was fit. In these models, temperature was not standardized. The selected model, as determined by the minimum AIC_c and denoted with a shaded box, was the random-clumped binomial model.

Model	**AIC_c**	**Effect on π**	**Effect on ρ**
Binomial	102.63	--	--
Beta-binomial	91.4	[constant]	Temperature
Random-clumped binomial	91.1	[constant]	Temperature
Beta-binomial GLOMM	91.3	[constant]	Temperature

Table 10. Parameter estimates from the random-clumped binomial model fit to the striped bass catches from paired hauls with the VA and new nets. SE is standard error; df is degrees of freedom. The *t*-statistic is used to test the null hypothesis that the estimate of the effect or intercept is not different from zero. *P* is the probability of observing a larger absolute value of *t* under the null hypothesis. Lower and upper refer to the lower and upper 95% confidence intervals of the estimated parameters.

Parameter	Effect	Estimate	SE	DF	*t*	*P*	Lower	Upper
π	Intercept	-0.6587	0.1417	21	-4.65	0.0001	-0.9535	-0.3639
ρ	Intercept	-3.3994	1.8103	21	-1.88	0.0744	-7.1641	0.3654
	Temperature	-2.8874	1.6187	21	-1.78	0.0889	-6.2536	0.4789

Table 11. AIC_c values for preliminary beta-binomial models fit to striped bass catches from paired hauls with the MD and new nets. Mean length refers to the mean size of fish captured by the MD net; net extension refers to the maximum distance offshore of the MD net; and constant indicates that no effects were modeled (intercept only model). For all models, standardized effects were used; if the algorithm could not optimize the fit of the model, no AIC_c value is given. The model with the minimum AIC_c is highlighted with a shaded box.

Effects on π	**Effects on ρ**	**AIC_c**
Net extension, bottom type, month	(constant)	124.0
Net extension, bottom type, month	Temperature	127.4
Net extension, bottom type, month	Bottom type	--
Net extension, bottom type, month	Month	127.5
Net extension, bottom type, month	Salinity	127.1
Net extension, bottom type, month	Calendar day	125.4
Net extension, bottom type, month	Net extension	127.5
Net extension, bottom type, month	Tide	125.8
Net extension, bottom type, month	Mean length	123.8
Net extension, bottom type	Mean length	123.5
Net extension, month	Mean length	130.6
Bottom type, month	Mean length	129.0
Bottom type	Mean length	126.0
Month	Mean length	129.4
Net extension	Mean length	128.3
Salinity	Mean length	129.2
Temperature	Mean length	129.5
Mean length	Mean length	129.2
Calendar day	Mean length	129.0
Tide	Mean length	129.0
[constant]	Mean length	126.7
Bottom type, salinity	Mean length	129.1
Bottom type, temperature	Mean length	128.3
Bottom type, mean length	Mean length	129.1
Bottom type, calendar day	Mean length	127.8
Bottom type, tide	Mean length	128.2

Bottom type, net extension	[constant]	123.4
Net extension, month	[constant]	128.4
Bottom type, month	[constant]	127.7
Bottom type, salinity	[constant]	127.8
Bottom type, temperature	[constant]	126.5
Bottom type, mean length	[constant]	127.8
Bottom type, calendar day	[constant]	126.6
Bottom type, tide	[constant]	126.3
Net extension, bottom type, tide	[constant]	125.2
Net extension, bottom type, calendar day	[constant]	126.8
Net extension, bottom type	Temperature	126.3
Net extension, bottom type	Calendar day	123.9
Temperature	Month	130.4
[constant]	Temperature	128.1
[constant]	Bottom type	126.2
[constant]	Salinity	127.7
[constant]	Month	127.7
[constant]	Calendar date	127.8
[constant]	Tide	128.1
[constant]	Net extension	125.9

Table 12. AIC_c values for calibration models fit to striped bass catches from paired hauls with the MD and new nets. The beta-binomial GLOMM is the generalized linear overdispersed mixed model using the beta-binomial distribution for the response. Constant indicates that an intercept only model was fit. Both the beta-binomial and the beta-binomial GLOMM had the same minimum AIC_c,; we selected the simpler beta-binomial model (denoted with a shaded box).

Model	**AIC_c**	**Effect on π**	**Effect on ρ**
Binomial	136.5	--	--
Beta-binomial	123.4	Bottom type, net extension	[constant]
Random-clumped binomial	133.0	Bottom type, net extension	[constant]
Beta-binomial GLOMM	123.4	Bottom type, net extension	[constant]

Table 13. Parameter estimates from the beta-binomial model fit to the striped bass catches from paired hauls with the MD and new nets. SE is standard error; df is degrees of freedom. The *t*-statistic is used to test the null hypothesis that the estimate of the effect or intercept is not different from zero. *P* is the probability of observing a larger absolute value of *t* under the null hypothesis. Lower and upper refer to the lower and upper 95% confidence intervals of the estimated parameters.

Parameter	**Effect**	**Estimate**	**SE**	**DF**	***t***	***P***	**Lower**	**Upper**
π	Intercept	-1.4027	0.8345	25	-1.68	0.1052	-3.1214	0.3160
	Net extension	-0.4082	0.1876	25	-2.18	0.0393	-0.7945	-0.0218
	Bottom type	0.7753	0.3039	25	2.55	0.0172	0.1495	1.4011
ρ	Intercept	-0.8299	0.3233	25	-2.57	0.0166	-1.4958	-0.1640

Table 14. AIC$_c$ values for calibration models fit to white perch catches from paired hauls with the MD and VA nets. The beta-binomial GLOMM is the generalized linear overdispersed mixed model using the beta-binomial distribution for the response. Both the beta-binomial and the beta-binomial GLOMM had the same minimum AIC$_c$; we selected the simpler beta-binomial model (denoted with a shaded box).

Model	**AIC$_c$**	**Effect on π**	**Effect on ρ**
Binomial	676.4	--	--
Beta-binomial	359.7	net extension	salinity
Random-clumped binomial	452.8	net extension	salinity
Beta-binomial GLOMM	359.7	net extension	salinity

Table 15. Parameter estimates from the beta-binomial model fit to white perch catches from paired hauls with the MD and VA nets. SE is standard error; df is degrees of freedom. The *t*-statistic is used to test the null hypothesis that the estimate of the effect or intercept is not different from zero. *P* is the probability of observing a larger absolute value of *t* under the null hypothesis. Lower and upper refer to the lower and upper 95% confidence intervals of the estimated parameters.

Parameter	**Effect**	**Estimate**	**SE**	**DF**	***t***	***P***	**Lower**	**Upper**
π	Intercept	-0.1578	0.1112	49	-1.42	0.1621	-0.3813	0.0656
	Net extension	0.2670	0.1079	49	2.48	0.0168	0.0503	0.4838
ρ	Intercept	-0.5960	0.1531	49	-3.89	0.0003	-0.9038	-0.2883
	Salinity	0.2739	0.1612	49	1.70	0.0957	-0.0500	0.5979

Table 16. AIC$_c$ values for calibration models fit to white perch catches from paired hauls with the VA and new nets. The beta-binomial GLOMM is the generalized linear overdispersed mixed model using the beta-binomial distribution for the response. DO indicates dissolved oxygen concentration. We selected the beta-binomial model (denoted with a shaded box) to describe these data.

Model	**AIC$_c$**	**Effect on π**	**Effect on ρ**
Binomial	317.0	--	--
Beta-binomial	189.4	net extension	temperature, DO
Random-clumped binomial	195.6	net extension	temperature, DO
Beta-binomial GLOMM	190.0	net extension	temperature, DO

Table 17. Parameter estimates from the beta-binomial model fit to white perch catches from paired hauls with the VA and new nets. SE is standard error; df is degrees of freedom. The *t*-statistic is used to test the null hypothesis that the estimate of the effect or intercept is not different from zero. *P* is the probability of observing a larger absolute value of *t* under the null hypothesis. Lower and upper refer to the lower and upper 95% confidence intervals of the estimated parameters. DO is dissolved oxygen concentration.

