8-2007

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Final Report to U.S. Army Corps of Engineers

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Virginia Institute of Marine Science
Center for Coastal Resources Management
Gloucester Point, Virginia August 2007

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Grant Title: Lynnhaven River Shallow Water Fish Survey and Shoreline Inventory

Principle Investigators: DM. Bilkovic, M. Berman and D. O'Brien
Funding Agency: U.S. Army Corps of Engineers
Award Number: W91236-06-C-0065
Project Number: W26GLG62289765
Budget/Project Period: 09/12/06 - 09/11/07

Suggested Citation:

Bilkovic DM, D Stanhope and K Angstadt. 2007. Shallow Water Fish Communities and Coastal Development Stressors in the Lynnhaven River. Final Report to U.S. Army Corps of Engineers. Center for Coastal Resources Management, Virginia Institute of Marine Science, Gloucester Point, Virginia. 44pp.

Executive Summary

Coastal development pressures in the Mid-Atlantic have been attributed to significant negative impacts to aquatic ecosystems. The Lynnhaven River watershed, located in the southernmost extent of the Chesapeake Bay and encompassing Virginia Beach, is an example of a shallow-water tidal system under intense development pressure that is confronted with multiple and often conflicting coastal management issues. Rapid development in and around the City of Virginia Beach over the past few decades has led to the loss of natural buffers and habitat (e.g. oyster, wetlands and seagrasses), increased sedimentation, and degraded water quality. The Lynnhaven Ecosystem Restoration Project, led by U.S Army Corps of Engineers, is an effort to collaborate with State and federal partners over a 5-year period to identify and implement the most effective strategies for improving water quality, restoring oysters and seagrasses, and managing siltation.

Limited quantitative information exists on the nekton assemblages utilizing shallow water habitats, such as tidal creeks, within the Lynnhaven River restoration area. To document nekton composition, and to investigate potential effects of development stressors, such as dredging and shoreline modification, three sets of paired dredged and undredged tidal creeks were surveyed in the Western Branch of the Lynnhaven River. Fish communities were sampled with multiple gear types once per month for three months (August, September, October, 2006). Abundance, average length and weight, diversity, and fish community indices were estimated for each creek and time period, and dredged compared with undredged systems for resemblance in fish composition and abundance.

Tidal creeks within Lynnhaven Bay support diverse and similar fish communities. Slight differences in community structure among creeks may be attributable to the location and size of watersheds. The effects of dredging were not apparent in fish community responses measured as abundance, biomass, diversity, and fish community indices. However, anthropogenic effects may be obscured in the short-term by the background variability of physical and water quality features of Lynnhaven Bay estuary, and long-term or cumulative effects are not quantifiable due to the dearth of historic information on fish communities. Available historic information may indicate a shift in fish community structure that could be associated with coastal development pressures, such as shoreline alteration and habitat loss of wetlands and oyster reefs. Accordingly, restoration and preservation of critical nursery habitats may augment fish productivity in Lynnhaven Bay.

Introduction

Coastal development pressures in the Mid-Atlantic have been attributed to significant negative impacts to the ecosystem, such as pollution, commercial and recreational fishing, land-use changes, vegetation or habitat degradation, shoreline modification and dredging. Development affects aquatic resources in complex and diverse ways, severing land-water linkages and disrupting critical functions. Shallow water habitats, such as tidal flats, creeks and shallow subtidal bottom, positioned in the landscape at the land-water interface are highly susceptible to development stressors. These highly productive habitats are established essential nursery areas for nekton, providing protection from predators, and foraging opportunities for numerous fish, shellfish and crustacean species. This critical resource area is under intense and increasing pressure from a variety of uses and users and generally exists without an operative comprehensive management plan. The cumulative effects of development are rarely assessed and generally unknown.

Significant anthropogenic coastal stressors are shoreline and watershed development which have been shown to influence aquatic resources on a variety of levels and reduce ecosystem integrity. Shoreline development can directly affect local water quality and aquatic communities through the loss of intertidal habitat, changes in hydrology, increases in nutrient inputs, loss of allocathanous material, increased recreational use, and a loss of natural erosion control. Shoreline hardening has been shown to affect benthic or interstitial invertebrate communities (Kiffney 2004; Bilkovic et al. 2006a; Seitz et al. 2006; Storry et al. 2006), fish egg mortality (Rice 2006), predator abundances (Seitz et al. 2006) and fish community integrity (Beauchamp et al. 1994; Jennings et al. 1999; Bilkovic et al. 2005; Bilkovic et al. 2006b).

Watershed development can have far-reaching impacts on water quality and hydrology that may influence aquatic communities downstream from the actual site of disturbance. Changes in water quality due to development (such as increased nutrient and sediment loads) alter benthic invertebrate communities (Lerberg et al. 2000, Dauer et al. 2000, Bilkovic et al. 2006a). Other development stressors, such as habitat fragmentation and increased impervious surfaces, can affect fish populations (Scheuerell & Schindler 2004), and degrade marsh and riparian bird community integrity (DeLuca et al. 2004, Hennings & Edge 2003). Watershed land use has also been strongly related to levels of estuarine sediment contaminants, which affect the condition and biodiversity of estuarine benthic communities (Comeleo et al. 1996; Paul et al. 2002; Morrisey et al. 2003; Kiddon et al. 2003; Hale et al. 2004).

Coastal dredging, in particular in shallow water systems, commonly accompanies watershed and shoreline development. Impacts of dredging and dredged material disposal in coastal systems have been generally defined to include habitat removal, burial of benthos, increased turbidity, alteration to current patterns, sediment, water quality, salinity and decreased flushing (e.g. Morton 1977, Johnston 1981, Newell et al 1998, Wilbur and Clarke 2001). Whether these effects are intensified or vary in shallow water systems is uncertain. Typically, shallow systems are dredged to provide boat access and maintenance dredging is required to prevent siltation, thus potential acute impacts become chronic stressors in the ecosystem. Alterations to topography and bathymetry by dredging may change the accessibility of these systems and subsequently influence the interactions of biotic communities. Predators will have enhanced access to the systems that previously served as prey refuge habitat. Food sources will also be disrupted due to the direct physical impact of dredging causing reductions in the primary and secondary productivity of macrobenthic, microalgal, oyster reef, vascular plant communities (Johnston 1981).

Critical to understanding the long and short-term effects of dredging on aquatic communities is an approximation of their rate of recovery. Brooks et al (2006) noted that no consistent pattern of macrobenthos response to dredging was found in the literature. Rates of recovery are reported to vary in relation to sediment character, system size, and salinity. For instance, recovery is reported as faster for benthic assemblages in lower versus higher salinity habitats (e.g. oligohaline vs. euhaline), or those associated with fine-grained sediments versus coarse-grained sediments (Newell et al. 1998). Primarily, efforts have examined the effects on and recovery rates of macrobenthic communities from dredging. However, for higher trophic levels in small tidal creeks after the immediate exposure to physical dredging activity impacts is suspended (e.g. entrainment, elevated suspended sediments, noise level), the indirect effect of reduced prey availability may determine nekton distribution, so their recovery rates may track the recolonization of food sources.

Lynnhaven River watershed located in the southernmost extent of the Chesapeake Bay is an example of a shallow-water tidal system under intense development pressure that is confronted with multiple and often conflicting coastal management issues. The watershed, located in the City of Virginia Beach, covers 51,000 acres, or approximately 1/4 of the area of Virginia Beach. The Lynnhaven River has approximately 150 miles of shoreline. Rapid development in and around the City of Virginia Beach over the past few decades has led to the loss of natural buffers and habitat (e.g. oyster, wetlands and seagrasses), increased sedimentation, and degraded water quality. The Lynnhaven Ecosystem Restoration Project, led by U.S Army Corps of Engineers, is an effort to collaborate with State and federal partners over a 5-year period to identify and implement the most effective strategies for improving water quality, restoring oysters and seagrasses, and managing siltation.

Limited quantitative knowledge exists on nekton assemblages utilizing shallow water habitats, such as tidal creeks, within the Lynnhaven River restoration area. Fish surveys were completed in several tidal creeks, with varying development stressors, to document and compare common fish assemblages. To estimate potential dredging impacts, assemblages were compared between pairs of dredged and natural tidal creeks for resemblance in composition and abundance. Other stressors evaluated with fish assemblages were shoreline hardening and developed lands. The degree of shoreline modification, and developed riparian land use within the system was determined with a comprehensive coastal inventory of shoreline condition. The latter may be used as an indicator of shoreline disturbance and potential habitat degradation for both pelagic and benthic organisms.

Methods

Fish Community Surveys

Site Descriptions

Physical Characteristics

Three sets of paired dredged and undredged tidal creeks were surveyed from the Western Branch of the Lynnhaven River (Figure 1). The creeks were all located on the Eastern shore of the Western Branch with average salinity of 18-22 ppt. Lynnhaven River is located at the extreme southern end of the Chesapeake Bay draining directly into the Atlantic Ocean. Its shallowness and convoluted shoreline result in complex hydrodynamics, and it is characterized by extreme fluctuations in physical conditions. Biological communities must be adapted to tolerate exposures to intense and rapid shifts in condition. Variability in the tidal systems was illustrated with continuous water quality sonde measures in two of the creeks, for example, during the surveyed period (August-October 2006) salinity ranged from approximately 2-36 ppt.

Creeks 1 and 2 (designated North-undredged and North-dredged, respectively) were the northernmost tidal creeks in the Western Branch surveyed. Creek 1 is an unnamed inlet that is undredged and adjacent to the recently dredged Creek 2 (permited activity occurred in February 2006). These systems had the smallest drainage area of the three pairs (0.06 and 0.09 km^2, respectively). Based on the National Land Cover Dataset (NLCD 2001), North-undredged is located in a mixed land use watershed consisting of approximately 25% residential development, 20% forest, 29% barren lands, 16% pasture/hay/crops, and 11% wetlands. North-dredged watershed land use is also mixed with the highest percentages of forest (43%), 13% residential development, 15% barren, 18% pasture/hay/crops and 12% wetlands (Figure 2).

Creeks 3 and 4 are located near and within the Hebden Creek system (designated Hebden-undredged and Hebden-dredged, respectively). The undredged system (Creek 3) is a tidal creek with a 0.9 km^2 watershed draining into the mainstem of Hebden creek. Creek 4 is a dredged system (dredged ~ March 2000) adjacent to the mainstem of Hebden Creek that has a drainage area of 0.3 km^2. Hebden-undredged is located in a mixed land use watershed with approximately 28% residential developed, 6% barren, 39% forest, 17% pasture/hay/crops and 10% wetlands. Hebden-dredged watershed is predominately forested (53%) with 20% residential development, 7% barren, 12% pasture/hay/crops and 8% wetlands (Figure 2).

