

**Using BRUVS to Characterize the Community of Sandy Shoal Habitats of the
Mid-Atlantic Bight**

by

Amanda Winton

A thesis submitted to the Faculty of the University of Delaware in partial
fulfillment of the requirements for the degree of Honors Degree in Major with
Distinction


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ABSTRACT

This study explores the biodiversity and community structure of two sandy shoal habitats on the East Atlantic coast of the United States: Sandbridge (Virginia) and Hens and Chickens (Delaware). Two different methodologies were used to characterize the communities: Baited Remote Underwater Video Surveillance/Systems (BRUVS) and longlines. We assess species relative abundance (MaxN) and diversity, evenness, and richness using Shannon's Diversity Index, Simpson's Diversity Index, Pielou's Evenness, and species richness metrics. We then examine environmental covariates such as water temperature, brightness, depth, distance from shore, proximity to the closest estuary, and tidal stage at both sites to determine if the environment drives differences in community composition. Generally, species diversity and richness were greater at Sandbridge. However, we observed no significant differences in biodiversity indices between the two locations, most likely due to a small sample size of videos. Our findings also reveal significant differences in environmental variables between the two shoals, particularly in brightness and the distances from shore and the closest estuary. Brightness exhibited a positive linear relationship with diversity indices and richness, suggesting that less turbid habitats may support more complex communities. Distance to the closest estuary presented a negative linear relationship with evenness, indicating that further proximity to the estuary may maintain a more balanced distribution of species. These trends also highlight that BRUVs are dependent on clear water conditions to effectively record data. This study also touches on the significance of using multiple sampling techniques to better assess marine compositions and diversity. Long-lining and BRUVS yielded distinct species captures with minimal overlap, indicating different

biases and strengths of each method. Water turbidity (brightness) limited species detection and identification, particularly at Hens and Chickens, highlighting a limitation of BRUVS in turbid waters. This study also suggests further research into temporal variations, additional environmental factors, and enhancements to sampling methods to improve biodiversity assessments.

Chapter 1

INTRODUCTION

Understanding community composition and diversity metrics is essential for evaluating ecosystem health, detecting environmental change, and informing conservation efforts. These metrics help ecologists identify shifts in communities from natural processes or human impacts such as pollution, habitat degradation, and climate change. To assess marine communities, ecologists employ various methods ranging from nondestructive visual techniques to more invasive capture-based approaches. The best sampling method can be selected based on environmental factors such as temperature, depth, and turbidity (Smit et al., 2020), as these can influence the visibility, detectability, and behavior of marine organisms, ultimately affecting the reliability of the collected data. Researchers must choose the appropriate method based on their specific objectives and study system.

One invasive capture-based sampling technique is longlining. Although less destructive than other methods, longlining still raises concerns. Boat usage during surveys contributes to fuel consumption and carbon emissions (Hilborn et al., 2023). Organisms are also disturbed and removed from their natural habitat when captured on hooks. Additionally, longlining only targets part of the community that responds to bait and will take a hook, so it will not sample everything. Larger, predatory species are more likely to be sampled than smaller invertebrates. There are alternatives to this method that are more sustainable, have less impact on species, and may sample more of the community.

Visual observations, such as those collected by SCUBA divers or remotely operated vehicles, are less destructive techniques for observing marine life (Wetz et al., 2020). Another approach utilizes Baited Remote Underwater Video Surveillance (BRUVS) to capture footage of aquatic organisms to assess their presence, relative abundance, and behavior in their natural habitat. BRUVS have advantages over other methods. These surveys can detect significantly more species and show a higher relative abundance than baited fish traps (Zhang et al., 2024) and capture a different species composition than trawls (Cappo et al., 2004). These non-invasive methods have advantages in understanding species diversity and abundance, but visual observations also have limitations. SCUBA-based surveys are depth-limited and restricted by diver bottom time, depth, visibility, and temperature. Moreover, BRUVS offer only a short snapshot of activity during deployment and may miss nocturnal or more mobile species. It is important to consider the benefits and costs of each method.

Many studies have utilized BRUVS to characterize communities and track individuals of species. Gomes et al. (2024) used a 360° BRUVS to overcome a restricted frame view and limit anchoring issues such as the overturning or drifting of the system. When water movement is more significant, systems can flip onto their sides, altering the perspective of the BRUVS and potentially rendering the video unusable. The new mechanism successfully identified the common species known to the area while significantly reducing equipment losses and anchoring problems. Another study tracked individual batoids using tail and spot patterns (Sherman et al., 2018). The researchers created a novel metric, MaxIND, for tracking individual organisms, ultimately estimating the population better than MaxN. Andradi-Brown et al. (2016) tracked reef fish communities. The researchers found that fish species and

richness were higher using BRUVS than Diver Operated Videos (DOV), but DOV recorded greater relative fish community biomass of herbivores. Their study highlights the importance of considering what component of the reef fish community researchers are most interested in surveying to pick an appropriate method. BRUVS are a widely used method for surveying communities.

However, BRUVS have several important limitations. We cannot count the number of animals unless they are individually identifiable, so the recorded parameter, MaxN, is the relative abundance of species. Moreover, we can only record what is visible within the camera's field of view, making BRUVS less effective for detecting small, cryptic species or organisms behind the camera. BRUVS may not detect all species in a habitat, potentially underestimating biodiversity. Visibility is also critical in turbid or low-light conditions, as footage can become too dark or unclear to analyze. To combat dark conditions, most deployments occur during the day, limiting their ability to capture data on nocturnal or crepuscular species. Adding a clear liquid optical chamber to a BRUVS system has improved detectability and identification of species (Jones et al., 2019). Also, bait adds variability since it only draws in organisms to the BRUVS within a limited attraction radius. However, bait choice may not be important. Baited deployments recorded significantly higher relative abundance and taxonomic diversity than unbaited deployments, but no single bait type consistently outperformed others in attracting more species (Jones et al., 2020). Species may have different food preferences, but more research is necessary. Although BRUVS are a valuable tool for analyzing marine communities, it has many limitations.

Habitat and environmental factors are critical in shaping community structure as well as how effectively BRUVS can survey a given community. Variables such as

turbidity (or brightness/water clarity), water temperature, depth, distance from shore, proximity to the nearest estuary, and temporal factors like seasonality and time of day all influence which species are present and how visible they are to the camera.

Different habitats will support distinct species, each preferring specific conditions that best suit their physiologies. A higher salinity environment will not house a freshwater species, and vice versa. When studying entire communities, it's important to consider how habitat characteristics shape not just the presence of individual species, but the overall diversity and structure of the ecosystem. These environmental factors influence not only the community composition but detectability of species, ultimately affecting the accuracy of BRUVS.

In this study, we used BRUVS to characterize the demersal community of two sandy shoal habitats off the coasts of Delaware and Virginia. While BRUVS recorded species' presence along the seafloor, we concurrently conducted longlining in the same habitat to target larger predatory species. Our overall objective was to determine which environmental factors drive changes in community composition in sandy shoal habitats. We also aimed to compare these two sampling methods and assess their relative effectiveness in characterizing the communities associated with these habitats. Characterizing communities is essential to understanding species diversity and abundance for conservation, management, and overall ecosystem health. Understanding what is out there can inform broader ecological and environmental assessments, especially in a changing climate.

Chapter 2

MATERIALS AND METHODS

The Chesapeake and Delaware Bays are two brackish water bodies along the East Coast of the United States. We deployed BRUVS at Sandbridge Shoal (SBS), off Virginia Beach, VA, and Hens and Chickens Shoal (HCS), off Rehoboth and Dewey Beach, DE (Figure 1). I analyzed a subset ($n = 4$ per region) of deployments, each lasting approximately 1.5 hours. I standardized each video to 51 minutes, and observations began when the camera hit the benthos. Videos are labeled 1-4 for SBS and 5-8 for HCS. All videos were recorded during the summer months (June through August) of 2022 and 2023, either in the morning or afternoon.

