

Fine-scale Habitat Use, Abundance, and Size Structure of Mummichog (*Fundulus heteroclitus*) Within an Estuarine Tidal Creek of Southern New Jersey

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Abstract

Estuarine fishes are exposed to increasing environmental pressures associated with habitat modification, urbanization, and climate change, making it important to understand how species utilize habitats at fine spatial scales. The mummichog (*Fundulus heteroclitus*) is a highly abundant and environmentally tolerant small bodied estuarine fish that plays an important role in salt marsh food webs and ecosystem function. Despite its ecological importance, fine-scale habitat use within tidal creek systems remains less understood. This study evaluated microhabitat associations, seasonal abundance patterns, and size structure of *F. heteroclitus* within a tidal creek of the Mullica River-Great Bay Estuary in southern New Jersey. Minnow traps were deployed weekly across five habitat types differing in depth, edge vegetation, flow exposure, and structural characteristics. Catch per unit effort (CPUE) was used to evaluate relative abundance, while total length was examined as an indicator of size structure across microhabitats and seasons. Habitat characteristics were stronger predictors of abundance than broad seasonal patterns, with the shallow marsh pool consistently supporting the highest CPUE throughout the study. Exposed and deeper habitats supported fewer individuals, highlighting the influence of fine-scale habitat variation on distribution. Size structure also varied among habitats, with larger individuals more frequently captured in the marsh pool and shallow boat basin, while deeper marsh-edge habitat supported smaller individuals. Across seasons, individuals were generally largest during fall, consistent with expected growth patterns of young-of-year *F. heteroclitus*. These findings demonstrate that even highly tolerant estuarine species are influenced by localized habitat conditions and that microhabitat variation contributes to population structure at small spatial scales. The use of high-frequency, standardized sampling highlights the value of sustained monitoring for resolving spatial and temporal variability in estuarine fish populations and establishing ecological baselines against which future environmental change can be evaluated. Accessible and replicable sampling approaches may facilitate long-term monitoring of small estuarine systems where sustained intensive sampling can be difficult to maintain.

Introduction

Estuaries are biologically diverse ecosystems which provide a wide range of services to resident and transient organisms and to surrounding coastal communities (Crump & Brown, 2024). Essential functions include providing spawning and nursery grounds for numerous fish species (Able & Grothues, 2021), transitional zones to support complex food webs, and local economy support through productive recreational and commercial fisheries. Estuarine systems consist of a variety of microhabitats, including marsh pools, intertidal creeks, and human-made structures, that differ in their physical, biological and chemical characteristics. Seasonal and tidal fluctuations alter temperature, salinity, dissolved oxygen, nutrient availability, and hydrologic connectivity, producing heterogeneous environmental conditions that influence fish distribution and habitat selection (Able et al., 2012). Fine scale variation in depth, substrate, vegetation and hydrodynamic conditions create distinct microhabitats that can influence fish distribution, abundance, and community composition (Lippson & Lippson, 2006).

In the Mid-Atlantic region, the Mullica River-Great Bay estuary (MRGBE) is particularly notable due to its undeveloped nature (Lanthrop, 2003), support of diverse fish assemblages (Able & Fahay, 1998), and broad range of habitat types including salt marshes, tidal creeks, and shallow marsh pools (Kennish et al., 2004). Although salinity is a dominant driver of estuarine fish assemblage structure (Peterson & Ross, 1991), microhabitat characteristics also shape distribution within similar salinity regimes (Colombant et al., 2020). Establishing baseline patterns of fish abundance, distribution, and habitat use within relatively undisturbed systems such as the MRGBE is critical for detecting future ecological changes associated with coastal development, shoreline modification and climate driven shifts in estuarine conditions.

Fundulus heteroclitus (also known as the mummichog or killifish) is a dominant and ecologically important estuarine fish species that plays a significant role in salt marsh ecosystems (Kneib, 1986). Its distribution and abundance are influenced by fine-scale variation in microhabitat characteristics, including differences in marsh structure and environmental conditions (Able et al., 2012). As a trophic intermediate, *F. heteroclitus* links lower trophic levels by consuming small invertebrate prey and transferring energy to higher-level predators, including piscivorous fishes, birds, and crabs (Kneib & Stiven, 1982; Kneib, 1982). The species is among the most abundant and widely distributed fishes inhabiting salt marshes along the western Atlantic coast (Able & Hagan, 2003; Lister et al., 2011), with a geographic range extending from Newfoundland to Florida and along Gulf Coast waters from Florida to Texas (Bigelow & Schroeder, 1953).

Due to its high abundance, ease of collection, broad environmental tolerance, and well-documented ontogenetic habitat shifts, *F. heteroclitus* has become a valuable organism for estuarine ecological research (Able et al., 2006). *Fundulus heteroclitus* can tolerate substantial fluctuations in environmental conditions, including salinity and pH; populations can exhibit physiological differences in their ability to tolerate and recover from osmotic stress along salinity gradients (Whitehead et al., 2012), while individuals generally exhibit strong site fidelity, with most remaining within 5–36 m of their capture location (Lotrich, 1975; Burnett et al., 2007). Occasional movements of 300–475 m and rare dispersal events exceeding 1 km have also been documented (Able et al., 2006; Crum et al., 2017). Observed genetic differentiation among populations is consistent with limited movement and restricted gene flow at the habitat-type level (Wagner et al., 2017). Atlantic killifish populations along salinity gradients can differ substantially in their ability to tolerate and recover from osmotic stress, even without obvious barriers to gene flow (Whitehead et al., 2012).

The life history of *F. heteroclitus* is tied to multiple estuarine microhabitat types across seasons. Spawning occurs in spring and summer within intertidal areas that are periodically submerged during spring tides where females deposit eggs on marsh grass (*Spartina alterniflora*) and ribbed mussel shells (Taylor et al., 1979; Able, 1984). These eggs remain exposed to air until the next spring tide when hatching occurs upon submersion. Young-of-year fish spend much of their first summer in marsh pools growing to an appropriate size when they move into deeper tidal creeks and habitats (Able et al., 2006).

During this same period, mature individuals spend high tide foraging in flooded intertidal marsh habitats before retreating to deeper waters in pools and creek channels at low tide (Kneib and Wagner, 1994).

Habitat structure can also influence growth and productivity. During the fall individuals can be found in a wide range of habitats as general movement increases (Smith and Able, 1994). There is evidence that *Fundulus heteroclitus* individuals grow fastest along riprap, followed by intermediate growth along bulkhead, and lowest growth along *Spartina* and *Phragmites* marshes. *Spartina* and *Phragmites* may support the highest overall fish abundance and population level productivity, whereas bulkhead supports the lowest productivity (Crum et al., 2017). Juvenile *Fundulus heteroclitus* may occur at greater densities in *Spartina* dominated than *Phragmites* dominated habitats (Hagan et al., 2007). Vegetation type alone may not explain patterns of abundance, as mummichog distribution can also be influenced by other microhabitat characteristics (Able & Hagan, 2000). Individual growth and population-level productivity do not necessarily correspond across habitat types therefore artificial shorelines (without vegetation) may alter habitat quality in complex ways, potentially increasing local abundance in some cases while reducing habitat suitability and productivity.

Health and reproductive indices of *Fundulus heteroclitus* may be impacted by various environmental conditions (Fritz and Garside, 1974). Indices vary among estuaries and between sexes, demonstrating that local environmental conditions influence physiological conditions and complicate the use of these metrics as universal indicators of ecosystem health (Leamon et al, 2000). Despite extensive research on the life history and habitat use of *F. heteroclitus* throughout its range, fine-scale patterns of habitat use within mesohaline estuarine zones of southern New Jersey remain less understood. Prior research on the species in the region has focused on areas closer to the oligohaline zones near Little Egg Inlet, not small scale spatial variation within more mesohaline portions of the estuary such as Nacote Creek. Overwintering strategies appear variable among populations, with evidence supporting multiple seasonal movement patterns (Fritz and Garside, 1974). Fish may move from subtidal and intertidal creeks into marsh pools to overwinter (Smith & Able, 1994), while others move upstream into deeper creek habitats (Fritz and Garside, 1974; Raposa, 2003). There is support for both strategies, as fish may select upstream salt marsh pools for overwintering, where fine-grained, organic-rich sediments provide thermal refuges that maintain temperatures above lethal thresholds and supported sediment burrowing (Raposa, 2003). The strong site fidelity observed in *Fundulus heteroclitus* suggests that changes in local abundance may be driven more by mortality, recruitment, or habitat quality than by movement to alternative habitats (Rudershausen et al., 2019). Populations are closely associated with specific tidal creek habitats, therefore, degradation or loss of individual marsh systems may have direct consequences for local population persistence, highlighting the importance of maintaining particular salt marsh micro habitats.

The objective of this study was to examine the fine-scale microhabitat use of *Fundulus heteroclitus* within the Great Bay Mullica River Estuary (GBMRE), with particular emphasis on spatial and seasonal variation in abundance and size structure in Nacote Creek. Understanding how this highly tolerant species utilizes different microhabitats provides insight into habitat-specific ecological patterns and how these may shift in response to seasonal changes and increasing human development. This study

demonstrates the value of accessible, standardized sampling approaches for sustained, high-frequency monitoring of estuarine fish populations and the establishment of ecological baselines. We hypothesized that *F. heteroclitus* abundance and size structure would differ among microhabitats, with vegetated shallow marsh habitats supporting greater abundance and that seasonal changes in temperature and habitat accessibility would influence patterns of habitat use.