Creeks 5 and 6 were the southernmost systems surveyed and are located within Buchanan Creek (designated Buchanan-undredged and Buchanan-dredged, respectively). The undredged system (Creek 5) had the largest drainage basin of 4.9 km^2, while the dredged system (Creek 6) was similar in watershed area to Hebden Creeks (0.6 km^2). Of particular note, the Buchanan-dredged creek was on average shallower in depth than the undredged system, due to siltation since the time of dredging six years prior (~ July 2000). Buchanan-undredged watershed land use is predominately residential development (82%) with 2% barren, 7% forest, 5% pasture/hay/crops and 3% wetlands. Likewise, Buchanan-dredged watershed land use consists of 78% residential development, 2% barren, 12% forest, 6% pasture/hay/crops and 2% wetlands (Figure 2).

Shoreline Condition Inventory

Shoreline condition within Lynnhaven River Watershed was comprehensively inventoried with a protocol specifically developed for Virginia and Maryland coastlines which includes a method for collecting, classifying, mapping, and reporting conditions to assess riparian shorelines. Shoreline inventory protocols and results are outlined in detail in the ***Lynnhaven Watershed Shoreline Situation Report*** and associated webpage (http://ccrm.vims.edu/shoreline_inventories/virginia/lynnhaven/lynnhaven_disclaimer.html). The percentages of shoreline land use types (developed, forested, grass, scrub-shrub), hardened structure (bulkhead, riprap revetment, dilapidated bulkhead, unconventional and debris) and marsh (fringe, extensive, and invasive *Phragmites australis*) were summarized for each of the six surveyed tidal creeks.

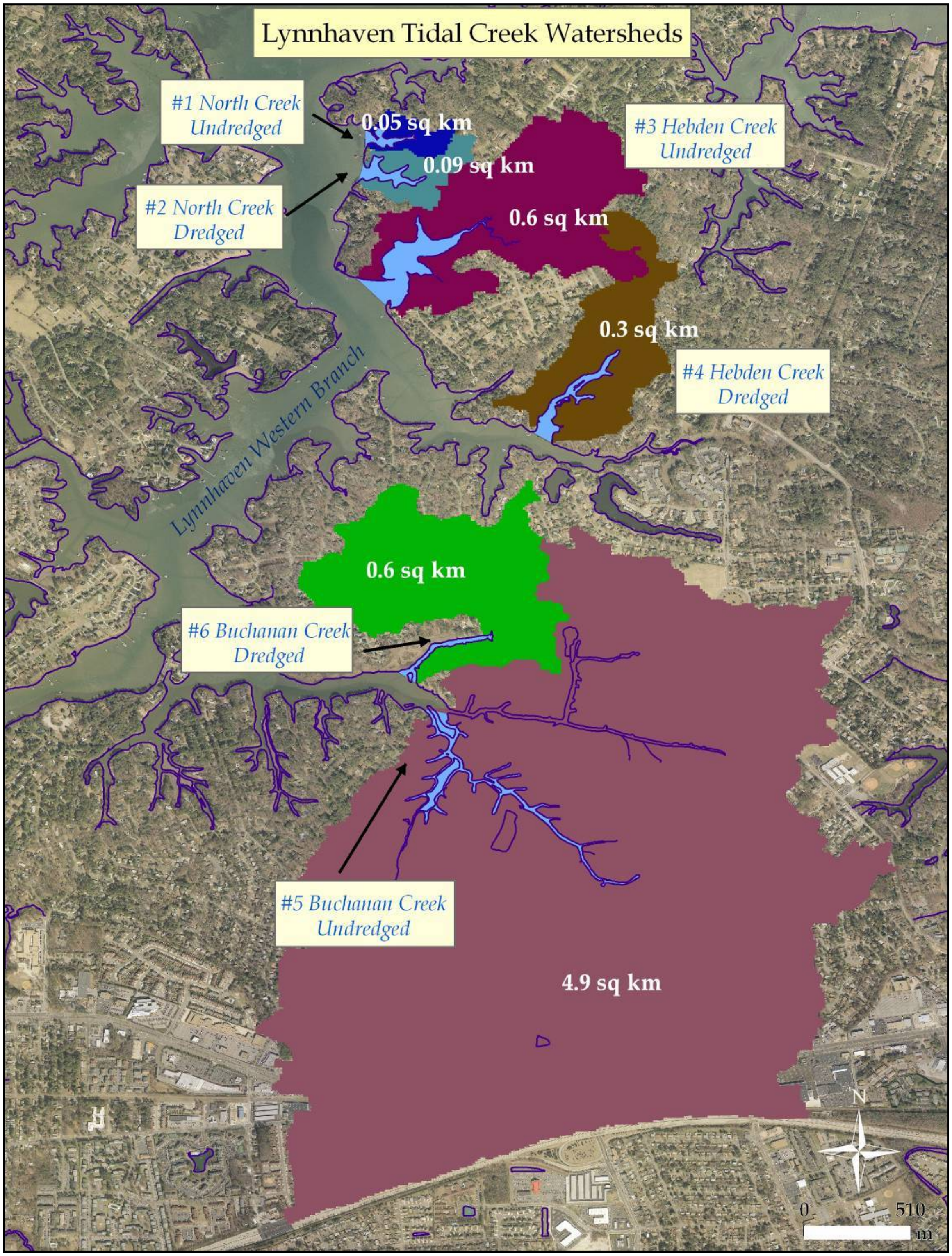

Figure 1. Lynnhaven tidal creek drainage boundaries and areas.

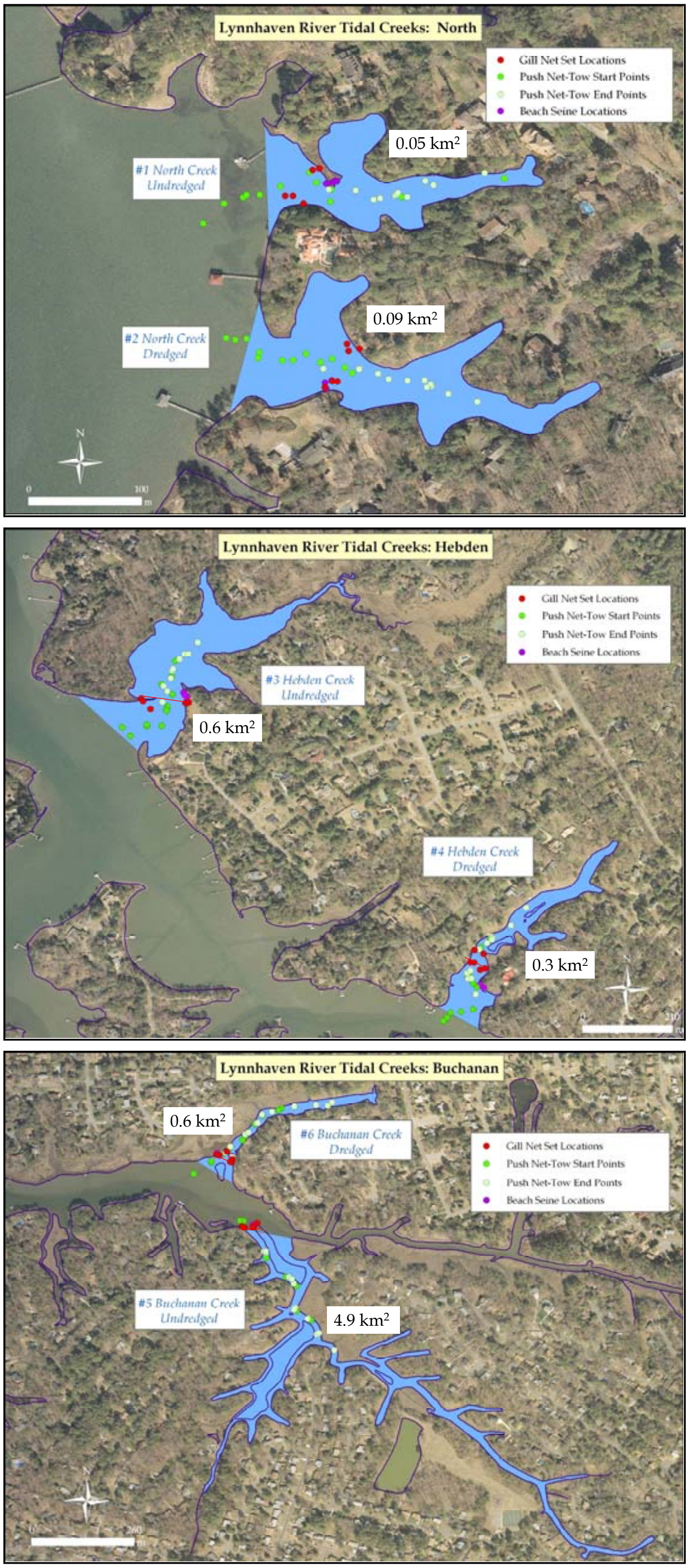

Figure 2. Survey locations for the three tidal creek systems: North, Hebden and Buchanan

Sampling Protocol

Fish communities were sampled with multiple gear types (gill net, beach seine and push net) once per month for three months (August, September, October) in 2006. Each gear type selects for various components of fish communities utilizing tidal creek habitat. Experimental gill nets had five panels of varying mesh size to target juvenile to adult fish, beach seines select for nearshore juvenile species, and push nets selectively capture small pelagic nekton. Monthly sampling occurred during 8-17 August, 18-21 September and 16-19 October 2006. Alternate survey methods were utilized in an individual creek on separate days only, for example gill nets might be deployed on the first sample date and push net hauls conducted in the same creek on the second sample date to reduce potential disturbance.

Gill nets were deployed on high ebb tide and extended across the creek mouth to block fish passage; nets were retrieved at low tide (approximately 2-3 hour sets). Each monofilament gill net (38 m long X 2.4 m deep) consists of 5 panels that are 7.6 m in length with the mesh sizes: 25.4 (#4 twine size), 38.1, 50.8, 63.5, 76.2 (#6 twine size) mm. An additional block net was necessary in Hebden-undredged creek in order to obstruct the entire creek mouth, data from capture on the auxiliary wing net were not included in analyses.

Push net hauls were conducted with a bow-mounted net of 1.83m wide X 0.6m high X 3.7 m in length. Funnel 2.4 m in length (6.4 mm delta) with 1.2 m long cod end (3.2 mm delta). Funnel mouth opening to cod end is 508 mm in diameter. The push net was attached to a frame, and cod end cinched closed with rope. Four replicate hauls were conducted in each tidal creek during monthly sampling events. The area of the net mouth was 1.83 m wide X 0.6 m high = 1.098 m^2, and the volume of the tow was determined by multiplying the area of the net by the distance towed (based on flowmeter revolutions).

Two beach seine replicate hauls (30.5 m x 1.22 m bagless seine of 6.4 mm bar mesh) were conducted near the mouth of each creek, and the volume of the haul was estimated by area (0.5 X bh = 0.5 X (distance of seine X distance of seine)) * maximum depth. One end of the seine was held on shore or as close to shore as possible. The other was fully stretched perpendicular to the shore and swept with the current over a quarter circle quadrant. Ideally, the area swept was equivalent to a 729 m^2 quadrant. When depths of 1.22 m or greater were encountered, the offshore end was deployed along this depth contour. After encircling an area the mouth of the seine was closed by crossing over the lead lines of each wing of the net. The seine was slowly hauled closed and the lead line continually checked to ensure contact with the bottom.

