Calibration of VIMS Research Vessel Catch Data To Ensure Continuity of Recruitment Indices for the Chesapeake Bay Region

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Executive Summary

The VIMS Juvenile Fish Trawl Survey, which has been in operation since 1955, has undergone considerable changes to the sampling gear, location of sampling sites, and the methodology used to select sampling sites. Recently, a new vessel, the R/V *Tidewater,* replaced the R/V *Fish Hawk,* which had been in service for 25 years. In addition to the change in vessel, a new net was used; this net design is more robust to deployment methods and performs more consistently under varying environmental conditions. Therefore, a calibration study was conducted whereby the two research vessels with different nets fished in the same area at the same time. This calibration study provides an estimate of the species-specific factors necessary to 'convert' the R/V *Tidewater* catches to those of the R/V *Fish Hawk*, taking into account the combination of vessel and net. All other protocols (tow duration, scope, vessel speed, and sample processing) remained unchanged. Comparison sampling with the R/V *Tidewater* and the R/V *Fish Hawk* began in April 2014 and concluded in May 2015; additional paired tows were completed in August 2016 to provide sufficient samples for Scup, Black Sea Bass, and adult Summer Flounder. We completed a total of 1,141 paired tows during 97 days-at-sea, capturing a total of 327,526 fishes, crabs, and shrimp aboard the R/V *Fish Hawk* and 323,580 fishes, crabs, and shrimp aboard the R/V *Tidewater*. From these data, we developed calibration factors for 41 species groups (species-age or species-size combinations). Calibration factors were estimated from the best-fitting model from among four candidate models that accounted for variability in catches between the two vessels. In addition, we examined species composition of the catches from the paired tows using multivariate analysis and found that catches from the two vessels were similar in all months and strata except for shallow stations in Chesapeake Bay. Our 'whole survey' approach allowed us to estimate calibration factors for species in all available habitats that are routinely monitored by the VIMS Juvenile Fish Trawl Survey. Further, our consideration of depth, tidal currents, tow direction, water clarity, tow distance, and salinity in the calibration models ensures that the estimates are applicable across the range of estuarine characteristics that are inhabited by these species. The estimated calibration factors will be applied to catches of the R/V *Tidewater* at the individual-tow level; relative abundance indices will be estimated using the random-stratified survey design in effect since 1988, thus preserving the integrity of the long-term survey data for estimating relative abundance of juvenile fishes and blue crabs in Chesapeake Bay.

Introduction

The VIMS Juvenile Fish Trawl Survey (VIMS trawl survey) provides monthly information on the abundance of juvenile fishes and blue crabs in estuarine waters of Virginia and has been in continuous operation for 61 years. Recently a new vessel, the R/V *Tidewater,* replaced the R/V *Fish Hawk,* which had been in service for 25 years. To permit continuation of the long-term series of recruitment observations for multiple species, species-specific catches of the R/V *Tidewater* must be calibrated against those of the R/V *Fish Hawk*. In addition to the change in vessel, we deployed a new net whose design is similar to that used by other multispecies surveys in the Bay and coastal ocean (i.e., CHESMMAP, NEAMAP [Bonzek et al. 2015] and the annual bottom trawl surveys conducted by the Northeast Fisheries Science Center [NOAA Fisheries Service 2015]). Flume-tank tests indicated that the new net is more robust to deployment methods and performs more consistently under varying environmental conditions. Thus, two critical elements were changed: the vessel and the net. Therefore, a calibration study was conducted whereby the two research vessels with different nets fished in the same area at the same time. This calibration study provides an estimate of the species-specific factors necessary to 'convert' the R/V *Tidewater* catches to those of the R/V *Fish Hawk*, taking into account the combination of vessel and net. All other protocols (tow duration, scope, vessel speed, and sample processing) remained unchanged.

Based on a research vessel calibration study conducted by the NOAA fisheries lab in Woods Hole, and on subsequent analysis of the data from the experiment, researchers recommend that a useful (relatively reliable) conversion factor from paired-tow data requires that a given species is observed in at least 30 paired tows (that is, the species is present in the catches of both tows). This can present a considerable challenge for some species, particularly those whose abundance or availability to the gear is low. Although the VIMS trawl survey primarily targets juvenile (age-0) fishes, older (designated as age-1+) fishes are also encountered. Calibration factors are therefore required for each species-age group because availability, selectivity, and efficiency of the net varies by species and by relative size of the individuals captured.

In this study, we estimate calibration factors for multiple fish and invertebrate species that inhabit estuarine waters of Virginia either as year-round residents (e.g., blue crabs, Striped Bass) or as seasonal occupants of nursery habitats (e.g., Summer Flounder, Atlantic Croaker). We report calibration factors as the relative catch efficiency of the *Fish Hawk* to the *Tidewater*. In this manner, future catches from the R/V *Tidewater* can be adjusted to remain comparable to the R/V *Fish Hawk* (i.e., that is, catches from the *Tidewater* will be reported in '*Fish Hawk* units'). This ensures continuity with previously reported recruitment indices because indices from 2015 and forward will be adjusted (rather than adjusting the existing multi-decadal time series).

Calibration factors (or relative catch efficiencies) can be estimated using a number of models, but one of the fundamental characteristics of catch data is that they follow a binomial distribution – either the species is captured by the paired tow (i.e., present in both tows of the pair) or not. The binomial distribution cannot account for the additional variation (overdispersion) that is typically observed (McCullagh and Nelder 1989), so models that specifically address overdispersion are also applied (Morel and Neerchal 2012). Here, we consider the following models: the binomial model, the beta-binomial model, the random-clumped binomial distribution model, and the generalized linear overdispersion mixed model (GLOMM) based on the beta-binomial distribution. The models increase in complexity by allowing additional random effects to account for the variation that is not explained by the simple binomial model; in addition to modeling the overdispersion in the binomial process, the GLOMM permits consideration of random effects. To our knowledge, these models have only recently been applied in the context of fisheries calibration factors (e.g., the hierarchical mixed effects models used by Miller [2013] is similar to the GLOMM and uses random effects to address variation in fish sizes).

Currently, we calculate recruitment indices for several species-age groups (e.g., young-of-the-year [YOY] Summer Flounder, age-1+ American Eel), and can reliably track variations in abundance of several other species (blue crab, Hogchoker, Northern Searobin, Spotted Hake, Kingfish *spp*., Blackcheek Tonguefish); some of these species represent a considerable portion of the total fish biomass in certain habitats. We designated 15 species as the primary species group (Table 1) because these are species of greatest interest to management (ASMFC and VMRC), or our indices are used in current stock assessments (e.g., Summer Flounder, Atlantic Menhaden, blue crabs), or our time series of relative abundance are used to evaluate management options (e.g., Spot and Atlantic Croaker). The primary species also include species whose abundances are tracked by regional management councils (e.g., Bay Anchovy, blue crab, horseshoe crab). The secondary species group (Table 2) includes numerically abundant species (such as Blackcheek Tonguefish, Hogchoker, and Spotted Hake), species of conservation concern (i.e., Alewife, Blueback Herring), and species captured in sufficient numbers of paired tows to estimate a calibration factor. Some of these species may become increasingly important as ecosystem-based fisheries management intensifies its focus on forage fishes (e.g., Gizzard Shad, Striped Anchovy; Table 2) and on species that have recently increased in abundance in the Bay in response to a changing climate (e.g., white shrimp). Our goal was to provide species-specific calibration factors for each of the species in the primary and secondary groups.

Additionally, the VIMS trawl survey encounters species whose abundance, distribution, or availability to the gear is limited. For many of these species, we were unable to obtain sufficient numbers of paired tows with positive catches, so we assigned such species to a functional guild, based on morphology (e.g., flatfishes) or behaviors (e.g., pelagic, demersal, schooling) that are thought to affect catchability (Table 3). For these, we provide calibration factors for individual guilds using data pooled across species within each guild or using calibration factors estimated from similar primary or secondary species. To confirm the robustness of the guild approach, we compared calibration factors for pairs of closely related species. For example, young-of-the-year Striped Bass and White Perch use the same nursery areas and are congeners; we expect similar catchability and calibration factors for these two species-age classes. We reasoned that if we estimated similar calibration factors for species pairs that are morphologically similar and that were well represented in our catches, then our guild-based approach would be reasonable for species with limited catches. We identified the following species pairs for comparison of calibration factors: (1) YOY stages of Striped Bass and White Perch; (2)

YOY stages of Alewife and Blueback Herring; (3) Age-1+ Blue Catfish and White Catfish; (4) Age-0+ Bay Anchovy and Striped Anchovy; and (5) YOY stages of Summer Flounder and Smallmouth Flounder.

Methods

Field Methods

Side-by-side tows were planned at every station sampled by the VIMS trawl survey (target of 1,224 paired tows), conditional on the availability of sufficient space for two vessels to operate safely. We used this 'whole survey' approach following the recommendation of the Independent Review Panel of the NMFS calibration study for FSV *Henry B Bigelow* and R/V *Albatross IV* (Independent Review Panel Report 2009). Use of this approach ensures sampling of the range of habitats, substrates, depths, and ecological communities that are typically encountered during survey operations and most importantly, avoids extrapolation to conditions outside those encountered (NEFSC Vessel Calibration Working Group 2007). Our 'whole survey' approach resulted in a maximum of 111 stations sampled monthly by both vessels.

Site selection

The VIMS trawl survey has been in operation since 1955 and has undergone considerable changes to the gear, the location of sampling sites, and the methodology used to select sampling sites. The current design, in operation since March 1996, uses a combination of fixed and random sites in the rivers, and random stations in the Virginia portion of Chesapeake Bay. Fixed sites were established in mid-channel waters along the axis of each river and spaced approximately 8.0 km apart. Each month, eight fixed sites are sampled in the James and Rappahannock rivers and nine fixed sites are sampled in the York River. Fixed sites range in depth from 3.7 to 10.7 m in the James River, from 3.7 to 18.3 m in the Rappahannock River, and from 4.0 to 12.2 m in the York River. Random sites were selected using a stratified random design where strata were defined by water depth and geographic region (e.g., western Bay, upper York River, lower James River). Depth is believed to influence fish assemblage composition and abundance (Gray et al. 2011) and is commonly used to stratify fisheries surveys (Gunderson 1993). Random stations were assigned to 1 of 4 depth strata: from 1.2 to 3.6 m, from 3.6 to 9.1 m, from 9.1 to 12.8 m, and greater than 12.8 m. Due to the presence of a salinity gradient in the rivers, four river zones were used as strata to ensure sampling throughout the range of available salinity from the mouth to the freshwater interface of each river. In each river for each month, one or two sites (depending on the area of the stratum) are selected randomly in each stratum from a list of available sites, resulting in 14 random sites sampled monthly in the James and Rappahannock rivers, and 13 random sites sampled monthly in the York River. Similar depth strata and zones were created in the Virginia portion of Chesapeake Bay for selection of random stations only. In the Bay, up to 45 random stations are chosen each month with fewer stations selected during winter months (i.e., 39 stations are sampled in December, February, and April, and no Bay stations are sampled in January or March).

Fish collections and environmental conditions affecting catch rates

We used a 9.1-m head line, 4-seam, semi-balloon otter trawl with 38.1 mm stretch-mesh body and a 6.4-mm mesh cod liner to collect fishes from the R/V *Fish Hawk*, an 8.5-m research vessel. On the

R/V *Tidewater*, a 13.1 m research vessel, we used a trawl with a 5.8-m head line with 40 mm stretch-mesh body and a 6.4-mm liner, which is essentially a 1/3 scale net (i.e., 374 X 4-cm net) of the gear used on the NEAMAP survey (400 X 12-cm net; Figure 1). As determined by preliminary field tests, the doors currently used on the R/V *Fish Hawk* (China-V doors) were adequate for opening the new net deployed on the R/V *Tidewater* and the same doors were used on each vessel during comparison tows (field test, 3 October 2013).

Paired tows were completed monthly from April 2014 to May 2015 at stations occupied by the VIMS trawl survey and following the stratified random sampling design of the survey. If either vessel encountered a snag or a re-tow was necessary, only the vessel with the issue repeated the tow; this is because tow durations are short and thus, a brief delay is not likely to affect fish distributions and abundance. To increase sample size for YOY Summer Flounder, Mobjack Bay was sampled in October 2014, specifically targeting Summer Flounder; other fish were ignored. Additional targeted paired tows were completed in the eastern portion of the Chesapeake Bay in August 2016 to supplement catches for YOY Scup, YOY Black Sea Bass, and Summer Flounder.