Methods

Study Site

The study was conducted in Port Republic, New Jersey at Stockton University Marine Field Station (SMFS) at 39.5349° N, 74.4632° W (WGS84) and an adjacent marsh pool. The SMFS is located approximately 18.5 km upstream from Little Egg Inlet along Nacote Creek. This location represents a tidal tributary within the Mullica River-Great Bay Estuary (MRGBE). This estuarine system remains relatively undeveloped with much of the surrounding land, including the Pinelands National Reserve, protected by government agencies (Kennish, 2004). Although the watershed is largely undisturbed compared to other watersheds of the region, localized anthropogenic modifications such as bulkheads and docks are present at the study site.

Sampling locations (referred to as stations) were selected based on microhabitat characteristics and accessibility. Five stations were established to represent distinct habitat types. Station 1 represented a creek-edge habitat characterized by pilings, bulkhead shoreline, and relatively moderate water depth. Station 2 was located within a shallow non-operating boat basin bordered by wooden bulkhead. If funding becomes available, there are plans to modify the area. Station 3 was positioned within the mid-creek channel off the edge of a dock. Station 4 represented a creek-edge habitat dominated by *Phragmites* with a more limited tidal range and shallower depth compared to Station 1. No physical barriers to fish movement existed between these closely spaced sampling stations. Station 5 was located within a marsh pool across the roadway from the main study area and was primarily dominated by *Spartina* with some *Phragmites* present. The 5 stations were located within a 317 m radius, with locations 1–4 within a 55 m radius as shown in Fig. 1.

Figure 1

Study Site and Sampling Stations

Procedure

Sampling of small-bodied estuarine fishes began weekly in August 2024 and remains ongoing. Fish were collected using un-baited conical ¼-inch galvanized wire mesh minnow traps deployed for up to 48 hours at each of the 5 sampling stations. Upon retrieval, catches were sorted, species were identified, and total

length was measured for up to the first 20 individuals of each species using a measuring board to the nearest 0.01 cm. Upon trap retrieval in situ water quality parameters, including temperature, salinity, pH, and turbidity, were measured using handheld instruments. Additional environmental variables were recorded during each sampling event. All data were reviewed for accuracy and entered into a centralized database for storage, management, and subsequent analyses. Although multiple species were captured, only *Fundulus heteroclitus* observations were included in the present study. The sampling protocol was adapted from the standardized fish and environmental monitoring procedures from Rutgers Marine Field Station (Vasslides et al., 2011).

Animal Use

Sampling protocols were approved by the Institutional Animal Care and Use Committee (IACUC) at Stockton University (Protocol #2024-025) and were conducted in accordance with institutional guidelines for the ethical handling of vertebrate animals. Methodology was designed to minimize stress and mortality of sampled fish, which resulted in some limitations to data collection. For example, the trap at location 5 was not deployed during periods of extreme heat to reduce mortality. Additional environmental constraints, including ice and flooding, occasionally limited site access and resulted in missed sampling events. Fish were collected under a scientific collection permit issued by the New Jersey Department of Environmental Protection, Division of Fish and Wildlife (Permit #2024 – 1833).

Analysis

This study analyzed approximately one year and four months of data collected during the initial monitoring period. All data processing and statistical analyses were conducted in RStudio (version 2025.09.2, build 418). Variables examined included abundance, total length (cm), water temperature (°C), and season. Abundance was standardized as catch per unit effort (CPUE), calculated as $\text{fish} \cdot \text{trap}^{-1} \cdot \text{h}^{-1}$, providing a relative index of abundance among sampling locations and time periods. CPUE has been previously used to characterize variation in *Fundulus heteroclitus* abundance and population patterns (Rudershausen et al., 2019). Calendar months were assigned to meteorological seasons as follows: winter (December - February), spring (March - May), summer (June - August), and fall (September - November) (Trenberth, 1983). This classification was appropriate for the study region because seasonal temperature patterns strongly influence estuarine conditions, with minimum water temperatures occurring during winter and maximum temperatures occurring during late summer. Total length was used as an indicator of size structure and evaluated among both habitat types and seasons.

Descriptive statistics were calculated and summarized by sampling station and season to characterize spatial and temporal patterns in abundance and size structure. Data normality was assessed using the Shapiro - Wilk test. Because the data did not meet assumptions of normality, nonparametric statistical approaches were used. Spearman's rank-order correlation was conducted to evaluate the relationships between water temperature, used as an indicator of seasonal variation, and both catch per unit effort

(CPUE) and total length. Differences in CPUE and total length were evaluated across stations and seasons using the Kruskal-Wallis test to assess variation among habitat types and temporal period. When significant differences were detected, Dunn - Bonferroni post hoc pairwise comparisons were performed to identify specific differences among groups, with all *p*-values adjusted using the Bonferroni correction.

Results

This study aimed to evaluate microhabitat use of *Fundulus heteroclitus* within a southern New Jersey estuary by assessing how abundance (catch per unit effort) and size structure (length) vary among microhabitats and across seasons. The abundance of *Fundulus heteroclitus* varied substantially among stations and across seasons with individual catches ranging between 0 to 227 individuals per sampling event. The number of sampling events varied between seasons and traps due to considerations of mortality and trap accessibility. A summary of total deployments and seasonal catches is provided in Table 1. In total, 264 sampling events conducted at five stations yielded 4,363 *Fundulus heteroclitus* (*N* = 4,363). The mean soak time for the traps was 40.29 hours (*SD* = 11.37) per deployment. Water temperatures varied by season and with air temperature. Water temperature values ranged from – 2 to 29°C with a mean of 16.75°C (*SD* = 6.58). Salinities ranged between 7ppt to 33ppt with a mean value of 18.97ppt (*SD* = 5.14).

Table 1
Number of trap deployments and total Fundulus heteroclitus captured by station and season

Station Number	Fall	Spring	Summer	Winter
	Deployments (<i>n</i> fish)			
1	28 (25)	12 (7)	16 (0)	5 (29)
2	28 (218)	12(130)	14(130)	5(100)
3	26(0)	12(0)	14(0)	3(0)
4	27(105)	12(11)	15(8)	5(10)
5	11(188)	7(139)	11(133)	1(20)
<i>Note.</i> Table listing number of sampling events (top) and number of <i>F. heteroclitus</i> caught (<i>n</i>) (bottom) per season. Station 3 was retained as a sampling location throughout the study because it represented a distinct mid-channel habitat, despite no <i>F. heteroclitus</i> being captured there during the sampling period.				

Substrate composition, vegetation presence, distance from the shoreline edge, amount and type of anthropogenic structure, and water depth varied among trap stations (See Table 2). Substrate composition across stations was predominantly characterized by soft mud sediments, with localized occurrences of shell material and accumulated organic detritus. Stations 2 and 5 were located in sheltered habitats with less tidal and flow exposure and relatively consistent bottom conditions. Station 5 contained accumulated organic detritus and was dominated by *Spartina alterniflora* vegetation along

the tidal edge, representing a shallow marsh pool habitat. Stations 1, 3, and 4 represented more exposed creek habitats with greater variation in depth and creek shoreline characteristics. Direct characterization was limited due to accessibility constraints. Mud sediment was frequently collected with trap retrievals, suggesting that soft-bottom habitats were consistent throughout sampling.

Table 2
Physical characteristics of sampling station microhabitats in Nacote Creek, New Jersey.

Station	Habitat Classification	Bottom Type	Depth (m)	Distance from Creek Edge (m)	Edge Attributes & Structure
1	Modified creek edge	Mud	~ 0.5 - > 2.5	9	Pilings/Wood Edge
2	Boat Basin/ artificial shoreline	Mud, Shell	< 0.5 - ~1.2	35	Boat Slip/Wood Edge
3	Mid-Channel creek	Mud	~ 1.7 - >2.5	18	Piling (mid-creek)
4	Vegetated creek edge	Mud	< 0.5 - ~1.9	9	<i>Phragmites sp.</i>
5	Marsh Pool	Mud, Detritus	< .5 - ~0.5	1	<i>Spartina alterniflora</i> (marsh pool), close proximity to asphalt roadway
<i>Note.</i> Table summarizes physical microhabitat characteristics recorded at each sampling station, including substrate type, depth range, distance from creek edge, and dominant shoreline or structural features.					

Water depth varied considerably among stations and temporally with tidal fluctuations. Stations 1 and 4 were located along creek-edge habitats and exhibited broad depth ranges associated with tidal variation. Station 1 ranged from < 0.5 m to > 2.5 m, while Station 4 ranged from < 0.5 m to approximately 1.9 m. Vegetation along the edge of Station 4 was dominated by *Phragmites sp.* Station 3 was positioned closer to the center of the creek channel and consistently exhibited greater depths, ranging from approximately 1.7 m to > 2.5 m. Stations 2 and 5 represented the shallowest habitats, consisting of a man-made boat basin and marsh pool, respectively. Water depth at Station 2 ranged from < 0.5 m to approximately 1.2 m, whereas Station 5 consistently remained shallow, ranging from < 0.5 m to approximately 0.5 m. Station 5 was bordered primarily by *Spartina alterniflora* vegetation and was located in close proximity to an asphalt roadway. These differences in depth and habitat structure provided a range of potential refuge, foraging, and overwintering conditions.

Sampling Effort and Catch

Sampling effort varied among stations and seasons due to site accessibility and animal welfare considerations (Table 1). Stations 1, 2, and 4 were sampled most consistently throughout the study period. Winter sampling at Station 5 was limited due to accessibility challenges, including flooding and ice conditions. A total of 4,363 *Fundulus heteroclitus* were captured during the study period. Total catch varied substantially among stations, with Station 2 yielding the greatest number of individuals ($n = 578$), followed by Station 5 ($n = 480$) and Station 4 ($n = 134$). Station 1 produced comparatively fewer individuals ($n = 61$), while no *F. heteroclitus* were captured at Station 3. Seasonal catches were generally greatest during fall and spring at Stations 2 and 5, whereas catches at Stations 1 and 4 remained comparatively low throughout the study period.