Fish captured were enumerated, measured (total length), weighed (subset of 25 individuals) and released, and select crustacean species enumerated. At each sample event, auxiliary data were collected, including dissolved oxygen, salinity, conductivity, pH, turbidity, tides, air and water temperature, and wind speed. Two dedicated water quality YSI sondes were placed in Buchanan dredged and undredged creeks for the entire survey period (August-October) to record dissolved oxygen, salinity, conductivity, pH, turbidity and temperature continuously. Precipitation data were obtained from *Wunderground.com,* Station KVAVIRGI14 located at the North end of the Beach in Virginia Beach, Virginia (Lat: N 36° 51' 57 '' (36.866°); Lon: W 75° 59' 47 '' (-75.996°). Precipitation were measured and recorded with Rainwise MK III hardware and Weather View 32 v60 software. Three sediment samples were obtained along an upstream-downstream transect from each system in the littoral zone and assessed for grain size and organic content.

Data Analyses

Fish community data were examined temporally and spatially. Replicates were pooled and data with combined gear type captures were used to describe the overall fish community makeup in each tidal creek. While no gear can inclusively sample every habitat or life-stage of fish species, the combination of gear types allowed us to relatively characterize predator and prey use of the tidal creeks during the period surveyed. Abundance, average length and weight, diversity, and fish community indices (FCI) were estimated for each creek and time period (August, September or October).

Fish Community Index

The fish community index (FCI) was developed and applied previously in the nearshore estuarine environs of the Chesapeake Bay (Bilkovic et al. 2005) to indicate biotic integrity. In the Lynnhaven River, the FCI was utilized to assess relative measures of fish community structure and function. The FCI consists of several metrics that represent key aspects of fish community integrity, as well as the elements of life history that are dependent on estuarine condition. To estimate each metric, fish species were initially placed into several guilds based on their documented life histories. Guilds were constructed based on reproductive strategy, trophic level, primary life history, habitat preference, and origin. Primary sources of life history information included Lippson and Moran (1974), Hardy (1978), Jenkins & Burkhead (1994), and Murdy et al. (1997). Metrics reside in four broad categories: taxonomic richness and diversity, abundance, trophic composition (Bilkovic et al. 2005, Table 1). For each site, individual metric values were calculated based on observed species composition and abundance in 2006.

Table 1. Fish community metrics assessed for use in a multimetric index

Fish Community Metric	Description
Species Richness/Diversity	
Species Richness	No. of species -1/log(abundance)
Proportion of benthic-associated species	No. of benthic-associated species/Total No. of species
No. of dominant species	No. of species that make up 90% of total abundance
No. of resident species	No. of estuarine resident species
Abundance	
Ln Abundance	Natural log of abundance
Trophic Composition	
Trophic Index	Relative proportions of three broadly-defined trophic guilds based on primary prey items: carnivores, planktivores, and benthivores (scaled to 5)
Nursery Function	
No. of estuarine spawning species	No. of species that predominately spawn in estuarine systems
No. of estuarine nursery species	No. of species that utilize estuarine systems as nursery habitat

Metric analyses

Abundance was normalized with natural logarithms. All other metrics had normal distributions and were not transformed. Individual metrics were standardized based on each metric distribution and aggregated, without weighting, into a Fish Community Index (FCI) score. For example, each species richness metric value was divided by the largest observed richness measure to standardize values (0-1) based on existing conditions for the year (no reference condition was considered); standardized metrics were then added to obtain the aggregate Fish Community Index.

The applicability and variability of metrics were assessed by calculating correlation coefficients for metric scores, and examining principal component analysis (PCA) coefficients of the metrics. Principal component analysis was applied to individual fish community metrics to evaluate the usefulness of the multi-metric index (FCI) as a descriptor of ecosystem integrity. Those metrics that are supported in a multi-metric index should exhibit similar associations. Metrics that exhibited similar trends in correlation with the aggregate FCI of all eight tested metrics were combined into a final FCI by summing standardized individual metric values.

Nekton and habitat comparisons
Relationships among nekton community measures (abundance, biomass, size, diversity. FCI) and tidal creek characteristics (dredged/undredged, location, month sampled, and shoreline condition) were examined with univariate (one-way analysis of variance), and multivariate (hierarchical cluster analysis, multi-dimensional scaling, and analysis of similarities) methods.

<u>Univariate Analyses</u>
Initially, individual gear type and monthly data were combined to assess the overall community structure in each creek for the entire survey period. Comparisons of average abundance, biomass, size, diversity, and fish community indices among sites were completed with one-way ANOVA. Abundance and biomass were log-transformed to meet normality requirements. Since survey gear in combination targeted both adult and juvenile life stages, average size estimates were anticipated to be similar among creeks when composite data were examined. Examining gear types independently reduces the variability in the size-structure of the community represented, for example beach seine collections selective targets juvenile and small adult fishes. Likewise, select common species from individual gear types were examined for size-related differences among creeks. Length data were log-transformed to make distributions normal prior to analyses.

<u>Multivariate Analyses</u>
Nearshore nekton community similarities among creeks were examined with hierarchical cluster analysis, nonparametric multidimensional scaling (nMDS) and analysis of similarities (ANOSIM) in PRIMER 6.0. Prior to the MDS ordination and hierarchical cluster analysis, species abundances were square-root transformed to moderately downweight the affect of dominant species, and a bray-curtis coefficient was used to calculate the similarity matrix. Hierarchical cluster analysis implements hierarchical agglomerative clustering, which is plotted on a dendrogram. The applied cluster mode algorithm was 'group average' which means the new node takes the average similarity of the individual nodes to calculate the distance between clusters. MDS ordinates sites based on similarities in species makeup, using rank order of distances to map out relationships. Sites with high similarity are placed close together on the MDS map. A stress coefficient represents the goodness of fit of the data to a nonparametric regression; higher stress indicates more scatter about the line and perfectly represented data tend towards zero. Typically, stress is minimized with the addition of dimensions, and 2-dimensional and 3-dimensional stress values are estimated. Acceptable ordinations of data occur when stress values are < 0.2 (Clarke & Warwick 2001). Factors were overlaid on the MDS plot to visualize community groupings in relation to potential influencing factors, such as dredged state. Subsequently, ANOSIM was used to test relationships among the following:

1) Dredged state: dredged or undredged
2) Month of survey: August, September, October
3) Location: Northern (North creeks), Mid-river (Hebden creeks) or Upper river (Buchanan creeks)

Exploration of species contributions to describing similarities within and dissimilarities among groups was completed with Similarity Percentages (SIMPER) procedure (PRIMER 6.0). This method uses relative abundances, represented by Bray-Curtis similarities, to determine those species contributing the most to overall dissimilarity between pairs of groups (Clarke & Warwick 2001).

Results

Physical Character of Creeks

The northernmost creek system varied from the other systems in physical character, and fish community structure. These systems had the smallest drainage area and connected directly to the main stem of the Western Branch of Lynnhaven Bay. On average, turbidity (NTU) was lower in the North Creeks compared to upriver systems (Table 2). Dissolved oxygen was significantly lower in Buchanan creeks versus the other systems (One-way ANOVA, $p = 0.002$). Other water quality measures followed an expected gradient from downriver to upriver, e.g. salinity and pH decreased moving upriver.

Table 2. Physical and water quality characteristics of tidal creeks. Abbreviations and units: Depth (ft), conductivity (Cond; mS/cm), dissolved oxygen (DO; mg/L), Nephelometric Turbidity Units (NTU), Salinity (ppt), Temperature (Temp; C°).

Site	Tidal Creek	Status	Depth	Cond	DO	NTU	pH	Salinity	Temp
1	North	Undredged	2.87	33.54	6.90	18.01	7.91	21.17	23.22
2	North	Dredged	4.45	33.73	7.12	18.42	7.94	21.13	23.24
3	Hebden	Undredged	3.18	33.77	6.87	38.27	7.79	21.16	24.37
4	Hebden	Dredged	4.20	33.40	6.59	54.72	7.66	20.90	23.43
5	Buchanan	Undredged	3.97	29.99	5.66	34.35	7.37	18.59	23.67
6	Buchanan	Dredged	3.48	31.00	5.81	48.08	7.48	19.35	23.31

<u>Sediment</u>

The tidal creeks are clay-silt dominated systems with organic content ranging between 5% and 18%. High levels of organic matter were evident in the tidal creeks with increasing amounts in the upriver sites (Figure 3). Although relationships were not significant, trends in sediment composition were evident. Silt and sand exhibited opposite trends, with higher amounts of silt and lower amounts of sand in the undredged systems versus the paired dredged system in the North and Hebden Creeks The narrow Buchanan-dredged creek system has experienced extensive siltation and patterns were opposite than observed with the other pairs.

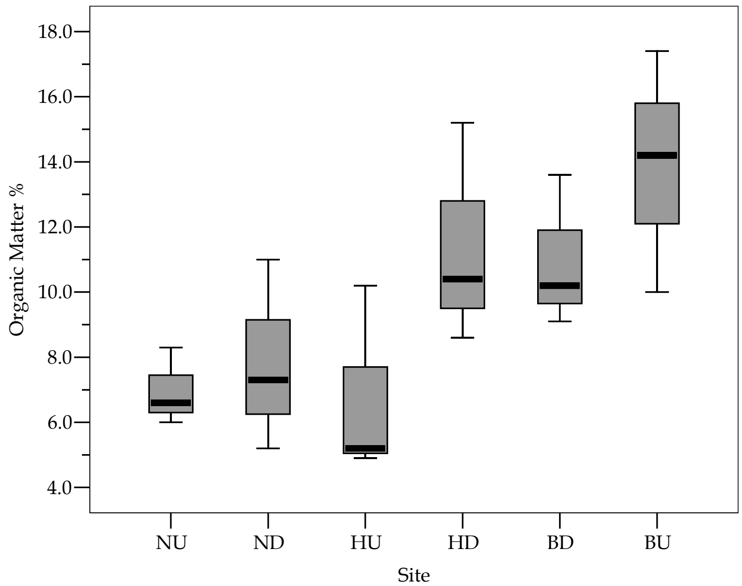

Figure 3. Variability in organic matter content in surface sediment of tidal creeks. Each boxplot represents the median and 25th and 75th percentiles; whiskers indicate 90th and 10th percentiles. Values associated with upriver creeks were significantly higher than downriver sites (One-way ANOVA, p = 0.05).

**Note: tidal creek abbreviations for graphics: NU=North-undredged, ND=North-dredged, HU=Hebden-undredged, HD=Hebden-dredged, BD=Buchanan-dredged, BU=Buchanan-undredged*

Depth

Average depths ranged from 2.8 to 4.3 feet. Between pairs, dredged creeks were on average ≥ 1 foot deeper than undredged creeks, with the exception of the Buchanan system where the dredged creek was shallower than the undredged (Figure 4). This may be in part due to the fact the narrow system was dredged six years ago and extensive siltation has occurred.