Each vessel completed a 5-min tow at approximately 2.5 knots at each site, and paired tows were typically obtained with less than 40 m separation between the vessels. Fishing procedures and catch processing methods were identical on each vessel with the exception that water quality data (temperature [°C]; salinity [psu]), depth (m), tow direction relative to the current, and tidal stage at time of sampling) were measured from the R/V *Fish Hawk* only. For one cruise (29 September 2014) in Mobjack Bay, we did not record salinity; therefore, we used the bottom salinity observed by the monthly monitoring conducted by the Chesapeake Bay Program in Mobjack Bay. Tow direction relative to the current was recorded as one of six categories (with the current, against the current, perpendicular to the current, oblique with the current, oblique against the current, and slack current), but analyzed as three categories: with the current, against the current, and other. Sampling protocol favored towing against the current and this was achieved in 79% (901 of 1,141 paired tows) of samples; 16.5% of tows were with the current, and the remaining 1.6% were completed in other conditions. Tidal stage was recorded as one of eight conditions (early flood, maximum flood, late flood, slack before ebb, early ebb, maximum ebb, late ebb, and slack before flood) using tidal predictions from NOAA and direct observations. For analysis, tidal stage observations were simplified by pooling into three categories: flood (48% of tows), ebb (50.7% of tows), and slack (1.3% of tows). In addition, the starting and ending coordinates of each vessel were recorded for each tow to calculate distance towed.

The catch was sorted by species and fishes, crabs, and shrimps were measured (fork length or total length for fishes, carapace width for crabs, and total length for shrimps) to the nearest mm using an electronic measuring board. Catches of a single species exhibiting multiple modal sizes and large catches were sub-sampled with at least 30 individuals from each species or size mode measured at each site. The remaining catch was counted and the size distribution of the sub-sampled catch was expanded proportionally to the total number captured. We used the monthly length thresholds applied by the VIMS trawl survey to designate age-0 fish (Tuckey and Fabrizio 2016); fish that exceeded these length thresholds were designated age-1+.

On average, the difference in the tow depth of the two vessels ranged from 0.3 to 0.6 m (Table 4). For most tows (90.6%), the difference in tow depth was such that both vessels sampled the same depth stratum even though the actual tow depths of the two vessels may have differed (Figure 2). In a few cases (9.4%), the R/V *Tidewater* sampled in depths that were not in the stratum sampled by the R/V *Fish Hawk*, but the differences in depth were relatively small (Table 5). Most of these cases (4.6% of the 1,141 tows) represent samples from stratum 2 (3.6 – 9.0 m) that were taken by the R/V *Tidewater* while the R/V *Fish Hawk* sampled in stratum 1 (1.2-3.6 m); this is not surprising given the deeper keel on the R/V *Tidewater* and the inability of the R/V *Tidewater* to sample in the shallowest areas. The largest observed differences in tow depths were in the middle Bay at a station located in 32 m of water, and at two deep stations in the Rappahannock River. For the Bay station, the R/V *Fish Hawk* sampled at 32.3 m, but the R/V *Tidewater*, sampling alongside the R/V *Fish Hawk*, sampled in 22.3 m. In the Rappahannock River, tow depths varied by 5.5 m and 4.3 m at two sites (18.9 m for the FH vs. 13.4 m for the TW; 18.3 m for the FH vs. 14.0 m for the TW). Regardless of the difference in depths obtained in these three cases, all samples were obtained from the deepest stratum. We also note that in all cases, the R/V *Fish Hawk* sampled within the depth thresholds of the stratum, but this was not always the case for the R/V *Tidewater*. In general (90.6% of the tows), the tow from each vessel was a valid sample from the targeted stratum.

We examined potential effects of covariates on the probability of capture to explain the variation in catches observed between the R/V *Fish Hawk* and R/V *Tidewater*. We included tow direction, tidal current, Secchi depth, tow depth, and offset in the statistical models used to estimate the calibration factors. The covariate 'offset' was calculated as the log of the ratio of the distance swept by the R/V *Fish Hawk* to the distance swept by the R/V *Tidewater* to standardize each tow (Figure 3). We included both tow direction and tidal current as they are independent factors (likelihood ratio chi-square = 1.861, P=0.17) that could potentially affect net performance and the resulting catch.

Statistical Methods

Gear selectivity was a concern because we wished to compare the catch of two gear designs (as well as vessel effects), therefore we eliminated smaller-sized individuals (< 30 mm TL or FL for fishes, and < 25 mm carapace width for crabs; Figure 4) to ensure our comparisons were focused on fishes and crabs that had fully recruited to both gears.

For some species and life-stage combinations, we observed an insufficient number of paired tows with positive catches (< 30 paired tows for which a particular species and life stage was captured by both vessels), such that estimation of a precise calibration factor was problematic. This occurred for species that were rare (e.g., Red Drum, Skilletfish) or relatively uncommon (e.g., American eel, YOY Black Sea Bass, YOY Scup) in our catches. Because the survey uses a stratified design (with 54 strata), and because multiple tows per stratum are typically completed in a given day, we considered using the stratum as the experimental unit, rather than the individual tow. For example, in a given stratum, both vessels completed paired tows at 3 stations, however, the R/V *Fish Hawk* captured YOY scup at 2 stations and the R/V *Tidewater* at only 1 station. In this case, only one-paired station tow could be used for estimation of the calibration factor. The stratum-pair approach increases the spatial scale of the experimental unit from the area sampled by an individual tow (about 350 m x the net opening) to the area of the stratum (highly variable). Use of stratum pairs (rather than station pairs) assumes that if both vessels capture a species in a given stratum in a given day, then such observations may be used to compare the efficiency of the two gears. To compare catch rates of the R/V *Fish Hawk* (reference gear) and R/V *Tidewater* (test gear) using the stratum-pair approach, catches for a given species-life stage were summed across all stations within the stratum. Unfortunately, the stratum-pair approach did not improve our ability to derive calibration factors for species-life stages that were poorly represented in the catches of the two vessels. For example, for YOY scup, 8 stratum pairs were identified vs. 6 stations pairs; for YOY Black Sea Bass, the same number of pairs (n=26) resulted from using either the station-pair or stratum-pair approach; and for age-1+ Black Sea Bass, 7 stratum pairs were identified vs. 6 station pairs. We believe that the lack of appreciable gain in paired samples was due to the fact that we have only a few stations in each stratum each month (typically 2 or 3). Because of the lack of appreciable gains, we did not consider the stratum-pair approach further.

Multivariate analysis

Many species are not captured in a sufficient number of tows to estimate calibration factors, but these species are important contributors to biodiversity and ecosystem function. Therefore, we examined species composition of the catch for each vessel using non-metric, multidimensional scaling (NMDS; Field et al. 1982). Tow-level data from each vessel were summed for each stratum (N=54 strata) and in a separate investigation, by month (N=12 months), to examine species composition between vessels. Similarity matrices were constructed using the Bray–Curtis similarity index calculated on fourth-root-transformed catch data to reduce the influence of numerically dominant species (Field et al. 1982). All multivariate community analyses were conducted using package vegan in R (R Development Core Team 2016; Oksanen et al. 2011).

Estimation of calibration factors

The models we consider explain the processes observed in the calibration experiment using two vessels to obtain side-by-side paired tows. The number of individuals representing a particular species and age class that is captured by each vessel is recorded and pairs are identified uniquely. (Henceforth, ‘species’ will be used to designate a particular species and age class.) Several outcomes are possible: either both vessels encounter the species, only one vessel encounters the species, or neither vessel encounters the species. Estimation of calibration factors requires information supplied from the first outcome because if only one vessel captured the species, then there are no observations with which to make vessel comparisons. The total number of individuals captured in a single pair by the two vessels follows a binomial distribution; furthermore, if gear deployments are identical then the total number of fish captured is the only source of variation in the catches and the variance from pair to pair is adequately explained by the binomial distribution (Liggett and Delwiche 2005).

However, deployments are not likely to be identical because of variations in operations (e.g., vessel speed, tow direction relative to the current) and gear efficiency associated with environmental conditions such as depth, current, bottom type, and composition of the catch. Thus, the additional variance associated with differences among deployments results in a random probability of success that varies among pairs; this random probability follows a beta distribution (Nelson et al. 2004). If we allow the number of individuals captured by one vessel to be conditional on the total number of individuals captured by both vessels, then we can use a beta-binomial distribution to describe the outcome. The beta-binomial distribution allows a random process to affect the outcome of a given pair and can be used to model the variation in relative catch efficiency among paired tows.

The beta-binomial model makes use of two probability distributions to describe the two processes associated with each observation. In the beta-binomial model, the number of paired tows in which both tows contain a particular species follows a binomial distribution which is conditional on the random probability of success, π, and the random probability of success follows a beta distribution; here, success is the presence of the species in the catch. Thus, each pair has its own probability of success and these random probabilities vary between pairs (Nelson et al. 2004). The assumption of the binomial portion of the model is that gear deployments are identical and the outcomes (probability of capture) are independent (Liggett and Delwiche 2005). The binomial distribution model assumes that the only source of variation is from the samples (number of fish captured), but in fact, gear deployments are also a source of variation because they vary in efficiency and operation, which leads to varying outcome probabilities (number of fish captured; Liggett and Delwiche 2005). When deployments result in variation from sample to sample (i.e., variation among paired tows), then the binomial distribution cannot fully account for the variation. Instead, the variance due to differences between deployments may be explained by the beta distribution. The variability represents overdispersion (relative to the binomial distribution), which can be estimated by the beta-binomial model with the parameter ρ (Liggett and Delwiche 2005).

To further allow variation among the paired tows, we considered the generalized linear overdispersion model (GLOM) in which a random-clumped binomial distribution is used to describe the mixture of two binomials (Morel and Neerchal 2012). The random clumped binomial distribution is identical to the beta-binomial when cluster size (number of observations in a cluster or the number of trials) is two. Like the beta-binomial model, the random-clumped binomial model is fit using two link functions - one link function fits the probability of success (π), and the other fits the overdispersion (ρ). With this model, cluster-specific covariates can be considered in either or both link functions (Morel and Neerchal 2012). Parameter estimation for GLOMs often requires standardizing or centering the covariate effects (Morel and Neerchal 2012).

If neither the beta-binomial model nor the random-clumped binomial model fits the data well, an added complexity can be considered to account for additional random effects. The generalized linear overdispersion mixed model or GLOMM (Morel and Neerchal 2012) allows treatment of the paired tows as random effects in the model; the random effect captures the deviations of the pair's response from the group average. GLOMMs allow incorporation of additional random effects due to variation among paired tows (Morel and Neerchal 2012). Thus, we considered a beta-binomial GLOMM. With the beta-binomial GLOMM, we modeled the random effect of the paired tows, so the probability of success varies by pair (this pair-level variation is not modeled explicitly with the beta-binomial model).

Variation in catch among paired tows was examined by partitioning covariates into two groups: (1) fixed effects, which are those that likely affect how each net performs and (2) random effects, which are those that affect the spatial clumping or aggregation of fish (i.e., overdispersion). For the binomial model, which allows only fixed effects, we included tow direction, tidal current, Secchi depth, tow depth, and offset in the model. For the other three models, we included the same fixed effects with the addition of the random effect of salinity. For all models, tow depth, salinity, and Secchi depth were standardized.

The simple binomial model with fixed covariate effects for π is:

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

where N_{xAi} is the number of a particular species in net A of paired-tow i and covariate level x, π_x is the probability of capture of that species by vessel A for covariate level x, and $N_{x(A+B)i}$ is the number of that species captured by both vessels (vessel A + vessel B) of paired-tow i and covariate level x (Morel and Neerchal 2012). The beta-binomial model with 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 differences among pairs of tows for covariate level x. Similarly, the random-clumped binomial model with fixed covariate effects for π and ρ is:

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

The GLOMM contained fixed covariate effects for π and ρ, as well as the random effect due to pairs of hauls:

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

where $N_{xAi}|u$ is the number of fish captured by vessel A of paired-tow i and covariate level x conditional on the random effect (u) of each paired tow, and $N_{x(A+B)i}|u$ is the number of fish captured by both vessels of paired-tow i and covariate level x conditional on the random effect (u) of paired tows. These 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 and Neerchal 2012). For example, in the beta-binomial, the link function for the probability of capture of a given species by vessel 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).