Catch Per Unit Effort

Catch per unit effort (CPUE) was used as a relative measure of fish abundance to account for variation in sampling effort among trap deployments and was calculated as the number of fish captured per hour. The mean CPUE across all traps was $0.431 \text{ fish} \cdot \text{hour}^{-1}$ ($SD = 1.07$). The weighted mean catch per trap was 0.063 for station 1, 0.862 for station 2, 0.000 for station 3, 0.060 for station 4, and 1.98 for station 5. There was a significant effect of station on abundance ($N = 264$, $\chi^2 = 127.29$, $df = 4$, $p < 2.2 \times 10^{-16}$) as shown in Fig. 2. There were several significant pairwise differences in abundance among stations. Station 1 ($M = 0.0468$, $SD = 0.201$) caught significantly less fish than station 2 ($M = 0.799$, $SD = 1.227$, $p < .001$) and station 5 ($M = 1.964$, $SD = 1.89$, $p < .001$). Station 2 caught significantly more fish than ($M = 0.799$, $SD = 1.227$) station 3 ($M = 0$, $SD = 0$, $p < .001$), and station 4 ($M = 0.079$, $SD = 0.221$, $p < .001$), and significantly less fish than station 5 ($M = 1.96$, $SD = 1.89$, $p < .001$). Station 3 ($M = 0$, $SD = 0$) caught significantly less fish than station 4 ($M = 0.079$, $SD = 0.221$, $p < .001$) and 5 ($M = 1.964$, $SD = 1.891$, $p < .001$). Station 4 ($M = 0.0797$, $SD = 0.221$) caught significantly less fish than station 5 ($M = 1.964$, $SD = 0.201$, $p < .001$). No significant differences were observed between station 1 and 3 ($p = .882$), between station 1 and 4 ($p = 1.00$), nor station 3 and 4 ($p = .069$).

Seasonal Catch Per Unit Effort

Abundance (CPUE) differed among sampling stations and across seasons (Table 3 and Fig. 3). Stations 2 and 5 consistently exhibited the highest CPUE values across the study period. At station 2, mean CPUE ranged from $0.446 \pm 0.587 \text{ fish} \cdot \text{h}^{-1}$ during summer to $2.03 \pm 1.52 \text{ fish} \cdot \text{h}^{-1}$ during winter. Station 5 exhibited high CPUE throughout the year, with mean values ranging from $1.58 \pm 1.41 \text{ fish} \cdot \text{h}^{-1}$ during fall to $2.27 \pm 0.846 \text{ fish} \cdot \text{h}^{-1}$ during spring. Stations 1 and 4 exhibited lower CPUE values, with most seasonal means below $0.15 \text{ fish} \cdot \text{h}^{-1}$. No individuals were captured at station 3 during any sampling event, resulting in CPUE values of zero throughout the study.

Table 3
Descriptive Statistics of Catch per Unit Effort (CPUE) Across Trap Stations and Seasons

Trap 1	Statistic	Winter	Spring	Summer	Fall
	n	5	12	16	28
	Mean ± SD	0.125 ± 0.121	0.0155 ± 0.0260	0.0 ± 0.0	0.0729 ± 0.366
	Median (IQR)	0.125 (0.167)	0.0 (0.262)	1.0 0.0 (0.0)	0.0 (0.0)
	Min–Max	0.0–0.292	0.0–0.0784	0.0–0.0	0.0–1.94
Trap 2	n	5	12	14	28
	Mean ± SD	2.03 ± 1.52	1.05 ± 1.48	0.446 ± 0.587	0.650 ± 1.20
	Median (IQR)	1.48 (0.354)	.333 (1.08)	0.104 (0.763)	0.0 (0.823)
	Min–Max	1.15–4.73	0.0–4.62	0.0–1.80	0.0–4.38
Trap 3	n	3	12	14	26
	Mean ± SD	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	Median (IQR)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Min–Max	0.0–0.0	0.0–0.0	0.0–0.0	0.0–0.0
Trap 4	n	5	12	15	27
	Mean ± SD	0.0417 ± 0.0255	0.0271 ± 0.0542	0.0129 ± 0.0400	0.147 ± 0.313
	Median (IQR)	0.0417 (0.0)	0.0 (0.0260)	0.0 (0.0)	0.0 (0.0312)
	Min–Max	0.0–0.0625	0.0–0.179	0.0–0.152	0.0–1.04
Trap 5	n	1	7	11	11
	Mean ± SD	1.85 ± n/a	2.27 ± 0.846	2.17 ± 2.77	1.58 ± 1.41
	Median (IQR)	1.85 (0)	2.29 (1.11)	1.29 (2.16)	1.17 (2.01)
	Min–Max	1.85–1.85	1.26–3.60	0.0–7.67	0.0941–4.54
Note. CPUE is a measure of abundance and was standardized by soak time.					

There was a weak but statistically significant negative association between water temperature and CPUE ($\rho = -0.1734$, $p = 0.0047$). It is important to note that no fish were caught at station 1 during the summer months.

Median CPUE values were frequently lower than corresponding means, particularly at stations 1, 2, and 4, indicating that catches were often dominated by a small number of sampling events with relatively high abundance. This pattern was particularly evident at station 2 during winter, where CPUE ranged from 1.15 to 4.73 fish·h⁻¹, and at station 5 during summer, where CPUE ranged from 0.0 to 7.67 fish·h⁻¹.

Variability in CPUE was greatest at station 5 during summer ($SD = 2.77 \text{ fish}\cdot\text{h}^{-1}$) and station 2 during winter ($SD = 1.52 \text{ fish}\cdot\text{h}^{-1}$), reflecting substantial variation among sampling events.

Significant seasonal variation in abundance (CPUE) was detected at station 1 $\chi^2(3, N = 61) = 18.09, p < .001$, and station 2, $\chi^2(3, N = 59) = 11.54, p = .009$. No significant seasonal differences were observed at station 3 ($N = 55$), station 4, $\chi^2(3, N = 59) = 6.38, p = .094$, or station 5, $\chi^2(3, N = 30) = 2.29, p = .515$. Seasonal differences in CPUE were significant at station 1. CPUE in fall ($M = 0.0729, SD = 0.365$) and summer ($M = 0, SD = 0$) were both significantly lower than in winter ($M = 0.125, SD = 0.120, p < .01$), while no other seasonal comparisons were significant (all $p \geq .10$). At station 2, CPUE in fall ($M = 0.649, SD = 0.1982$) was significantly less than winter ($M = 2.02, SD = 0.152, p = .013$), and there were significantly more fish caught in the winter as compared to summer ($M = 0.445, SD = 0.586, p = .039$), with no other significant seasonal contrasts for other stations (all $p \geq .42$).

Length

The weighted mean length per location was 5.10 cm for station 1, 6.60 cm for station 2, 6.09 cm for station 4 and 6.13 cm for station 5 as visualized in Fig. 4. There was a significant effect of location on length $\chi^2(3, N = 1,253) = 28.22, p < .001$. Individuals captured at station 1 ($M = 5.66, SD = 1.47$) were significantly shorter than those at station 2 ($M = 6.59, SD = 1.372, p < .001$), station 4 ($M = 6.31, SD = 1.710, p = .013$), and station 5 ($M = 6.439, SD = 1.580, p < .001$).

Seasonal Length

Fish length varied among stations and seasons as shown in Table 4 and Fig. 5. Mean length at station 1 ranged from 5.31 ± 1.19 cm during winter to 6.54 ± 1.60 cm during spring. Fish captured at station 2 were generally larger and exhibited relatively consistent mean lengths across seasons, ranging from 6.32 ± 1.06 cm during summer to 6.74 ± 1.41 cm during spring. Station 4 exhibited a noticeable increase in mean length during fall (6.53 ± 1.75 cm) compared to winter (5.06 ± 1.07 cm), spring (5.94 ± 1.50 cm), and summer (5.65 ± 1.34 cm).

Table 4
Descriptive Statistics of Length (cm) Across Trap Stations and Seasons

Trap 1	Statistic	Winter	Spring	Summer	Fall
	n	29	7	0	25
	Mean ± SD	5.31 ± 1.19	6.54 ± 1.60	0.0 ± 0.0	5.84 ± 1.59
	Median (IQR)	5 (0.90)	5.3 (2.55)	0.0 (0.0)	5.6 (1.50)
	Min–Max	3.2–9.2	5.1–9.5	0.0–0.0	3.7–9.7
Trap 2	n	100	130	130	218
	Mean ± SD	6.55 ± 1.21	6.74 ± 1.41	6.32 ± 1.06	6.69 ± 1.56
	Median (IQR)	6.6 (1.72)	6.8 (2.28)	6.35 (1.67)	6.8 (2.5)
	Min–Max	4.1–9.8	4.1–9.8	4.1–8.8	3.4–9.8
Trap 3	n	0	0	0	0
	Mean ± SD	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	Median (IQR)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Min–Max	0.0–0.0	0.0–0.0	0.0–0.0	0.0–0.0
Trap 4	n	10	11	8	105
	Mean ± SD	5.06 ± 1.07	5.94 ± 1.50	5.65 ± 1.34	6.53 ± 1.75
	Median (IQR)	4.95 (0.675)	5.5 (1.3)	5.55 (1.63)	6.6 (2.6)
	Min–Max	3.9–7.8	3.9–9.4	3.9–7.9	2.6–10.1
Trap 5	n	20	139	133	188
	Mean ± SD	6.56 ± 1.78	5.96 ± 1.49	5.79 ± 1.32	7.24 ± 1.42
	Median (IQR)	6.8 (3.37)	5.6 (1.85)	5.5 (1.7)	7.3 (2.02)
	Min–Max	4.2–9.3	3.1–11.8	3.3–9.9	2.2–10.5
Note. Length is captured in cm.					