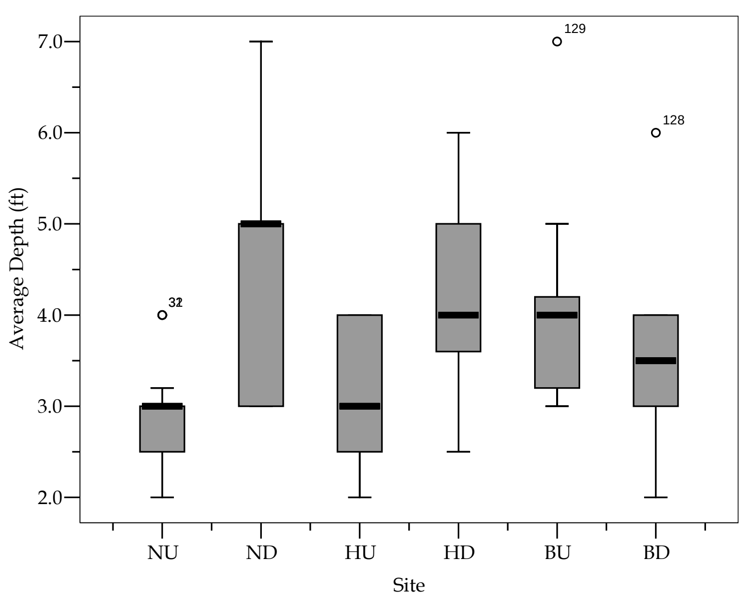

Figure 4. Tidal creek depth variability which includes depths in channel (push net, gill net) and at channel edge (beach seine) for every sampling event (n=129). Each boxplot represents the median and 25th and 75th percentiles; whiskers indicate 90th and 10th percentiles and outliers are shown by points (○).

Water quality patterns

Continuous water quality stations in Buchanan dredged and undredged creeks indicated that from August-October 2006, the systems responded similarly to precipitation events including the extreme Hurricane Ernesto event on September 1, 2006. The system was experiencing a drought as sampling began in August as indicated by salinities in excess of 30 ppt, the high precipitation Hurricane event led to drops in salinity to near zero. Salinity typically remained between 10 and 20 ppt following the storm. During the season sampled, conditions fluctuated from extremes, for example salinity ranged from approximately 2-35 ppt and dissolved oxygen from 2-11 mg/L (Figure 5).

Riparian Land Use

All six tidal creeks are comprised of equal to or greater than 50% residential riparian land use, with total hardened shorelines ranging from 0 to 32% (Hebden-undredged had 0% hardened shoreline and the other creeks were typically 20% and greater). While the tidal creeks are heavily developed, fringe marsh predominated shorelines in all creeks (55 - 94%) (Table 3). The amount of *Phragmites australis* was the highest in the most developed shoreline of Buchanan dredged creek (92% residential riparian land use and 22% *Phragmites australis*; Figure 6).

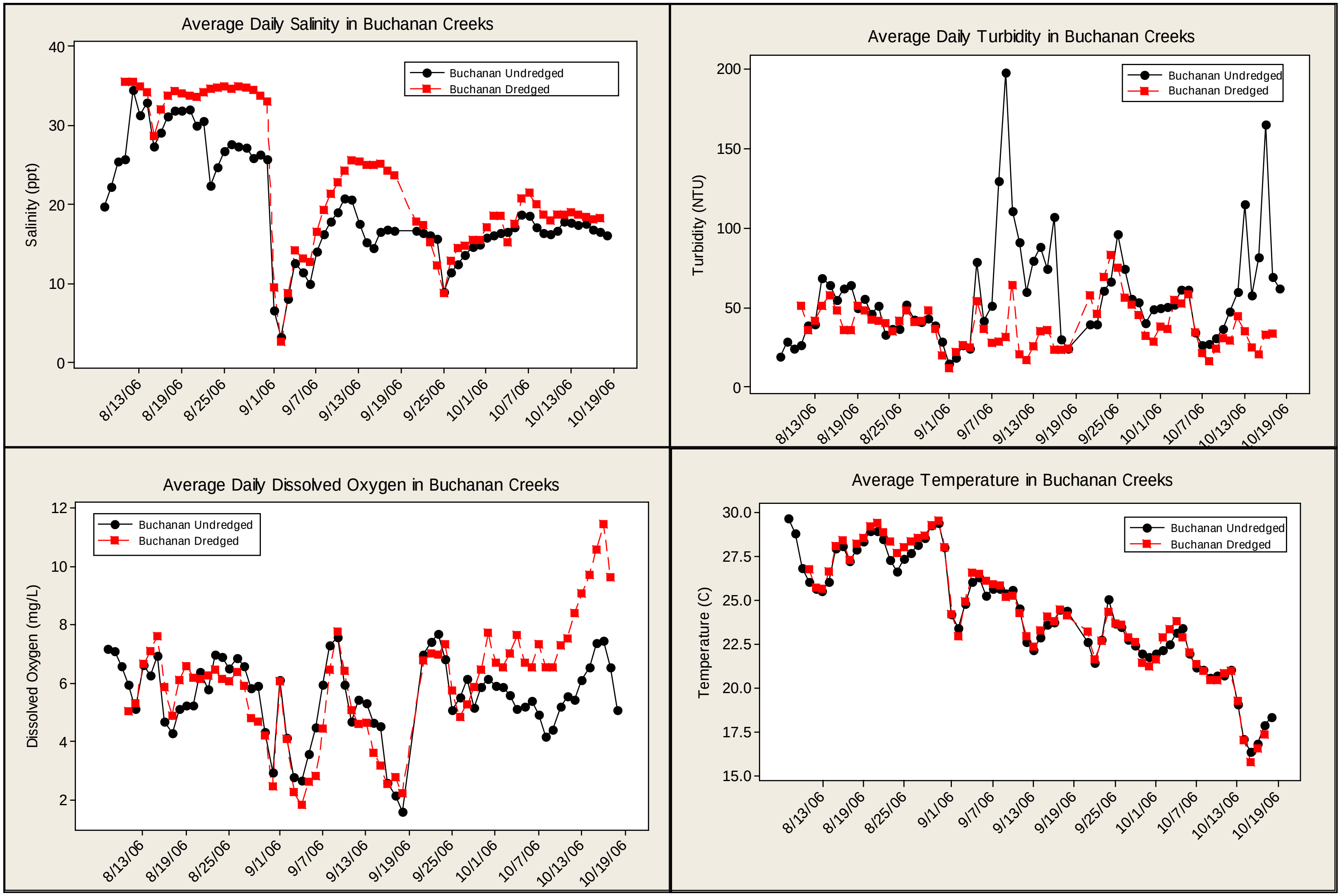

Figure 5. Average daily salinity, turbidity, dissolved oxygen and water temperature for Buchanan-undredged and Buchanan-dredged tidal creeks from August-October 2006.

Table 3. Shoreline condition of tidal creeks represented as the percentage of surveyed shoreline in each category of shoreline structure, riparian land use and marsh type.

			Shoreline Structure			Riparian Land Use				Marsh		
No	Creek	Status	Bulkhead	Riprap	Total	Residential	Forest	Grass	Scrub-shrub	Fringe	Extensive	Phragmites
1	North	undredged	21.07	8.88	29.96	49.56	33.00	2.26	15.18	79.09	0.00	0.00
2	North	dredged	12.89	9.55	24.43	71.84	12.16	5.05	10.94	59.72	0.00	1.81
3	Hebden	undredged	0.00	0.00	0.00	63.05	22.28	4.05	10.63	71.28	0.00	6.30
4	Hebden	dredged	9.71	8.78	20.20	50.50	48.19	1.31	0.00	54.81	0.00	9.42
5	Buchanan	undredged	0.31	3.03	8.85	65.22	28.37	2.72	3.69	77.55	18.93	1.07
6	Buchanan	dredged	32.20	0.00	32.20	91.13	8.87	0.00	0.00	93.52	0.00	22.17

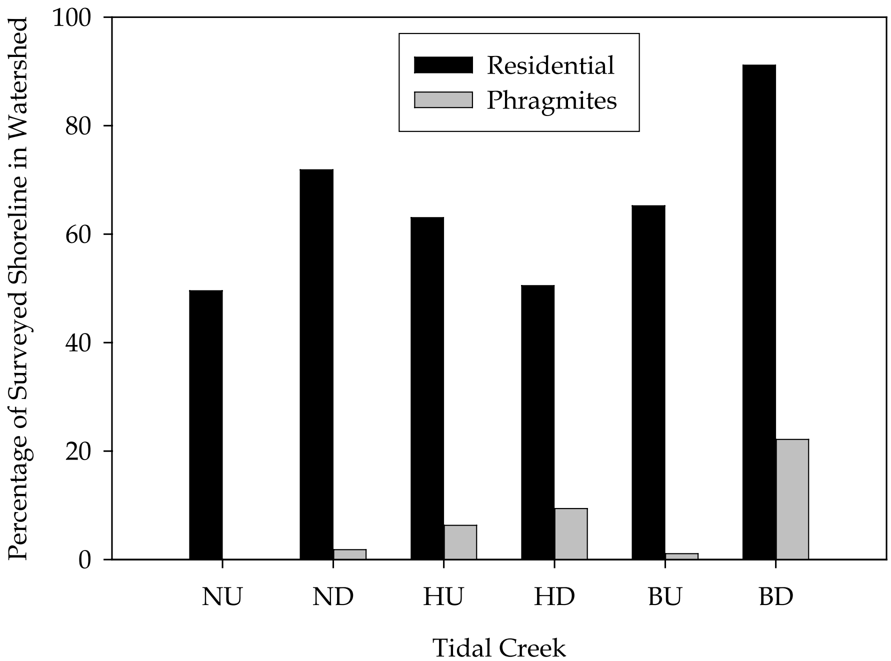

Figure 6. Percentage of surveyed shoreline in each tidal creek (with residential riparian land use (30m buffer)) and the invasive marsh plant *Phragmites australis* present.

Fish Community index

All but one of the examined fish community metrics were positively correlated with the summed metrics (FCI). The majority of correlations among metrics were positive. Total number of individuals (transformed into natural logarithms) had low, negative correlations with the FCI and negative correlations with other individual metrics. Principal components analysis of individual fish community metrics supported the use of all but one of the metrics (i.e., abundance, natural logarithm transformed) in a composite FCI. The first and second principal components accounted for 80 % of the variance in the dataset. All metrics were positively associated with PC1, except for low negative loading for total abundance. When considering correlation patterns and PCA analyses, the use of all the metrics, with the exception of total abundance, was supported for the application of a nearshore FCI in the Lynnhaven River.

Nekton Community

A total of 5973 nekton and 30 species were collected from the six tidal creeks surveyed in August-October. The catches in the systems combined were dominated Atlantic silverside, bay anchovy, gizzard shad, sliver perch and Atlantic menhaden (90% of catch; Table 4). Note: Immature anchoa spp. captured in the push net seine were assumed to be bay anchovy since striped anchovy spawn offshore, and its larvae and juveniles are not generally found inshore (Richards and Castagna 1970, Schauss, Jr 1977). Average sizes of fishes were 13.9 +- 4.6 cm (2.3—50cm). The majority (72%; 66 of 93) of the blue crabs captured were young of year (in first year, typically early juvenile stages), indicating that the Lynnhaven River is used as a nursery ground. Twenty-seven adults were captured (12 female and 15 male).