Each of these models was fit to the data from paired tows, and calibration factors were estimated as π/(1-π) using estimates of π from the best model as determined by Akaike's Information Criterion adjusted for small sample sizes (AIC_c). The variance of the calibration factor was estimated using the standard error of π and the delta approach to variance estimation of the ratio (π/(1-π)). The four models were implemented in SAS v. 9.3 using the GLIMMIX procedure for the simple binomial model (Schabenberger 2005), 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 GLOM model. The NLMIXED implementation of the GLOM model used numerically integrated marginal likelihoods and assumed that the random effect due to paired hauls was normally distributed.

Results

Fish collection and processing

Comparison sampling between the R/V *Tidewater* and the R/V *Fish Hawk* began in April 2014 and concluded in May 2015 (Table 7; Figure 5). We completed 90% of planned paired tows (N=1,101 paired tows) during 97 days-at-sea. To supplement paired tows for select species (e.g., Scup, Black Sea Bass, adult Summer Flounder), sampling was also conducted during two days in August 2016 (N = 40 additional paired tows, for a survey total of 1,141 paired tows) resulting in a total of 327,526 fishes, crabs, and shrimp captured by the R/V *Fish Hawk* and 323,580 fishes, crabs, and shrimp captured by the R/V *Tidewater* (Table 6). Total catches of the two vessels differed by 3,946 individuals out of a total of 651,106 organisms captured, or a 0.6% difference. Rare or uncommon species were observed among the catch from each vessel with the R/V *Fish Hawk* capturing 18 species that were not captured by the R/V *Tidewater,* and the R/V *Tidewater* capturing 14 species not captured by the R/V *Fish Hawk* (Table 6).

Species composition and multivariate analysis

Species assemblages sampled by the two vessels were similar across strata (i.e., samples clustered together in the NMDS plot; Figure 6). For this analysis, we used the data from the planned tows (N=1,101) because the full catch from the targeted sampling in August 2016 was not sorted, counted, or measured. Paired tows from the same river strata were closely spaced in the plot indicating a similar number of species and individuals were captured between the pairs. We observed the same result for paired tows from the Bay strata, however, one stratum, shallow Bay stations sampled by the R/V *Tidewater*, did not group with the other Bay strata or with the shallow Bay strata sampled by the R/V *Fish Hawk*.

Temporal patterns in species composition exhibited regional variation (Figure 7). We observed differences in regional species composition such that locations sampled in the Bay clustered closely together, but apart from those sampled in the tributaries. Paired tows collected in the same region and month were spaced closely together indicating that both vessels sampled a similar species assemblage (Figure 6).

Calibration factor estimation

We estimated calibration factors for 41 species groups (considering YOY and Age-1+ as separate groups) and compared the results of four competing models (Tables 8 and 9). The beta-binomial model was best supported by the data for the majority of the species examined (Table 8). Data from 11 species supported the simple binomial model and one species (Scup) was best modeled using the beta-binomial random GLOMM. The number of paired tows for those species that were supported by a model other than the beta-binomial model was low, and typically less than 30 paired tows (Striped Bass age 1+ and White Catfish age 1+ had 35 and 32 paired tows, respectively). All other species groups were captured in more than 49 paired tows (Table 9). Often, the four competing models for an individual species had the same or similar AICc values and in these instances, we considered the 'best' model to be the simpler model with fewer assumptions needed to estimate the calibration factor.

The use of surrogate species to estimate calibration factors for species that were present in less than 30 paired tows was not supported by our data. We compared calibration factors for five similar species pairs (Alewife YOY/Blueback Herring YOY, Bay Anchovy/Striped Anchovy, Summer Flounder YOY/Smallmouth Flounder, White Catfish age-1+/Blue Catfish age-1+, and Striped Bass YOY/White Perch YOY); in all cases, each species in the pair was captured in more than 30 paired tows. We expected the calibration factors of species pairs to be similar as judged by the overlapping 95% confidence intervals. However, we found that, despite similar morphologies and expected capture probabilities, the estimated calibration factors were drastically different in most cases (Figure 8). Only the calibration factors for Bay Anchovy and Striped Anchovy were similar, suggesting that the use of calibration factors from surrogate species is best avoided, or if necessary, should acknowledge the high uncertainty associated with this approach.

Calibration factors estimated from the best model ranged from a low of 0.63356 (SE = 0.04896) for YOY Black Sea Bass to a high of 2.77472 (SE = 0.02795) for Smallmouth Flounder (Table 9). These calibration factors will be used as a multiplier to convert catches from the R/V *Tidewater* to equivalent catches of the R/V *Fish Hawk*.

Discussion

The spatial and temporal scales of this comparison study encompassed the entire seasonal and spatial domain of the VIMS trawl survey. To our knowledge, this is the most comprehensive study ever conducted that developed species-specific calibration factors to quantify the effects of changes to the survey platform (i.e., vessel and gear). The results of this study will allow us to maintain continuity between the historic dataset and future collections. The multispecies nature of the trawl survey necessitated the year-long effort, and the natural variability in recruitment of fishes required the flexibility to conduct extra targeted sampling to meet modeling needs. Despite our best efforts, several key species (e.g., American Eel age 1+, Black Sea Bass age 1+, Scup YOY) did not meet our targeted 30 paired tows required to estimate a calibration factor as suggested by the NEFSC Vessel Calibration Working Group (2007). For the species with fewer than 30 paired tows, in all but one case, the simplest model was the best model supported by the data (Appendix 1), whereas for species with greater than 30 paired tows, the data supported the beta-binomial model. The beta-binomial model allowed the inclusion of the random effect of salinity to explain variation between paired tows that may affect the aggregation of species in space and time (Appendix 2). The use of more complex models to account for between-paired tow variation was not supported by the data as AICc values between simpler and more complex models were often similar. Therefore, we chose to use parsimony as our guide to select the best model.

Unfortunately, the use of surrogate-species calibration factors to estimate calibration factors for similar species captured in too few paired tows is unsupported. The five species pairs we examined to test the hypothesis that similar species have similar catch rates suggest that despite taxonomic, morphological, or presumed behavioral similarities, calibration factors can vary widely. Differences observed in the estimated calibration factors for each pair imply that factors that were unaccounted in our models, affected capture rates. A possible explanation for observed differences in calibration factors between similar species could be related to subtle differences in behavioral characteristics during trawl gear encounters. With little support to use the surrogate species approach, we suggest assuming a one-to-one capture probability for those species captured in fewer than 25 paired tows (that is, no calibration factor is applied to the catches of the R/V *Tidewater*).

Biodiversity metrics at the stratum and month level were similar for the paired tows. Each vessel captured unique species that were not encountered by the other vessel, which is likely a result of random variability rather than a characteristic of the collection process related to the net or vessel. The only notable difference in species assemblages between the R/V *Fish hawk* and the R/V *Tidewater* occurred in the shallow Bay stations. A possible reason for the observed differences is that the draft of the R/V *Tidewater* is 1.52 m and likely affected the catch in these shallow depths compared with the shallower 0.9 m draft of the R/V *Fish Hawk*. Biodiversity investigations using calibrated collections from the R/V *Tidewater* should be comparable with historic data collected by the R/V *Fish Hawk* with the exception of the shallow Bay stations.

Data from the VIMS trawl survey are used in stock assessments, management council compliance reports, graduate student research projects, published manuscripts, and by numerous external agencies and individuals. Due to the wide distribution of the data and to maintain consistency with previous work, we elected to develop calibration factors that convert R/V *Tidewater* collections into R/V *Fish Hawk* 'units'. We will use the calibration factor at the individual-tow level and continue to estimate relative abundance indices using the random-stratified survey design in effect since 1988. Our 'whole survey' approach allowed us to estimate calibration factors for species in all available habitats that are routinely monitored by the VIMS trawl survey. Further, inclusion of depth, tidal currents, tow direction, water clarity, tow distance, and salinity in our calibration models provided calibration factors that are applicable across the range of estuarine conditions and characteristics inhabited by these species. With properly calibrated catches, we can preserve the integrity of the long-term survey data for estimating relative abundance of juvenile fishes and blue crabs in Chesapeake Bay.

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Table 1. Number of paired tows (N) with positive catches for the primary species of interest captured as young-of-the-year (YOY) or age-1+ fish by the VIMS Juvenile Fish Trawl Survey; number of tows are also shown for blue crabs and horseshoe crabs. The primary sampling period refers to the months during which recruitment is assessed for YOY fishes.

Species	Life stage	Primary sampling period	N
American Eel	Age 1+		27
Atlantic Croaker	YOY	May-Aug (Apr-Jul)	284
	Age 1+		200
Bay Anchovy	YOY	Jul-Dec	504
	Age 1+		263
Black Sea Bass	YOY	May-Jul	26
	Age 1+		6
Blue Catfish	YOY	Dec-Mar(Oct-Dec)	78
	Age 1+		126
Scup	YOY	Jun-Sep	28
Silver Perch	YOY	Sep-Nov	119
	Age 1+		17
Spot	YOY	Jul-Oct	187
	Age 1+		106
Striped Bass	YOY	Dec-Feb	93
	Age 1+		35
Summer Flounder	YOY	Sep-Nov	146
	Age 1+		25
Weakfish	YOY	Aug-Oct	221
	Age 1+		88
White Catfish	YOY	Jan-Apr	10
	Age 1+		33
White Perch	YOY	Dec-Feb	164
	Age 1+		212
Blue crab	-		468
Horseshoe crab	-		7

Table 2. Number of paired tows (N) with positive catches for the secondary species of interest captured by the VIMS Juvenile Fish Trawl Survey. Species for which we observed less than 25 paired tows with positive catches were omitted from this table.

Species	**N**
Alewife	86
Atlantic Menhaden	90
Blackcheek Tonguefish	131
Blueback Herring	89
Gizzard Shad	50
Harvestfish	27
Hogchoker	447
Inshore Lizardfish	26
Kingfish spp.	123
Naked goby	26
Northern Pipefish	28
Northern Searobin	103
Oyster Toadfish	68
Smallmouth Flounder	73
Spotted Hake	210
Striped Anchovy	52
White shrimp	52

Table 3. Other species encountered by the VIMS Juvenile Fish Trawl Survey. These species were observed in fewer than 25 paired tows; the species in the 'similar to' column are suggested surrogates whose catch data may be used for estimation of the calibration factor for species in the corresponding guild.

Guild	Composition	Similar to
Pelagics	Butterfish, Hickory Shad, Threadfin Shad, Spotted Seatrout, Atlantic Spadefish, Longnose Gar, Silver Seatrout	Gizzard Shad, Harvestfish
Flatfishes	Windowpane, Winter Flounder, Fringed Flounder	Smallmouth Flounder, Summer Flounder
Small schooling fishes	Atlantic Silverside, Rough Silverside, Atlantic Herring, Spottail Shiner, Atlantic Thread Herring	Atlantic Menhaden, Striped Anchovy
Skates & rays	Clearnose Skate, Bluntnose Stingray, Bullnose Ray	
Gobies	Seaboard Goby, Feather Blenny, Skilletfish,	Naked Goby, Inshore Lizardfish, Oyster Toadfish
Searobins	Striped Searobin	Northern Searobin
Drums	Red Drum, Black Drum, Banded Drum	
Hakes	Silver Hake, Red Hake	Spotted Hake
Catfishes	Channel Catfish, White Catfish	Blue Catfish
Others	Northern Puffer, Lined Seahorse	Northern Pipefish

Table 4. Tow depths (m) for the R/V *Fish Hawk* and R/V *Tidewater* by depth strata. N is the number of paired tows; std dev is the standard deviation, min is the minimum depth, and max is the maximum depth. Difference is the difference between the mean *Fish Hawk* depth and mean *Tidewater* depth.

Depth (m)	Vessel	N	Mean	Std dev	Min	Max	Difference
1.2 - 3.5	Fish Hawk	162	2.63	0.544	1.5	3.4	0.60
	Tidewater	162	3.23	0.540	1.8	4.3	
3.6 - 9.0	Fish Hawk	474	6.46	1.398	3.7	8.8	0.40
	Tidewater	474	6.86	1.420	2.7	10.4	
9.1 - 12.7	Fish Hawk	302	10.72	1.017	9.1	12.5	0.31
	Tidewater	302	11.03	1.072	7.6	14.0	
> 12.8	Fish Hawk	203	16.08	2.557	12.8	32.3	0.32
	Tidewater	203	16.40	2.374	12.8	27.7	

Table 5. Number of paired tows with inconsistent stratum sampling (N=105) by the R/V *Fish Hawk* (FH) and R/V *Tidewater* (TW); the diagonal elements (shaded) represent consistent sampling of strata and these numbers are not provided here. Note that sampling in the deepest stratum was consistent among vessels (i.e., all paired tows in this stratum were completed at depths > 12.8 m). The bias for the TW is to sample deeper sites than the FH, and this is largely driven by results from the shallowest stratum (1.2 to 3.6 m). These 105 paired tows represent 9.2% of the total tows (1,141) analyzed in this study.