Station 5 contained both high numbers of individuals and the largest fish observed during the study. Average length ranged from 5.79 ± 1.32 cm during summer to 7.24 ± 1.42 cm during fall. Average fall lengths were generally greater than those observed during other seasons across most stations. Length ranges were broad at several stations, particularly station 5 where fish ranged from 3.1 to 11.8 cm during spring and from 2.2 to 10.5 cm during fall. Station 4 exhibited a fall size range of 2.6 to 10.1 cm. These wide ranges likely reflect the presence of multiple size classes within individual habitats throughout the study period. It is important to note that variation in class sizes was beyond the scope of this study.

Results indicated no significant association between fish length (cm) and water temperature ($p = -0.193$, $p = .308$). Average fall lengths were significantly larger than spring, summer, and winter lengths for all locations. Significant seasonal variation in length was detected at station 2 $\chi^2(3, N = 578) = 8.37$, $p = .039$; station 4, $\chi^2(3, N = 134) = 10.04$, $p = .018$; and station 5, $\chi^2(3, N = 480) = 93.76$, $p < .001$. No seasonal differences were observed at station 1 ($p = .176$), station 2 ($p > .05$) and station 3 was excluded from analysis due to insufficient sample size ($n = 0$). At station 4 significant difference in length was observed between fall ($M = 6.52$, $SD = 1.749$) and winter ($M = 5.06$, $SD = 1.068$, all $p = .031$). At station 5, individuals captured in fall ($M = 7.24$, $SD = 1.41$) were significantly larger than those captured in spring ($M = 5.96$, $SD = 1.486$) and summer ($M = 5.78$, $SD = 1.324$, both $p < .001$).

Discussion

This study evaluated microhabitat use by *Fundulus heteroclitus* within an intertidal creek located in a southern New Jersey estuary. Spatial and seasonal variation in abundance (catch per unit effort; CPUE) and size (length) were examined across multiple microhabitats in Nacote Creek. Observations emphasize the role of local environmental conditions, including substrate composition, depth, vegetation, flow exposure, and habitat structure. Abundant and tolerant organisms such as *F. heteroclitus* may be especially important to monitor during periods of increasing urbanization and climate change, due to their large populations and ecological functions. This study addressed two primary questions: (1) how does abundance of *Fundulus heteroclitus* vary among microhabitats and across seasons, and (2) how does size structure of *Fundulus heteroclitus* vary among microhabitats and across seasons? The adaptation of an established, standardized sampling protocol provides a practical and replicable approach for sustained, high-frequency monitoring while facilitating comparisons of estuarine fish populations across study systems.

Microhabitat Variation and *Fundulus heteroclitus* Abundance

Habitat characteristics were stronger predictors of abundance than broad seasonal patterns. The marsh pool characterized with shallow water lined dominantly with *Spartina* grass (Station 5) consistently supported the highest abundance across the study period followed by the shallow boat basin with wooden bulkhead (Station 2). Among the marsh edge habitats, Station 4, characterized by a shallow natural edge with muddy substrate and dominated by *Phragmites* vegetation, supported the highest abundance of *Fundulus heteroclitus*, followed by Station 1, which consisted of deeper water adjacent to a man-made wooden bulkhead and pilings. Station 3, the deepest mid-creek location with greater water movement and similar structural features, yielded no *F. heteroclitus* captures throughout the study. Differences in depth, water flow, structure, vegetation and substrate may play a role in these differences. Deeper habitats with less vegetation generally exhibited lower abundance. The marsh edge habitats were used less consistently than the marsh pool or boat basin, however, fish may have utilized these habitats in ways that were not fully captured by the sampling design.

Fish abundance was not evenly distributed throughout the creek system, indicating that tolerance does not eliminate the importance of specific habitat requirements. Abundance patterns suggest that shallow habitats were highly preferred, particularly those associated with marsh vegetation and protected edges. The observed differences among stations separated by less than a few hundred meters demonstrate that fine-scale variation in habitat structure can influence population distribution. These findings emphasize the importance of considering microhabitat characteristics when evaluating habitat suitability.

Observations are consistent with previous studies demonstrating strong associations between *F. heteroclitus* and shallow marsh habitats, tidal creeks, and vegetated intertidal areas, where habitat structure and tidal connectivity influence habitat use (Teo & Able, 2003). Sheltered shallow habitats containing vegetation and complex structure may provide important refuge and foraging opportunities, particularly in environments where temperature, salinity, and dissolved oxygen fluctuate over short spatial and temporal scales. Individuals often exhibit site fidelity and remain associated with specific marsh and tidal creek habitats, suggesting that fine-scale habitat characteristics may influence distribution and persistence (Smith & Able, 1994). Marsh pools and other shallow-water habitats may serve as important refuges by reducing environmental stress and concentrating resources during periods of environmental variability. *F. heteroclitus* is considered a highly tolerant estuarine species capable of persisting across broad gradients of temperature, salinity, and dissolved oxygen. This tolerance does not eliminate the importance of specific microhabitat features that enhance survival and recruitment (Abraham, 1985; Nordlie, 2006). The ability to exploit variable estuarine environments, combined with high fecundity, likely contributes to the persistence of this species across dynamic coastal habitats (Wagner et al., 2017).

Microhabitat Variation and *Fundulus heteroclitus* Abundance Across Seasons

Seasonal variation influenced abundance and its effects were not consistent across all microhabitats. A weak but significant negative relationship between water temperature and abundance indicates that higher catch rates occurred during winter months. Significant seasonal differences in abundance were only detected at select trap locations, specifically those associated with marsh edge and shallow habitats. Certain microhabitats may be more sensitive to seasonal environmental changes while others function as more relatively stable throughout the year. This variability highlights the importance of considering both spatial and temporal scales. Seasonal effects may be mediated by highly specific habitat conditions. The marsh pool consistently supported the highest abundance of fish, unlike the other stations the abundance remained relatively high throughout all seasons. This suggests that the marsh pool functions as an important habitat through the year rather and may be an important habitat for multiple life history stages. The boat basin (Station 2) supported the second highest abundance and there was significantly greater winter abundance. The boat basin may also function as an overwintering refuge or aggregation area during cold periods.

Seasonal effects were present but less pronounced than the habitat differences. The absence of fish from station 3 represents the idea that habitat is avoided or used briefly. This highlights the importance of microhabitat characteristics in shaping fish distribution. The persistence of high winter abundance in both the marsh pool and boat basin suggests that overwintering habitat favored shallow, less turbulent protected habitats (Smith & Able, 1994). While marsh pools likely provide refuge through shallow water, vegetation, and resource availability, the boat basin may provide similar benefits through reduced flow, increased structural complexity from pilings and bulkheads, and protection from environmental fluctuations. These findings demonstrate that both natural and anthropogenic habitats can provide important seasonal refuge, particularly when suitable structural features are available. Variation among individuals in habitat use may further contribute to the persistence of *F. heteroclitus* across heterogeneous estuarine landscapes (Fritz and Garside, 1974).

Microhabitat Variation and *Fundulus heteroclitus* Size

Significant differences in fish size among stations suggest ontogenetic variation in habitat use within the creek system. On average, the smallest individuals were captured at the deeper marsh edge (Station 1), whereas the largest individuals were observed at the marsh pool (Station 5). The distribution of fish sizes among habitats suggests that different microhabitats may support distinct life stages, with larger individuals more commonly associated with some habitats and smaller individuals with others.

The marsh pool habitat (Station 5) was unique because it exhibited both the highest fish abundance and the largest individuals captured during the study. This habitat may provide favorable conditions for larger fish by offering refuge, stable environmental conditions, or abundant food resources. The marsh pool supported a broad range of size classes, suggesting that it may function as habitat for multiple life-history stages rather than exclusively as a nursery habitat. It may also function as an important seasonal refuge as evidenced by a relatively high winter abundance. The relatively large fish observed near the shallow marsh edge (Station 4) suggest these habitats may support larger individuals during portions of the year. The deeper marsh edge (Station 1) consistently supported smaller fish, while the shallow boat basin (Station 2) exhibited relatively consistent fish sizes throughout the study. These habitats may provide suitable conditions year-round. The observed spatial variation among stations separated by a relatively small geographic distance is consistent with previous research demonstrating strong site fidelity and localized habitat use in *F. heteroclitus* (Teo & Able, 2003).

Juveniles of *F. heteroclitus* are known to utilize shallow habitats as nursery areas, whereas larger individuals may occupy habitats that provide greater foraging opportunities, refuge, or reduced energetic costs. Habitat selection likely reflects tradeoffs among resource availability, predation risk, environmental stress, and habitat complexity. Consistent with previous research demonstrating ontogenetic shifts in habitat use (Able et al., 2006), the spatial differences in fish length observed among stations suggest that individuals may utilize different portions of the creek system depending on life stage. In this study, larger individuals were more frequently associated with the marsh pool and boat basin habitats, whereas smaller individuals were more commonly captured along the deeper marsh

edge. These patterns suggest that habitat use within the creek is structured not only by abundance and seasonal availability but also by the ecological requirements associated with different size classes.