Parameter	Effect	Estimate	SE	DF	*t*	*P*	Lower	Upper
π	Intercept	-0.4633	0.1238	27	-3.74	0.0009	-0.7174	-0.2092
	Net extension	0.5525	0.1495	27	3.70	0.0010	0.2458	0.8591
ρ	Intercept	-0.8774	0.2550	27	-3.44	0.0019	-1.4006	-0.3542
	Temperature	0.8921	0.3717	27	2.40	0.0236	0.1294	1.6548
	DO	-0.5471	0.3095	27	-1.77	0.0884	-1.1822	0.0880

Table 18. AIC$_c$ values for calibration models fit to white perch catches from paired hauls with the MD and new nets. The beta-binomial GLOMM is the generalized linear overdispersed mixed model using the beta-binomial distribution for the response. DO indicates dissolved oxygen concentration. We selected the beta-binomial (denoted with a shaded box) to describe these data because the GLOMM model did not permit estimation of the variance of the model parameters using a bootstrap approach (models did not converge).

Model	**AIC$_c$**	**Effect on π**	**Effect on ρ**
Binomial	463.5	--	--
Beta-binomial	213.8	turbidity	DO
Random-clumped binomial	262.6	turbidity	DO
Beta-binomial GLOMM	213.7	turbidity	DO

Table 19. Parameter estimates from the beta-binomial model fit to white perch catches from paired hauls with the MD and new nets. SE is standard error; df is degrees of freedom. The *t*-statistic is used to test the null hypothesis that the estimate of the effect or intercept is not different from zero. *P* is the probability of observing a larger absolute value of *t* under the null hypothesis. Lower and upper refer to the lower and upper 95% confidence intervals of the estimated parameters. DO is dissolved oxygen concentration.

Parameter	Effect	Estimate	SE	DF	*t*	*P*	Lower	Upper
π	Intercept	0.6844	0.1480	29	4.62	<0.0001	0.3816	0.9872
	Turbidity	-0.3558	0.1446	29	-2.46	0.0201	-0.6516	-0.0600
ρ	Intercept	-0.5186	0.2009	29	-2.58	0.0151	-0.9295	-0.1078
	DO	-0.3586	0.1894	29	-1.89	0.0683	-0.7460	0.0287

Table 20. Number of paired hauls with the MD-VA, VA-New, and MD-New nets in which a species was encountered in both nets. Due to low sample sizes for most species, calibration factors were estimated for striped bass and white perch only.

Species	**MD-VA**	**VA-New**	**MD-New**
Alewife	3	0	4
American shad	16	7	4
Atlantic croaker	0	0	0
Atlantic menhaden	1	3	5
Atlantic silverside	39	12	24
Banded killifish	17	13	6
Blueback herring	11	8	5
Inland silverside	17	12	8
Spot	5	1	2
Spottail shiner	27	18	16
Striped bass	50	21	25
White perch	49	27	29

Figure 1. Location of the historic seine survey sites in the Chesapeake Bay region. Not all sites were sampled in the calibration study. Both index and auxiliary sites are sampled each year.

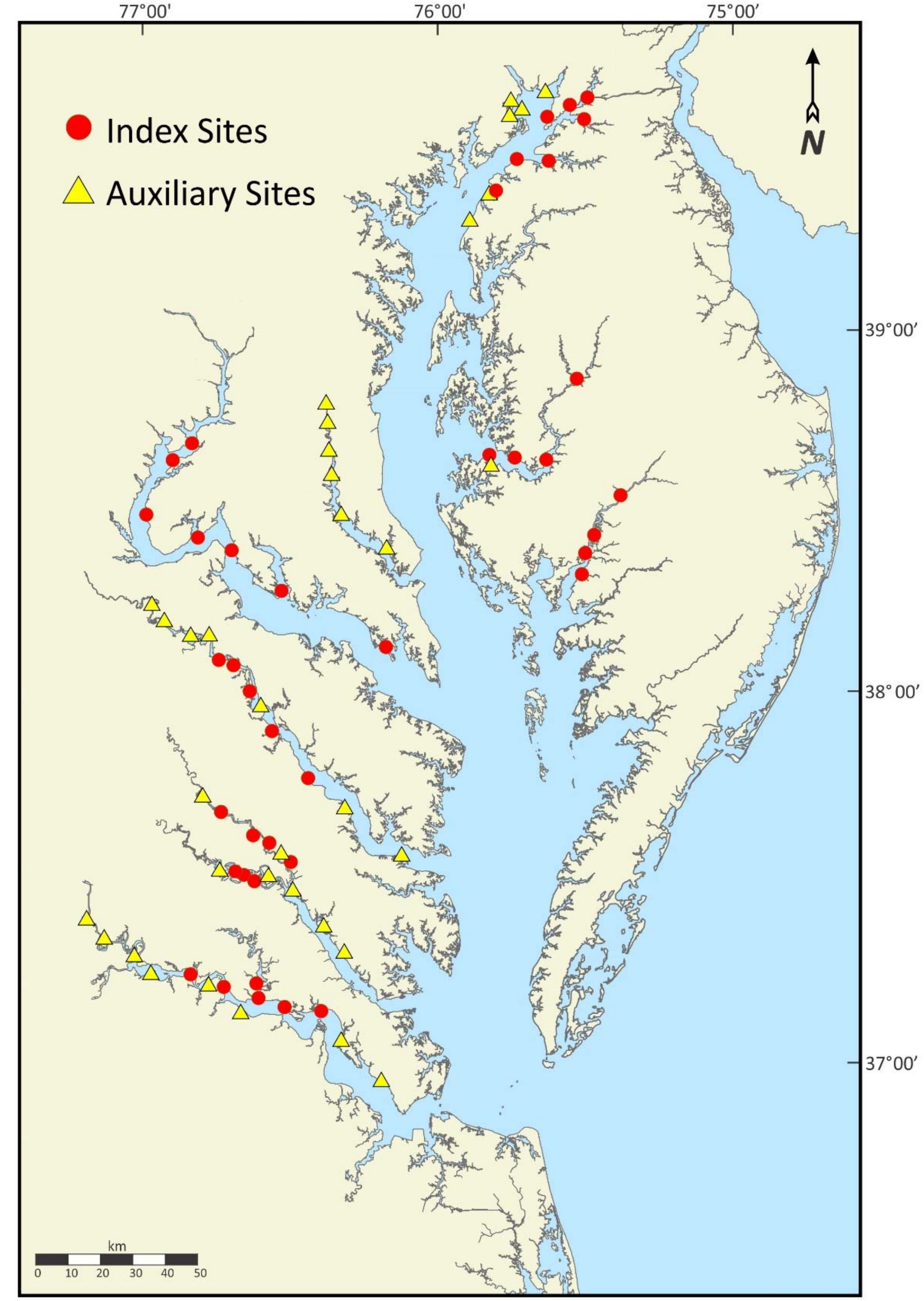


Figure 2. Example of a site where two 100-ft seine nets could be deployed side by side; this site is on the James River, about 29 miles upstream from the mouth.

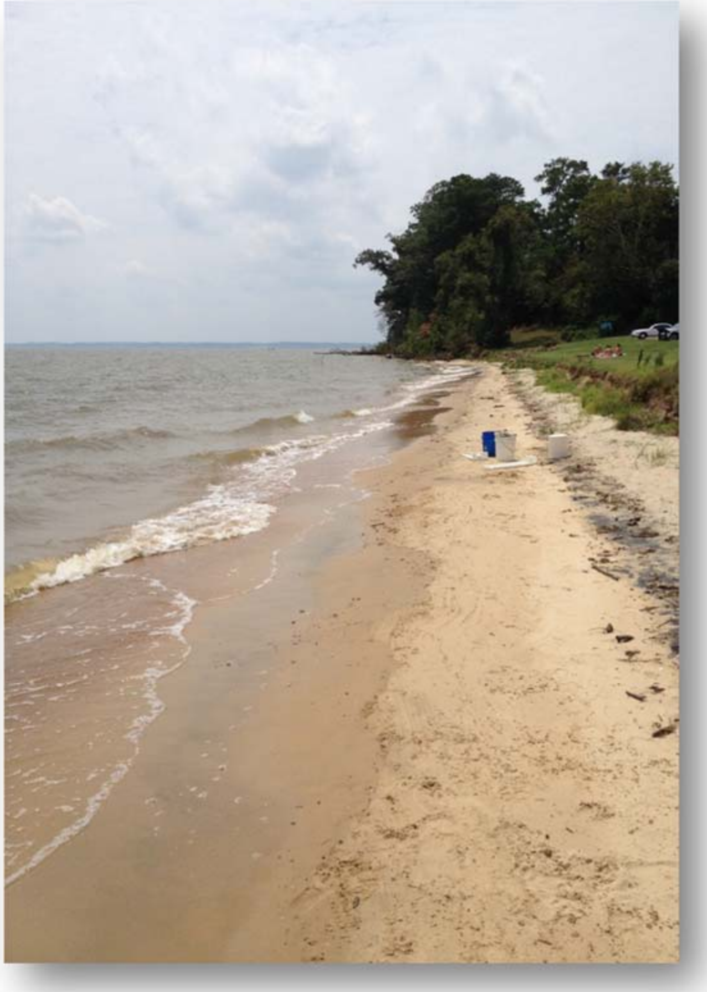


Figure 3. Frequency histogram of tidal stage during the time of sampling by field crews of the VIMS Juvenile Striped Bass Seine Survey, 1990 – 2016. Frequency represents individual seine hauls; 72% occurred during the ebb tide, 22% during flood tide, 6% during low slack, and 1% during high slack.