Stratum Sampled by FH	Stratum Sampled by TW				Total
	1.2 – 3.6 m	**3.6 – 9.1 m**	**9.1 – 12.8 m**	**> 12.8 m**	
1.2 – 3.6 m		51	0	0	51
3.6 – 9.1 m	2		29	0	31
9.1 – 12.8 m	1	3		19	23
> 12.8 m	0	0	0		0

Table 6. The total number of fish, crabs, and shrimp of all sizes captured by the R/V *Fish Hawk* and the R/V *Tidewater* during 1,141 side-by-side tows.

Species	Fish Hawk	Tidewater	Species (continued)	Fish Hawk	Tidewater	Species (continued)	Fish Hawk	Tidewater
Alewife	1,141	582	Cownose ray		3	Sheepshead	8	8
American eel	169	87	Eastern silvery minnow		2	Silver hake	5	12
American shad	291	312	Feather blenny	64	33	Silver jenny		1
Atlantic bumper	1		Fourspot flounder	1		Silver perch	1,967	2,401
Atlantic croaker	29,356	19,681	Fringed flounder	17	22	Skilletfish	33	26
Atlantic cutlassfish	18	1	Gizzard shad	532	310	Smallmouth flounder	1,534	346
Atlantic herring	1	1	Golden shiner		5	Smooth butterfly ray	2	3
Atlantic mackerel	3	3	Gray snapper		4	Smooth dogfish	1	2
Atlantic menhaden	2,921	763	Green goby	3	1	Southern stingray	1	2
Atlantic moonfish	51	16	Harvestfish	163	147	Spiny butterfly ray	5	3
Atlantic needlefish		1	Hickory shad	216	31	Spiny dogfish		4
Atlantic silverside	168	310	Hogchoker	75,202	61,500	Spot	8,305	8,149
Atlantic spadefish	16	16	Horseshoe crab	32	35	Spotfin butterflyfish	3	1
Atlantic stingray	19	1	Inshore lizardfish	131	50	Spotfin mojarra	2	
Atlantic sturgeon		3	King mackerel	4		Spottail shiner	83	40
Atlantic thread herring	23	39	Kingfish spp	5,664	1,027	Spotted goatfish	1	
Banded drum	27	33	Lined seahorse	77	35	Spotted hake	9,811	13,063
Banded killifish	1		Longnose gar	14	6	Spotted seatrout	41	17
Bay anchovy	109,825	149,360	Lookdown	7	2	Star drum		1
Black drum	31	42	Naked goby	300	109	Striped anchovy	1,562	1,102
Black sea bass	184	188	Northern pipefish	210	144	Striped bass	3,447	2,288
Blackcheek tonguefish	2,572	1,057	Northern puffer	206	91	Striped blenny	2	
Blue catfish	6,534	5,561	Northern searobin	3,631	2,067	Striped burrfish	10	3
Blue crab, adult female	678	685	Northern sennet	1		Striped cusk-eel	1	3
Blue crab, juvenile female	4,292	2,562	Northern stargazer	3	3	Striped killifish	1	
Blue crab, male	5,081	3,029	Oyster toadfish	428	421	Striped mullet		1
Blue runner	5		Pigfish	20	12	Striped searobin	144	67
Blueback herring	2,150	2,604	Pink shrimp	4	6	Summer flounder	637	591
Bluefish	18	15	Planehead filefish	1		Tautog	2	4
Bluespotted cornetfish	2		Pumpkinseed	1		Tessellated darter	41	57
Bluespotted sunfish	1		Rainwater killifish	2		Threadfin shad	97	52
Bluntnose stingray	7	12	Red drum	15	3	Weakfish	8,555	6,850
Brown bullhead	4	16	Red hake	34	9	White catfish	251	522
Brown shrimp	14	8	Rough scad	1	1	White perch	37,413	34,073
Bullnose ray	7	7	Rough silverside		1	White shrimp	343	452
Butterfish	185	123	Roughtail stingray	1		Windowpane	138	83
Chain pipefish	1		Sandbar shark		1	Winter skate	2	1
Channel catfish	7	6	Scup	67	46	Yellow perch	3	2
Clearnose skate	78	49	Sea lamprey	50	17			
Cobia		1	Seaboard goby	81	30			
Common carp	8	2	Sharptail goby	2		**Total**	**327,526**	**323,580**

Table 7. Number of paired tows conducted by month by the R/V Fish Hawk and R/V Tidewater, April 2014 – May 2015, and August 2016.

Month	**Number of Paired Tows**
January	64
February	59
March	53
April	126
May	218
June	81
July	86
August	106
September	24
October	109
November	110
December	105
Total	**1,141**

Table 8. Model AICc values used to determine the best-fit model for estimating the calibration factor for each speices and age or size category. The shaded box indicates the model chosen in case of ties or closely competing models based on the most parsimonious model. NA indicates the model did not converge.

Species	Age	Binomial	Beta-binomial	Random-clumped Binomial	Beta-binomial GLOMM
Alewife	YOY	432.5	374.6	378.1	374.6
American eel	1+	77.0	81.1	81.1	NA
Atlantic croaker	YOY	5226.7	1802.7	2777.7	1802.0
	1+	3303.7	1342.5	1878.6	1341.7
Atlantic menhaden	all	881.6	379.5	472.2	369.2
Bay anchovy	YOY	70359.9	4251.3	NA	NA
	1+	13589.8	2060.7	4499.3	2079.0
Blackcheek tonguefish	1+	1032.3	638.5	738.2	638.5
Black sea bass	YOY	82.5	87.8	87.8	NA
	1+	81.5	NA	NA	NA
Blueback herring	YOY	1310.2	472.2	558.5	477.1
Blue catfish	YOY	805.9	499.5	533.6	499.5
	1+	787.0	637.1	655.4	637.2
Blue crab	> 25mm	3225.5	2384.2	2580.0	2384.1
Gizzard shad	all	211.3	198.3	197.3	198.4
Harvestfish	all	99.8	102.8	102.2	NA
Hogchoker	all	17244.1	3659.9	NA	NA
Inshore lizardfish	all	72.9	77.0	77.0	NA
Kingfishes	all	1357.5	691.7	816.3	691.7
Naked goby	all	89.5	95.8	95.6	95.8
Northern pipefish	all	77.1	82.7	82.7	82.7
Northern searobin	all	1484.0	607.4	878.1	607.8
Oyster toadfish	all	330.5	256.6	270.1	256.7
Smallmouth flounder	all	340.9	316.9	315.7	316.9
Scup	YOY	299.9	304.4	304.4	173.8
Silver perch	YOY	763.3	613.3	640.6	NA
	1+	83.6	90.4	90.6	NA
Spot	YOY	1842.4	1105.0	1313.6	1104.8
	1+	1628.2	657.7	792.6	660.9
Spotted hake	all	3250.1	1395.1	1961.9	1429.9
Striped anchovy	all	456.5	291.9	333.6	291.2
Striped bass	YOY	779.8	440.6	483.3	440.0
	1+	112.1	115.1	114.9	115.1
Summer flounder	YOY	457.7	456.5	455.3	456.5
	1+	67.7	73.3	73.3	NA
Weakfish	YOY	2684.4	1260.6	1741.5	NA
	1+	567.6	404.2	423.7	404.2
White catfish	1+	115.6	116.0	115.6	116.0
White perch	YOY	5118.4	1176.6	1518.7	NA
	1+	7042.8	1458.8	2262.8	1458.8
White shrimp	all	213.2	207.7	206.5	207.7

Table 9. Calibration factor and standard error calculated from the best-fit model identified using AICc for each species and age or size category. YOY = young-of-the-year, mean π is the probability of being captured in one net versus the other, N is the number of paired tows, ρ is the overdispersion parameter (not estimated for the binomial model). The standard error of the calibration factor was estimated using the Delta method.

				95% CI			Overdispers	Calibration	Cal. Fact.
Species	Age	Mean π	SE	Lower	Upper	N	ρ	Factor	SE
Alewife	YOY	0.62233	0.00351	0.61535	0.62931	85	0.289	1.64781	0.00734
American eel	1+	0.46613	0.02675	0.41114	0.52112	27	.	0.87312	0.06779
Atlantic croaker	YOY	0.59629	0.00205	0.59225	0.60032	283	0.421	1.47703	0.00730
	1+	0.55306	0.00545	0.54231	0.56380	200	0.331	1.23744	0.02974
Atlantic menhaden	1+	0.62109	0.00569	0.60977	0.63240	89	0.414	1.63915	0.02007
Bay anchovy	YOY	0.44487	0.00246	0.44004	0.44971	504	0.544	0.80138	0.00990
	1+	0.46135	0.00276	0.45592	0.46679	262	0.494	0.85649	0.00688
Blackcheek tonguefish	1+	0.61507	0.00427	0.60661	0.62352	131	0.377	1.59787	0.01612
Black sea bass	YOY	0.38784	0.02709	0.33193	0.44376	25	.	0.63356	0.04896
	1+	0.67147	0.06716	0.49883	0.84410	6	.	2.04386	0.25074
Blueback herring	YOY	0.51777	0.00567	0.50649	0.52904	87	0.445	1.07370	0.01203
Blue catfish	YOY	0.50057	0.00619	0.48825	0.51289	78	0.328	1.00228	0.01198
	1+	0.58829	0.00492	0.57856	0.59803	123	0.268	1.42889	0.01757
Blue crab	> 25 mm	0.59396	0.00328	0.58751	0.60041	466	0.342	1.46281	0.03041
Gizzard shad	all	0.60239	0.01134	0.57959	0.62519	49	0.200	1.51503	0.03986
Harvestfish	all	0.48858	0.01526	0.45721	0.51995	27	.	0.95534	0.02404
Hogchoker	all	0.56873	0.00329	0.56226	0.57190	444	0.391	1.31873	0.02584
Inshore lizardfish	all	0.60945	0.02076	0.56669	0.65222	26	.	1.56049	0.07346
Kingfishes	all	0.72618	0.00323	0.71979	0.73258	123	0.439	2.65203	0.01712
Naked goby	all	0.61570	0.02894	0.55609	0.67530	26	.	1.60213	0.14744
Northern pipefish	all	0.51257	0.01761	0.47644	0.54870	28	.	1.05158	0.03655
Northern searobin	all	0.61126	0.01033	0.59078	0.63175	102	0.471	1.57241	0.07202
Oyster toadfish	all	0.47020	0.01159	0.44706	0.49333	68	0.378	0.88750	0.03254
Smallmouth flounder	all	0.73508	0.00522	0.72467	0.74549	72	0.275	2.77472	0.02795
Scup	YOY	0.57394	0.00790	0.55769	0.59018	27	0.179	1.34709	0.00928
Silver perch	YOY	0.42934	0.00388	0.42164	0.43703	118	0.296	0.75236	0.00545
	1+	0.55326	0.03882	0.47096	0.63555	17	.	1.23844	0.12837
Spot	YOY	0.53819	0.00306	0.53215	0.54424	187	0.356	1.16539	0.00821
	1+	0.46131	0.00816	0.44514	0.47749	106	0.424	0.85636	0.02432
Spotted hake	all	0.48979	0.00615	0.47766	0.50192	210	0.383	0.95998	0.03051
Striped anchovy	all	0.45969	0.01824	0.42307	0.49631	52	0.473	0.87094	0.05926
Striped bass	YOY	0.54564	0.00692	0.53189	0.55938	90	0.368	1.20090	0.02088
	1+	0.46806	0.10270	0.44718	0.48893	35	.	0.87991	1.30462
Summer flounder	YOY	0.50758	0.00520	0.49729	0.51786	146	0.205	1.03079	0.01628
	1+	0.47646	0.01549	0.44448	0.50844	25	.	0.91007	0.02188
Weakfish	YOY	0.54388	0.00240	0.53916	0.54861	220	0.32	1.19241	0.00609
	1+	0.47870	0.00630	0.46617	0.49122	88	0.366	0.91828	0.01285
White catfish	1+	0.40890	0.01793	0.37234	0.44546	32	.	0.69176	0.02944
White perch	YOY	0.51641	0.00656	0.50345	0.52936	161	0.368	1.06787	0.02963
	1+	0.53866	0.00389	0.53098	0.54633	210	0.393	1.16760	0.01493
White shrimp	all	0.46751	0.01081	0.44580	0.48921	52	0.217	0.87797	0.02143

Figure 1. The new trawl with a 5.8-m head line, 40 mm stretch-mesh body, and a 6.4-mm liner used aboard the R/V *Tidewater* (Left), and the 9.1-m head line, 4-seam, semi-balloon otter trawl with 38.1 mm stretch-mesh body and a 6.4-mm mesh cod liner used to collect fishes from the R/V *Fish Hawk* (Right).