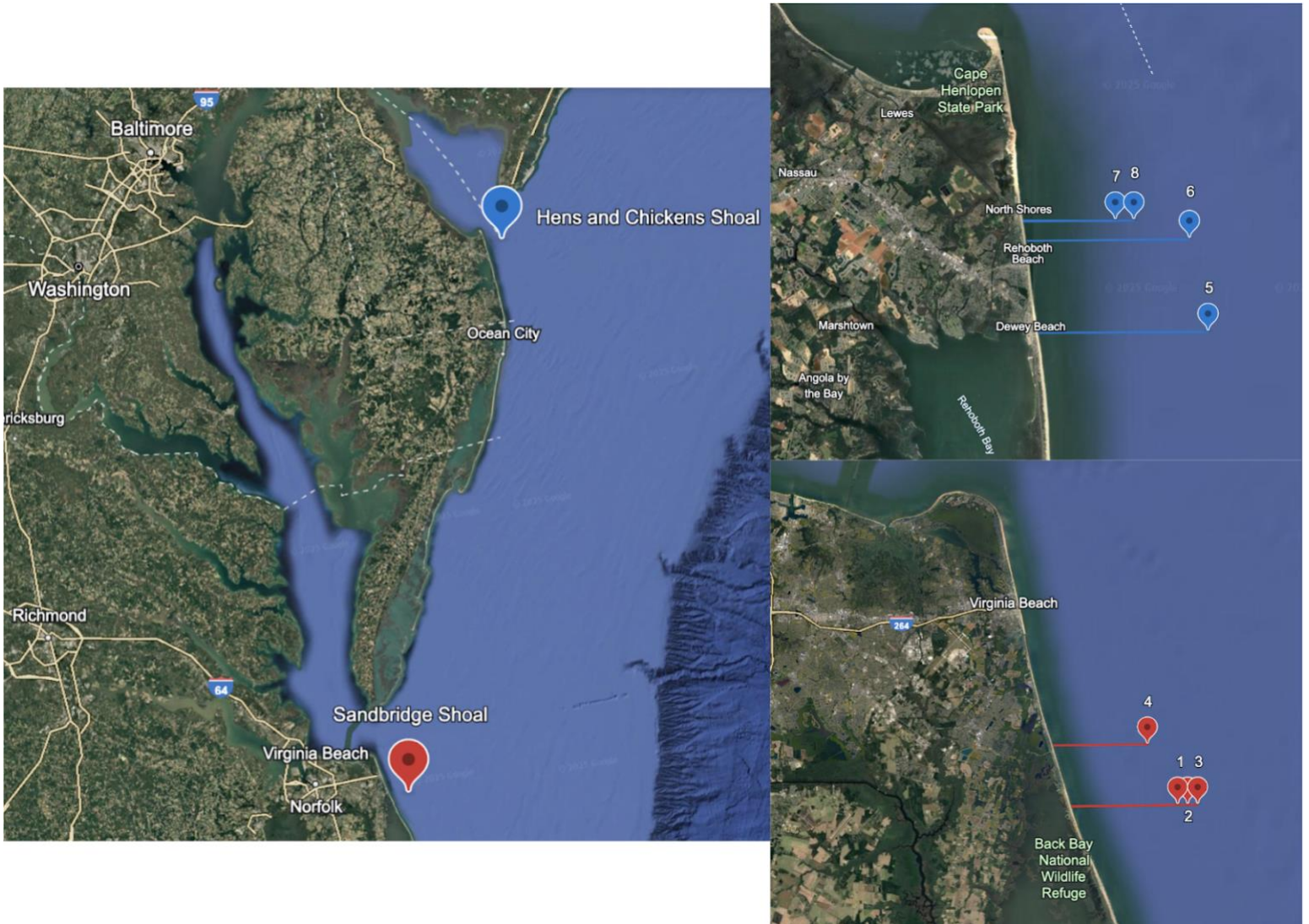
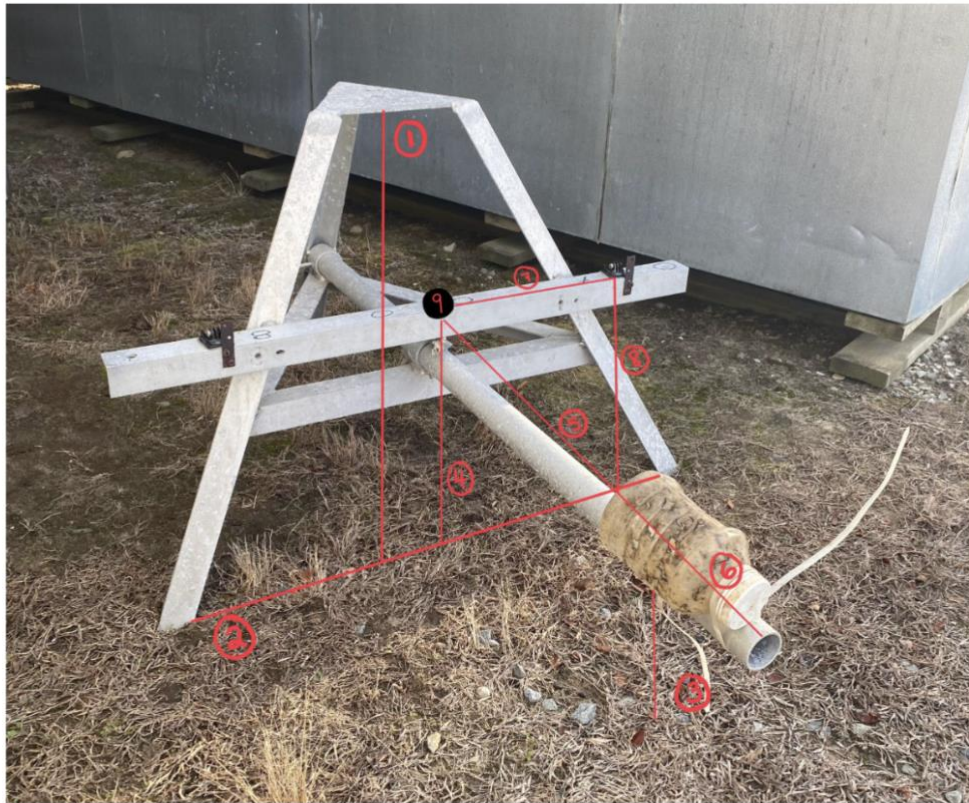


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BRUVS consisted of a GoPro Hero 7 Black camera (30 fps frame rate, wide view setting) attached to an aluminum arm, part of a larger custom metal frame (Figure 2). We deployed either one (single) or two (stereo) cameras on the BRUVS. Stereo BRUVS have two cameras recording simultaneously on opposite sides of the BRUVS frame, which, due to their overlapping visual fields, can be used with specialized software to estimate additional metrics such as the 3D location, movements, or size of individual animals. I watched one of the cameras in the stereo BRUVS to standardize observations across the single and stereo BRUVS. Videos 1-3 and 5 used a single camera. For videos 6 and 8, I looked at the right camera of the stereo BRUVS; for videos 4 and 7, I looked at the left. To serve as bait, we sliced two whole mackerels (700 ± 100 g) and zip-tied them to the end of the arm within a plastic mesh cage or container with holes positioned 60.96 cm from the camera. During long-lining surveys, we deployed the BRUVS to rest on the bottom, with the camera positioned 48.26 cm above the substrate. Depending on water clarity, some videos captured both the pelagic zone and benthos, while others, hindered by turbidity, recorded only the area around the arm (Figure 3). We attached a rope to a surface float for retrieval.



Measurement	Value (cm)
1: Top of Metal to Ground	76.2
2: Length of Side of Triangle on Ground	104.1
3: Height of Bait from Ground	30.5
4: Height of Camera to Ground	48.3
5: Distance between Camera and Bait	60.9
6: Distance of Arm from Camera	91.4
7: Distance of Stereo Camera to Middle Camera	38.1
8: Distance of Stereo Camera to Bait	60.9
9. Location of single camera. Stereo BRUVS are positioned at the ends of the metal bar on the black attachments.	

Figure 2. The Baited Remote Underwater Video System (BRUVS). BRUVS consist of a metal frame for the structure, a metal arm extending for bait placement, and a camera mounting piece. The labeled measurements (1-8) correspond to the dimensions in the accompanying table. The black circle labeled “9” indicates the position of the single middle camera, while stereo BRUVS cameras are mounted at the ends of the metal bar on the black attachments.

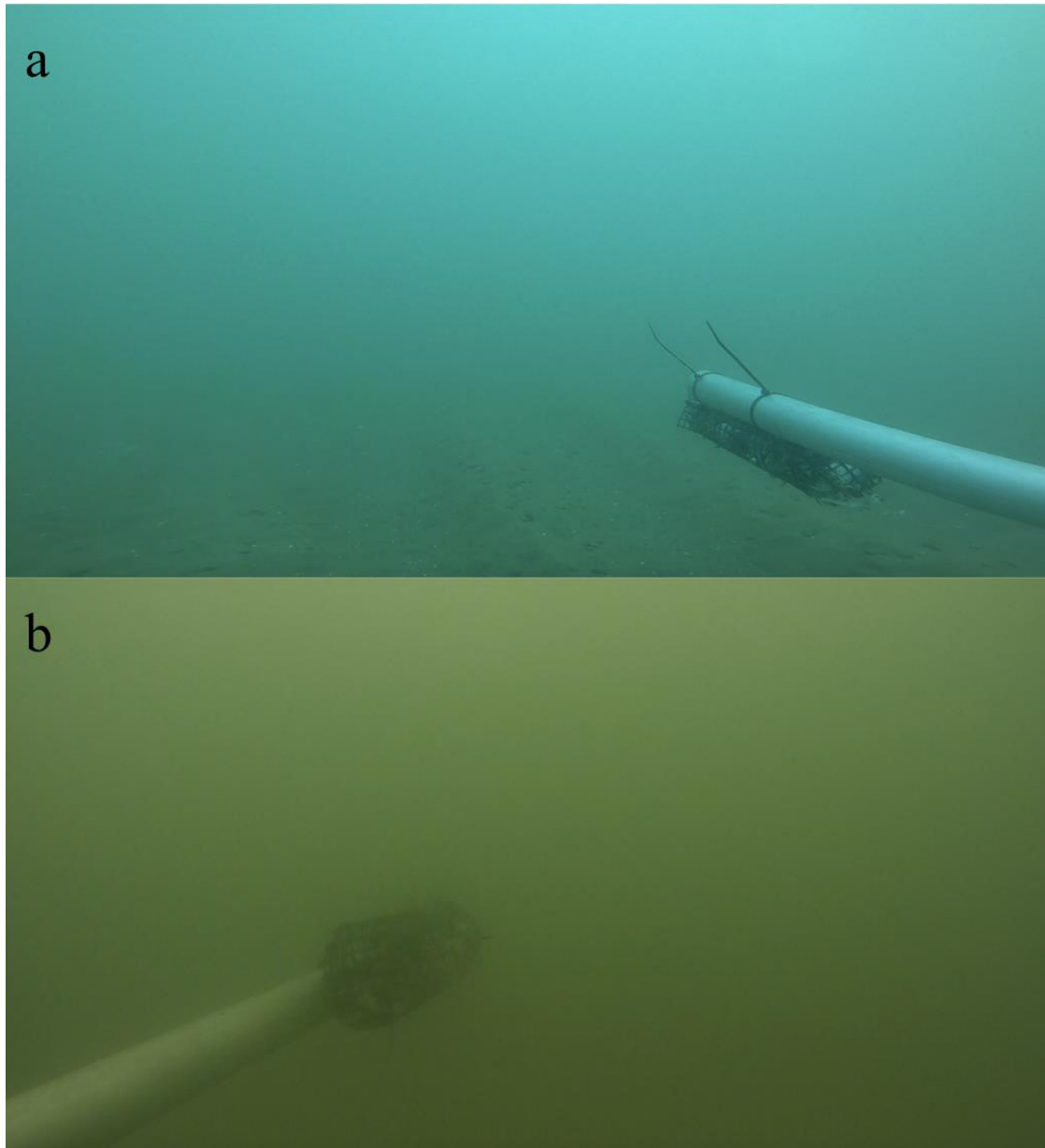


Figure 3. Two BRUVS deployments. (a) BRUVS deployment in SBS from video 4. The arm and bait are visible, and the benthic habitat is observable with low turbidity. (b) BRUVS deployment in HCS from video 6, captured using the right camera of a stereo BRUVS system. The arm and bait are visible, but the turbidity is much higher, limiting visibility.