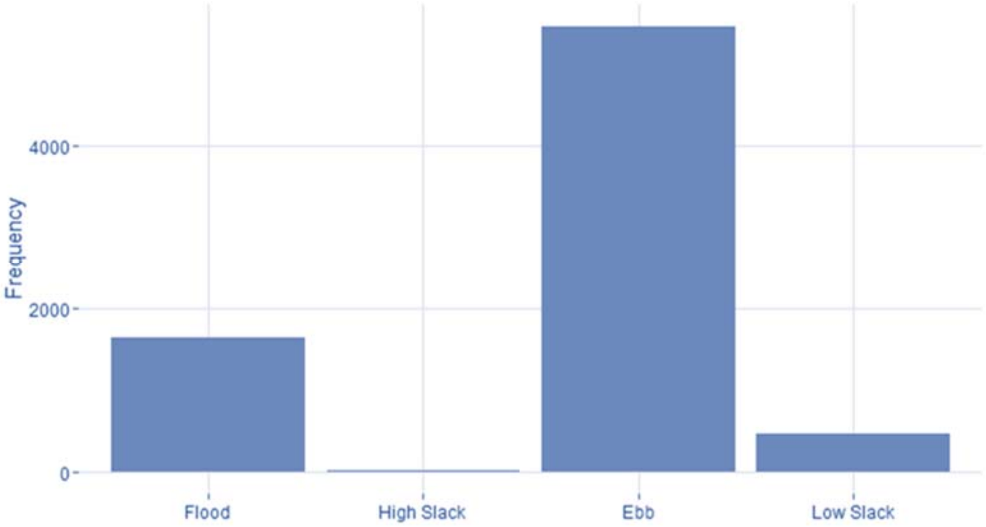


Figure 4. Water temperatures (°C) observed during the MD-VA paired-net trials in summer 2015; Maryland sites are in red and Virginia sites are in blue. The solid lines are linear regressions fit to the data and are provided as visual aids only.

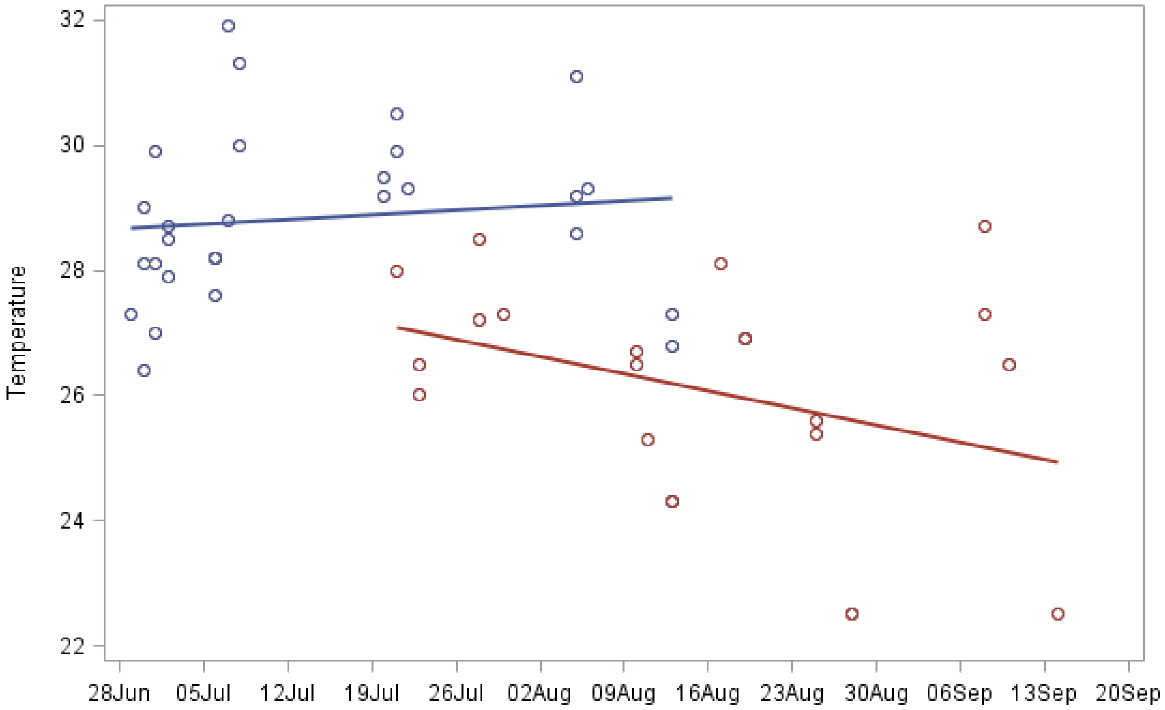


Figure 5. Mean length (fork length, mm) of juvenile striped bass captured during summer 2015 at sites in Maryland (left panel) and Virginia (right panel) using MD and VA seine nets (both net types were used in each jurisdiction). Solid lines represent linear regressions fit to the data and are provided as visual aids only.

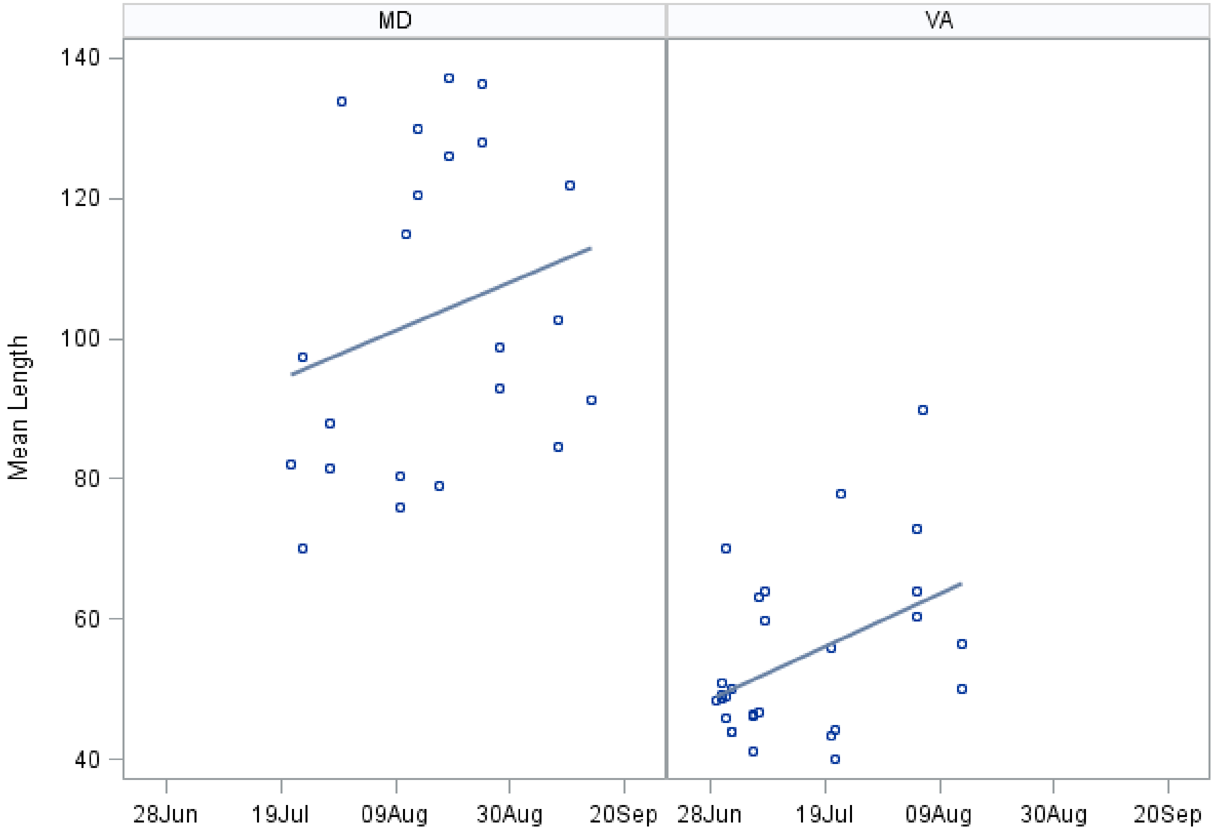


Figure 6. Relationship between π and water temperature (°C) for YOY striped bass captured in paired hauls with the MD and VA nets. Estimates of π were from the beta-binomial model (see Tables 5 and 6).