Table 4. Summary description of fish assemblages for tidal creeks surveyed. Table abbreviations: TL=total length (cm), SD = standard deviation, Min= minimum, Max=maximum, Wt=weight (g), Ave Den = Average Density (#/100m^3).

Common Name	Scientific Name	Total	Ave TL	SD TL	Min TL	Max TL	Ave Wt	SD Wt	Beach Seine Ave Den	Beach Seine SD Den	Haul Seine Ave Den	Haul Seine SD Den
Atlantic Silverside	*Menidia menidia*	2367	6.9	1.6	3.8	9.9	4.3	11.9	1.2	1.6	58.7	106.4
Bay anchovy	*Anchoa mitchilli*	1733	5.0	1.1	2.8	7.7	0.8	0.7	1.6	2.8	30.1	29.4
Silver perch	*Bairdiella chrysoura*	465	9.8	2.6	5.8	19.8	15.1	29.7	5.4	9.9	1.5	0.5
Gizzard shad	*Dorosoma cepedianum*	452	28.3	13.6	8.0	48.0	370.7	331.7	3.4	4.7	1.9	1.4
Atlantic menhaden	*Brevoortia tyrannus*	391	14.1	1.9	9.5	18.3	32.1	18.9	7.0	11.8	1.0	0.0
Mummichog	*Fundulus heteroclitus*	181	6.8	1.0	4.6	9.8	6.5	7.0	5.6	5.7	35.2	0.0
Blue Crab	*Callinectes sapidus*	93							1.5	1.8	0.0	0.0
Spot	*Leiostomus xanthurus*	65	15.5	1.5	11.5	22.0	64.7	35.5	1.7	2.6	1.3	0.0
Striped mullet	*Mugil cephalus*	63	16.7	4.1	8.3	23.0	44.3	28.5	2.0	2.1	1.3	0.4
Striped anchovy	*Anchoa hepsetus*	39	6.8	0.8	5.6	8.9	2.0	1.0	1.0	0.9	2.5	1.4
Atlantic croaker	*Micropogonias undulatus*	32	13.7	12.1	3.2	34.0	134.4	207.4	1.2	1.3	1.4	0.0
Red drum	*Sciaenops ocellatus*	23	34.6	3.8	26.0	43.8	519.0	180.1	0.2	0.0	0.0	0.0
White perch	*Morone americana*	20	10.8	2.5	7.7	16.0	18.7	16.5	1.0	1.5	0.0	0.0
Striped killifish	*Fundulus majalis*	12	6.0	0.7	5.0	6.9	2.5	0.8	0.9	1.2	0.0	0.0
Spotfin mojarra	*Eucinostomus argenteus*	7	6.6	0.2	6.3	6.7	2.7	1.8	2.5	3.2	0.0	0.0
American eel	*Anguilla rostrata*	4	36.0	13.7	21.0	50.0	273.1	250.5	0.2	0.0	1.1	0.3
Striped bass	*Morone saxatilis*	4	13.1	10.5	2.3	20.5	45.6	55.8	0.4	0.0	0.0	0.0
Summer flounder	*Paralichthys dentatus*	4	32.5	15.6	12.8	50.0	599.5	651.4	1.2	0.7	0.0	0.0
Naked goby	*Gobiosoma bosc*	3	3.4	1.5	2.3	4.4	1.4		0.4	0.2	0.0	0.0
Blackcheek tonguefish	*Symphurus plagiusa*	2	7.7		7.7	7.7	2.8		1.3	0.0	0.0	0.0
Bluefish	*Pomatomus saltatrix*	2	22.0	11.2	14.1	29.9	126.3	142.1	0.2	0.0	0.0	0.0
Permit	*Trachinottus falcatus*	2	6.4	0.8	5.8	7.0	3.2	0.7	0.2	0.0	1.3	0.0
Sheepshead minnow	*Cyprinodon variegatus*	2	4.6	0.6	4.1	5.0	2.0		1.5	1.7	0.0	0.0
Crevalle jack	*Caranx hippos*	1	10.5		10.5	10.5			0.3	0.0	0.0	0.0
Hogchoker	*Trinectes maculatus*	1	14.8		14.8	14.8	6.5		0.0	0.0	0.0	0.0
Ladyfish	*Elops saurus*	1	11.7		11.7	11.7	8.6		0.2	0.0	0.0	0.0
Sharptail goby	*Gobionellus oceanicus*	1	13.0		13.0	13.0	11.3		0.0	0.0	0.0	0.0
Spotted seatrout	*Cynoscion nebulosus*	1	43.0		43.0	43.0	739.4		0.0	0.0	0.0	0.0
Tripletail	*Lobotes surinamensis*	1	3.6		3.6	3.6	1.2		0.6	0.0	1.1	0.0
Weakfish	*Cynoscion regalis*	1	8.0		8.0	8.0	3.7		0.2	0.0	0.0	0.0
Total Abundance and Average Measures		5973	14.2	4.8	2.3	50.0	108.7	103.8	1.4	1.8	4.6	4.7

Fish community characteristics (e.g. total abundance, biomass, size, diversity) were similar among the tidal creeks and across months surveyed based on parametric testing (GLM Univariate Analysis of Variance, p=0.12, p=0.46, p=0.21, p=0.66, respectively) (Figures 7 and 8). Fish community indices were also similar among creeks (One-way ANOVA, p=0.898; Figure 9). However, differences between the northern downriver tidal creeks with the smallest drainage area and upriver systems (Hebden and Buchanan) were noted in multivariate analyses of communities (Hierarchical Cluster analysis and MDS) which examines similarity in abundance by species (Pairwise ANOSIM, North vs Hebden p=0.004; North vs Buchanan p =0.03) (Figures 10 and 11).

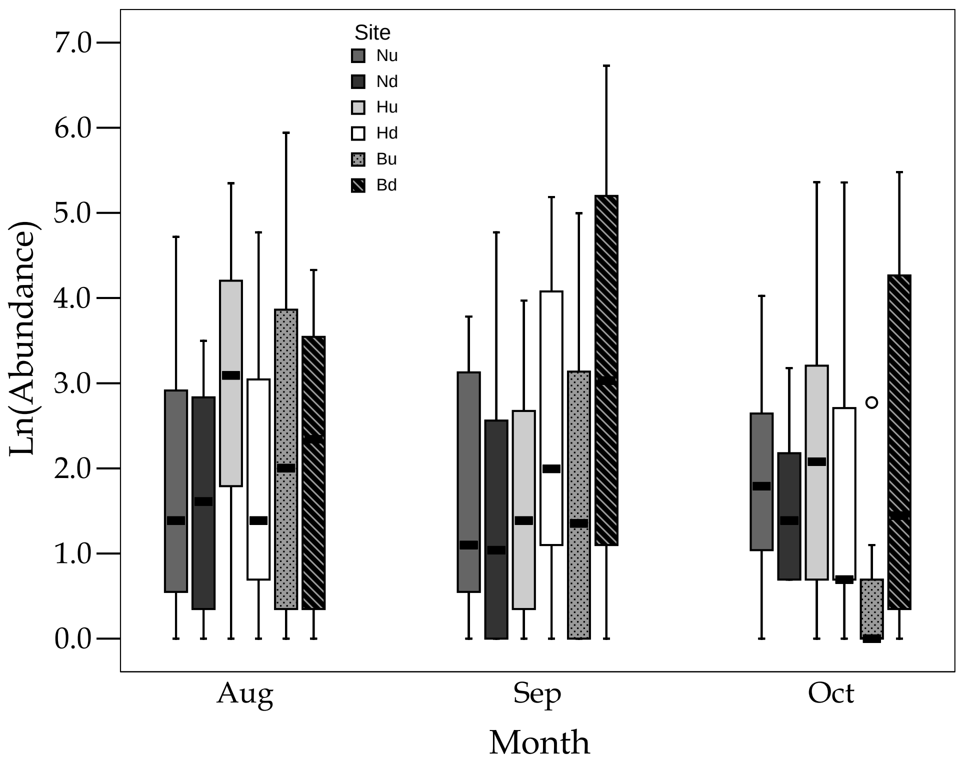

Figure 7. Fish abundance (natural-log transformed) by site and month. The box represents the middle 50% of the data with median values indicated by the bar. The lines (whiskers) extending from the box represent the upper and lower 25% of the data (excluding outliers). Outliers are represented by an open circle (◦).

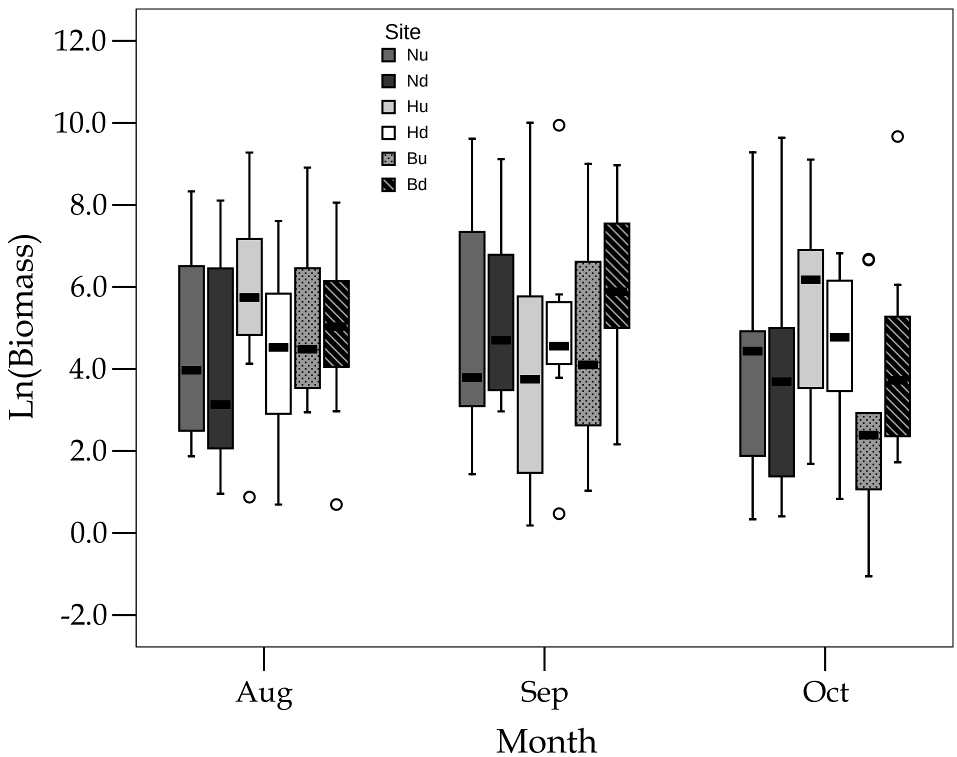

Figure 8. Fish biomass (natural-log transformed) by site and month. Boxplot details are as described in Figure 7 heading.