The spatial extent of the BRUV deployments was estimated using the minimum convex polygon tool in Google Earth, resulting in a total area of 6.01 km² for Delaware and 3.77 km² for Virginia. On average, Delaware deployments were closer to shore (5.67 ± 1.26 km SD) compared to Virginia deployments (8.93 ± 1.08 km SD). Similarly, Delaware sites were closer to the nearest estuary (11.85 ± 2.80 km SD) than Virginia (31.60 ± 2.89 km SD). To determine this, a line was drawn across the mouth of each estuary between the two bordering land masses (New Jersey and Delaware for the Delaware Estuary; Maryland and Virginia for the Chesapeake Bay). The distance from each BRUV deployment to the estuary was measured from the point on the line closest to the lower land mass (Delaware for Delaware deployments and Virginia for Virginia deployments). The closest estuary to SBS is the Chesapeake Bay, and to HCS is the Delaware Estuary. Geographic coordinates for Virginia ranged from 36.7066 to 36.7498 (latitude) and -75.8316 to -75.8586 (longitude), while Delaware ranged from 38.6906 to 38.7329 (latitude) and -74.9882 to -75.0331 (longitude) (Table A1). Sandy shoals with ripples characterize the benthic habitat in Virginia. The benthic habitat in Delaware could not be definitively identified in the videos due to turbidity, although it is also a sandy shoal habitat.

I used ImageJ software (<http://imagej.org>) to measure the brightness of each video to represent a turbidity measurement. I took ten evenly spaced screenshots across the video from each deployment and used the brightness tool to measure the brightness at the same spot on the BRUVS arm in each screenshot (Table A2). I averaged those ten measurements to determine the average turbidity for each video. In addition to the average, we also examined the variability in brightness across screenshots within each video to assess how much water clarity varied during the

deployment. Higher variability in brightness values may indicate more dynamic turbidity conditions over short time scales.

I generated several metrics from the videos, including the date, start and end times, and the total duration of each video. In addition, for each organism observed, I recorded the time of entry and exit from the frame, along with the MaxN, which is the maximum number of individuals of a species observed in a single frame during a video. MaxN is widely used in BRUVS studies as a standardized estimate of relative abundance (Garratt et al., 2024; Osgood et al., 2019; Sherman et al., 2020), where higher MaxN values indicate greater relative abundance of a species in the area. MaxN values were used for analysis and converted into Sightings Per Unit Effort (SPUE), calculated by dividing MaxN by the total standardized video duration (51 minutes). Organisms were identified to the lowest possible taxonomic level, ranging from class to species, based on available references and in consultation with faculty advisors.

The BiodiversityR package was used in R Statistical Software (v4.4.3; R Core Team 2025) to calculate biodiversity indices for each video. These include Shannon's Diversity Index, Simpson's Diversity Index, Pielou's Evenness Index, and species richness, the total number of species per video. These indices describe different aspects of community structure, and I used them as response variables in further analyses.

Shannon's Diversity Index uses the proportion of the individuals of a given species to the total number of individuals in the community. It is calculated as the negative sum of this proportion multiplied by the natural log of this proportion [$H' = -\sum (p_i * \ln(p_i))$]. For this study, I used MaxN to estimate the individuals of a given species and MaxN to estimate the total number of individuals in the community.

Shannon accounts for species abundance when calculating diversity. A value of 0 indicates that I only counted one species.

Simpson's Diversity Index accounts for species richness (the total number of species present) and evenness (the relative abundance of each species compared to each other). As species richness and evenness increase, diversity increases. It is calculated as one minus the sum of the total number of organisms of a particular species divided by the total number of organisms of all species [$D = 1 - \sum(n/N)^2$]. For this study, I used MaxN to estimate the total number of organisms for each species. A value of zero indicates that I only counted one species.

Pileou's Evenness Index refers to how evenly distributed individuals are of each species. If there is a higher evenness, each species contains about the same number of individuals. It is calculated by dividing the Shannon Diversity value by the maximum Shannon Diversity value. A value of zero indicates a very uneven community distribution.

All statistical analyses were conducted in R Statistical Software and JMP software (JMP®, Version <Pro 17>. SAS Institute Inc., Cary, NC, 1989–2025) to assess the relationships between environmental factors and biodiversity indices. All analyses used an $\alpha = 0.05$. I chose to use JMP alongside R to double-check coding, easily display graphs, and perform statistical tests such as exact tests. It is also helpful for showing the distribution of variables to detect abnormality.

To assess the impact of environmental covariates (temperature, brightness, depth, distance to shore, distance to estuary) on biodiversity indices (Shannon, Simpson, Evenness, and Species Richness), I used generalized linear models (GLMs) implemented using the Vegan package in R, as well as linear regression using JMP

software. I chose these environmental variables because they were easily accessible from long-lining surveys done during the BRUVS deployments, easily calculated, or easily found online. I ran a GLM to determine the effect of the environmental covariates on species presence and absence. These data follow a binomial distribution where zero is absent and one is present. A logistic regression is appropriate for binary data and identifying the factors influencing presence. Additionally, I ran a negative binomial GLM to investigate the effect of environmental variables on species abundance. I chose a negative binomial model because of the result of the dispersion test ($p = 0.0005414$), which detected overdispersion, meaning I cannot use a Poisson GLM.

I conducted a correlation analysis between distance to shore and distance to estuary to determine whether these two spatial variables were related. While they are both spatial, I can not assume they are correlated unless both moving away from shore also means moving away from the estuary. By testing for correlation, I aimed to assess whether these two covariates could be treated as independent predictors in my models or whether potential collinearity needed to be considered.

To determine whether biodiversity differed significantly between the two locations, I conducted 2-Sample Exact Tests for each biodiversity index (Shannon, Simpson, Evenness, and Richness). Traditional parametric tests assume normally distributed data, but the exact test does not rely on normality assumptions and is more useful with small sample sizes. Since not all the data met the assumption of normality and homogeneity of variances, we used the exact test.

I investigated how biodiversity indices and environmental covariates were impacted by tidal stages (slack vs non-slack, ebb vs flood) as tides affect species'

behavior and habitat use, potentially impacting our data. I defined slack tide as the period (about 30 minutes before and after high/low tide) when water movement is the lowest. An ebb tide is when the tide is going out, and a flood tide is when the tide is incoming. I took tides from NOAA tide predictions (*Tide Predictions - NOAA Tides & Currents*, 2025).

Chapter 3

RESULTS

This study aimed to examine the potential drivers of differences between two sandy shoal habitats on the east Atlantic coast of the United States. I measured water temperature, brightness, depth, distance to shore, and distance to the nearest estuary for two locations. I looked at the impact of tidal stages and slack conditions. I calculated MaxN, Shannon's Diversity, Simpson's Diversity, Pileou's Evenness, and species richness for both locations. I hypothesized that the environmental covariates would exhibit significant differences between shoals, influencing the biodiversity and richness of the areas.

The environmental covariates differed between locations. The average water temperature at SBS was higher ($24.7^{\circ}\text{C} \pm 1.5$) than at HCS ($22.6^{\circ}\text{C} \pm 1.3$). BRUV deployments at SBS were slightly deeper ($14.4 \text{ m} \pm 1.2$) than HCS ($13.4 \text{ m} \pm 2.6$). The average brightness at SBS was much higher (141.5 ± 43.4) compared to HCS (64.8 ± 15.1) (Table A1). Brightness ($p = 0.029$), Distance to Shore ($p = 0.029$), and Distance to Estuary ($p = 0.029$) were significantly different between locations (Figure 4).

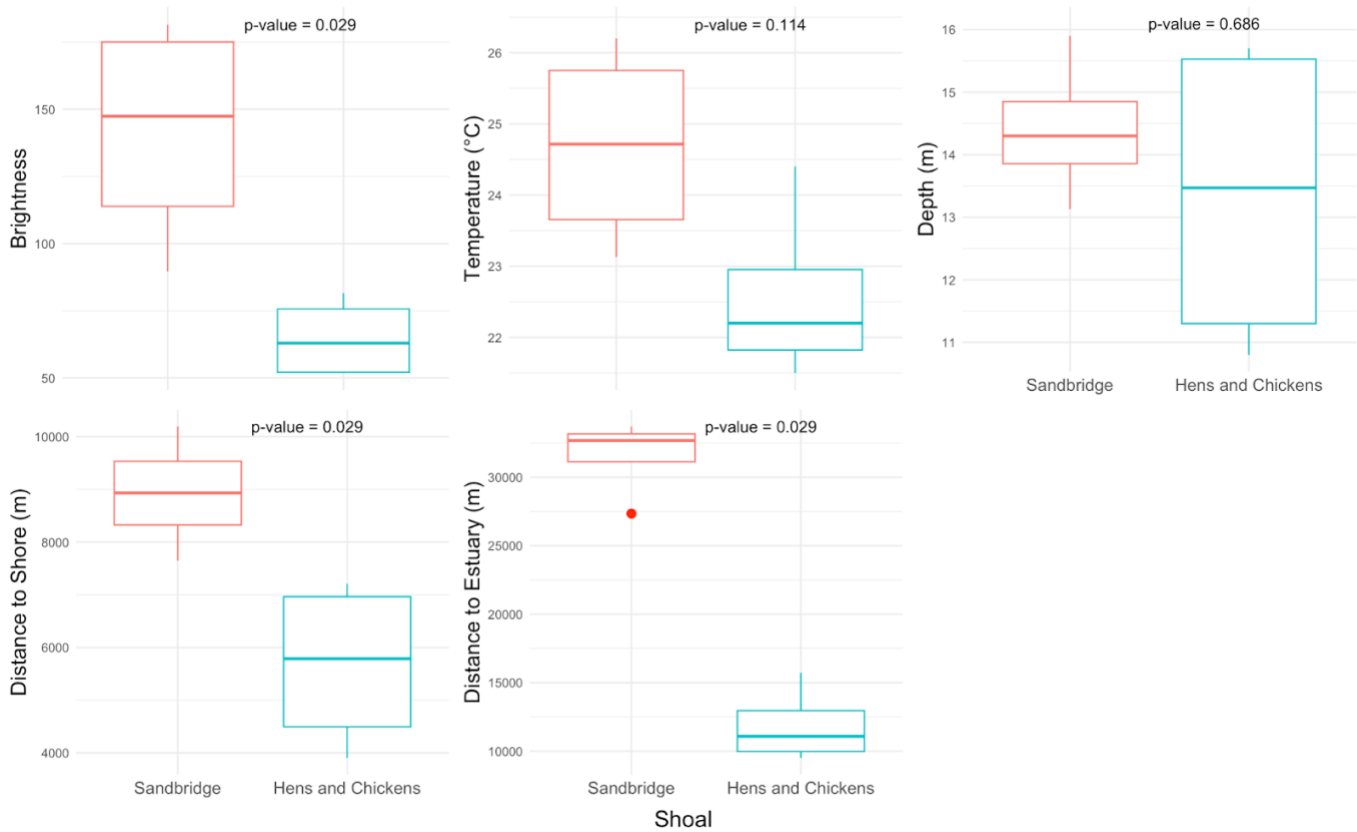


Figure 4. Box plots of environmental covariates comparing SBS (red) to HCS (blue). P-values (Wilcoxon tests) are shown at the top of each figure ($\alpha = 0.05$). Red dots indicate outliers.