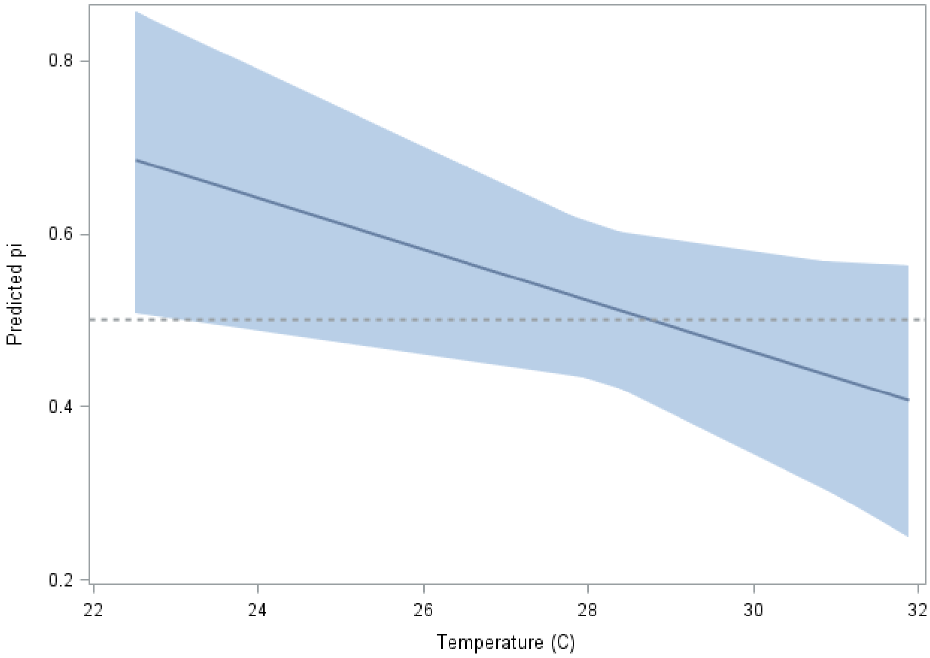


Figure 7. Frequency histogram for estimates of π, the probability of capture of juvenile striped bass in the VA net relative to the MD net; the panel on the left shows the individual estimates of π using the consecutive haul approach (MD), and the panel on the right shows the estimates of π using the side-by-side approach (VA). These estimates are from the best-fitting model, which was the beta-binomial model (see Table 5).

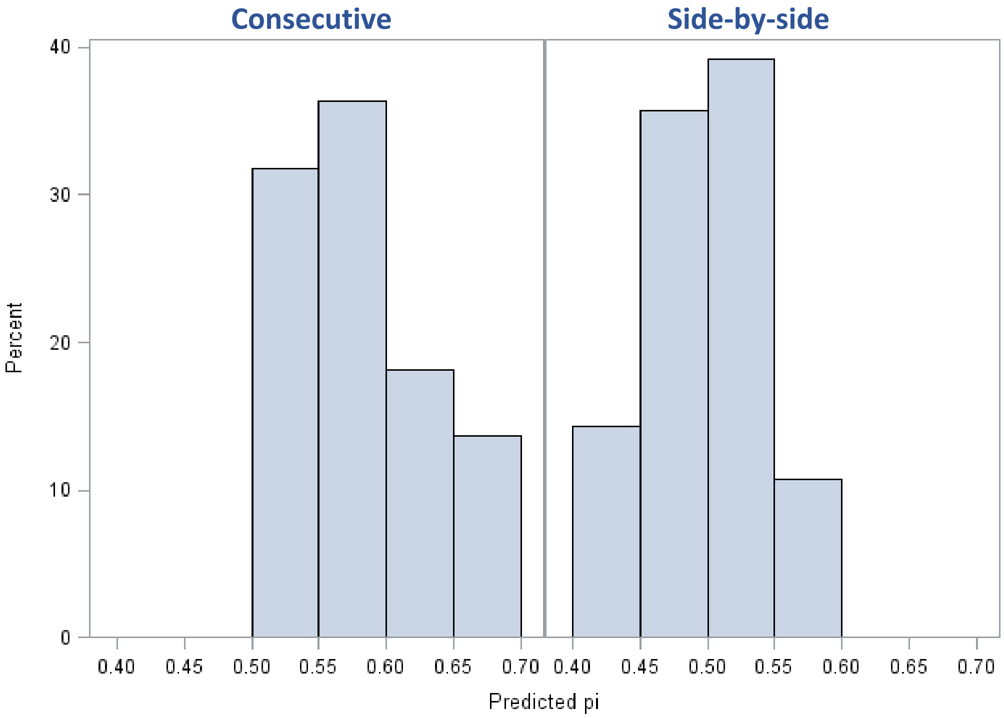
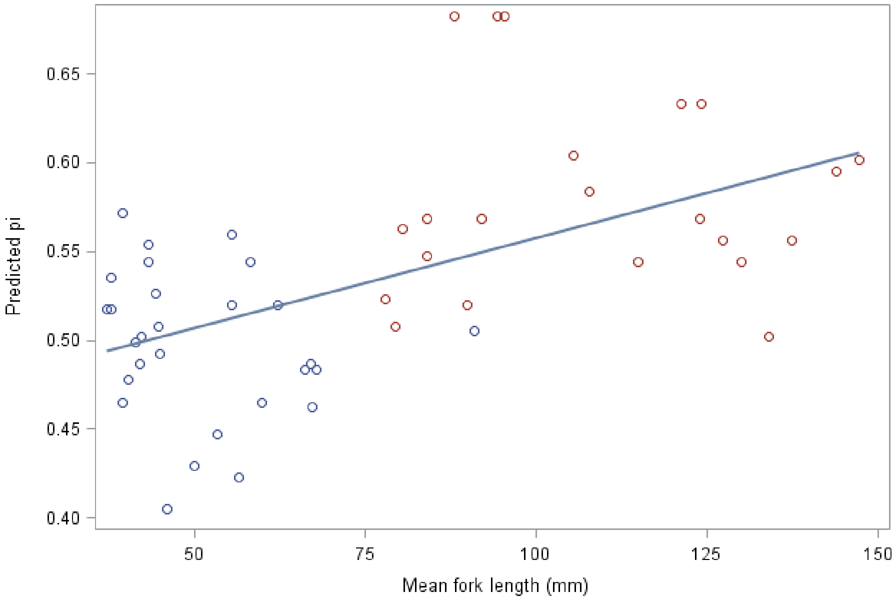


Figure 8. Relationship between observed mean fork length (mm) and estimated probabilities of capture (π) of juvenile striped bass in the VA net relative to the MD net. The mean length data are from the striped bass captured in the VA net. Estimates of π are from the best-fitting model, which is the beta-binomial model (see Table 5); VIMS data are shown in blue and MD DNR data are shown in red. The solid lines represent linear regressions fit to the data and are provided as visual aids only. Panel (A) shows the fit of the regression across all data; panel (B) provides regressions fit to the VIMS (blue line) and MD DNR (red line) data separately.