Fine-scale differences in microhabitat characteristics may influence the distribution and persistence of multiple life-history stages within a relatively small geographic area. Although age structure was beyond the scope of the present study, total length provided a useful proxy for evaluating size-based habitat patterns. Future studies incorporating direct age determination methods, mark-recapture approaches, or validated age-length relationships would provide additional insight into recruitment patterns, habitat-specific utilization, and potential movement among habitats throughout the life cycle of *F. heteroclitus*.

Microhabitat Variation and *Fundulus heteroclitus* Size across Seasons

Across all stations, average fish length generally increased from winter through fall, consistent with expected seasonal growth patterns of young-of-year *Fundulus heteroclitus* (Smith & Able, 1994). The increase in length was most pronounced in the marsh pool (Station 5), while the shallow marsh edge (Station 4) exhibited a similar but less substantial trend. Average fish length in the shallow boat basin (Station 2) remained relatively stable throughout the year, although the largest average size was still observed during the fall.

These patterns indicate that seasonal growth and recruitment contributed to variation in size structure among habitats. Spring and summer recruitment resulted in the presence of smaller individuals, while continued growth throughout the growing season produced larger fall size classes. By fall, when young-of-year fish have completed much of their annual growth (Smith & Able, 1994), individuals may become more broadly distributed among available habitats. The larger individuals observed in the marsh pool (Station 5) and along the shallow marsh edge (Station 4) may reflect seasonal retention or movement of larger fish into these habitats.

Seasonal differences in size distributions also varied among habitats. The marsh pool (Station 5) exhibited the widest range of fish sizes during spring, whereas the shallow marsh edge (Station 4) showed the greatest size range during fall. The shallow boat basin (Station 2) maintained relatively consistent fish sizes throughout the year. These patterns suggest that some habitats supported multiple size classes simultaneously, while others were occupied by narrower portions of the population as seasonal growth and recruitment progressed.

Microhabitat Associations and Life History Patterns

Significant spatial and seasonal differences in length suggest that habitat use by *Fundulus heteroclitus* varies among size classes and changes throughout the year. Individuals captured during the fall were generally larger than those captured during other seasons, consistent with expected growth patterns of young-of-year individuals throughout the growing season (Smith & Able, 1994). Spatial variation in size structure suggests potential ontogenetic differences in habitat use, with smaller individuals occurring

more frequently in marsh-edge habitats on average, whereas larger individuals were more commonly associated with the boat basin and marsh pool. The marsh pool supported not only the largest individuals but also the widest range of fish sizes and the highest overall abundance. Although the marsh pool and boat basin differed in vegetation, both shared shallow, relatively sheltered conditions and consistently supported higher abundances than the marsh-edge habitats. These findings suggest that reduced water movement and shallow depth may be important habitat features influencing *F. heteroclitus* distribution, with vegetation likely providing additional benefits where present. Although originally constructed as a boat basin, its shallow depth precludes boat use. It functions as a manmade shallow embayment along the creek margin and is not representative of the deeper boat basins commonly associated with urban coastal development. Station 1, characterized by a deeper habitat adjacent to a wooden bulkhead and pilings, supported fewer *Fundulus heteroclitus* than Station 4, a shallower natural marsh-edge habitat. Both marsh-edge stations consistently exhibited lower abundance than the shallow boat basin and marsh pool habitats. No *F. heteroclitus* were captured at Station 3 throughout the study which was retained for comparison because it represented a distinct habitat type. Station 3 was the deepest location, experienced the greatest water flow, and was situated furthest from the marsh edge, providing an important contrast to the shallow, sheltered habitats that supported the highest abundances.

These findings support previous research demonstrating that fine-scale microhabitat characteristics influence the distribution and habitat use of *F. heteroclitus* within estuarine systems. Although this species is strongly associated with shallow intertidal habitats, previous studies indicate that *F. heteroclitus* can successfully utilize restored marsh environments when appropriate structural complexity and hydrological connectivity are maintained (Teo & Able, 2003). The apparent tolerance of this species to habitat modification should be interpreted cautiously. Habitat suitability is likely dependent on site-specific characteristics, including vegetation, habitat complexity, tidal access, and availability of suitable refuge areas.

Overall, *F. heteroclitus* exhibited significant spatial and seasonal variation in abundance and size structure among microhabitats, demonstrating that even within a relatively small geographic area, localized habitat conditions influence population structure. These findings contribute to a greater understanding of *F. heteroclitus* habitat use within mesohaline estuarine systems and provide a foundation for future studies investigating movement patterns, habitat connectivity, and overwintering ecology.

Abundance Patterns and Size Structure across Microhabitats and Seasons

An important outcome of this study was the apparent distinction between patterns of abundance and size structure. While abundance varied among microhabitats and showed some seasonal associations, size distributions were primarily structured by location rather than temperature. This suggests that processes influencing habitat occupancy, such as movement and aggregation, may differ from those

influencing size composition, which may reflect longer-term processes including growth, recruitment, and survival. Habitat characteristics influence where fish occur, while different ecological processes contribute to variation in abundance patterns and size structure.

Temperature exhibited a statistically significant but relatively weak relationship with abundance, suggesting that while seasonal environmental conditions may influence distribution and activity, temperature alone is unlikely to be the primary driver of habitat use. The lack of a relationship between temperature and length further suggests that seasonal environmental variation influenced abundance patterns differently than size structure. Size composition appeared more strongly associated with localized habitat characteristics and life-history processes. These results suggest that structural aspects of habitat, including proximity to marsh edge, water depth, vegetation, and degree of shelter from flow, may exert greater influence on microhabitat selection than season alone. Although temperature remains an important indicator of seasonal change, these findings reinforce the importance of considering multiple interacting environmental drivers when evaluating habitat use in estuarine fishes.

Previous Studies and Regional Context

The patterns observed in this study are broadly consistent with previous research demonstrating the importance of habitat characteristics in structuring populations of *Fundulus heteroclitus*. Much of the existing literature has focused on systems with stronger marine influence or was conducted several decades ago, limiting its applicability to contemporary estuarine conditions influenced by urbanization, habitat modification, and climate change.

By focusing on a southern New Jersey estuary and incorporating fine-scale spatial resolution, this study provides updated insight into habitat use within a region that has received comparatively less attention. The observed variability among microhabitats, combined with seasonal effects, suggests that fine-scale environmental heterogeneity remains a critical factor influencing fish distributions. The boat basin functions more like a shallow marsh habitat than a typical boat basin. This distinction is important because our findings suggest that this species preferentially uses shallow habitats over deeper waters. As urbanization continues and shallow marsh habitats are lost or altered, understanding how this species uses the remaining shallow environments will become increasingly important. These findings reinforce the importance of localized, contemporary assessments of habitat use, particularly in estuarine environments undergoing continued environmental change. *F. heteroclitus* are also an important bait fish that are routinely captured by recreational and commercial users, making standardized monitoring protocols particularly valuable for understanding how their populations respond to environmental change and human activity.

Study Limitations

Several limitations should be considered when interpreting the results of this study. Sampling relies on fixed trap locations, which may introduce potential bias associated with trap placement and capture efficiency. The boat basin can be isolated from the main creek channel during very low tides and restricted connectivity may have contributed to the observed abundance by influencing fish distribution

and movement. Catch here may be particularly relevant when considering the ecological role of human-made structures, as increasing urbanization may alter habitat connectivity and influence the distribution and abundance of estuarine fishes. The study design was not intended to directly quantify movement patterns therefore discussion regarding migration, habitat transitions, and overwintering strategies remain inferential.

Unequal sample sizes among stations and limited sampling events at certain locations may have reduced the ability to detect patterns, particularly related to fish size structure. These differences were largely due to variable environmental conditions that occasionally prevented sampling at specific locations. Although stations were located within a relatively small geographic area, results represent habitat use within this specific creek system and may not fully represent patterns across other estuarine environments.

Catch per unit effort (CPUE) was standardized based on trap deployment duration; however, variation in soak time may still influence capture rates. Galvanized minnow traps were used in this study, as they have been shown to produce higher catch rates than black vinyl-coated traps (Paradis et al., 2012). It remains unclear whether observed catch rates are influenced by differences in trap retention (i.e., fish escaping after entry) or by behavioral responses, such as attraction to or avoidance of traps containing higher densities of fish for this specific sampling approach.

Non-target species captured in the traps were not included in the present analyses. The presence of other organisms may influence mummichog catch rates through competition, predation, or other ecological interactions while also providing valuable information on community composition and biodiversity. The shallow marsh-edge site (Station 4) exhibited the greatest species diversity among all sampling locations, suggesting that this habitat may support a more diverse estuarine community.

Environmental variables were measured using handheld instruments rather than more advanced multiparameter sondes (e.g., YSI systems), which may limit the precision and temporal resolution of environmental measurements. Handheld monitoring provided a practical and cost-effective approach for repeated field sampling across multiple stations. Although several environmental variables were recorded during the study, only water temperature was included in the analyses.

An additional limitation involved summer conditions at the marsh pool habitat. During periods of elevated water temperature, increased mortality was observed within traps, resulting in the exclusion of trap deployments during these conditions according to established sampling protocols. *Fundulus heteroclitus* is highly tolerant of environmental stress and can utilize aquatic surface respiration and facultative aerial gas exchange during hypoxic or stressful conditions (Halpin & Martin, 1999; Burnett et al., 2007). Submerged traps may restrict access to the air-water interface and limit behavioral responses that reduce physiological stress, potentially increasing mortality during periods of elevated temperature. Although not directly assessed in this study, this mechanism provides a plausible explanation for observed patterns and warrants further investigation.