Tidal conditions during deployments at both locations were generally similar. There were two flood tides and two ebb tides at each location, and one slack and three non-slack at each location (Table A3). I did not find any significant effects of tides in our results (Table A4).

Many environmental covariates were positively linearly related (Table A5), suggesting the environmental metrics may be predictive of each other and, therefore, duplicative explanatory parameters. Distance to Estuary and Brightness are the most likely to be duplicative, as the closer one is to an estuary, the more turbid the

conditions and the lower the brightness. The correlation analysis of distance from shore and distance to estuary shows a positive correlation with a Pearson correlation coefficient = 0.903.

I also combined community metrics estimated from BRUVS with those estimated from long-lining to more fully characterize the community and assess how our understanding of community metrics varies by method. Of the eight BRUVS deployments, seven species were recorded via the long lining survey, including: *Rhizoprionodon terraenovae* (Atlantic sharpnose shark), *Myliobatis freminvillii* (Bullnose ray), *Raja eglanteria* (Clearnose skate), *Carcharhinus obscurus* (Dusky shark), *Carcharhinus plumbeus* (Sandbar shark), *Mustelus canis* (Dusky smooth-hound shark), and *Carcharhinus brevipinna* (Spinner shark). Species overlap between the two methods was minimal. On July 18, 2022, in BRUVS video one, *Raja eglanteria* had a MaxN of one, while the total catch for longlining was three individuals of the same species. No other species recorded on BRUVS matched those captured by longlining.

Across eight BRUVS deployments, I recorded a total of 23 organisms. Of these, two organisms were identified to the class level, two to the order level, three to the family level, one to the genus level, and 14 to the species level (Table 1). One fish could not be identified due to poor turbidity. I recorded 19 species at SBS, 79% (15 species) of which were unique to that location (Table 1). Eight species were observed at HCS, 38% (three species) of which were unique to that location (Table 1). 17% of species (four species) occurred at both shoals (Table 1). The MaxN of species varied more at SBS (1-17) than HCS (1-6) (Table 1). The SPUE of individuals ranged from 1.78-8.24 at SBS and from 1.78-3.53 at HCS. The class Gastropoda had the highest

MaxN and SPUE for both locations. SPUE showed the same trends as MaxN, so MaxN was used for analysis (Figure 5).

Table 1. MaxN values of each organism by video. A value of 0 indicates that the organism was not observed, while any value ≥ 1 represents the MaxN count of that species in the respective video. The taxonomic identifications of the species are as follows: Atlantic Croaker (*Micropogonias undulatus*), Atlantic Menhaden (*Brevoortia tyrannus*), Black Sea Bass (*Centropristis striata*), Blue Crab (*Callinectes sapidus*), Channeled Whelk (*Busycotypus canaliculatus*), Clearnose Skate (*Raja eglanteria*), Ctenophora (*Ctenophora*), Hard Clam (*Mercenaria mercenaria*), Hermit Crab (*Paragus spp.*), Moon Jellyfish (*Aurelia aurita*), Pinfish (*Lagodon rhomboides*), Salp (*Salpida*), Sand Tiger Shark (*Carcharias taurus*), Sea Robin (*Prionotus carolinus*), Sea Star (*Asteroidea*), Snail (*Gastropoda*), Spider Crab (*Libinia emarginata*), Spot (*Leiostomus xanthurus*), Summer Flounder (*Paralichthys dentatus*), Unidentified Carcharhinidae (*Carcharhinidae*), Unidentified Crab (*Decapoda*), Unidentified fish (*Actinopterygii*), Unidentified Myliobatiformes (*Myliobatiformes*).

Video	Shoal	Blue Crab	Channeled Whelk	Ctenophora	Hard Clam	Hermit Crab	Moon jelly	Salp	Sea Star	Snail	Spider Crab	Unidentified Crab	Cleamose Skate	Sand Tiger Shark	Unidentified Carcharhinidae	Unidentified Myliobatiformes	Atlantic Croaker	Atlantic Menhaden	Black Sea Bass	Pinfish	Sea Robin	Spot	Summer Flounder	Unknown fish
1	SBS	1	0	4	0	7	1	0	0	5	1	1	1	0	1	0	0	0	1	0	1	0	1	0
2	SBS	0	1	1	1	6	0	0	0	7	0	1	1	0	0	0	0	0	0	1	3	0	3	0
3	SBS	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0
4	SBS	0	0	5	0	1	0	1	1	5	0	1	0	0	0	0	0	0	0	0	1	0	1	0
5	HCS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0
6	HCS	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
7	HCS	0	0	0	0	0	0	0	0	3	0	2	0	0	0	1	1	0	1	0	0	0	0	1
8	HCS	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0

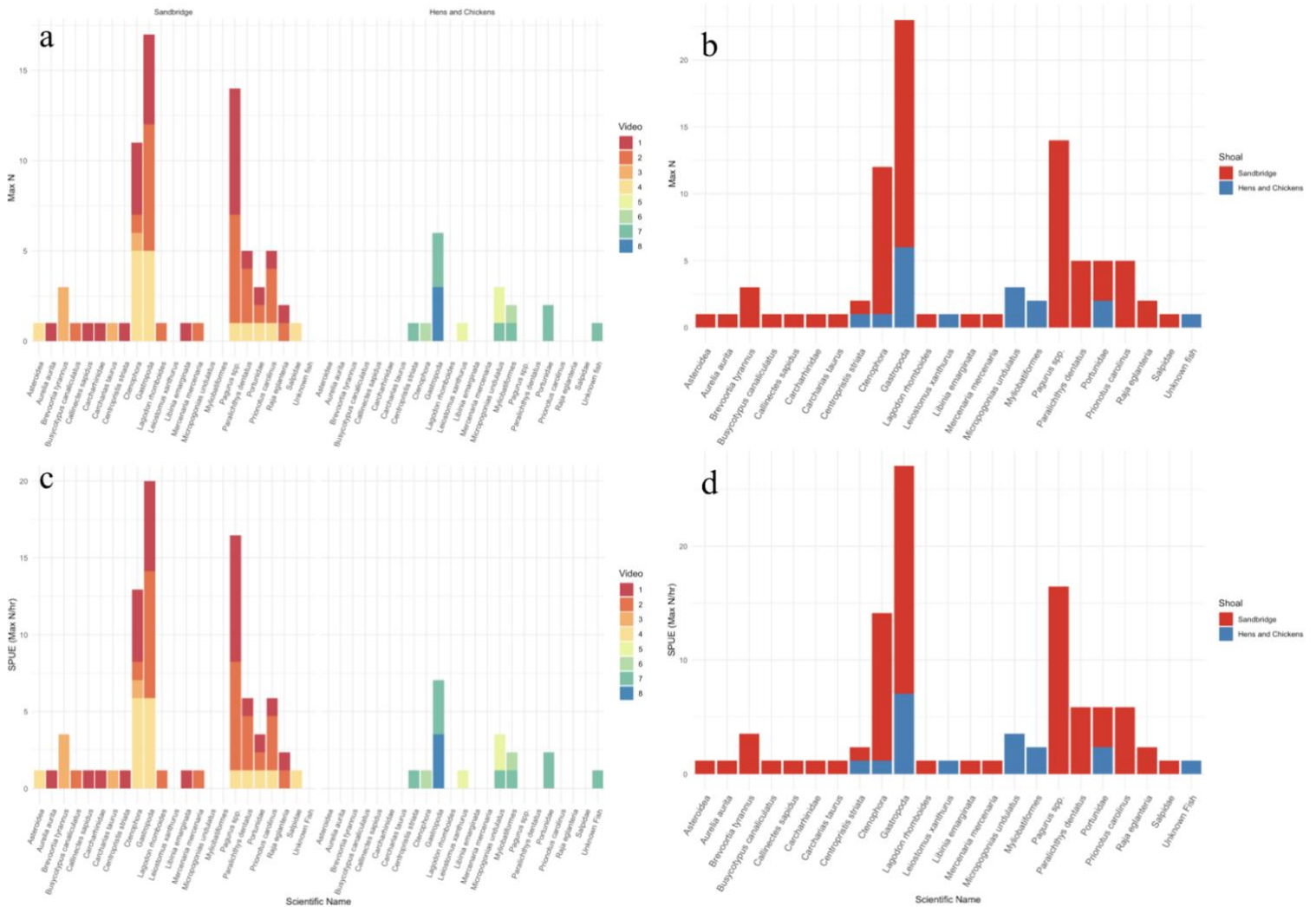


Figure 5. Maximum number of individuals (MaxN) and Sightings per Unit Effort (SPUE) for each species observed in SBS and HCS. (a) MaxN by species, broken down by individual videos. (b) MaxN by species, grouped by shoal. (c) SPUE by species, broken down by individual videos. (d) SPUE by species, grouped by shoal. Colors in (a) and (c) represent different videos, while colors in (b) and (d) differentiate between SBS and HCS.

Biodiversity metrics evaluate populations and communities by offering quantitative measures for qualitative data. We can then estimate species diversity, abundance, and distribution. The most frequently used metrics are Shannon's Diversity, Simpson's Diversity, and Pielou's Evenness. These indices range from zero to one. Zero indicates low diversity or evenness, and one indicates high diversity or evenness. Analyzing these indices enables researchers to assess the impact of environmental factors, habitat conditions, and human activities on marine communities more effectively.