(A)



(B)

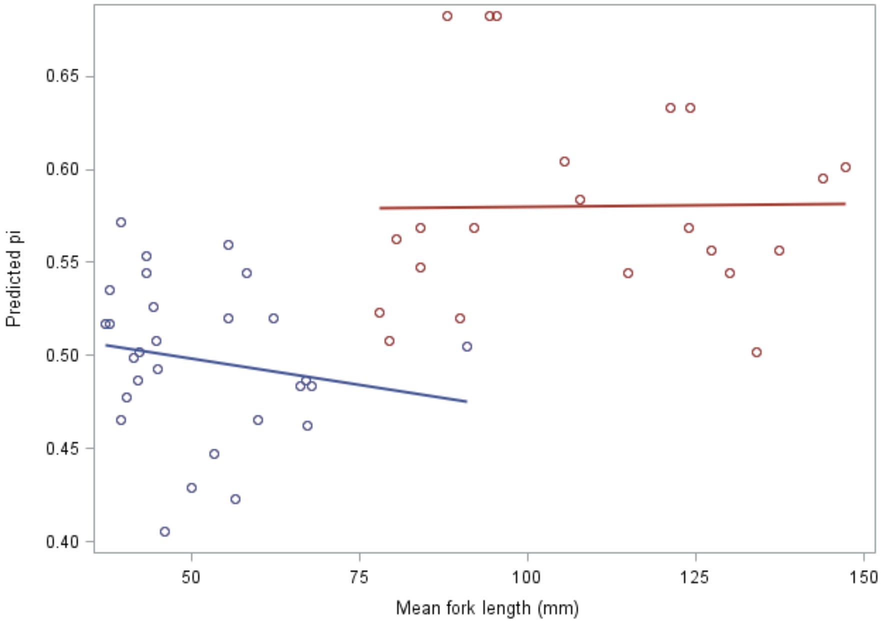


Figure 9. Relationship between predicted ρ from the best-fitting model (beta-binomial) and (A) date, (B) water temperature (°C), and (C) mean fish length (mm fork length). Estimates of ρ are from the model describing the probability of capture of juvenile striped bass in the VA net relative to the MD net. Four estimates are provided because variation in ρ was best described by month (June, July, August, and September): ρ increased from June to September.

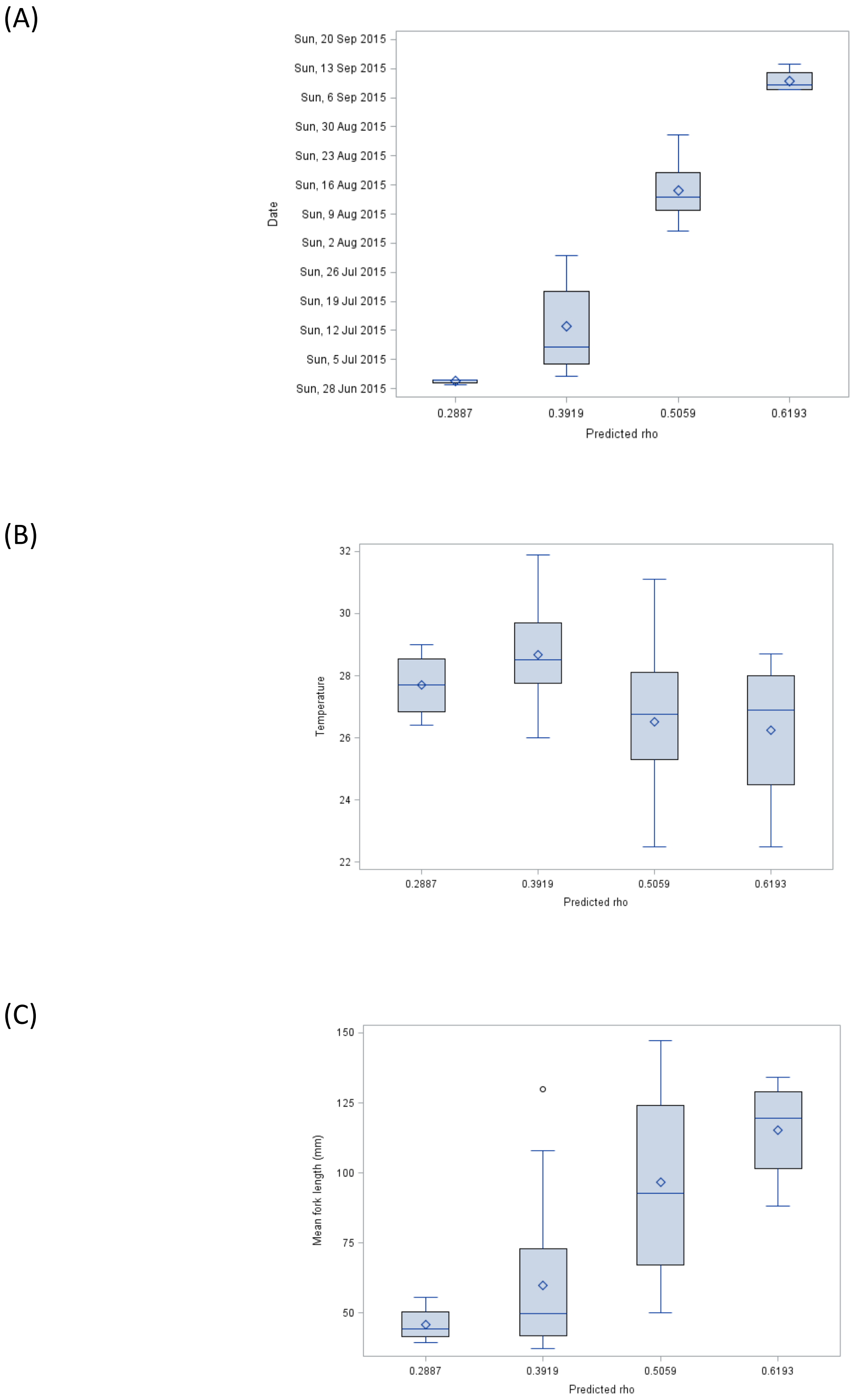


Figure 10. Distribution of estimates of ρ from the best-fitting model (beta-binomial); these estimates are from the model describing the probability of capture of juvenile striped bass in the VA net relative to the MD net. (A) The panel on the left shows values of ρ for consecutive paired hauls (used by MD DNR), and the panel on the right shows values of ρ for side-by-side paired hauls (used by VIMS). (B) Panels showing the distribution of ρ among four tidal stages.