Future Directions and Broader Applications

Future studies should further evaluate how trap deployment duration influences standardized abundance estimates for this species and trap type. Longer soak times are generally assumed to increase fish catch by allowing more individuals to enter traps. Incorporating underwater video could provide valuable insight into fish behavior within and around traps, including rates of entry and exit, as well as predation among captured fish. These observations would improve understanding of how soak time influences catch rates and the accuracy of abundance estimates. These results may also influence CPUE estimates for this species and trap type, as well as have implications for stakeholders who capture *F. heteroclitus* for bait.

Movement-based approaches, including mark-recapture studies and telemetry, would provide additional insight into habitat connectivity and determine whether individuals remain resident within specific habitats or move among microhabitats seasonally. These approaches would be particularly valuable for directly evaluating proposed overwintering strategies, including whether individuals remain within local creek habitats or utilize marsh pools as seasonal refuges. Expanding sampling across additional microhabitats and estuarine systems, along with multi-year monitoring, would help determine whether observed abundance and size patterns are consistent across broader spatial and temporal scales or influenced by annual environmental variability. Future studies should also consider incorporating analyses of non-target species captured in traps. Examining community composition alongside mummichog abundance could provide additional insight into biodiversity patterns and potential ecological interactions influencing habitat use.

Future research should also examine the influence of additional factors, including but not limited to salinity, dissolved oxygen, water depth, vegetation density, tide, water flow and predator abundance, to better evaluate the mechanisms driving habitat selection. Comparing handheld measurements with higher-resolution environmental monitoring systems may also help determine how well some field-based measurements capture fine-scale environmental variability relevant to *Fundulus heteroclitus* habitat use.

This study highlights the importance of fine-scale spatial sampling for understanding estuarine fish ecology. The relatively low-cost and accessible sampling approach used here provides a framework that could be expanded across estuarine systems and potentially incorporated into collaborative monitoring efforts involving educators, citizen scientists, and other stakeholder groups. Improved understanding of CPUE methodology, including the influence of soak duration on catch rates, would further strengthen the application of this approach for long-term monitoring, particularly for those who use traps to capture killifish for bait or commercial purposes.

Conclusion

Fundulus heteroclitus abundance and size structure are influenced by fine-scale variation in microhabitat characteristics within a southern New Jersey mesohaline estuarine system. Individuals were not

distributed uniformly throughout subhabitats in the creek. Differences in depth, vegetation, substrate, flow exposure, and habitat structure contributed to variation in abundance among sampling locations, highlighting the importance of localized habitat conditions in shaping population patterns.

Size structure varied both spatially and seasonally, suggesting that habitat use changes among life-history stages and throughout the year. These findings emphasize that ecological tolerance does not eliminate the importance of habitat complexity and availability of suitable microhabitats. Understanding how abundant species respond to fine-scale habitat variation is increasingly important as estuarine systems experience pressures from urbanization, climate change, and habitat modification. The results provide a foundation for future studies incorporating movement-based approaches, long-term monitoring, sampling methodology, and expanded environmental measurements to further evaluate habitat connectivity and overwintering dynamics.

From an ecological perspective, these findings demonstrate that fine-scale habitat variation influences the distribution of *Fundulus heteroclitus* even within a relatively small spatial area. The importance of marsh pool habitats, particularly within the mesohaline region of the Mullica River-Great Bay Estuary, suggests these habitats may serve an important ecological role. Continued investigation of these habitats is important as estuarine systems experience increasing pressures from urbanization, habitat modification, and climate change.

Beyond advancing understanding of *F. heteroclitus* ecology, this study demonstrates the value of accessible monitoring approaches for estuarine assessment. The relatively low-cost methodology used here has potential applications for collaborative monitoring involving researchers, educators, students, citizen scientists, and other stakeholders such as recreational anglers who depend on healthy estuarine ecosystems and this species particularly as a bait source. Continued investigation of habitat use by abundant foundational species can improve conservation planning and support informed management of changing coastal environments.

Declarations

Conflict of Interest

The authors declare that there are no conflicts of interest to disclose.

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Author Contribution

B.G. contributed to the data analysis, preparation of tables and figures, and manuscript writing. D.C. maintained and conducted the experimental component of the study, contributed substantially to manuscript writing, and reviewed B.G.'s analyses and contributions. Both authors reviewed and approved the final manuscript.

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Data Availability

Data supporting the findings of this study are available from the corresponding author upon reasonable request. The complete dataset is not currently publicly available because it is part of an ongoing, long-term ecological monitoring program in which data collection and quality control are continuing. The dataset is therefore maintained as an active research dataset to ensure consistency in sampling, validation, and integration of future observations. Relevant data can be made available by the corresponding author upon reasonable request.

Data Availability

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

References

1. Able, K. W. (1984). Variation in Spawning Site Selection of the Mummichog, *Fundulus heteroclitus*. *Copeia*, 1984(2), 522–525. <https://doi.org/10.2307/1445207>
2. Able, K. W., and M.P. Fahay. (1998). The first year in the life of estuarine fishes in the Middle Atlantic Bight. New Brunswick: Rutgers University Press.
3. Able, K. W. & Hagan, S. M. (2000). Effects of common reed (*Phragmites australis*) invasion on marsh surface macrofauna: Response of fishes and decapod crustaceans. *Estuaries*, 23(1), 633–646. <https://doi.org/10.2307/1352890>
4. Able, K. W., Vivian, D. N., Petruzzelli, G., & Hagan, S. M. (2012). Connectivity among salt marsh subhabitats: Residency and movements of the mummichog (*Fundulus heteroclitus*). *Estuaries and Coasts*, 35(3), 743–753. <https://doi.org/10.1007/s12237-011-9474-4>
5. Abraham, B. J. (1985). *Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic)—Mummichog and striped killifish* (U.S. Fish and Wildlife Service Biological Report No. 82(11.40)). U.S. Army Corps of Engineers.

6. Burnett, K. G., Bain, L. J., Baldwin, W. S., Callard, G. V., Cohen, S., Di Giulio, R. T., ... Van Veld, P. A. (2007). *Fundulus* as the premier teleost model in environmental biology: Opportunities for new insights using genomics. *Comparative Biochemistry and Physiology Part D: Genomics and Proteomics*, 2(4), 257–286. <https://doi.org/10.1016/j.cbd.2007.07.002>
7. Fritz, E. S. & Garside, E. T. (1974). Comparison of age composition, growth, and fecundity between two populations each of *Fundulus heteroclitus* and *F. diaphanus* (Pisces: Cyprinodontidae). *Canadian Journal of Zoology*, 53(4), 361 – 269. <https://doi.org/10.1139/z75-047>
8. Hagan, S. M., S. A. Brown, and K. W. Able. (2007). Production of mummichog (*Fundulus heteroclitus*): Response in marshes treated for common reed (*Phragmites australis*) removal. *Wetlands* 27: 54–67. [https://doi.org/10.1672/0277-5212\(2007\)27\[54:POMFHR\]2.0.CO;2](https://doi.org/10.1672/0277-5212(2007)27[54:POMFHR]2.0.CO;2)
9. Halpin, P. M., & Martin, K. L. M. (1999). Aerial respiration in the salt marsh fish *Fundulus heteroclitus* (Fundulidae). *Copeia*, 1999(3), 743–748. <https://doi.org/10.2307/1447607>
10. Kneib, R. T. (1986). The role of *Fundulus heteroclitus* in salt marsh trophic dynamics. *American Zoologist*, 26, 259–269.
11. Leamon, J. H., Schultz, E. T., & Crivello, J. F. (2000). Variation Among Four Health Indices in Natural Populations of the Estuarine Fish, *Fundulus heteroclitus* (Pisces, Cyprinodontidae), from Five Geographically Proximate Estuaries. *Environmental Biology of Fishes*, 57(4), 451–458. <https://doi.org/10.1023/A:1007622822837>
12. Lippson, A. J. & Lippson, R. L. (2006). *Life in the Chesapeake Bay*. Johns Hopkins University Press.
13. Lotrich, V. A. (1975). Summer Home Range and Movements of *Fundulus Heteroclitus* (Pisces: Cyprinodontidae) in a Tidal Creek. *Ecology (Durham)*, 56(1), 191–198. <https://doi.org/10.2307/1935311>
14. Nordlie, F. G. (2006). Physiological responses and adaptations of fishes to altered salinity regimes. *Reviews in Fish Biology and Fisheries*, 16, 403–423. <https://doi.org/10.1007/s11160-006-9012-1>
15. Paradis, Y., Dupuch, A., & Magnan, P. (2012). Comparison of catch efficiencies between black and galvanized minnow traps. *North American Journal of Fisheries Management*, 32(3), 539–543.
16. Rudershausen, P. J., Hightower, J. E., Buckel, J. A., O'Donnell, M. J., Dubreuil, T., & Letcher, B. H. (2019). Survival and density of a dominant fish species across a gradient of urbanization in North Carolina tidal creeks. *Estuaries and Coasts*, 42(6), 1632–1653.
17. Smith, K. J. & Able, K. W. (1994). Salt-marsh tide pools as winter refuges for the mummichog (*Fundulus heteroclitus*), in New Jersey. *Estuaries*, 17(1B), 226–234. 1352572
18. Taylor, M. H., Leach, G. J., DiMichele, L., Levitan, W. M., & Jacob, W. F. (1979). Lunar Spawning Cycle in the Mummichog, *Fundulus heteroclitus* (Pisces: Cyprinodontidae). *Copeia*, 1979(2), 291–297. <https://doi.org/10.2307/1443417>
19. Trenberth, K. E., 1983: What are the Seasons?. *Bull. Amer. Meteor. Soc.*, 64, 1276–1282, [https://doi.org/10.1175/1520-0477\(1983\)064%3C1276:WATS%3E2.0.CO;2](https://doi.org/10.1175/1520-0477(1983)064%3C1276:WATS%3E2.0.CO;2).
20. Teo, S. L. H. & Able, K. W. (2003). Growth and production of the mummichog (*Fundulus heteroclitus*) in a restored salt marsh. *Estuaries*, 26(1), 51–63. <https://doi.org/10.1007/BF02691693>