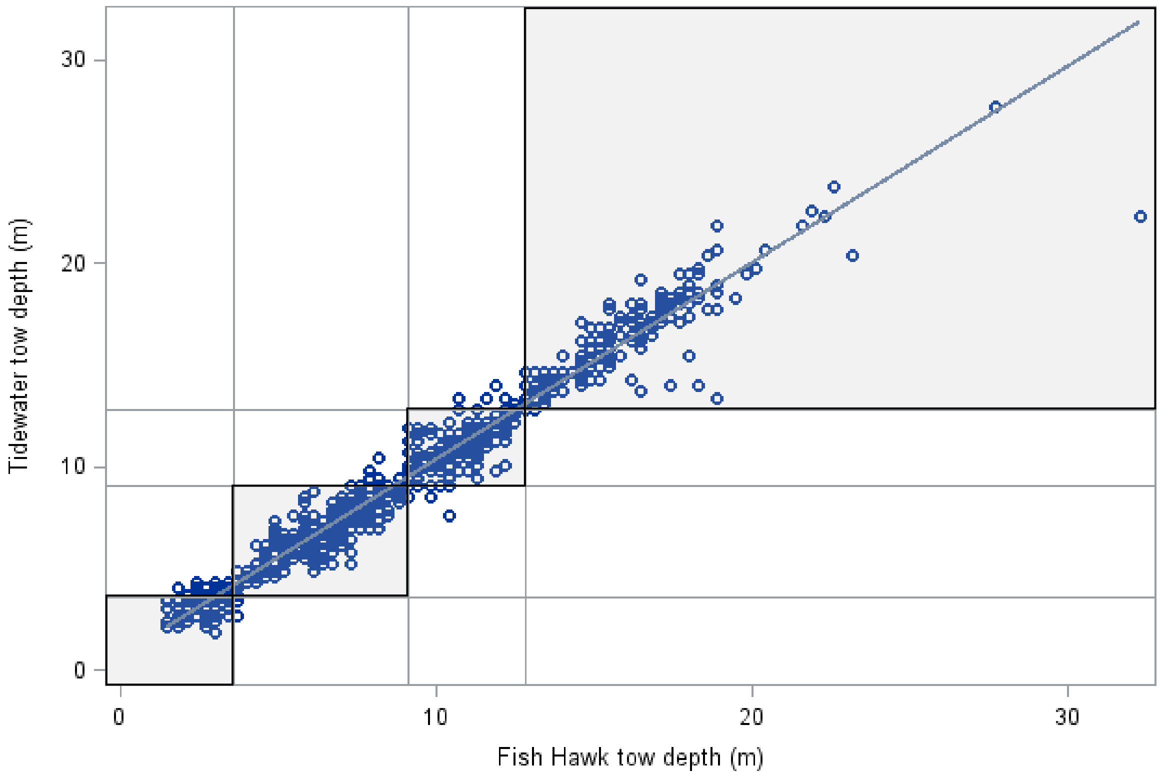

Figure 2. Tow depth (m) of the 1,141 paired tows completed by the R/V *Fish Hawk* and R/V *Tidewater*. Reference lines are at the stratum limits of 3.6, 9.1, and 12.8 m. Observations outside the shaded areas indicate that one of the paired tows was completed at a depth corresponding to a different stratum; this occurred for 105 (9.0%) of the paired tows, with about half of those resulting from the inability of the R/V *Tidewater* to sample shallow areas (stratum depths of 1.2 – 3.6 m).

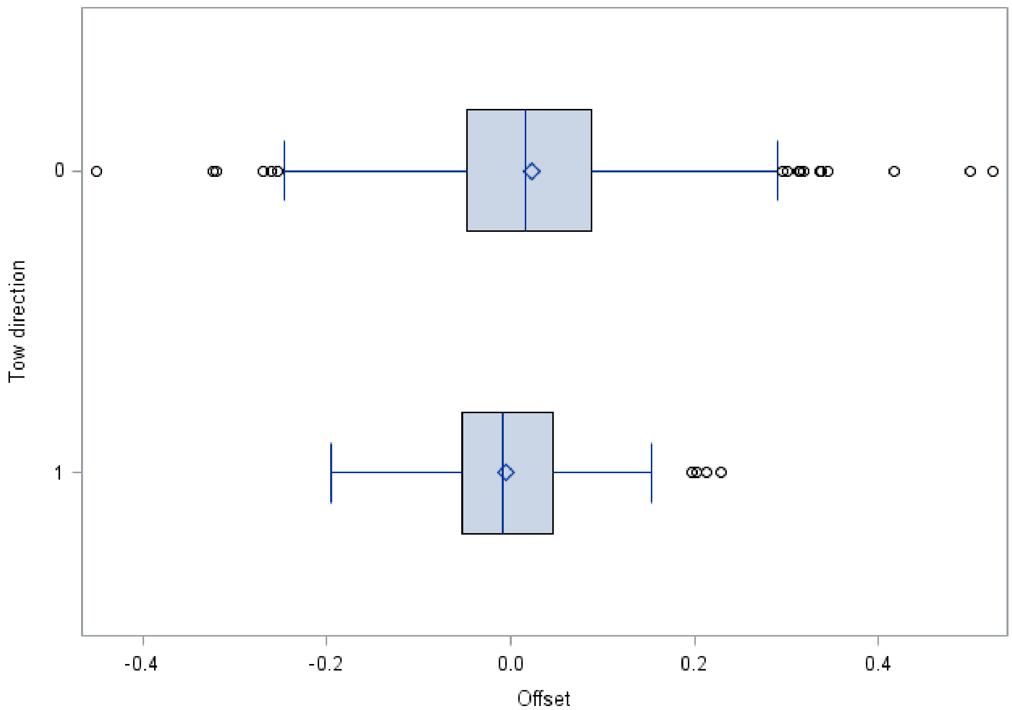

Figure 3. Distribution of the offset describing relative sampling effort of the R/V *Fish Hawk* and R/V *Tidewater* for 829 paired tows that contained young-of-the-year fish conducted against the tidal current (0) and with the tidal current (1). The offset was calculated as the log of the ratio of the distance swept by the R/V *Fish Hawk* to the distance swept by the R/V *Tidewater*. Greater variation in relative sampling effort was observed when paired tows were completed against the current; however, we note that many more paired tows were completed against the current (n=696) than with the current (n=133).

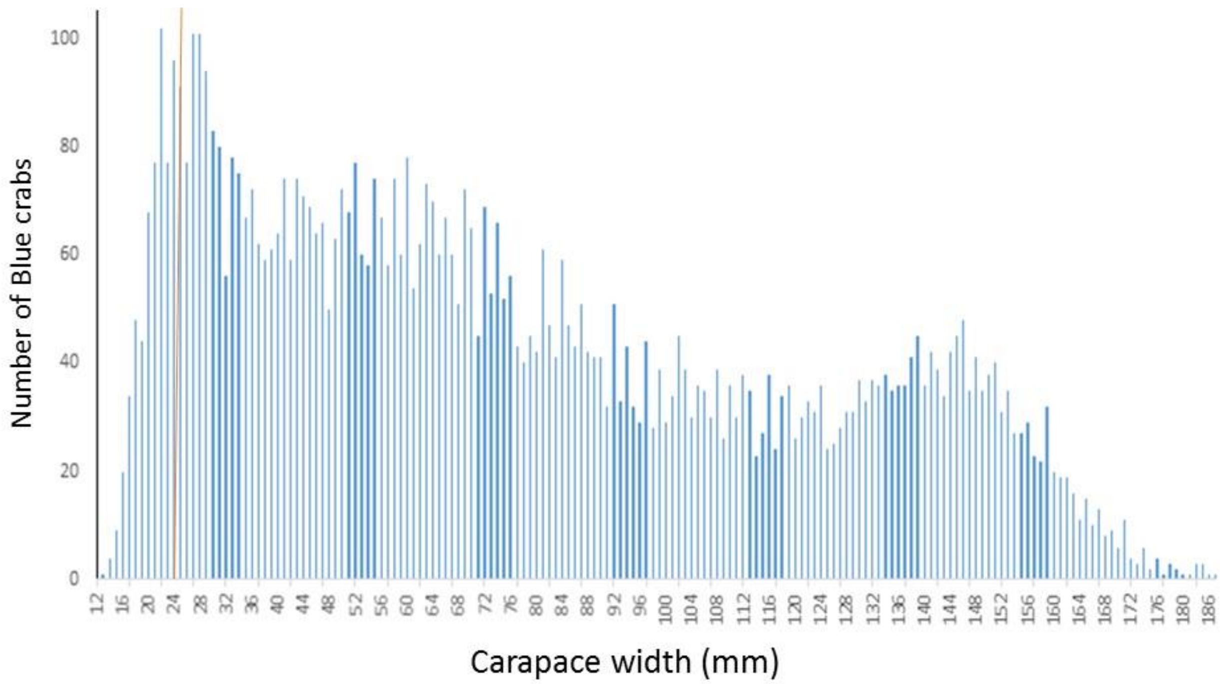

Figure 4. Size-frequency distribution for blue crabs captured by the R/V *Tidewater*, May 2015 to June 2016, in estuarine waters of Virginia. The orange dotted line indicates the 25-mm size threshold used for the calibration study.

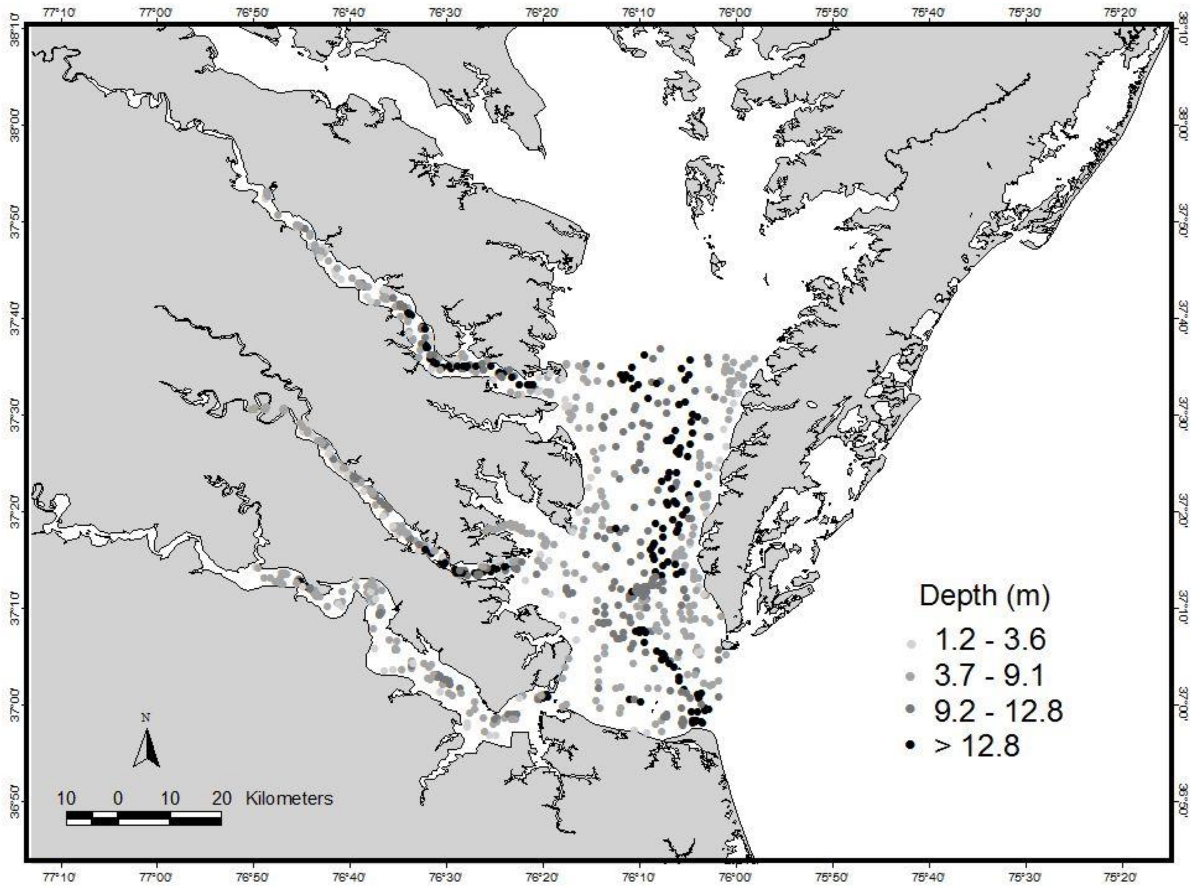

Figure 5. Map of 1,141 sites sampled during side-by-side comparison tows between the R/V *Fish Hawk* and the R/V *Tidewater* from April 2014 to May 2015 (including additional tows in Mobjack Bay) and August 2016. Depth strata are indicated by color.