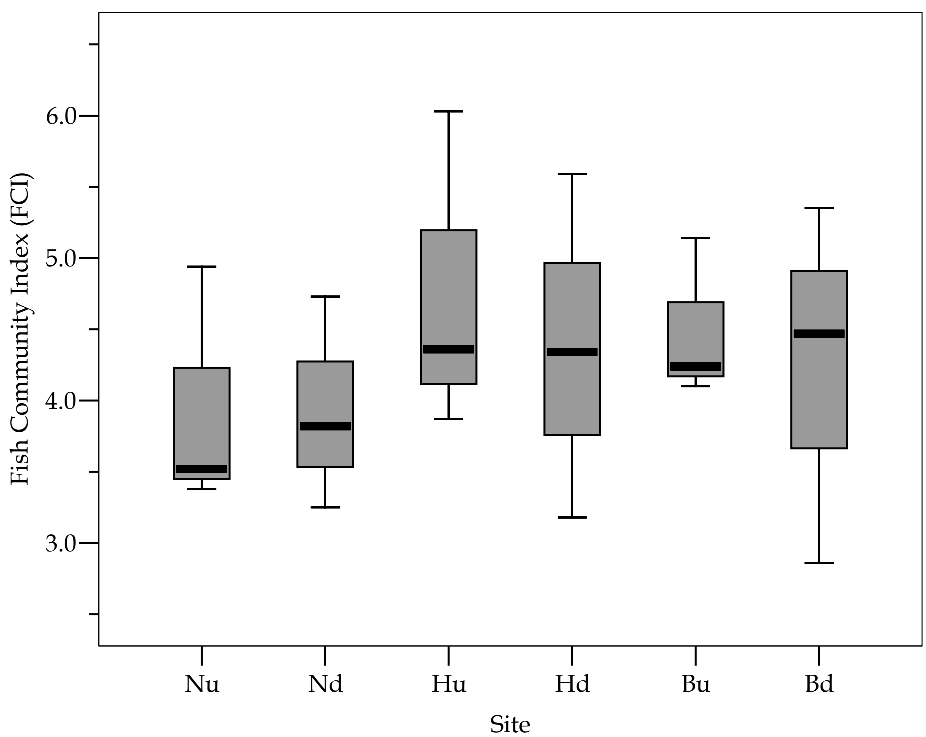

Figure 9. Fish community index variability by tidal creek. Each boxplot represents the median and 25th and 75th percentiles; whiskers indicate 90th and 10th percentiles.

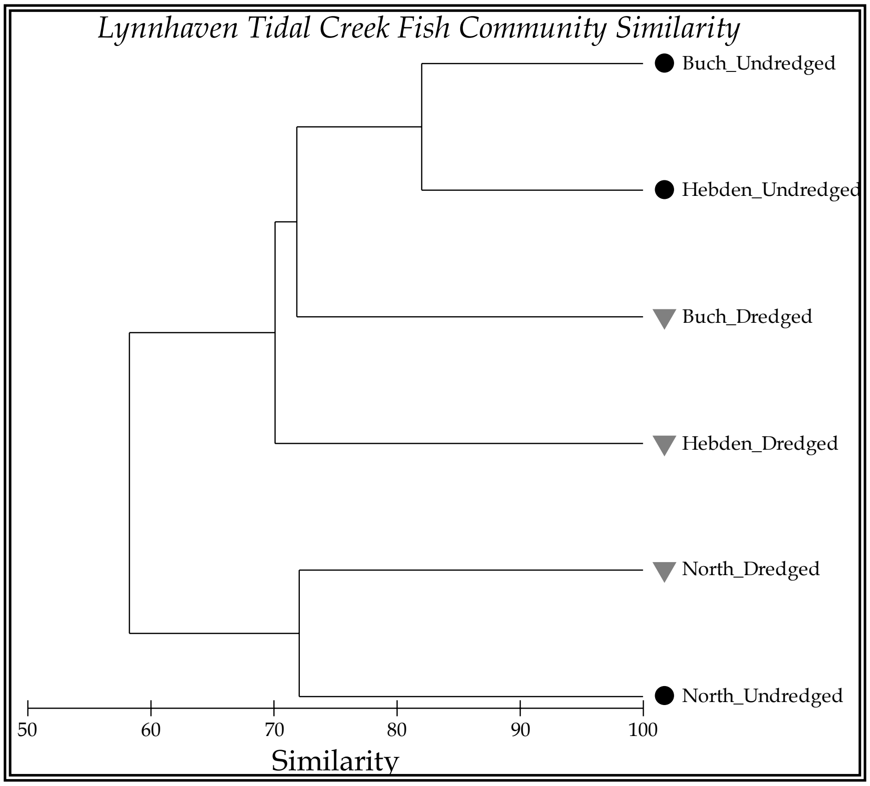

Figure 10. Dendrogram of hierarchical cluster analyses of fish assemblages in tidal creeks.

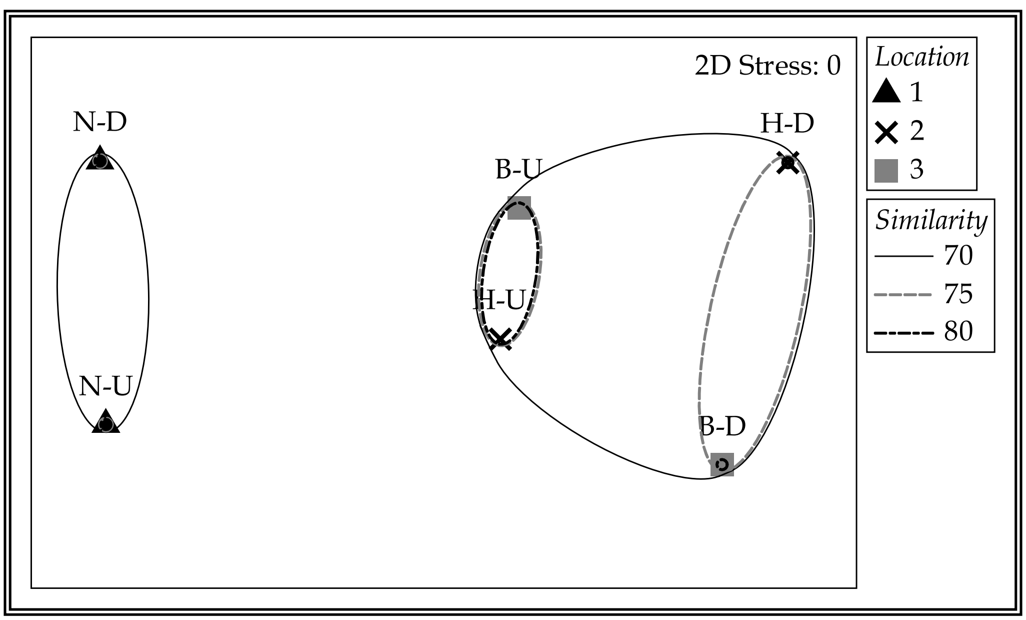

Figure 11. MDS ordination plot with hierarchical clusters superimposed. Location within the Lynnhaven Watershed (North—South) is also superimposed as 1= North creeks, 2= Hebden creeks and 3= Buchanan creeks. North Creeks (N-U and N-D) are distinct from southern creeks: Hebden and Buchanan. Further clustering occurs between southern undredged systems versus dredged systems.

Several factors may account for differences observed (Table 5). First, higher abundances were associated with the larger watersheds of the upriver creeks (Hebden and Buchanan) than in the small North watersheds, and secondly, slightly higher species numbers made up 99% of catch in upriver undredged systems in relation to each sister dredged system, which was not the case for North Creek which also had the most recently dredged system. Watershed size did not appear to dictate the number of species present overall. In the upriver creek systems (Hebden and Buchanan), higher abundances were noted particularly for Atlantic silverside, bay anchovy, silver perch, spot, blue crab, and red drum than in the small North Creek systems (Table 6).

Table 5. Characteristics of tidal creeks and fish assemblages in Lynnhaven Bay. Headings are defined as D/U (Dredged or Undredged), Size = drainage area, Abu = Fish abundance, No Spp = 99%is the number of species comprising 99% of the catch. Higher abundances occurred in the larger systems: Hebden and Buchanan. The number of species was higher for undredged southern systems (Hebden and Buchanan) versus paired dredged systems (bolded).

Creek	D/U	Size (km^2)	Abu	No Spp = 99%
North	U	0.05	414	10
North	D	0.09	294	10
Hebden	U	0.6	1050	**12**
Hebden	D	0.3	1117	10
Buchanan	U	4.9	968	**10**
Buchanan	D	0.6	2129	8

Table 6. Species contributions to dissimilarities between location (1=North; 2=Hebden; 3=Buchanan). Average dissimilarity (Av.Diss) represents the contribution of each species to the overall dissimilarity between groups. The ratio of Av.Diss to standard deviation (Diss/SD) signifies good discriminating species for the groups with relatively large values; Cum% rescales the % each species contributes to dissimilarities (Contrib%) to the cumulative % of total dissimilarity. Species are ordered in decreasing contribution. Group Av.Abund is based on values in the Bray-Curtis similarity matrix and does not represent true abundance estimates.

Groups 1 & 2 (North & Hebden Creeks)
Average dissimilarity = 52.24

Species	Group 1 Av.Abund	Group 2 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum%
Atlantic silverside	2.86	11.13	11.78	1.84	22.55	22.55
Bay anchovy	5.16	9.90	7.62	1.54	14.60	37.15
Silver perch	3.10	5.04	4.10	1.22	7.84	44.99
Atlantic menhaden	2.99	1.93	4.08	1.00	7.81	52.79
Gizzard shad	4.18	4.87	3.37	1.38	6.46	59.25
Spot	0.00	2.42	3.29	2.24	6.29	65.54
Mummichog	0.97	2.18	2.82	1.17	5.40	70.94
Blue Crab	0.97	2.98	2.67	1.48	5.11	76.05
Striped mullet	1.32	1.88	2.34	1.33	4.47	80.52
Striped anchovy	0.90	1.15	1.75	1.18	3.35	83.87
Atlantic croaker	1.09	0.81	1.36	1.34	2.60	86.47
Red drum	0.40	0.84	1.20	0.94	2.30	88.77
Striped killifish	0.57	0.74	1.08	1.06	2.06	90.83

Groups 1 & 3 (North & Buchanan Creeks)
Average dissimilarity = 54.72

Species	Group 1 Av.Abund	Group 3 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum%
Atlantic silverside	2.86	13.20	13.76	1.69	25.14	25.14
Bay anchovy	5.16	10.21	8.88	1.53	16.23	41.37
Atlantic menhaden	2.99	4.15	5.83	1.08	10.65	52.02
Silver perch	3.10	4.32	4.02	1.18	7.35	59.37
Mummichog	0.97	2.88	3.68	1.11	6.72	66.09
Gizzard shad	4.18	4.66	3.23	1.03	5.91	71.99
Striped mullet	1.32	0.83	1.77	0.99	3.23	75.22
Atlantic croaker	1.09	0.72	1.69	1.55	3.09	78.31
Striped anchovy	0.90	0.70	1.61	1.08	2.95	81.26
Spot	0.00	1.27	1.50	0.83	2.74	84.00
White perch	0.00	1.05	1.49	1.10	2.73	86.73
Red drum	0.40	1.26	1.41	1.41	2.58	89.31
Blue Crab	0.97	1.80	1.30	1.26	2.38	91.69

Groups 2 & 3 (Hebden and Buchanan Creeks)
Average dissimilarity = 42.31

Species	Group 2 Av.Abund	Group 3 Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum%
Atlantic silverside	11.13	13.20	7.62	1.11	18.02	18.02
Bay anchovy	9.90	10.21	6.42	1.50	15.17	33.19
Silver perch	5.04	4.32	4.03	1.25	9.52	42.71
Atlantic menhaden	1.93	4.15	3.59	1.08	8.48	51.18
Mummichog	2.18	2.88	2.94	1.18	6.96	58.14
Gizzard shad	4.87	4.66	2.85	1.19	6.73	64.87
Spot	2.42	1.27	2.11	1.42	4.98	69.84
Striped mullet	1.88	0.83	1.93	1.07	4.57	74.42
Blue Crab	2.98	1.80	1.57	1.17	3.70	78.12
Striped anchovy	1.15	0.70	1.35	1.09	3.18	81.30
Atlantic croaker	0.81	0.72	1.12	1.08	2.65	83.94
Red drum	0.84	1.26	1.04	1.48	2.46	86.40
White perch	0.69	1.05	1.03	1.22	2.43	88.84
Striped killifish	0.74	0.00	0.76	0.78	1.79	90.63

Comparisons of total hardened shoreline and fish community index indicated no significant difference among amounts of hardened shoreline (Figure 12). The large amount of residential development within the riparian zone (>50%) present in all creeks may be a superseding stressor influencing fish communities, reducing the apparent effect of shoreline hardening.