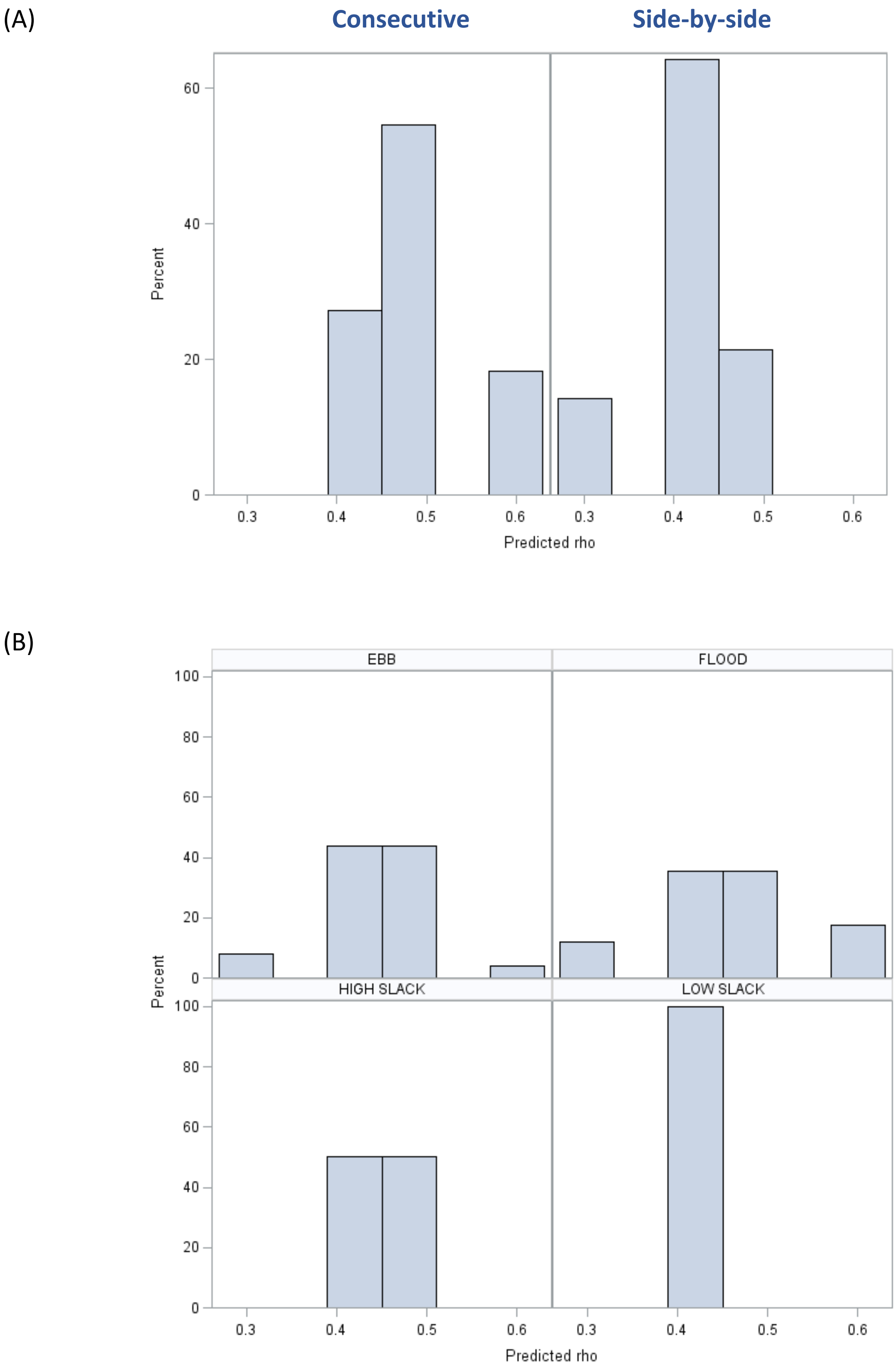


Figure 11. Temporal variation in mean size (fork length, mm) of juvenile striped bass captured during the 21 paired-haul trials with the VA and new nets during summer 2015; these means are for fish captured with the VA net. The red dots are from sites in the Rappahannock River, the blue dots are from the James River, and the green dots are from sites in the York River. The solid lines represent linear regressions fit to the data and are provided as visual aids only (red=Rappahannock; blue=James; green=York).

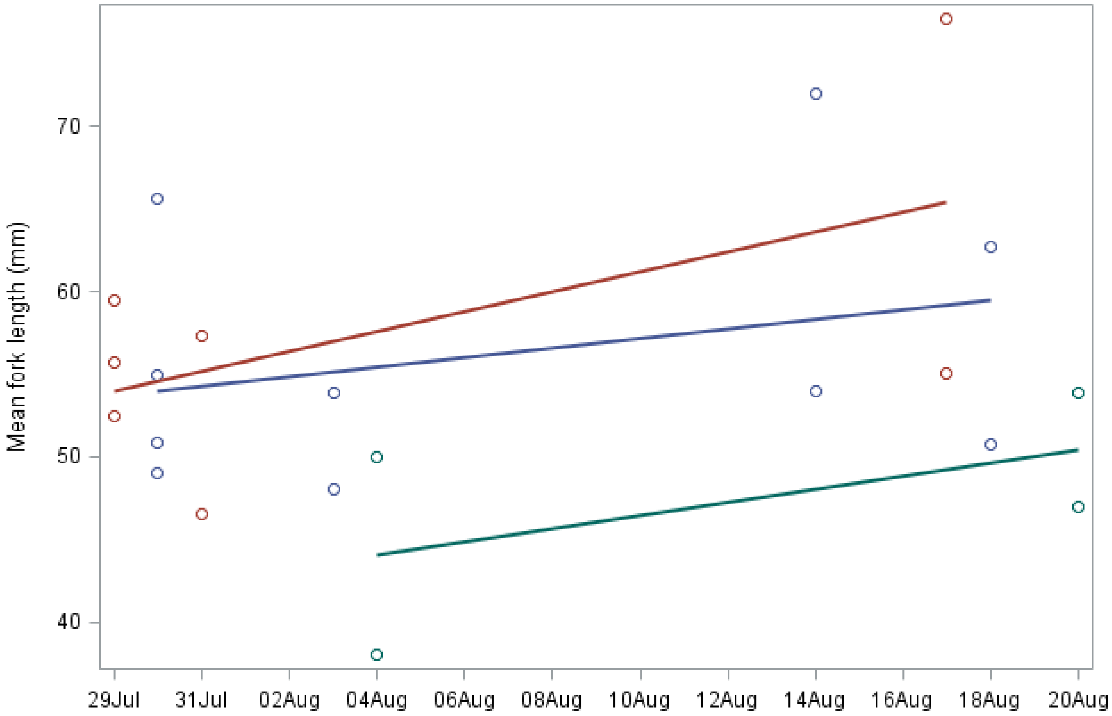


Figure 12. Distribution of ρ from the random-clumped binomial model fit to the paired-haul catches with the VA and new nets.

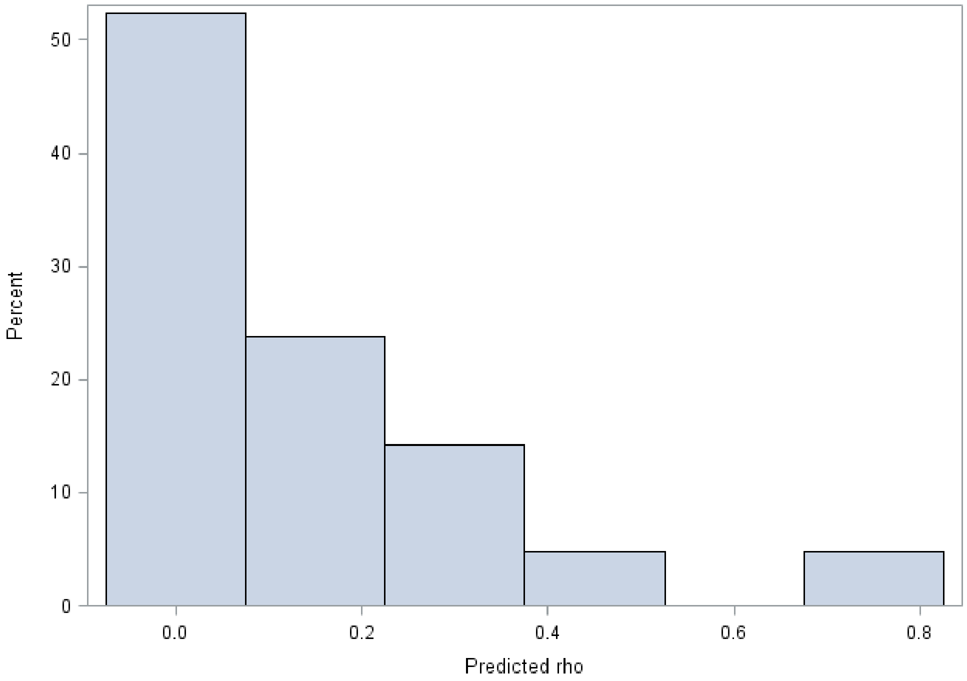


Figure 13. Relationship between temperature (°C) and ρ estimated from the random-clumped binomial model fit to the paired-haul catches with the VA and new nets.