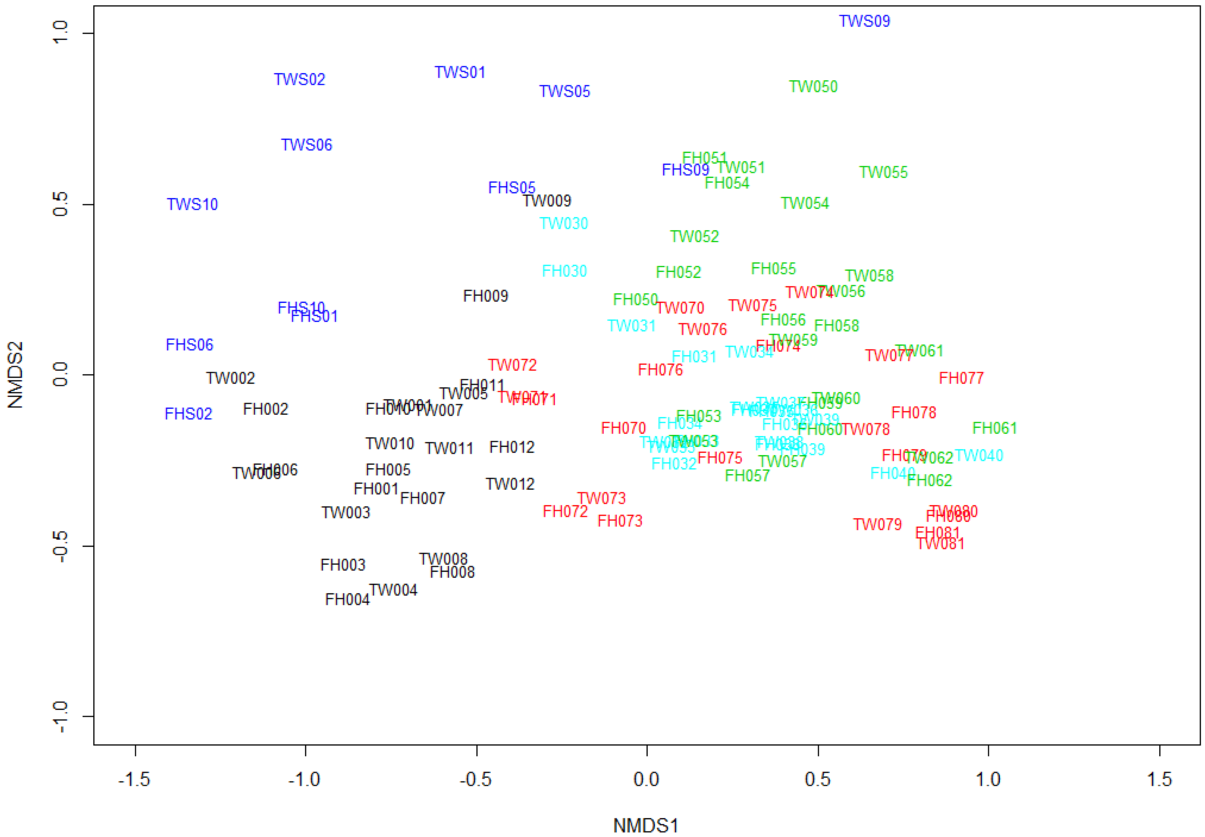

Figure 6. A comparison of species composition among strata sampled by the R/V *Fish Hawk* (FH) and the R/V *Tidewater* (TW); the numbers in the label represent individual strata. Bay strata are shown in black, shallow Bay strata in dark blue, James River strata in red, Rappahannock River strata in green, and York River strata in light blue. Stress = 0.13.

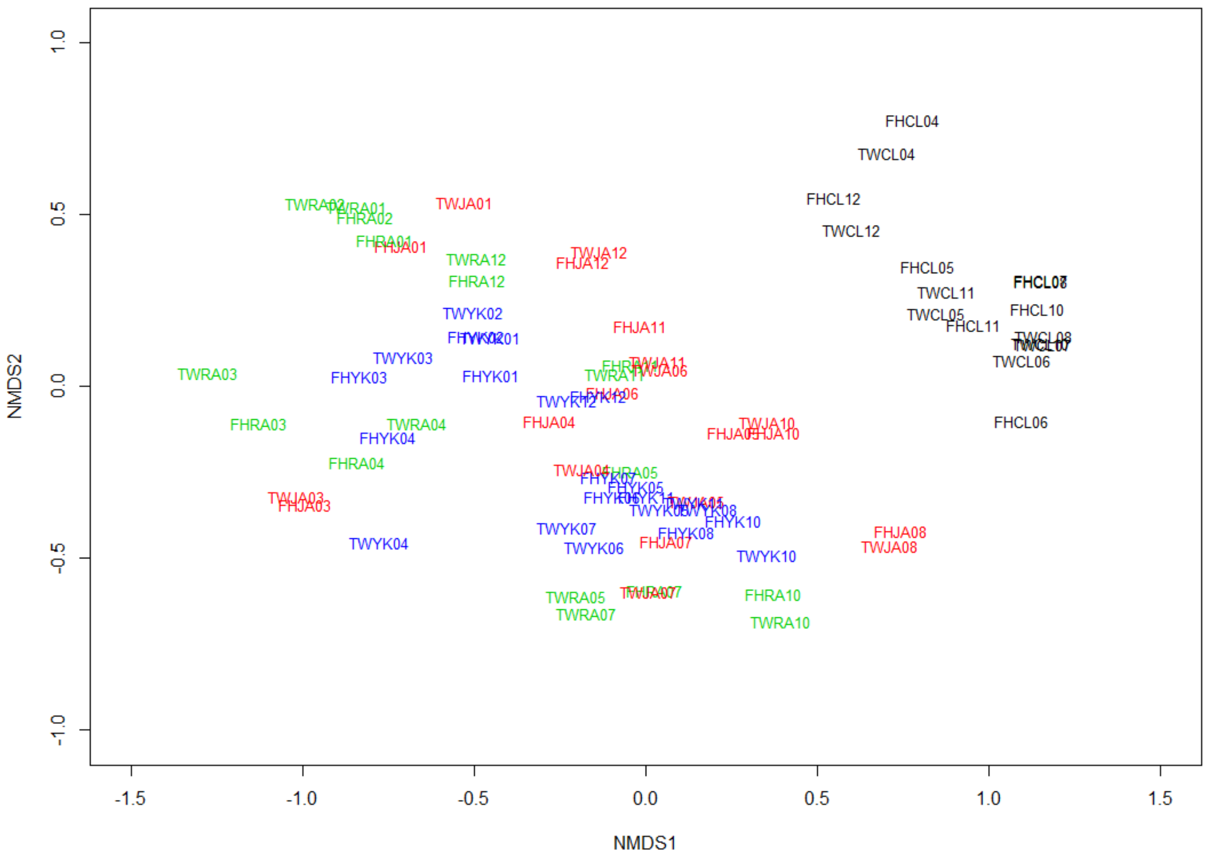

Figure 7. A comparison of species composition among months sampled by the R/V *Fish Hawk* (FH) and the R/V *Tidewater* (TW). Bay strata (CL) are shown in black, York River strata (YK) in dark blue, James River strata (JA) in red, and Rappahannock River strata (RA) in green. Month is designated by two digits (e.g., January = 01). Stress = 0.10.

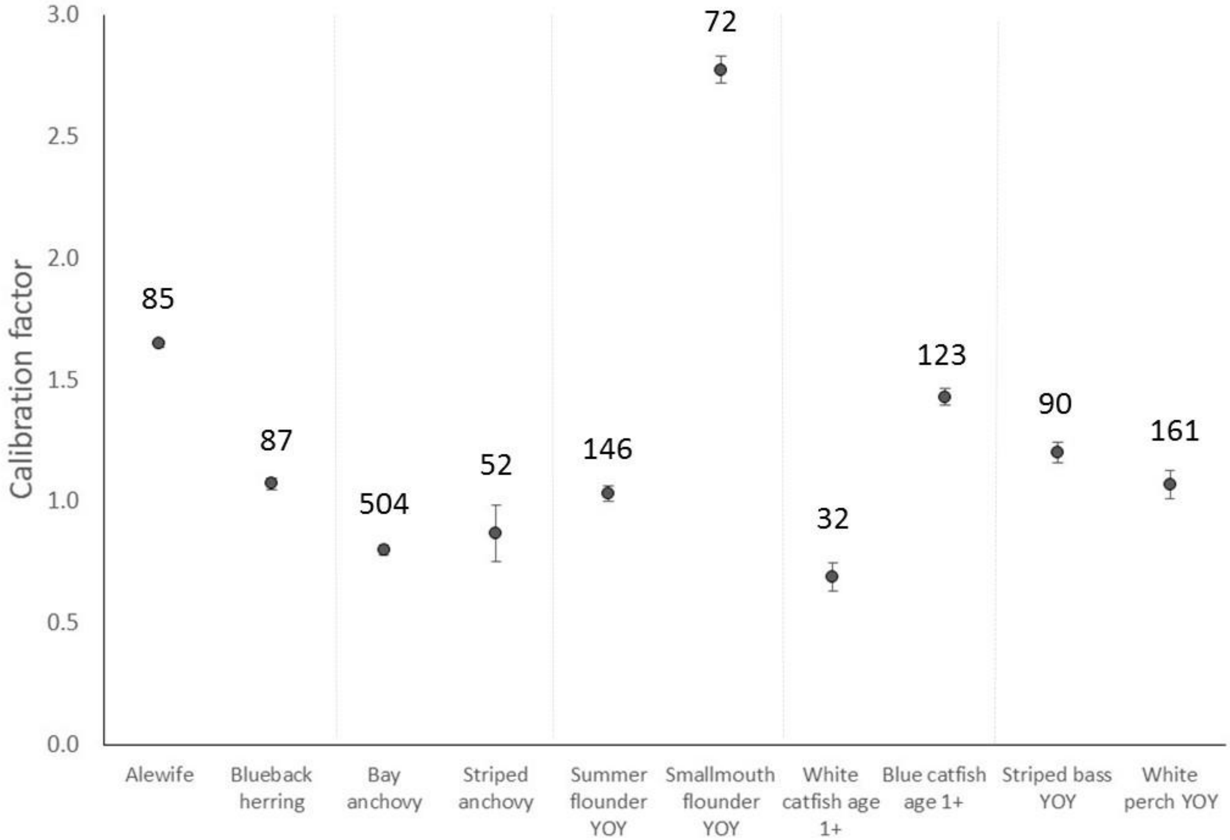

Figure 8. A comparison of species with similar morphologies and, therefore, expected similar probabilities of capture, were used to test the use of surrogate species in the estimation of a calibration factor for species captured in too few paired tows (< 25). Shown are the species pairs, separated by light gray lines, with their corresponding calibration factors, 95% confidence intervals, and the number of paired tows. All species were captured in > 30 paired tows, yet the estimated calibration factors differed within pairs, except for the Bay Anchovy and Striped Anchovy.

Appendix 1. Parameter estimates and corresponding statistics from the binomial model.