Biodiversity metrics varied across both locations, where SBS was generally more diverse with a higher species richness. Shannon's Diversity Index was greater at SBS (1.707 ± 0.526) than at HCS (0.752 ± 0.692). Simpson's Diversity Index was also greater at SBS (0.752 ± 0.131) than at HCS (0.434 ± 0.326). Richness was generally greater at SBS (8.250 ± 3.862) than HCS (2.750 ± 2.217). Pielou's Evenness was greater at HCS (0.951 ± 0.043) than SBS (0.858 ± 0.006). Video 8 (HCS) recorded no diversity (0) and, therefore, was not applicable for an evenness calculation (Table 2). The differences in biodiversity indices between shoals were not statistically significant (Figure 6). There was also no significant impact on biodiversity indices by tidal stages and slack conditions (Table A4).

Table 2. Biodiversity metrics for each video, including Shannon's Diversity Index, Simpson's Diversity Index, Pielou's Evenness, and Species Richness. A value of 0 indicates only one species was present, meaning no diversity. "N/A" suggests an inability to calculate the metric. SBS deployments are listed first, followed by HCS deployments.

Video	Shoal	Shannon's Diversity Index	Simpson's Diversity Index	Species Richness	Pielou's Evenness Index
1	Sandbridge	2.130	0.842	12	0.857
2	Sandbridge	1.980	0.826	10	0.860
3	Sandbridge	0.950	0.560	3	0.865
4	Sandbridge	1.767	0.781	8	0.850
5	Hens and Chickens	0.637	0.444	2	0.918
6	Hens and Chickens	0.693	0.500	2	1.000
7	Hens and Chickens	1.680	0.790	6	0.936
8	Hens and Chickens	0	0	1	N/A

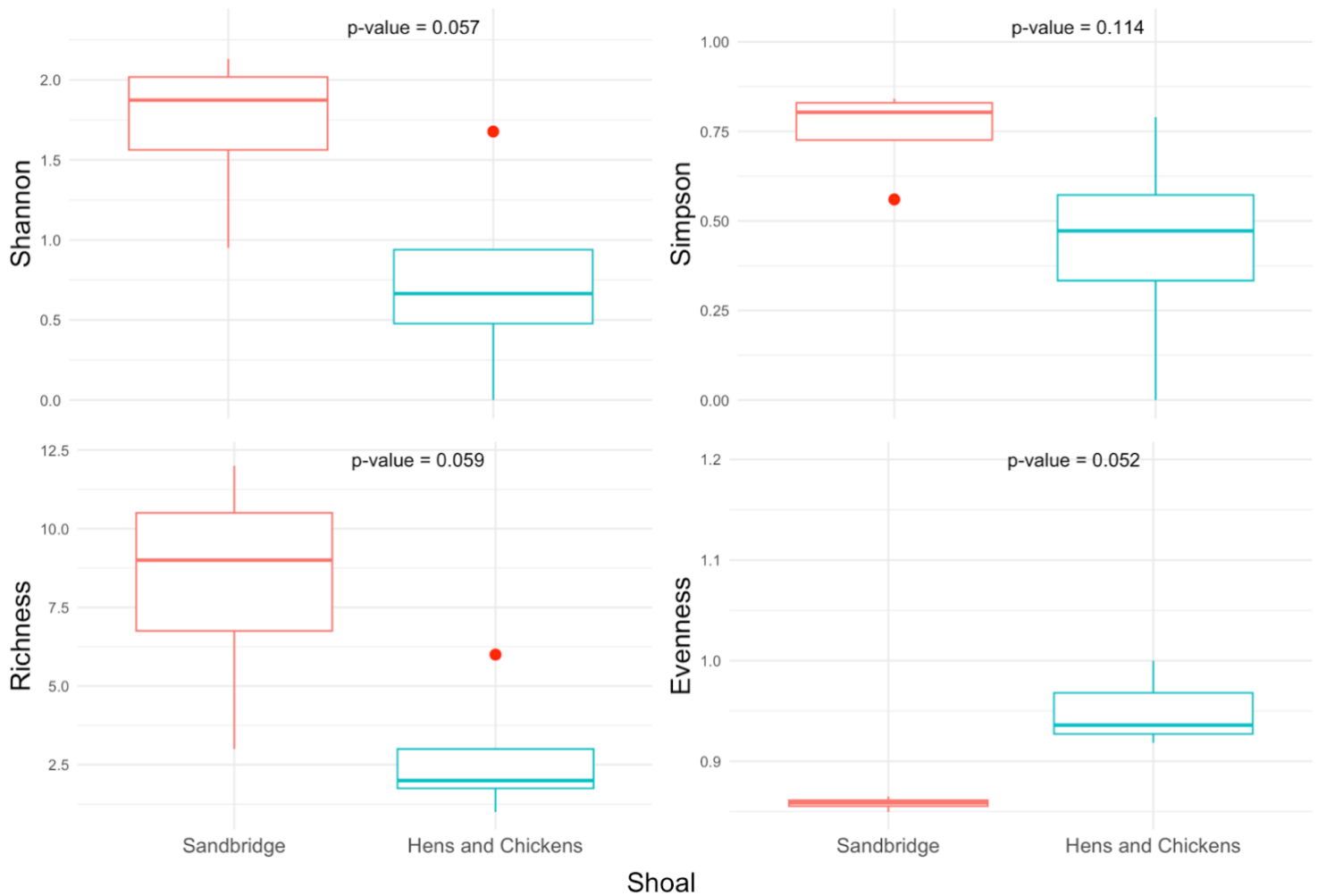


Figure 6. Box plots of biodiversity indices comparing SBS (red) to HCS (blue). P-values of statistical tests (2 Sample Exact tests) are shown at the top of each figure ($\alpha = 0.05$). Red dots indicate outliers.

The biodiversity indices, including Shannon ($p = 0.010$), Simpson ($p = 0.042$), and Richness ($p = 0.001$), showed significant relationships with brightness (Figure 7). Pielou's Evenness was significantly related to the distance from the estuary ($p = 0.011$) (Figure 8).

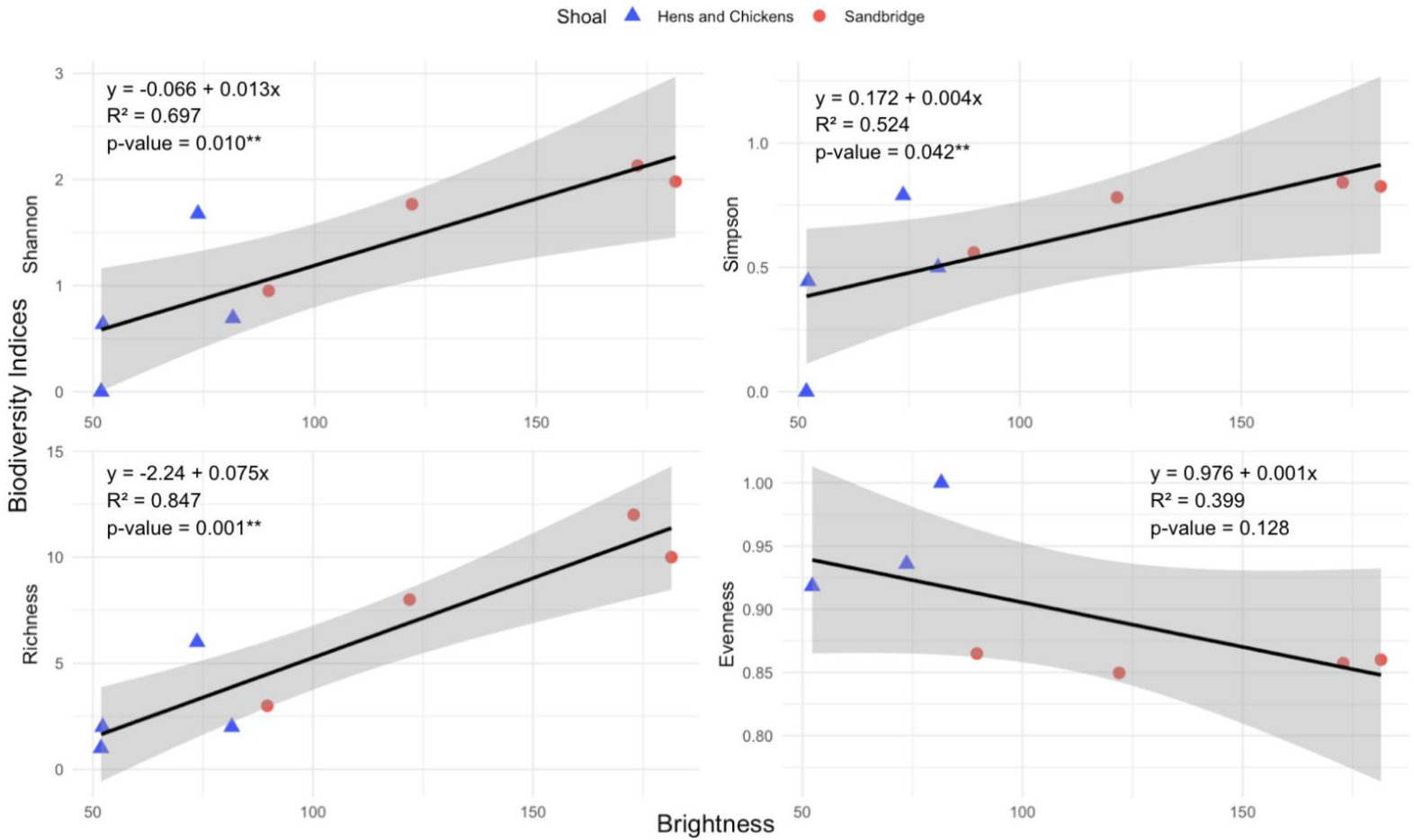


Figure 7. Relationships between brightness and biodiversity indices (Shannon, Simpson, Richness, and Evenness). Each panel shows a linear regression with the equation, R² value, and p-value ($\alpha = 0.05$). Black regression lines indicate trends, with shaded gray areas representing 95% confidence intervals. Red circles are from SBS, and blue triangles are from HCS.