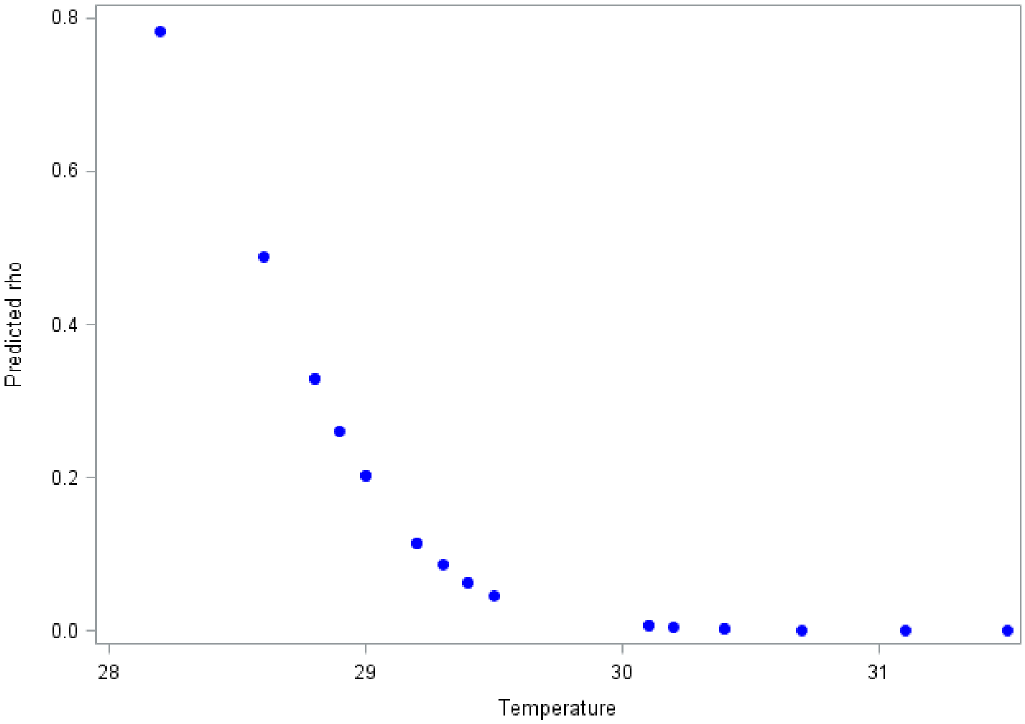


Figure 14. Relationship of mean size (fork length, mm) of juvenile striped bass to ρ estimated from the random-clumped binomial model fit to the paired-haul catches with the VA and new nets. Mean size was estimated from fish captured in the VA net.

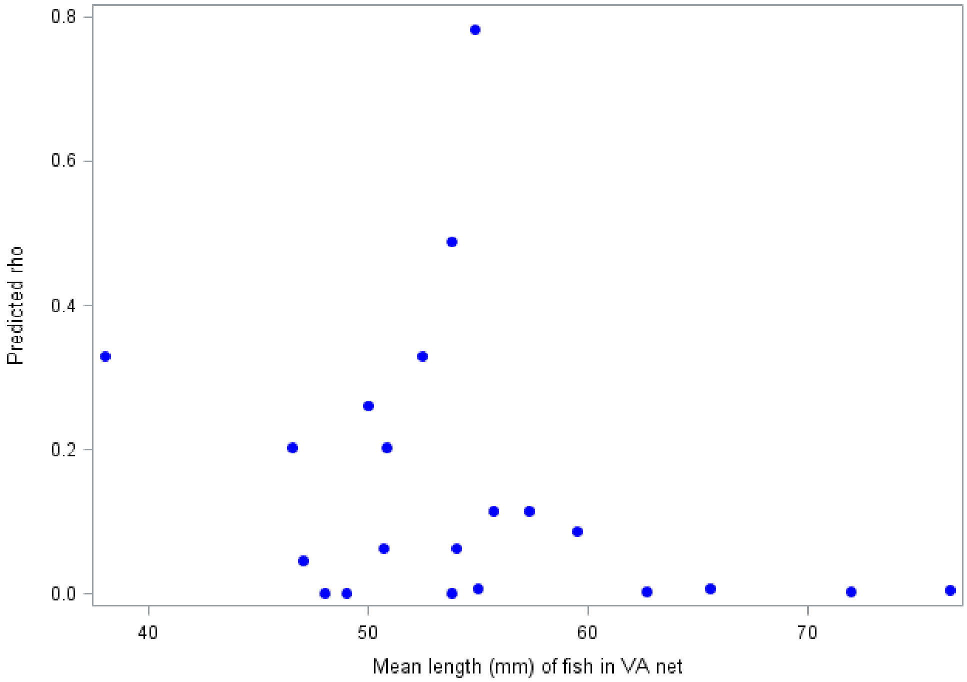


Figure 15. Temporal variation in water temperatures (°C) in striped bass nursery areas in Virginia during deployment of the MD and new net pairs. The solid line is the linear regression fit to the observations (open circles); the shaded area is the 95% confidence interval on the regression line, and the dotted lines denote the 95% prediction limits; the slope of the regression (-0.0523) is significantly different from 0 (*t*=-2.54, *P*=0.0185).

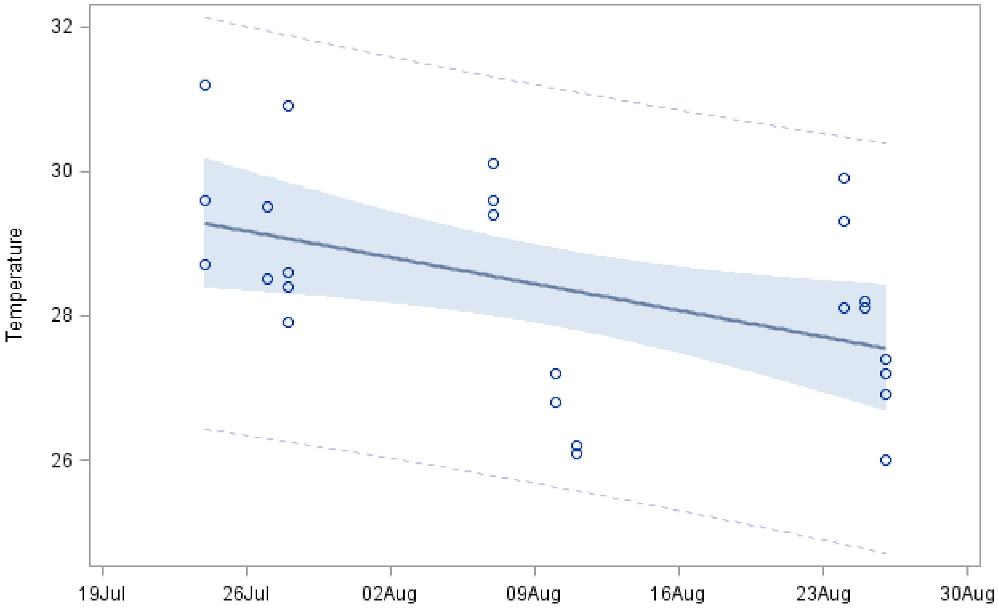


Figure 16. Mean size (fork length, mm) of juvenile striped bass captured during the 25 paired-haul trials with the MD and new nets in Virginia during summer 2015; these means are for fish captured with the MD net. The green dots are from sites in the York River, the red dots are from sites in the Rappahannock River, and the blue dots are from the James River sites. The solid lines represent linear regressions fit to the data and are provided as visual aids only (green=York, red=Rappahannock, blue=James).

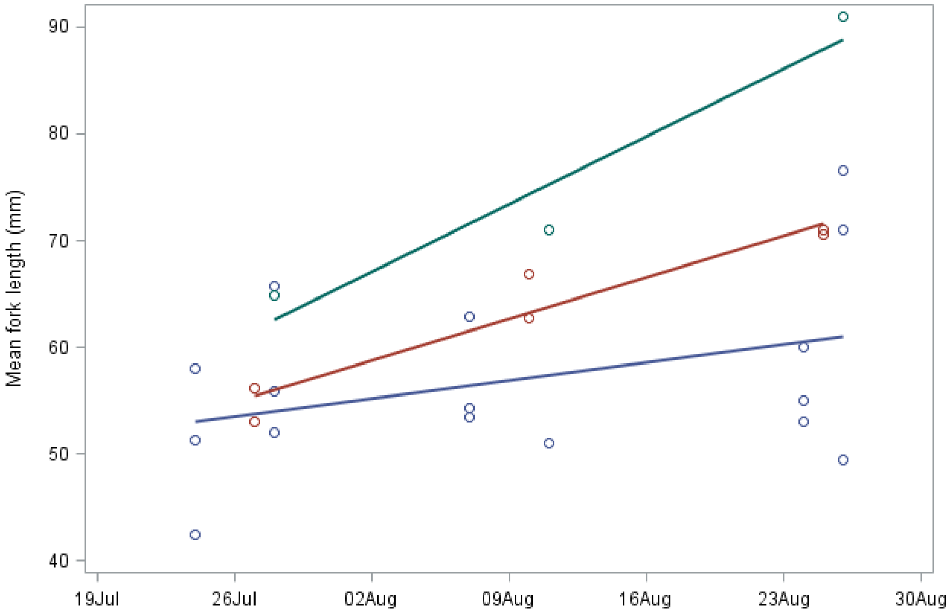


Figure 17. Distribution of π relative to bottom type as estimated by the beta-binomial calibration model for the MD and new nets; in this model, π varied with bottom type and maximum net extension. The MD net was more efficient in sand than the new net; whereas the efficiency of the two nets was similar in mud (π ~ 0.5).