Species	Parameter	Estimate	SE	DF	F	P
American eel age-1+	**Towdir**	-0.4189	1.1158	21	0.14	0.7111
	Current	0.0768	0.5337	21	0.02	0.8870
	Secchi	0.2475	0.8500	21	0.08	0.7738
	Depth	-0.1326	0.0723	21	3.36	0.0810
	Offset	-0.6119	2.7567	21	0.05	0.8265
Black sea bass YOY	**Towdir**	-1.2005	1.2971	19	0.86	0.3663
	Current	-0.6052	0.4398	19	1.89	0.1848
	Secchi	0.2401	0.2404	19	1.00	0.3304
	Depth	0.1353	0.0570	19	5.63	0.0283
	Offset	-1.4039	2.0868	19	0.45	0.5092
Black sea bass age-1+	**Towdir**	.	.	.	.	.
	Current	0.9269	2.1619	1	0.18	0.7422
	Secchi	-1.6381	2.5486	1	0.41	0.6363
	Depth	0.0209	0.1973	1	0.01	0.9327
	Offset	-10.7728	11.8375	1	0.83	0.5300
Harvestfish	**Towdir**	0.0911	0.3566	21	0.07	0.8008
	Current	-0.1157	0.3075	21	0.14	0.7105
	Secchi	0.4654	0.3938	21	1.40	0.2505
	Depth	0.0257	0.0470	21	0.30	0.5900
	Offset	1.7165	2.1674	21	0.63	0.4372
Inshore lizardfish	**Towdir**	0.3157	0.4808	20	0.43	0.5189
	Current	-0.4197	0.7096	20	0.35	0.5608
	Secchi	0.0137	0.3457	20	0.00	0.9687
	Depth	-0.1475	0.0875	20	2.84	0.1074
	Offset	-1.2114	3.8309	20	0.10	0.7551
Naked goby	**Towdir**	-2.1748	1.0698	20	4.13	0.0555
	Current	-0.1942	0.3316	20	0.34	0.5647
	Secchi	1.1523	0.3859	20	8.92	0.0073
	Depth	0.0161	0.0440	20	0.13	0.7190
	Offset	-2.2774	1.4453	20	2.48	0.1308
Northern pipefish	**Towdir**	0.3388	1.4594	22	0.05	0.8186
	Current	-0.3226	0.5334	22	0.37	0.5515
	Secchi	0.3114	0.2394	22	1.69	0.2068
	Depth	-0.0343	0.0461	22	0.55	0.4644
	Offset	-2.8633	2.7072	22	1.12	0.3017
Silver perch age-1+	**Towdir**	-0.5176	0.7567	11	0.47	0.5081
	Current	0.8451	0.7601	11	1.24	0.2899
	Secchi	-1.5767	0.7568	11	4.34	0.0613
	Depth	0.1053	0.0714	11	2.18	0.1683
	Offset	-3.0869	4.2075	11	0.54	0.4785

Appendix 1. Continued.

Species	Parameter	Estimate	SE	DF	F	P
Striped bass age-1+	**Towdir**	0.2046	0.4561	29	0.20	0.6570
	Current	-0.1341	0.3230	29	0.17	0.6810
	Secchi	-0.5963	0.4877	29	1.50	0.2313
	Depth	0.0350	0.0313	29	1.25	0.2722
	Offset	0.8322	1.8646	29	0.20	0.6587
Summer flounder age-1+	**Towdir**	0.5341	1.0871	19	0.24	0.6288
	Current	0.4264	0.5851	19	0.53	0.4751
	Secchi	-0.4109	0.4534	19	0.82	0.3762
	Depth	0.0038	0.0582	19	0.00	0.9488
	Offset	-2.6104	2.7963	19	0.87	0.3623
White catfish age-1+	**Towdir**	-0.3297	0.4646	26	0.50	0.4843
	Current	-0.4597	0.3228	26	2.03	0.1663
	Secchi	-0.5652	0.9329	26	0.37	0.5499
	Depth	0.1503	0.0628	26	5.73	0.0242
	Offset	1.2829	1.3024	26	0.97	0.3337

Appendix 2. Parameter estimates and corresponding statistics from the beta-binomial model.
*The beta-binomial model for Scup YOY also included a random-tow effect (GLOMM).

Species	Parameter	Estimate	SE	DF	t	P	Lower	Upper
Alewife YOY	**Mean π**	0.4626	0.2138	85	2.16	0.0333	0.0375	0.8877
	Towdir	0.0899	0.2799	85	0.32	0.7490	-0.4666	0.6463
	Current	-0.1994	0.2439	85	-0.82	0.4161	-0.6844	0.2857
	Secchi	-0.0836	0.2304	85	-0.36	0.7175	-0.5417	0.3744
	Depth	0.0177	0.0263	85	0.67	0.5038	-0.0346	0.0699
	Mean ρ	-1.3025	0.5928	85	-2.20	0.0307	-2.4812	-0.1239
	Salinity	0.0287	0.0370	85	0.77	0.4406	-0.0449	0.1022
Atlantic croaker YOY	**Mean π**	0.6135	0.1429	282	4.29	<.0001	0.3323	0.8948
	Towdir	0.0575	0.1814	282	0.32	0.7516	-0.2995	0.4144
	Current	-0.1768	0.1318	282	-1.34	0.1808	-0.4363	0.0826
	Secchi	-0.0061	0.1076	282	-0.06	0.9551	-0.2179	0.2058
	Depth	-0.0194	0.0159	282	-1.23	0.2215	-0.0507	0.0118
	Mean ρ	-0.5314	0.2004	282	-2.65	0.0085	-0.9259	-0.1369
	Salinity	0.0137	0.0121	282	1.13	0.2578	-0.0101	0.0375
Atlantic croaker age 1+	**Mean π**	0.6763	0.1434	200	4.71	<.0001	0.3935	0.9592
	Towdir	-0.2273	0.1522	200	-1.49	0.1369	-0.5274	0.0728
	Current	-0.1705	0.1312	200	-1.30	0.1953	-0.4293	0.0883
	Secchi	-0.4042	0.1181	200	-3.42	0.0008	-0.6371	-0.1713
	Depth	-0.0036	0.0152	200	-0.24	0.8136	-0.0335	0.0264
	Mean ρ	-0.8965	0.2168	200	-4.14	<.0001	-1.3240	-0.4690
	Salinity	0.0134	0.0134	200	1.00	0.3170	-0.0129	0.0397
Atlantic menhaden	**Mean π**	0.5865	0.2607	88	2.25	0.0269	0.0685	1.1045
	Towdir	0.2338	0.3385	88	0.69	0.4915	-0.4389	0.9065
	Current	-0.4697	0.2846	88	-1.65	0.1024	-1.0353	0.0958
	Secchi	0.1446	0.3030	88	0.48	0.6345	-0.4577	0.7468
	Depth	-0.0165	0.0367	88	-0.45	0.6540	-0.0894	0.0564
	Mean ρ	-0.8250	0.3444	88	-2.40	0.0187	-1.5094	-0.1406
	Salinity	0.0368	0.0206	88	1.79	0.0767	-0.0040	0.0777
Bay anchovy YOY	**Mean π**	-0.1342	0.1249	503	-1.07	0.2832	-0.3797	0.1113
	Towdir	0.1290	0.1276	503	1.01	0.3123	-0.1216	0.3797
	Current	0.1453	0.1122	503	1.29	0.1960	-0.0752	0.3659
	Secchi	-0.2929	0.0720	503	-4.07	<.0001	-0.4343	-0.1516
	Depth	0.0260	0.0138	503	1.88	0.0601	-0.0011	0.0530
	Mean ρ	-0.3996	0.1459	503	-2.74	0.0064	-0.6862	-0.1130
	Salinity	0.0340	0.0079	503	4.32	<.0001	0.0185	0.0495
Bay anchovy age 1+	**Mean π**	-0.4577	0.1537	262	-2.98	0.0032	-0.7605	-0.1550
	Towdir	0.0690	0.1742	262	0.40	0.6925	-0.2740	0.4119
	Current	0.1827	0.1512	262	1.21	0.2281	-0.1150	0.4804
	Secchi	0.0091	0.1084	262	0.08	0.9333	-0.2044	0.2226
	Depth	0.0246	0.0181	262	1.36	0.1759	-0.0111	0.0603
	Mean ρ	-0.5980	0.2002	262	-2.99	0.0031	-0.9922	-0.2039
	Salinity	0.0341	0.0110	262	3.09	0.0022	0.0123	0.0558

Appendix 2. Continued

Species	Parameter	Estimate	SE	DF	t	P	Lower	Upper
Blackcheek tonguefish	**Mean π**	0.8579	0.2437	131	3.52	0.0006	0.3758	1.3399
	Towdir	0.2777	0.3369	131	0.82	0.4112	-0.3887	0.9441
	Current	-0.2314	0.1893	131	-1.22	0.2236	-0.6058	0.1430
	Secchi	-0.1439	0.1369	131	-1.05	0.2951	-0.4146	0.1269
	Depth	-0.0162	0.0205	131	-0.79	0.4293	-0.0567	0.0242
	Mean ρ	-0.8580	0.5378	131	-1.60	0.1131	-1.9219	0.2060
	Salinity	0.0185	0.0259	131	0.71	0.4771	-0.0328	0.0698
Blueback herring YOY	**Mean π**	0.0293	0.2671	87	0.11	0.9131	-0.5017	0.5602
	Towdir	0.3875	0.3065	87	1.26	0.2096	-0.2217	0.9966
	Current	0.2993	0.2796	87	1.07	0.2874	-0.2564	0.8550
	Secchi	0.0890	0.2188	87	0.41	0.6851	-0.3459	0.5240
	Depth	-0.0136	0.0288	87	-0.47	0.6378	-0.0708	0.0436
	Mean ρ	-0.2400	0.3267	87	-0.73	0.4645	-0.8895	0.4094
	Salinity	0.0012	0.0204	87	0.06	0.9524	-0.0394	0.0418
Blue catfish YOY	**Mean π**	-0.4945	0.3043	78	-1.63	0.1082	-1.1003	0.1113
	Towdir	0.1848	0.2811	78	0.66	0.5129	-0.3749	0.7444
	Current	0.1835	0.2088	78	0.88	0.3821	-0.2321	0.5992
	Secchi	0.1409	0.6308	78	0.22	0.8238	-1.1150	1.3968
	Depth	0.0610	0.0347	78	1.76	0.0826	-0.0081	0.1301
	Mean ρ	-0.8187	0.1829	78	-4.48	<.0001	-1.1828	-0.4546
	Salinity	0.0431	0.0622	78	0.69	0.4901	-0.0807	0.1670
Blue catfish age 1+	**Mean π**	-0.0642	0.2122	123	-0.30	0.7628	-0.4842	0.3559
	Towdir	-0.0176	0.2203	123	-0.08	0.9363	-0.4537	0.4184
	Current	0.2914	0.1768	123	1.65	0.1018	-0.0585	0.6413
	Secchi	0.1883	0.3505	123	0.54	0.5920	-0.5054	0.8821
	Depth	0.0434	0.0267	123	1.63	0.1064	-0.0094	0.0961
	Mean ρ	-0.7299	0.2336	123	-3.12	0.0022	-1.1922	-0.2675
	Salinity	-0.0553	0.0486	123	-1.14	0.2576	-0.1516	0.0410
Blue crab > 25mm	**Mean π**	0.7838	0.0964	464	8.13	<.0001	0.5944	0.9731
	Towdir	0.3910	0.1266	464	3.09	0.0021	0.1423	0.6397
	Current	-0.1397	0.0895	464	-1.56	0.1194	-0.3156	0.0363
	Secchi	0.1051	0.0734	464	1.43	0.1530	-0.0392	0.2493
	Depth	-0.0621	0.0107	464	-5.82	<.0001	-0.0831	-0.0411
	Mean ρ	-0.8081	0.1401	464	-5.77	<.0001	-1.0833	-0.5328
	Salinity	0.0108	0.0090	464	1.20	0.2318	-0.0069	0.0285
Gizzard shad	**Mean π**	0.2827	0.2884	49	0.98	0.3317	-0.2968	0.8622
	Towdir	-0.1627	0.2883	49	-0.56	0.5752	-0.7421	0.4167
	Current	0.2249	0.2707	49	0.83	0.4101	-0.3192	0.7690
	Secchi	-0.7200	0.3377	49	-2.13	0.0380	-1.3986	-0.0415
	Depth	0.0817	0.0436	49	1.87	0.0671	-0.0060	0.1693
	Mean ρ	-2.0256	0.8653	49	-2.34	0.0233	-3.7644	-0.2868
	Salinity	0.0638	0.0607	49	1.05	0.2981	-0.0581	0.1858