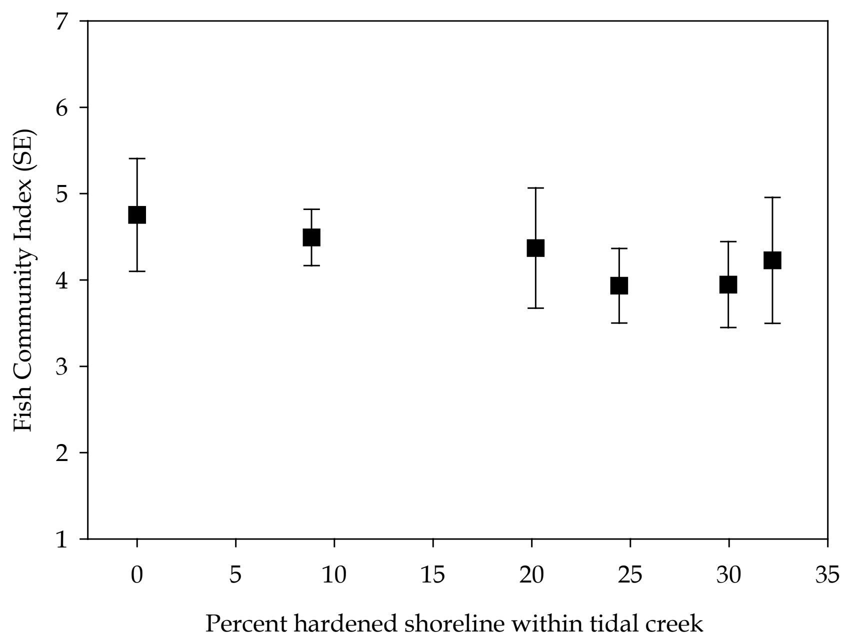

Figure 12. Fish community index (± standard error) in relation to amount of hardened shoreline within the tidal creek.

There were no consistent patterns in length distribution for individual species across creeks. Patterns may have been obscured, since there were only a limited number of species that had high enough abundance across all creeks for an accurate comparison of average sizes by individual gear type (e.g. beach seine only). No significant differences in sizes were observed with gill net data for the common species red drum and spot.

Beach seine data for silver perch and Atlantic menhaden were compared independently. Atlantic menhaden were largest in North-undredged (average: 14.7 ± 1.3 cm) and Buchanan-undredged (14.3 ± 1.3 cm) creeks, with significant differences between North-undredged and Hebden–undredged (12.7 ± 0.9 cm), Hebden-dredged (12.4 ± 0.9 cm), and Buchanan-dredged (13.5 ± 2.1 cm) creeks (One-way Anova, $p<0.0001$; Tukey pairwise test). Also, Buchanan-undredged creek supported larger sized menhaden than Hebden-undredged creek. Silver perch were larger in North-dredged (9.1 ± 2.7 cm) than Hebden-undredged creek (8.0 ± 1.4 cm), with similar sizes among all other creeks (One-way ANOVA, $p = 0.04$; Tukey pairwise test).

Comparisons of Atlantic silverside and bay anchovy average lengths were completed with push net seine data. Atlantic silverside were largest in North-dredged creek (8.8 ± 1.7 cm compared to other creek averages of 4.2-5.8 cm), but low collection numbers in this system may have skewed results (One-way ANOVA, $p < 0.0001$). Bay anchovy were largest in Hebden-undredged and North-dredged creeks with significant differences between Hebden-undredged (4.1 ± 0.7 cm) and North-undredged (3.8 ± 0.8 cm), Hebden-dredged (3.7 ± 0.7 cm), and Buchanan-undredged (3.7 ± 0.9 cm and dredged (3.7 ± 0.9 cm creeks (One-way ANOVA, $p < 0.0001$) (Table 7).

Table 7. Comparison of average total lengths (cm ± standard deviation) for select species common within all creeks by associated gear type (beach or haul seine). Significant differences (One-way ANOVA, Tukey Pairwise comparisons) between creeks for each species are noted with superscript alpha characters (e.g. [b]).

Beach Seine		
Creek	Atlantic Menhaden	Silver perch
North-undredged	**14.7 ± 1.3** [a]	8.2 ± 1.7
North-dredged	13.4 ± 1.6 [a]	**9.1 ± 2.7** [c]
Hebden-undredged	12.7 ± 0.9 [a b]	8.0 ± 1.4 [c]
Hebden-dredged	12.4 ± 0.9 [a]	8.6 ± 1.3
Buchanan-undredged	**14.3 ± 1.3** [b]	8.3 ± 1.3
Buchanan-dredged	13.5 ± 2.1 [a]	8.3 ± 1.4

Haul Seine		
Creek	Atlantic Silverside	Bay Anchovy
North-undredged	5.8 ± 1.0 [d]	3.8 ± 0.8 [e]
North-dredged	**8.8 ± 1.7** [d]	4.0 ± 0.6
Hebden-undredged	5.0 ± 1.0 [d]	**4.1 ± 0.7** [e]
Hebden-dredged	4.6 ± 0.7 [d]	3.7 ± 0.7 [e]
Buchanan-undredged	4.2 ± 0.6 [d]	3.7 ± 0.9 [e]
Buchanan-dredged	4.4 ± 0.6 [d]	3.7 ± 0.9 [e]

Nekton Communities and tidal creek characteristics

Differences among creeks were observed in relation to the size, location and sample time of tidal creek watersheds, however dredged and undredged tidal creeks supported similar nekton communities (ANOSIM; p=0.617; Global R = -0.025). Temporally, pairwise ANOSIM comparisons indicated that communities differed between August and October (R-statistic=0.309, p=0.015). Spatially, communities varied between the northernmost creeks and upriver creeks (Hebden and Buchanan) (North vs Hebden, p=0.004, R-statistic = 0.404; North vs. Buchanan p=0.035, R-statistic=0.233; Hebden vs. Buchanan p = 0.807, R-statistic= -0.072). This trend correlates with watershed size as well, with the northernmost creeks significantly smaller than the upriver creeks. Thus, spatial location and watershed size may be factors contributing to nekton assemblages.

Discussion

Tidal creek nekton communities and Lynnhaven Bay

Diverse fish communities utilize the Lynnhaven Bay as feeding/nursery grounds which may be in part due to its location in the estuarine landscape near the mouth of the Chesapeake Bay exposing it to an influx of migratory species. Other factors promoting diversity are the presence of a variety of critical habitats, including mudflats, marsh and shallow water. Numerous studies have documented the utilization of shallow-water habitats, tidal creeks and marshes by nekton for nursery areas. For example, shallow-water has been described as important nursery habitat for spot, silver perch, spotted seatrout, and Atlantic croaker in the Chesapeake Bay (Chao and Musick 1977). Tidal creeks and marshes (vegetated and nonvegetated) are reported nursery habitats for several species including spot, spotted seatrout, silver perch, pinfish, striped mullet, Atlantic menhaden, spotfin mojarra, red drum, and blue crab (Weinstein 1979, Weinstein and Brooks 1983, O'Neil and Weinstein 1987, Minello et al. 2003, King et al. 2005), and subtidal creek habitats may be critical to larval spot, gobies, bay anchovy, and Atlantic croaker (Allen and Barker 1990).

Limited quantitative historical information on fish communities in Lynnhaven Bay exists. However, Schauss, Jr. (1977) reported similar levels of species diversity as this study (31 species observed in February 1973-January 1974 beach seine and plankton collections), and that it was a significant nursery ground for several species including bay anchovy, spot, white mullet, *Gobiosoma* spp (goby) and green goby. While exact comparisons of abundance cannot be conducted due to varying sampling effort and some gear differences, general trends can be informative. In our survey, several species were prevalent that were absent or in low abundance in the historic survey including Atlantic menhaden, gizzard shad, white perch, and silver perch. Oppositely, in 1973, sheepshead minnow, spotfin mojarra, striped killifish, naked goby and blackcheek tonguefish were more prevalent in surveys than presently observed. This may indicate a shift in fish community structure has occurred, possibly due to further reduction in marsh and oyster reef habitats.

Nekton community differences among tidal creeks and anthropogenic stressors

All six tidal creeks surveyed primarily supported similar fish communities, however slight differences among fish communities (seen in multivariate analyses) may be attributable to the size and locations of watersheds (i.e. small North creeks differed from southern creeks). Additional confounding factors include the close proximity to the Lynnhaven Bay mouth and Mainstem Chesapeake Bay of the North creek systems allowing for regular migration of transients. The extreme variability in physical and chemical features in this highly dynamic estuarine system may be driving influences structuring fish communities and may obscure responses to anthropogenic impacts, such as dredging.

The fish assemblage in the most recently dredged system (February 2006) resembled those in the adjacent undredged system (North creeks), which may indicate a quick recovery rate for fish communities post-dredging. Immediate dredging impacts may include entrainment mortalities, behavioral effects, noise effects, and fish gill injury from exposure to high suspended sediment loads which are expected to be localized and temporary (Nightingale and Simenstad 2001). However, presence of fish does not mean that negative impacts do not occur from dredging activities, information on prey communities is necessary, as well as long-term studies to estimate effects. Many studies assessing the negative effects of dredging on nearshore fish fauna have primarily focused on the effects of sediment disposal (e.g. Lindeman and Snyder 1999). In Lynnhaven Bay, dredged sediment from small tidal creeks is removed from the system minimizing burial impacts; however, sedimentation impacts may occur due to the input of fine sediments post-dredging over a longer time span. Similarly, long-term and cumulative effects on habitats and biota may occur that have yet to be measured. For example, elevated turbidities could hinder primary productivity and larval feeding with negative implications to higher trophic levels, and the conversion of habitats (e.g. shallow subtidal to deeper subtidal) could result in a shift in ecosystem dynamics with unknown cumulative effects. Seasonal restrictions on dredging activities may minimize direct physical impacts to fish species with sensitive early life stages in the estuary during the restricted period (often Spring-Summer when migration, peak spawning, and nursery use occurs). However, those species with early life stages in the estuary during dredging activities, such as Atlantic croaker and spot (winter spawners), may still experience direct losses from sedimentation effects, entrainment, smothering, and reduced feeding.