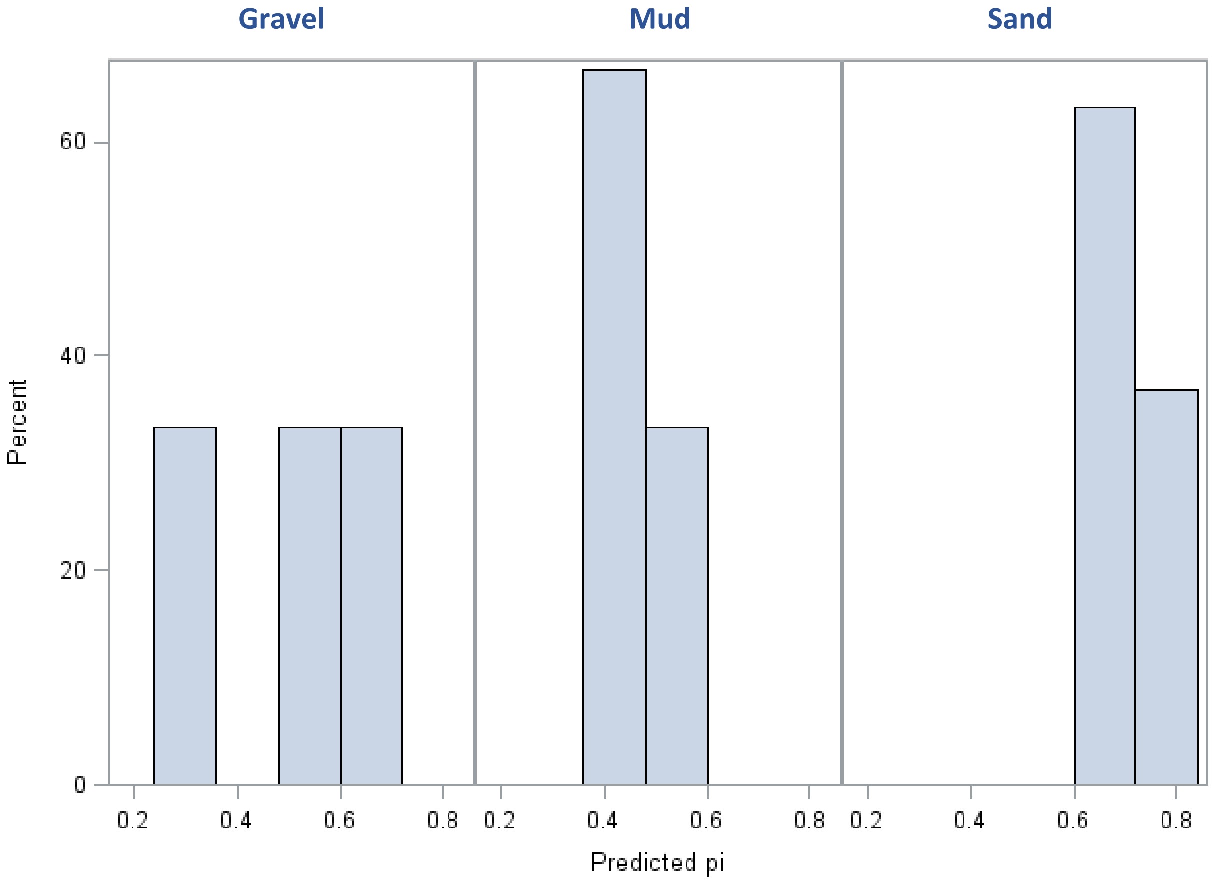


Figure 18. Distribution of π relative to bottom type and maximum net extension (ft) as estimated by the beta-binomial calibration model for the MD and new nets. The MD net was more efficient in sand than the new net (greater values of π); whereas the efficiency of the two nets was similar in mud (π ~ 0.5). Across all bottom types, the efficiency of the MD net relative to the new net decreased as the maximum extension of the net approached 100 ft (the size of the net).

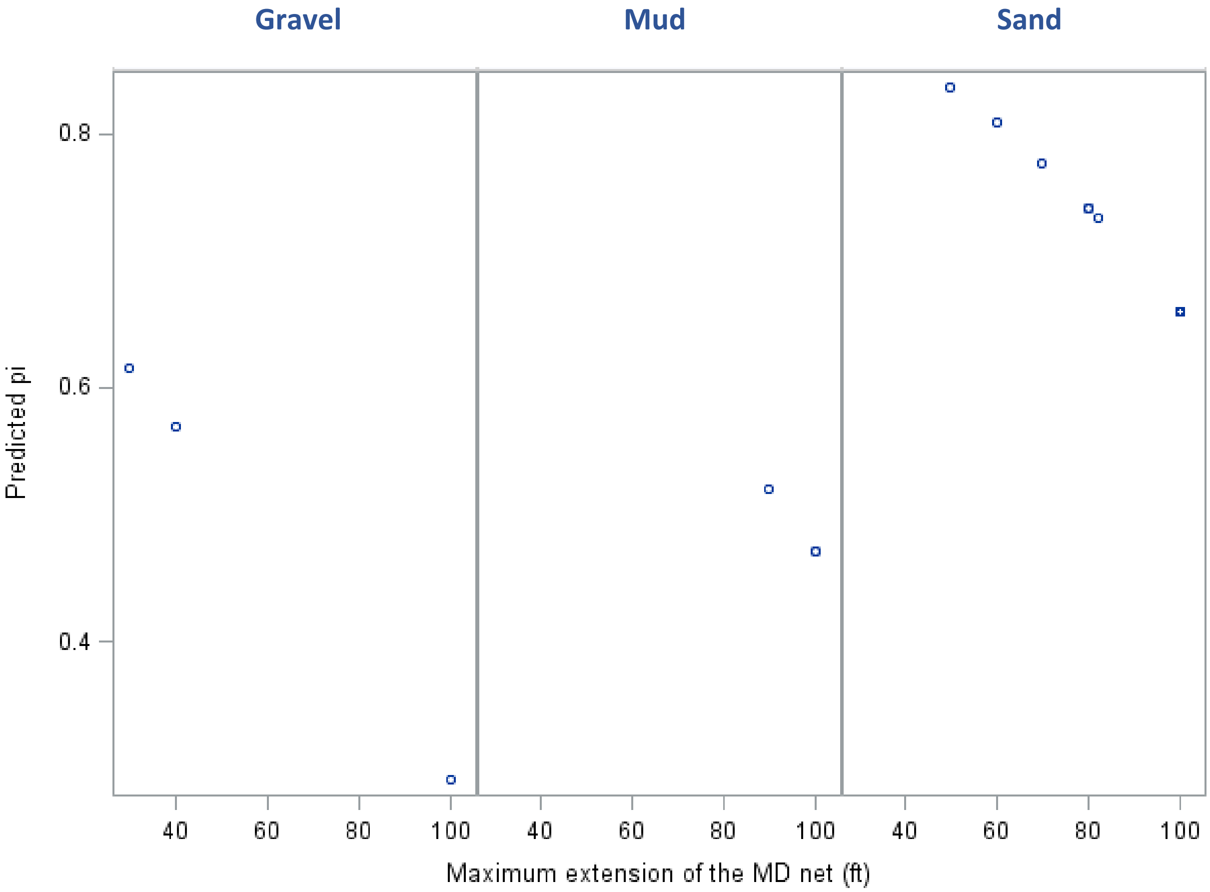


Figure 19. Frequency distribution of water temperature (°C) in nursery areas of Virginia in the James (JA), Rappahannock (RA), and York (YK) rivers during summer, 1967 to 1973 and 1980 to 2016. The vertical reference line is 24°C.