21. U.S. Fish and Wildlife Service. (2019). *Ecological Risk Screening Summary: Mummichog (Fundulus heteroclitus)*. <https://www.fws.gov/sites/default/files/documents/Ecological-Risk-Screening-Summary-Mummichog.pdf>
22. Vasslides, J. M., Rackovan, J. L., Toth, J. L., Hagan, R., & Able, K. W. (2011). Metadata manual for fish and environmental records at the Rutgers University Marine Field Station.
23. Wagner DN, Baris TZ, Dayan DI, Du X, Oleksiak MF, Crawford DL. Fine-scale genetic structure due to adaptive divergence among microhabitats. *Heredity* (Edinb). 2017;118(6):594–604. doi: 10.1038/hdy.2017.6. Epub 2017 Mar 15. PMID: 28295034; PMCID: PMC5436028.
24. Whitehead, A., Roach, J. L., Zhang, S., & Galvez, F. (2012). Genomic mechanisms of evolved physiological plasticity in killifish distributed along an environmental salinity gradient. *Proceedings of the National Academy of Sciences*, 109(35), 14146–14151. <https://doi.org/10.1073/pnas.1207012109>

Figures

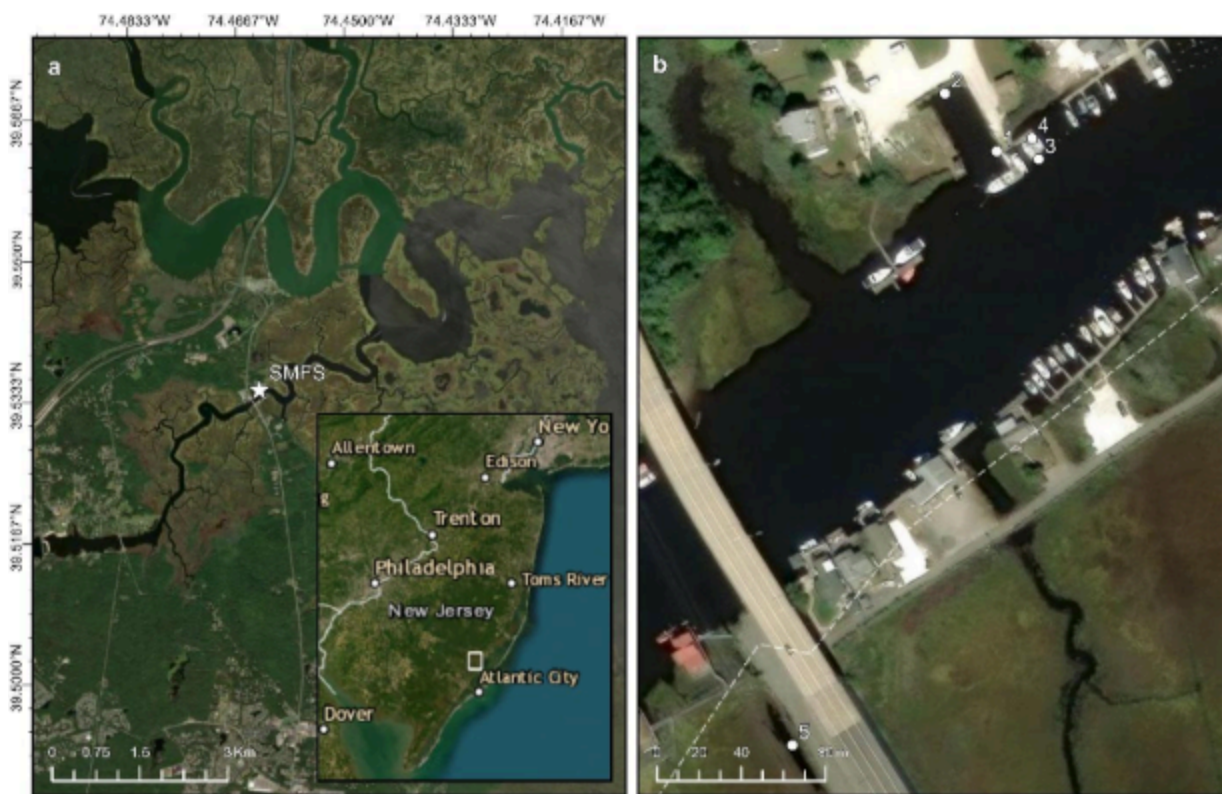


Figure 1

Study Site and Sampling Stations

Figure 1 Caption. Maps of study area and sampling design within the Mullica River-Great Bay estuary (a) Location of Nacote Creek within the estuary (b) Sampling design with stations 1 through 5 marked. These locations are where traps were placed.

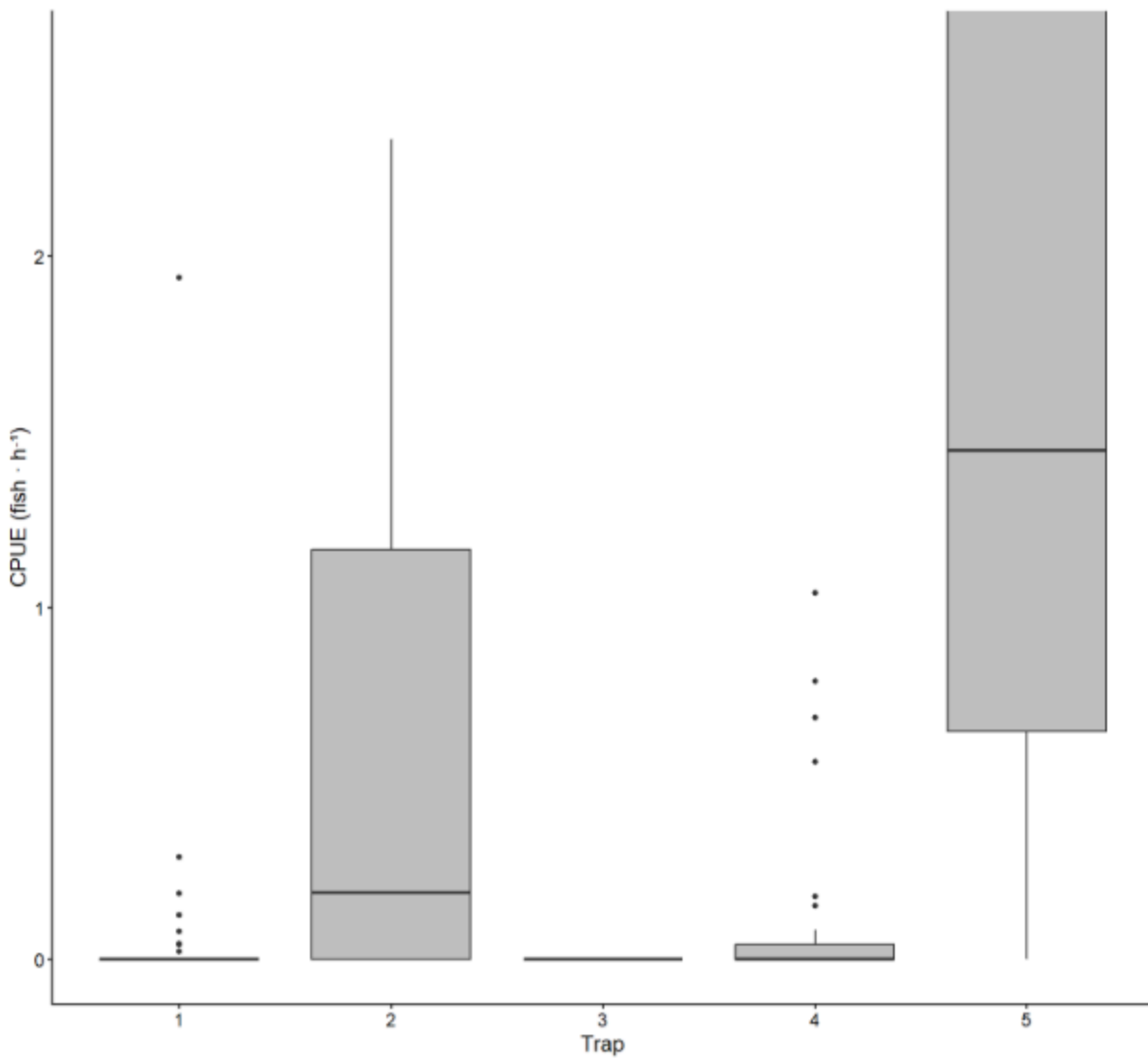


Figure 2

CPUE across Stations

Figure 2 Caption: Boxplot visualizing differences in 95th percentile of CPUE across all stations.