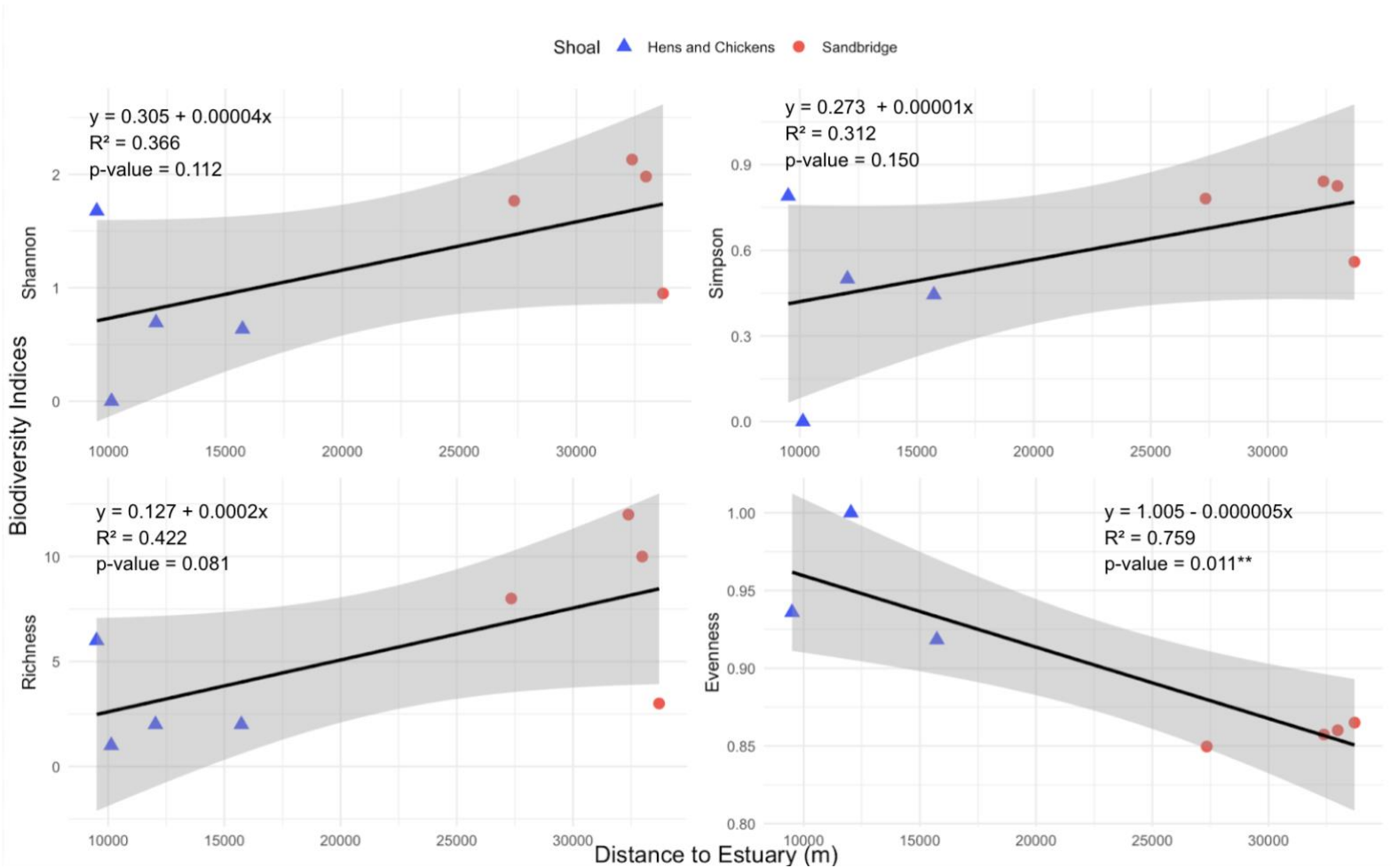


Figure 8. Relationships between distance from the nearest estuary in meters and biodiversity indices (Shannon, Simpson, Richness, and Evenness). Each panel shows a linear regression with the equation, R² value, and p-value ($\alpha = 0.05$). Black regression lines indicate trends, with shaded gray areas representing 95% confidence intervals. Red circles are from SBS, and blue triangles are from HCS.

I did not find many significant relationships between biodiversity metrics and environmental covariates (temperature, brightness, depth, distance to shore, and distance to estuary). The environmental covariates showed no significance on species presence/absence. However, temperature ($p = 0.047$) and brightness ($p = 0.003$) showed a significant effect on

species abundance (MaxN). Moreover, many of the linear regressions approached statistical significance, and further sampling efforts could reveal more conclusive results (Figures A1, A2, and A3).

Chapter 4

DISCUSSION

This is the first study to examine the relative abundance and community composition of species in the Delaware and Chesapeake Bays using BRUVS. I observed different communities in the two study locations, though differences in environmental conditions and methodological issues influenced my ability to characterize the communities. Despite these issues, I was able to identify some similarities and differences in the communities at both sites. Gastropods were the most common species observed at both sites. Snails were observed on and between sand ripples at SBS, where there was better visibility, and on the metal BRUVS arm in HCS, where conditions were generally more turbid. I also observed *Centropristis striata* (Black Sea Bass), Ctenophores, and Portunid crabs in both bays. The ctenophores in SBS were most likely a combination of *Mnemiopsis leidyi* and *Beroe ovata*, two species in the Chesapeake Bay (Bishop, 1972). In SBS, I also observed *Paragus spp.* The hermit crabs were likely some combination of *Paragus longicarpus*, *Paragus pollicaris*, and *Paragus annulipes* (Hermit Crabs, 2025). It was challenging to identify invertebrates to lower taxonomic levels compared to fishes. Since Ctenophores are only visible when they float directly in front of the metal of the BRUVS, and they are clear and mostly blurry when the current is fast, they are harder to accurately identify. Incomplete detection of ctenophores can lead to an undercount, especially in more turbid bays like Delaware. I recorded one ctenophore in HCS, but this does not mean more are not present. Additionally, it is difficult to identify the hermit crabs and snails since their distinguishing features are quite small and blurry. Overall, BRUVS are less useful for sampling these organisms in turbid environments,

such as in the coastal waters of the Mid-Atlantic bight. These shoal and soft-bottom habitats may be biologically rich, but hard to sample visually due to limitations in water clarity and organism characteristics (small, benthic, or transparent organisms).

The observed differences in species diversity, richness, evenness, and abundance between SBS and HCS suggest that environmental conditions (Grimmel et al., 2020) and methodological factors (Jones et al., 2021) shape our ability to quantify community composition using BRUVS. Brightness, our proxy for visibility and turbidity, significantly impacted the diversity, richness, and abundance of species, but this is most likely due to the fundamental role that water clarity plays on the ability of BRUVS to collect data. One can see and record more species if the video is more transparent, brighter, and less turbid (Cappo et al., 2004). Moreover, the distance to the estuary significantly impacted evenness. The closer the video is to the estuary, the more even the community, meaning the MaxN of each species recorded was about the same. This increase in evenness could be due to HCS being closer to the mouth of the estuary, which is known for more turbid conditions. Since we could not see things very clearly in Delaware, we recorded fewer species and fewer individuals of those species, which led to a more even community. Additionally, we found a significant relationship between species relative abundance and both temperature and brightness. In general, we observe more individuals of a species if the video is brighter, clarity is greater and temperature is higher. Depth, distance to shore, and distance to estuary showed no significant effect on species relative abundance, but this was most likely due to limited variation in these factors across sites and deployments. Physical habitat may not change much over small spatial scales (depth, distance), but visibility can alter perceived community composition.

When assessing BRUVS as a sampling method, there are many things to consider. After dropping the BRUVS, we will likely see no organisms for the first few minutes, likely because the initial disturbance from the frame entering the water causes nearby organisms to temporarily disperse. Once the bait settles and animals begin to detect its presence, organisms appear in the footage. As a result, all parts of a video do not necessarily have the same chance of recording organisms, which is a form of sampling bias. Another factor that likely influences our data is the tidal stage. Although tidal stage did not have a significant impact in this study, the movement of organisms are often influenced by the current. If there is a weaker current during slack tide, we will likely see more things due to reduced water movement, better visibility, and a more localized scent plume from the bait (Taylor et al., 2013). Additionally, organisms could be disturbed by the long-lining surveys while we deployed the BRUVS. Other studies reveal that species' first arrival times were quicker in areas that were closed to fishing (Coghlan et al., 2017). These areas likely experience less frequent human disturbance, so organisms may be less wary of anthropogenic disturbances such as a BRUVS deployment, making them more likely to approach the BRUVS quicker.

Longlines and BRUVS sample very different species, highlighting how the sampling approach influences the observed community composition (McLean et al., 2015). Several factors may explain these differences. Longlines use baited hooks resting on the seafloor, which may attract larger predatory species that actively seek out food. These animals need to be able to bite or swallow the bait and hooks, which are usually a few inches across. In contrast, BRUVS record marine life present in the area and those drawn to the bait, allowing for the observation of species that may not

interact with fishing gear. Additionally, BRUVS detect smaller organisms, such as snails and hermit crabs, that are unlikely to be attracted to or physically capable of biting the hooks used in longlines. These methodological differences show the importance of using multiple sampling techniques to more fully characterize the composition of marine communities.

Turbidity and brightness played an important role in this study. Because HCS was closer to the brackish water of the estuary, the turbidity was much higher, and in turn the brightness, our metric of visibility, was much lower. Lower water clarity led to an increased difficulty in identifying species on the BRUVS and an inability to identify an individual fish. We found lower estimates of species relative abundance (MaxN) in Delaware, but this does not necessarily mean diversity is lower. Turbidity is not necessarily driving community composition; rather, it influences what you can observe on the BRUVS. Brightness is not only an environmental covariate but a factor influencing the effectiveness of the sampling method. Another issue with turbidity was the inability to see the benthic community in Delaware, which directly impacted my ability to characterize the smaller and benthic species. However, turbidity may also impact what species are present in a given area. Brackish water is not suitable for species with a narrow salinity tolerance. Moreover, turbidity can alter community composition by reducing light penetration and increasing light scattering, ultimately impairing foraging ability of visually oriented predators (Lunt & Smee, 2019). This shift in foraging efficiency can lead to changes in the abundance of predators and prey, thus reshaping the community over time.