Appendix 2. Continued

Species	Parameter	Estimate	SE	DF	t	P	Lower	Upper
Hogchoker	**Mean π**	0.7783	0.0932	443	8.35	<.0001	0.5952	0.9615
	Towdir	0.1050	0.1267	443	0.83	0.4078	-0.1440	0.3540
	Current	-0.2264	0.0892	443	-2.54	0.0115	-0.4017	-0.0511
	Secchi	0.1360	0.1050	443	1.29	0.1960	-0.0704	0.3424
	Depth	-0.0686	0.0123	443	-5.59	<.0001	-0.0927	-0.0445
	Mean ρ	-0.6960	0.1006	443	-6.92	<.0001	-0.8936	-0.4984
	Salinity	0.0203	0.0075	443	2.69	0.0075	0.0055	0.0351
Kingfishes	**Mean π**	1.1055	0.2747	123	4.02	<.0001	0.5617	1.6493
	Towdir	-0.4574	0.4177	123	-1.10	0.2756	-1.2842	0.3694
	Current	-0.2123	0.1994	123	-1.06	0.2893	-0.6071	0.1825
	Secchi	0.0052	0.1411	123	0.04	0.9706	-0.2741	0.2846
	Depth	-0.0076	0.0214	123	-0.35	0.7244	-0.0499	0.0348
	Mean ρ	-0.4838	0.5349	123	-0.90	0.3676	-1.5427	0.5751
	Salinity	0.0117	0.0260	123	0.45	0.6542	-0.0398	0.0632
Northern searobin	**Mean π**	1.8819	0.4064	102	4.63	<.0001	1.0757	2.6881
	Towdir	0.3725	0.3417	102	1.09	0.2782	-0.3052	1.0503
	Current	-0.3525	0.2436	102	-1.45	0.1510	-0.8356	0.1307
	Secchi	-0.4996	0.1641	102	-3.04	0.0030	-0.8251	-0.1741
	Depth	-0.0387	0.0228	102	-1.70	0.0918	-0.0839	0.0064
	Mean ρ	-0.9830	0.8210	102	-1.20	0.2339	-2.6115	0.6454
	Salinity	0.0373	0.0352	102	1.06	0.2926	-0.0326	0.1071
Oyster toadfish	**Mean π**	0.9878	0.4286	68	2.30	0.0243	0.1325	1.8432
	Towdir	-0.1216	0.5942	68	-0.20	0.8384	-1.3073	1.0641
	Current	-0.2155	0.3112	68	-0.69	0.4911	-0.8365	0.4056
	Secchi	-0.0266	0.1925	68	-0.14	0.8906	-0.4107	0.3576
	Depth	-0.0991	0.0378	68	-2.62	0.0107	-0.1745	-0.0238
	Mean ρ	0.3905	0.9883	68	0.40	0.6940	-1.5816	2.3626
	Salinity	-0.0479	0.0540	68	-0.89	0.3785	-0.1556	0.0599
Scup YOY*	**Mean π**	-0.1074	1.2920	26	-0.08	0.9344	-2.7632	2.5483
	Towdir	0.0979	0.7431	26	0.13	0.8962	-1.4297	1.6254
	Current	-0.1301	0.4369	26	-0.30	0.7682	-1.0281	0.7679
	Secchi	0.0259	0.3318	26	0.08	0.9384	-0.6561	0.7079
	Depth	0.0368	0.1398	26	0.26	0.7943	-0.2506	0.3242
	Mean ρ	-9.3191	11.7021	26	-0.80	0.4330	-33.3732	14.7351
	Salinity	0.2803	0.4186	26	0.67	0.5090	-0.5802	1.1407
Silver perch YOY	**Mean π**	-0.3054	0.1063	118	-2.87	0.0048	-0.5159	-0.0949
	Towdir	0.4961	0.1787	118	2.78	0.0064	0.1422	0.8501
	Current	-0.2278	0.0863	118	-2.64	0.0095	-0.3987	-0.0568
	Secchi	-0.1807	0.0658	118	-2.75	0.0070	-0.3109	-0.0504
	Depth	0.0233	0.0102	118	2.28	0.0246	0.0030	0.0435
	Mean ρ	0.4902	0.1747	118	2.81	0.0059	0.1443	0.8361
	Salinity	-0.3822	.	118	.	.	.	.

Appendix 2. Continued

Species	Parameter	Estimate	SE	DF	t	P	Lower	Upper
Smallmouth flounder	**Mean π**	1.1277	0.4752	72	2.37	0.0203	0.1805	2.0749
	Towdir	-0.1493	0.3697	72	-0.40	0.6875	-0.8862	0.5876
	Current	-0.4912	0.2486	72	-1.98	0.0520	-0.9868	0.0044
	Secchi	0.0504	0.1351	72	0.37	0.7104	-0.2190	0.3198
	Depth	-0.0141	0.0312	72	-0.45	0.6524	-0.0762	0.0480
	Mean ρ	0.3478	1.8007	72	0.19	0.8474	-3.2419	3.9375
	Salinity	-0.0549	0.0735	72	-0.75	0.4576	-0.2014	0.0916
Spot YOY	**Mean π**	0.0913	0.0794	187	1.15	0.2520	-0.0654	0.2479
	Towdir	0.1187	0.1786	187	0.66	0.5072	-0.2337	0.4711
	Current	0.0667	0.1433	187	0.47	0.6422	-0.2159	0.3493
	Secchi	0.1113	0.0829	187	1.34	0.1809	-0.0522	0.2748
	Depth	-0.1740	0.0775	187	-2.25	0.0259	-0.3268	-0.0212
	Mean ρ	-0.5999	0.0945	187	-6.35	<.0001	-0.7864	-0.4134
	Salinity	-0.2090	0.0887	187	-2.36	0.0195	-0.3840	-0.0341
Spot age 1+	**Mean π**	0.6309	0.2834	106	2.23	0.0281	0.0690	1.1928
	Towdir	-0.2809	0.2346	106	-1.20	0.2339	-0.7460	0.1843
	Current	-0.1460	0.2498	106	-0.58	0.5602	-0.6413	0.3493
	Secchi	-0.1230	0.1767	106	-0.70	0.4880	-0.4734	0.2274
	Depth	-0.0554	0.0212	106	-2.61	0.0102	-0.0973	-0.0134
	Mean ρ	-0.0284	0.4811	106	-0.06	0.9530	-0.9823	0.9254
	Salinity	-0.0152	0.0256	106	-0.59	0.5547	-0.0659	0.0356
Spotted hake	**Mean π**	0.1516	0.2096	208	0.72	0.4704	-0.2617	0.5648
	Towdir	0.4888	0.1648	208	2.97	0.0034	0.1639	0.8136
	Current	0.0053	0.1430	208	0.04	0.9704	-0.2766	0.2872
	Secchi	0.2196	0.0809	208	2.71	0.0072	0.0601	0.3791
	Depth	-0.0618	0.0153	208	-4.03	<.0001	-0.0921	-0.0316
	Mean ρ	-0.9770	0.4139	208	-2.36	0.0192	-1.7931	-0.1610
	Salinity	0.0244	0.0191	208	1.28	0.2033	-0.0133	0.0621
Striped anchovy	**Mean π**	-1.4743	0.5125	52	-2.88	0.0058	-2.5028	-0.4458
	Towdir	0.5306	0.3917	52	1.35	0.1813	-0.2553	1.3165
	Current	0.4638	0.4214	52	1.10	0.2762	-0.3819	1.3095
	Secchi	0.6267	0.2078	52	3.02	0.0040	0.2097	1.0437
	Depth	-0.0192	0.0600	52	-0.32	0.7508	-0.1396	0.1012
	Mean ρ	1.3894	1.2370	52	1.12	0.2665	-1.0927	3.8716
	Salinity	-0.0640	0.0531	52	-1.21	0.2334	-0.1704	0.0425
Striped bass YOY	**Mean π**	0.6772	0.2371	89	2.86	0.0053	0.2060	1.1483
	Towdir	-0.0154	0.2917	89	-0.05	0.9582	-0.5950	0.5643
	Current	-0.2829	0.2603	89	-1.09	0.2800	-0.8002	0.2343
	Secchi	0.1380	0.3696	89	0.37	0.7098	-0.5964	0.8724
	Depth	-0.0673	0.0319	89	-2.11	0.0376	-0.1306	-0.0040
	Mean ρ	-0.4123	0.2721	89	-1.52	0.1333	-0.9530	0.1284
	Salinity	-0.0160	0.0230	89	-0.69	0.4890	-0.0616	0.0297

Appendix 2. Continued

Species	Parameter	Estimate	SE	DF	t	P	Lower	Upper
Summer flounder YOY	**Mean π**	0.0330	0.2436	146	0.14	0.8924	-0.4485	0.5145
	Towdir	0.3240	0.2594	146	1.25	0.2136	-0.1886	0.8367
	Current	-0.3170	0.1768	146	-1.79	0.0750	-0.6663	0.0324
	Secchi	0.2033	0.0809	146	2.51	0.0131	0.0433	0.3632
	Depth	-0.0329	0.0212	146	-1.55	0.1229	-0.0749	0.0090
	Mean ρ	0.8471	1.0108	146	0.84	0.4034	-1.1506	2.8449
	Salinity	-0.1064	0.0579	146	-1.84	0.0682	-0.2209	0.0080
Weakfish YOY	**Mean π**	0.3651	0.1434	220	2.55	0.0116	0.0825	0.6476
	Towdir	-0.0103	0.1697	220	-0.06	0.9515	-0.3448	0.3241
	Current	-0.1076	0.1212	220	-0.89	0.3758	-0.3465	0.1313
	Secchi	0.0943	0.1051	220	0.90	0.3706	-0.1128	0.3014
	Depth	-0.0302	0.0152	220	-1.99	0.0477	-0.0601	-0.0003
	Mean ρ	-0.5013	0.2631	220	-1.91	0.0580	-1.0198	0.0172
	Salinity	-0.0150	0.0151	220	-0.99	0.3219	-0.0448	0.0148
Weakfish age 1+	**Mean π**	0.3052	0.3320	88	0.92	0.3605	-0.3546	0.9650
	Towdir	-0.2775	0.3044	88	-0.91	0.3644	-0.8823	0.3274
	Current	0.0455	0.2494	88	0.18	0.8558	-0.4502	0.5411
	Secchi	-0.4430	0.2571	88	-1.72	0.0883	-0.9539	0.0678
	Depth	0.0140	0.0268	88	0.52	0.6019	-0.0392	0.0672
	Mean ρ	-0.5536	0.6837	88	-0.81	0.4202	-1.9123	0.8050
	Salinity	0.0001	0.0324	88	0.00	0.9971	-0.0643	0.0645
White perch YOY	**Mean π**	0.2617	0.1632	160	1.60	0.1107	-0.0605	0.5840
	Towdir	-0.3137	0.1825	160	-1.72	0.0876	-0.6742	0.0467
	Current	0.2679	0.1540	160	1.74	0.0839	-0.0363	0.5721
	Secchi	0.9049	0.2773	160	3.26	0.0013	0.3572	1.4526
	Depth	-0.0951	0.0243	160	-3.92	0.0001	-0.1431	-0.0472
	Mean ρ	-0.8137	0.1679	160	-4.85	<.0001	-1.1452	-0.4821
	Salinity	0.0311	0.0165	160	1.88	0.0620	-0.0016	0.0637
White perch age 1+	**Mean π**	0.3099	0.1430	209	2.17	0.0314	0.0280	0.5919
	Towdir	-0.1914	0.1735	209	-1.10	0.2712	-0.5334	0.1506
	Current	0.3430	0.1424	209	2.41	0.0169	0.0622	0.6238
	Secchi	0.0277	0.1949	209	0.14	0.8872	-0.3566	0.4120
	Depth	-0.0314	0.0212	209	-1.49	0.1388	-0.0731	0.0103
	Mean ρ	-0.7794	0.1482	209	-5.26	<.0001	-1.0716	-0.4872
	Salinity	0.0380	0.0134	209	2.84	0.0050	0.0116	0.0644
White shrimp	**Mean π**	0.0019	0.2718	52	0.01	0.9945	-0.5435	0.5473
	Towdir	0.2750	0.5846	52	0.47	0.6400	-0.8982	1.4482
	Current	-0.0958	0.2583	52	-0.37	0.7122	-0.6141	0.4225
	Secchi	0.5255	0.2193	52	2.40	0.0202	0.0854	0.9657
	Depth	-0.0822	0.0355	52	-2.31	0.0247	-0.1535	-0.0109
	Mean ρ	-0.8425	0.9198	52	-0.92	0.3639	-2.6882	1.0032
	Salinity	-0.0243	0.0510	52	-0.48	0.6365	-0.1266	0.0781