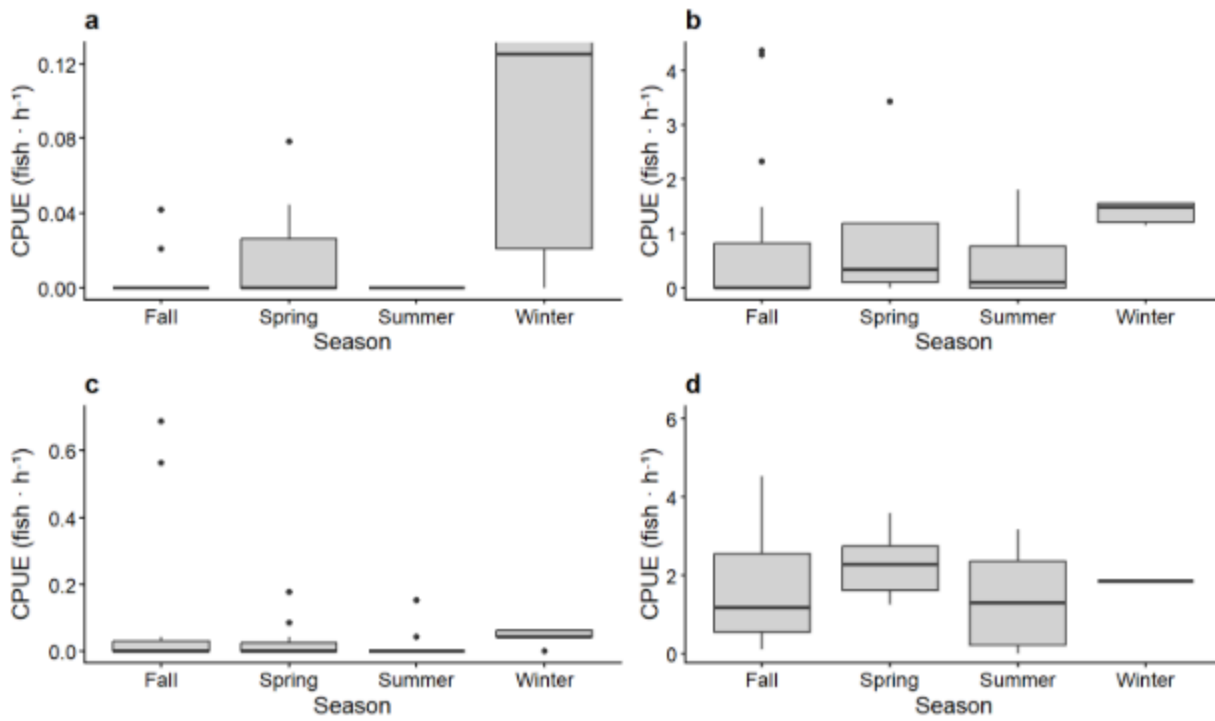


Figure 3

CPUE Across Station and Season

Caption Figure 3. Boxplots display seasonal differences in 95th percentile of CPUE among (a) station 1, (b) station 2, (c) station 4, and (d) station 5.

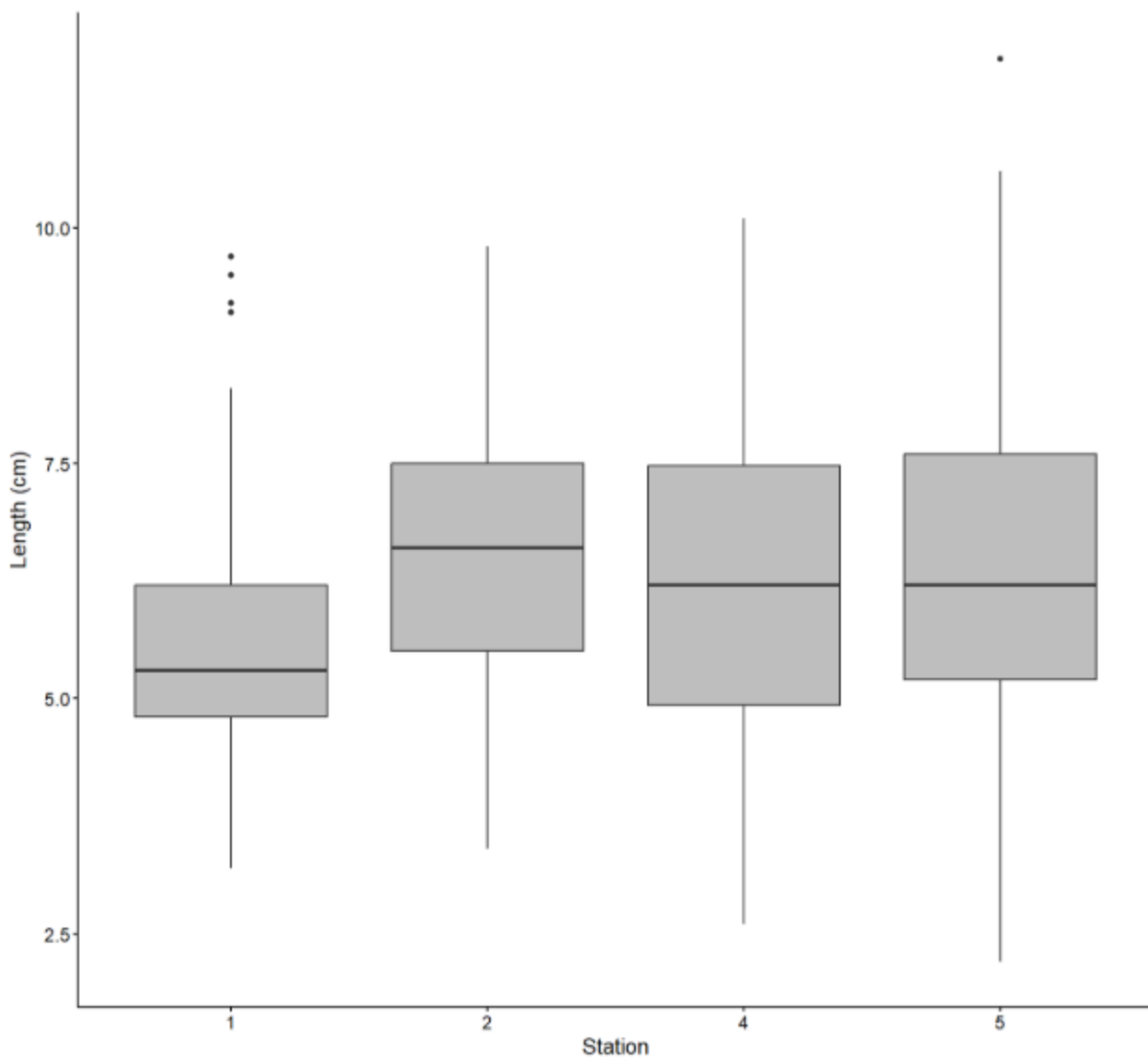


Figure 4

Length by Station Location

Caption Figure 4. Boxplot visualizing differences in fish total length between stations.

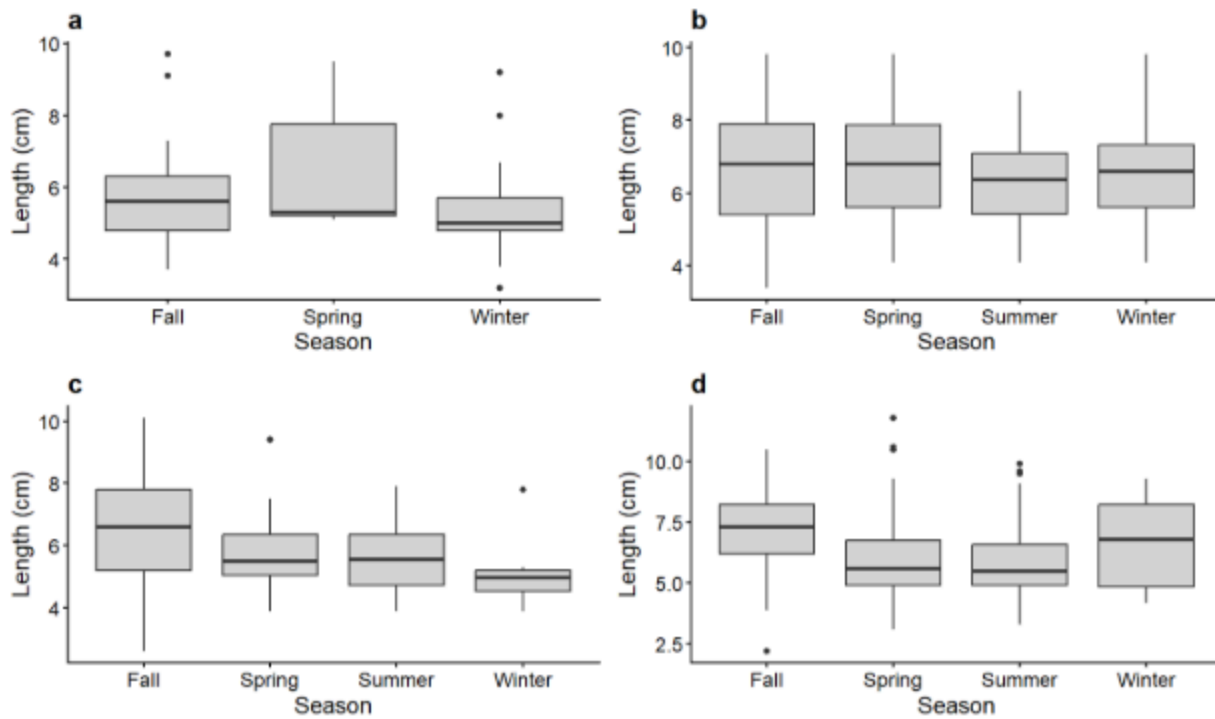


Figure 5

Length by Season and Station Location

Caption Figure 5. Boxplots displaying seasonal lengths between (a) station 1, (b) station 2, (c) station 4, and (d) station 5.