There were several other important methodological limitations in this study. One limitation was the difficulty in identifying species to low taxonomic levels. Some

species could be identified down to the species level, but for some, we were only 40-90% sure that the organism identified was the actual species seen. The uncertainty was due to problems with water clarity and small species. Additionally, in video 3, the camera was not positioned normally due to an anchoring issue. It dropped on its side, and the camera was facing upward. I could still see a shark and three fish swimming around the BRUVS throughout the video, but the field of view was different than the other deployments. Another limitation was the small sample size. I only watched four videos per bay, chosen randomly (about 8 hours of film). Some videos were on the same day, just hours apart, so there may be some pseudoreplication. Although all videos were recorded during the summer months, some were collected in different years, so interannual variability may also influence the results. If I could redo the experiment, I would watch more videos to compile more data, hoping to see stronger correlations between the covariates and biodiversity metrics. I would watch more videos in one season over the course of a few years or watch more videos over the course of one year to analyze changes in community compositions between seasons.

Overall, this study illustrates that the community variation between Sandbridge Shoal and Hens and Chickens Shoal observed is more likely to be shaped by methodological limitations than ecological factors. Brightness, the proxy for turbidity, was the most important predictor of biodiversity metrics, emphasizing the importance of visibility to species recognition in BRUVS. Both locations most likely supported benthic invertebrates and small fishes typical of Mid-Atlantic soft-bottom habitats, but the greater turbidity at HCS limited the detection and classification of animals. Shoal communities could be more diverse than BRUVS can report in turbid waters. In conclusion, this research demonstrates the utility and constraints of BRUVS in

describing marine communities and highlights the need for multi-method approaches and long-term datasets to understand soft-bottom habitats in the Mid-Atlantic.

This study poses several questions for future research. There may be temporal variations in species that we have yet to explore. Diversity and abundance could fluctuate with the seasons or times of day (Birt et al., 2012; Sherman et al., 2020). A long-term dataset might uncover patterns associated with migration or spawning. Other environmental factors could affect community composition. Analyzing sediment composition and patterns with a more advanced camera positioned at SBS would be beneficial. We could also examine other environmental drivers by utilizing additional instruments, including wind, nutrient availability, and oxygen levels.

Chapter 5

CONCLUSION

This study contributes to findings on the biodiversity and community composition of sandy shoal habitats in the Mid-Atlantic bight. By utilizing BRUVS, I found differences and similarities in community composition between two study locations (Sandbridge, VA and Hens and Chickens, DE). Smaller, invertebrate species were abundant in SBS, but harder to identify and class. There were significant effects of environmental covariates on biodiversity, particularly for brightness and proximity to the nearest estuary. Our findings suggest that water clarity plays an important role in what one can see on the BRUVS, limiting what can be detected and identified in very turbid environments. BRUVS are most useful in clear water, further from an estuary, where we can identify individuals at the species level. I also compared longlining to BRUVS, which had its own species composition with minimal overlap, indicating that we need to use multiple sampling methods to assess an area comprehensively. Overall, this study shows the complexity of assessing marine biodiversity and the need to find the best sampling method for each habitat to better understand and assess the factors influencing community composition and diversity.

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Appendix A

APPENDIX A

Table A1. Recorded parameters for BRUVS deployments, including video number, shoal location, date, latitude, longitude, temperature (°C), depth (m), distance from shore (m), and distance from estuary (m). SBS deployments are listed first, followed by HCS deployments.

Video	Shoal	Date	Latitude	Longitude	Temperature (°C)	Depth (m)	Distance from Shore (m)	Distance from Estuary (m)
1	Sandbridge	7/18/2022	36.707	-75.8327	25.6	15.9	8,548	32,381
2	Sandbridge	7/18/2022	36.707	-75.823	26.2	14.1	9,310	32,977
3	Sandbridge	7/19/2022	36.707	-75.8147	23.8	13.1	10,191	33,703
4	Sandbridge	6/28/2023	36.7506	-75.8593	23.1	14.5	7,647	27,342
5	Hens and Chickens	8/24/2022	38.691	-74.988	22.5	15.7	7,207	15,731
6	Hens and Chickens	7/25/2023	38.726	-74.997	24.4	10.8	6,880	12,035
7	Hens and Chickens	8/17/2023	38.733	-75.033	21.9	15.5	4,693	9,503
8	Hens and Chickens	8/17/2023	38.733	-75.024	21.5	11.5	3,903	10,133

Table A2. Brightness values were taken from Image J for 10 screenshots per video.
 The 10 values were averaged together to create one brightness value per shoal, which serves as a turbidity measurement. There are no units.

Video Screenshot	1	2	3	4	5	6	7	8
1	167.7	181.7	89.6	121.0	53.5	85.6	71.5	54.6
2	170.0	181.2	93.7	119.2	55.5	83.4	75.2	53.7
3	171.7	181.5	87.7	115.4	44.3	82.7	73.6	36.8
4	171.8	180.8	87.6	123.4	57.9	86.0	72.4	50.8
5	172.3	182.0	90.3	122.0	53.5	75.0	73.0	57.2
6	172.4	180.4	90.9	119.5	59.0	84.1	74.6	47.9
7	174.4	182.6	92.2	122.1	56.3	79.7	75.4	56.9
8	175.4	183.9	86.1	121.3	58.1	76.2	77.1	52.7
9	176.3	178.8	87.3	127.6	44.1	82.1	72.5	55.2
10	176.3	181.2	90.7	127.8	40.1	80.7	71.4	52.7
Average	172.8	181.4	89.6	121.9	52.2	81.6	73.7	51.9

Table A3. Summary of tidal conditions for each video recording, including location, tidal stage (ebb or flood), and whether the condition was classified as slack or non-slack.

Video	Shoal	Tidal Stage	Slack/Non-Slack
1	Sandbridge	Ebb	Non-Slack
2	Sandbridge	Flood	Non-Slack
3	Sandbridge	Ebb	Non-Slack
4	Sandbridge	Flood	Slack
5	Hens and Chickens	Ebb	Non-Slack
6	Hens and Chickens	Flood	Non-Slack
7	Hens and Chickens	Flood	Slack
8	Hens and Chickens	Ebb	Non-Slack

Table A4. Results of a 2-sample exact test comparing environmental covariates and biodiversity indices across tidal stages (ebb vs. flood) and slack conditions (slack vs. non-slack). P-values indicate the statistical significance of differences in brightness, depth, temperature, distance to shore, estuary, and biodiversity indices (Shannon, Simpson, richness, and evenness) using $\alpha = 0.05$.

Covariant/Metric	Tidal Stage	P-value ($\alpha = 0.05$)
Brightness	Ebb vs Flood	.486
Brightness	Slack vs Non-Slack	1.00
Depth	Ebb vs Flood	.686
Depth	Slack vs Non-Slack	.643
Temperature	Ebb vs Flood	.686
Temperature	Slack vs Non-Slack	.429
Distance to Shore	Ebb vs Flood	.886
Distance to Shore	Slack vs Non-Slack	.643
Distance to Estuary	Ebb vs Flood	.689
Distance to Estuary	Slack vs Non-Slack	.429
Shannon's	Ebb vs Flood	.486
Shannon's	Slack vs Non-Slack	.643
Simpson's	Ebb vs Flood	.486
Simpson's	Slack vs Non-Slack	.643
Evenness	Ebb vs Flood	.857
Evenness	Slack vs Non-Slack	.857
Richness	Ebb vs Flood	.543
Richness	Slack vs Non-Slack	.571

Table A5. Linear Regression of Environmental Covariates. Fit line was used in JMP to run a linear regression of x on y. Significant p-values are highlighted with $\alpha = 0.05$ and the corresponding regression equations and R^2 values for each pair of environmental covariates.

Environmental covariate (x)	Environmental covariate (y)	p-value	Line Equation	R^2
Temperature	Brightness	0.004	$20.62 + 0.0292x$	0.766
Distance to Estuary	Temperature	0.039	$21.16 + 0.0001x$	0.534
Distance to Estuary	Brightness	0.021	$23.55 + 0.0037x$	0.615
Distance to Shore	Temperature	0.029	$19.27 + 0.0006x$	0.578

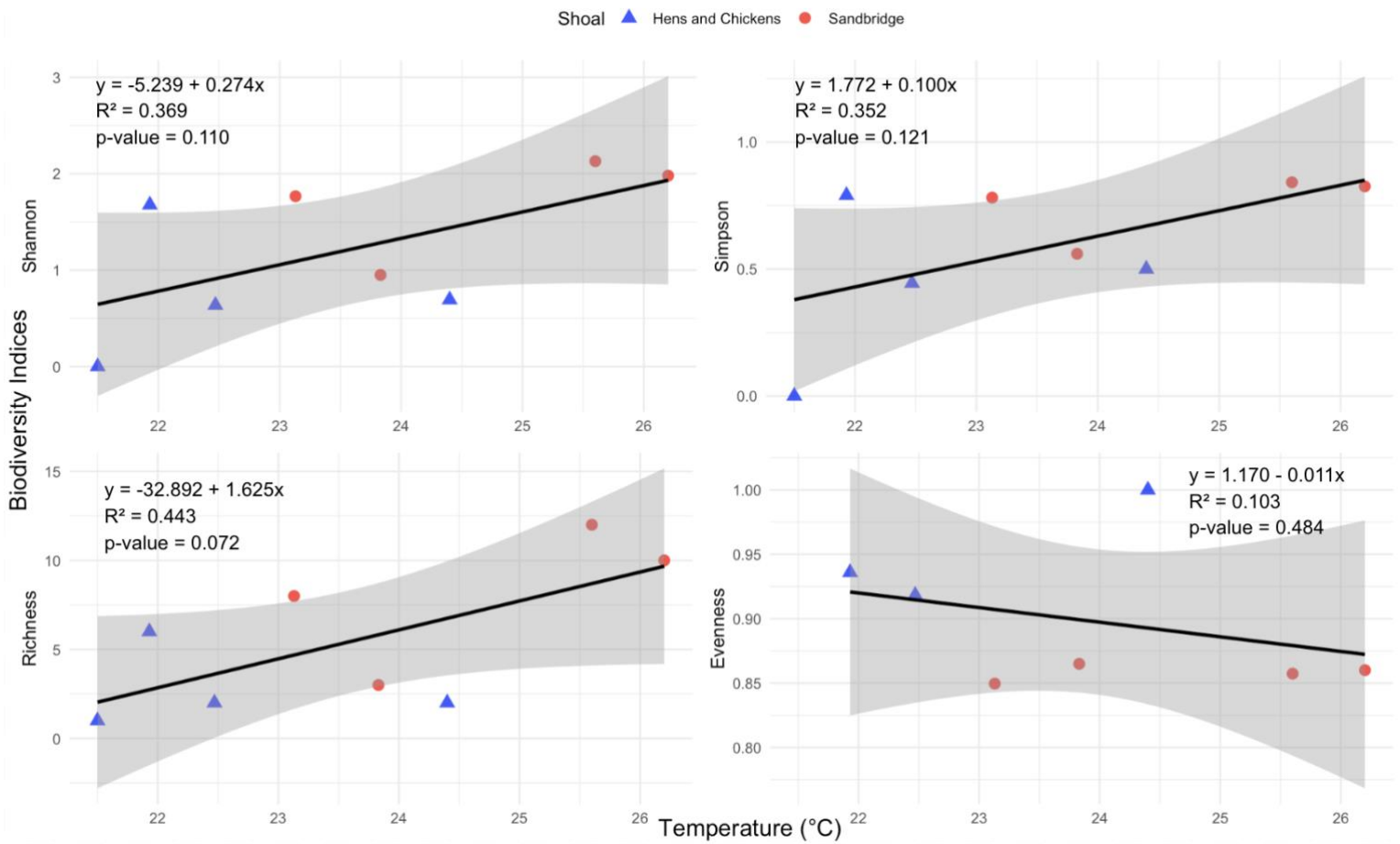


Figure A1. Relationships between temperature and biodiversity indices (Shannon, Simpson, Richness, and Evenness). Each panel shows a linear regression with the equation, R² value, and p-value ($\alpha = 0.05$). Black regression lines indicate trends, with shaded gray areas representing 95% confidence intervals. Red circles are from SBS, and blue triangles are from HCS.

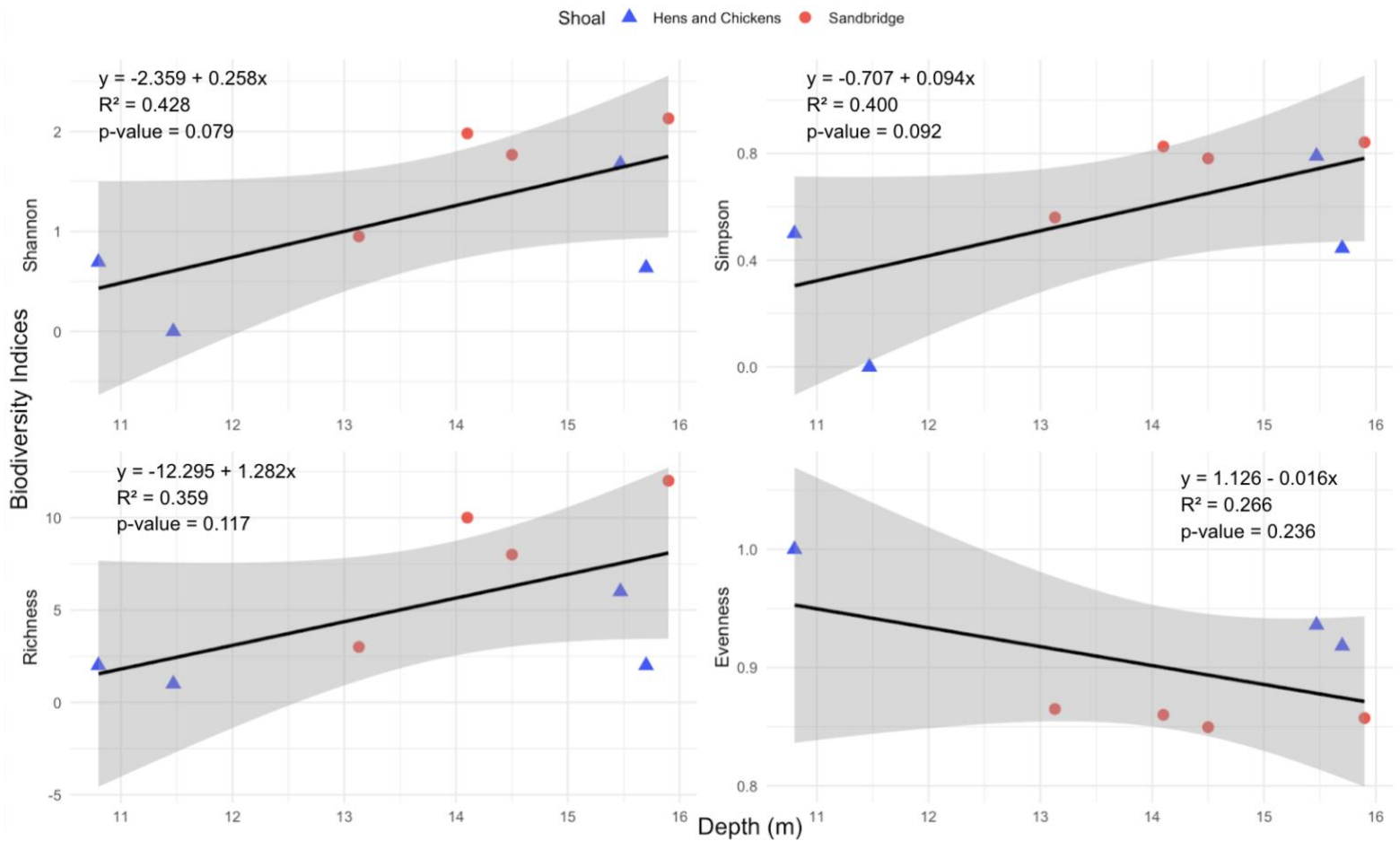


Figure A2. Relationships between depth and biodiversity indices (Shannon, Simpson, Richness, and Evenness). Each panel shows a linear regression with the equation, R² value, and p-value ($\alpha = 0.05$). Black regression lines indicate trends, with shaded gray areas representing 95% confidence intervals. Red circles are from SBS, and blue triangles are from HCS.

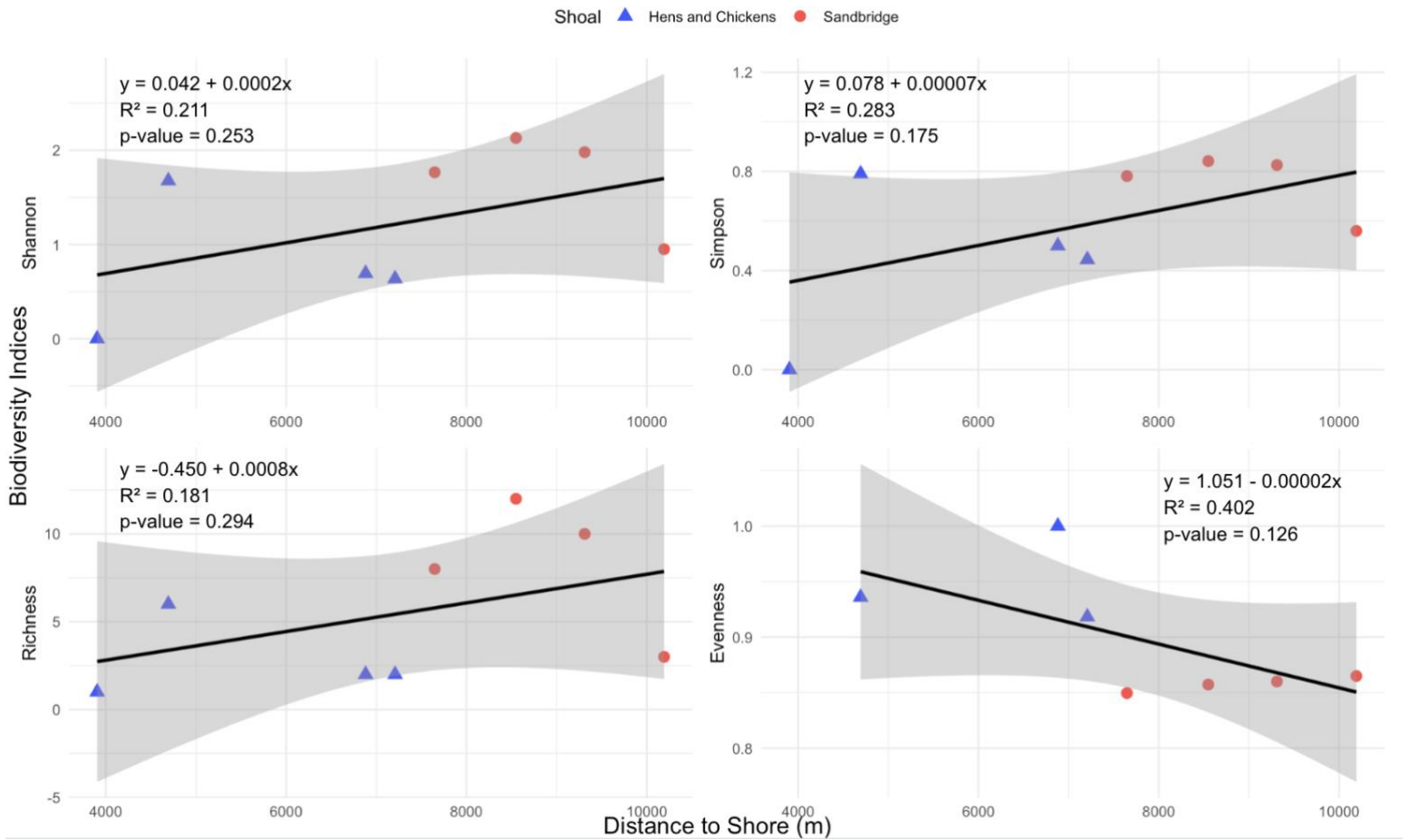


Figure A3. Relationships between distance from shore (m) and biodiversity indices (Shannon, Simpson, Richness, and Evenness). Each panel shows a linear regression with the equation, R^2 value, and p -value ($\alpha = 0.05$). Black regression lines indicate trends, with shaded gray areas representing 95% confidence intervals. Red circles are from SBS, and blue triangles are from HCS.