Value of Habitat Restoration

Habitat restoration efforts in the Lynnhaven watershed include extensive oyster reef enhancements, as well as small-scale tidal wetland and seagrass restoration projects. Since SAV restoration in the past has not been successful, efforts are primarily focused on water quality improvement to encourage seagrass bed growth. Tidal wetlands restoration efforts currently planned will not achieve a net gain of wetland acreage or address previous losses (Lynnhaven Watershed Management Plan (Draft); *http://www.dcr.virginia.gov/soil_&_water/documents/09-LynnhavenWMP.pdf*). Thus, oyster reef enhancement and water quality improvement are anticipated to have the largest potential impact on fish and benthic communities in Lynnhaven Bay.

Numerous tidal creek fish species have been observed associated with reefs, however, the importance of shell bottom to highly mobile species is most likely underestimated in part due to limited studies and sampling difficulties (Breitburg 1999). Studies have noted a higher abundance and diversity of fish on shell bottom than adjacent soft bottom, (e.g. Harding and Mann 1999; Posey et al. 1999; Lenihan et al. 2001). However, it is not well understood to what extent oyster reefs enhance the overall productivity of species that are observed on reefs.

Successful oyster restoration projects may be gauged by historic oyster demographics and ecological health, as well as the trophic interactions on the reef (Mann and Harding 1997). Oyster reef communities are dependent on the oyster as both a physical habitat and a major prey item. Trophic linkages with oysters are well documented at some levels, such as the abundant resident reef fishes (gobies and blennies) which are critical prey for several larger pelagic predatory species. Blue crab forage heavily on oysters and associated fauna, notably feeding on dense seasonal populations of new oyster recruits (Menzel and Hopkins 1955; Krantz and Chamberlin 1978; Mann and Harding 1997).

Of the nekton species noted in our survey of Lynnhaven Bay, only five species were not observed associated with oyster reefs in surveys of reef faunal communities in the Mid-Atlantic (gizzard shad, ladyfish, striped killifish, tripletail and permit). Table 8 outlines information and sources on species observed in our survey as it relates to potential levels of oyster reef habitat use. For instance, some species may depend on reefs for food or protection, while other species may be generalists and feed both inside and outside of the reefs. Five resident species have been identified in the Chesapeake Bay which clearly use oyster reef as primary and essential habitat: naked goby, striped, and feather blenny (*Chasmodes bosquianus* and *Hypsoblennius hentz*), skilletfish (*Gobiesox strumosus*), and oyster toadfish (*Opsanus tau*). These benthic species use oyster reefs as breeding and feeding habitat and as shelter from predators. Most of the resident species are an abundant food fish for economically important species like striped bass, bluefish and weakfish and spotted seatrout (Markle and Grant 1970; Breitburg 1999; Harding and Mann 1999), and may serve as indicator species of estuarine health, in particular, the health of oyster reef habitat. For example, naked goby population size is very likely linked to the quantity and quality of their preferred habitat, oyster reef in tidepools and subtidal areas (Dahlberg and Conyers 1973; Crabtree and Dean 1982; Breitburg 1999; Harding and Mann 2000; Lehnert and Allen 2002). The potential exists for enhanced fish productivity in Lynnhaven Bay as oyster reef restoration continues.

Land use and shoreline development

The amount of land use and shoreline development in the tidal creeks surveyed often surpassed (>50% developed riparian land use and >20% hardened shorelines) reported ecological thresholds in biotic responses to stressors. Ecological thresholds that mark breakpoints at which a system or community notably responds (perhaps irreversibly) to a disturbance have been supported in a variety of systems and scales. The current literature suggests that tributary development (e.g. land use, impervious surface) exceeding 10-25% compromises the integrity of the ecosystem and its ability to perform functions (Limburg & Schmidt 1990, Wang et al. 1997, Paul and Meyer 2001, DeLuca et al. 2004, Bilkovic et al. 2006a, Brooks et al. 2006). In the James River, reduced fish community integrity was observed at relatively low riparian development levels (>23%) (Bilkovic et al. *in review,* Bilkovic et al. 2006b). As little as 10 % watershed development within a large estuary and between 10-20 % urbanization within streams have been linked with degradation of fish communities (Limburg & Schmidt 1990, Wang et al. 1997). A review of reported thresholds of impervious surface area within stream catchments indicated that between 10 and 20 % was associated with stream and fish community degradation (Paul & Meyer 2001). The lack of pre-development fish community data prevents us from definitively determining if shifts in communities have occurred within the Lynnhaven Watershed. However, relative comparisons of current assemblages may help target promising habitats and regions for future restoration and conservation efforts.

Summary

Tidal Creeks within Lynnhaven Bay support diverse and similar fish communities. Slight differences in community structure among creeks may be attributable to the location and size of watersheds. The effects of dredging were not apparent in fish community responses measured as abundance, biomass, diversity, and fish community indices. However, anthropogenic effects may be obscured in the short-term by the dynamic nature and background variability of physical and water quality features of the Lynnhaven Bay estuary, and long-term or cumulative effects are not quantifiable due to the dearth of historic information on fish communities. Available historic information may indicate a shift in fish community structure that could be associated with coastal development pressures, such as shoreline alteration and habitat loss of wetlands and oyster reefs. Accordingly, restoration and preservation of critical nursery habitats may augment fish productivity in Lynnhaven Bay.

Acknowledgements

Walter Priest and Randy Owen provided invaluable assistance in the survey design and field collections. We thank the staff of Center for Coastal Resources Management for logistical field support and technical expertise including Sharon Killeen, Molly Roggero, Dave Weiss, Dan Schatt, and Karinna Nunez.

Table 8. Species links to oyster reef ecosystems. Fish utilizing shell bottom have been categorized as resident, facultative, or transient (Breitburg 1999; Coen et al. 1999): 1) resident fish use oyster reefs as their primary habitat; 2) facultative fish are generally associated with structured habitats and utilize oyster reefs as well as other habitat with vertical relief or shelter sites (e.g. seagrass beds); and 3) transient fish may forage on or near reefs but are wide-ranging; some species listed as transient may be facultative residents, but are not defined as such if they are highly mobile and their duration of residency on the reef has not been studied. Source data from outside of the Chesapeake Bay are indicated with the State abbreviation in parentheses when first cited.

Common Name	Scientific Name	Oyster Reef Association	Select Sources
American eel	*Anguilla rostrata*	Transient	Coen et al. 1999; Mann and Harding 1997; 1998; Harding and Mann 1999; Lenihan et al. 2001 (NC)
Atlantic croaker	*Micropogonias undulatus*	Transient*	Luckenbach and Nestlerode (unpubl. data); Mann and Harding 1997; 1998; Coen et al. 1999; Harding and Mann 1999; Lenihan et al. 2001
Atlantic menhaden	*Brevoortia tyrannus*	Transient	Coen et al. 1999; Mann and Harding 1997; 1998; Harding and Mann 1999
Atlantic silverside	*Menidia menidia*	Transient*	Breitburg 1999; Wenner et al. 1996 (SC); Coen et al. 1999; Coen and Luckenbach 1998 (NC, unpubl. data)
Bay anchovy	*Anchoa mitchilli*	Transient*	Luckenbach and Nestlerode (unpubl. data); Mann and Harding 1997; 1998; Harding and Mann 1999; Coen et al. 1999; Lehnert and Allen 2002 (SC)
Blackcheek tonguefish	*Symphurus plagiusa*	Transient	Luckenbach and Nestlerode (unpubl. data); Coen et al. 1999; Meyer and Townsend 2000 (NC)
Blue crab	*Callinectes sapidus*	Transient*	Luckenbach and Nestlerode (unpubl. data); Mann and Harding 1997; 1998; Coen et al. 1999; Meyer and Townsend 2000; Lenihan et al. 2001; Lehnert and Allen 2002
Bluefish	*Pomatomus saltatrix*	Transient	Coen et al. 1999; Mann and Harding 1997; 1998; Harding and Mann 1999; Luckenbach and Nestlerode (unpubl. data)
Crevalle jack	*Caranx hippos*	Transient	Lehnert and Allen 2002
Gizzard shad	*Dorosoma cepedianum*	----------	None reported
Hogchoker	*Trinectes maculatus*	Transient	Breitburg 1999; Mann and Harding 1997; 1998; Harding and Mann 1999
Ladyfish	*Elops saurus*	----------	None reported
Mummichog	*Fundulus heteroclitus*	Transient	Luckenbach and Nestlerode (unpubl. data);
Naked goby	*Gobiosoma bosc*	Resident	Dahlberg and Conyers 1973 (GA); Mann and Harding 1997; 1998; Breitburg 1999; Harding and Mann 1999; 2000; Lehnert and Allen 2002; Meyer and Townsend 2000; Lenihan et al. 2001

Common Name	Scientific Name	Oyster Reef Association	Select Sources
Permit	*Trachinottus falcatus*	----------	None reported
Red drum	*Sciaenops ocellatus*	Transient*	Wenner et al. 1996; Coen et al. 1999; Coen and Luckenbach 1998 (unpubl. data); Grabowski et al. 2005
Sharptail goby	*Gobionellus oceanicus*	Resident	Meyer and Townsend 2000 (*Gobionellus* spp)
Sheepshead minnow	*Cyprinodon variegatus*	Transient	Wenner et al. 1996, Coen et al. 1997 (SC)
Silver perch	*Bairdiella chrysoura*	Transient*	Luckenbach and Nestlerode (unpubl. data); Mann and Harding 1997; 1998; Coen et al. 1999; Harding and Mann 1999; Lenihan et al. 2001
Spot	*Leiostomus xanthurus*	Transient	Luckenbach and Nestlerode (unpubl. data); Mann and Harding 1997; 1998; Coen et al. 1999; Harding and Mann 1999; Meyer and Townsend 2000; Lehnert and Allen 2002; Grabowski et al. 2005 (NC)
Spotfin mojarra	*Eucinostomus argenteus*	Transient	Luckenbach and Nestlerode (unpubl. data);
Spotted seatrout	*Cynoscion nebulosus*	Transient	Luckenbach and Nestlerode (unpubl. data); Mann and Harding 1997; 1998; Coen et al. 1999; Harding and Mann 1999
Striped anchovy	*Anchoa hepsetus*	Transient	Luckenbach and Nestlerode (unpubl. data);
Striped bass	*Morone saxatilis*	Transient	Luckenbach and Nestlerode (unpubl. data); Mann and Harding 1997; 1998; Coen et al. 1999; Harding and Mann 1999
Striped killifish	*Fundulus majalis*	----------	None reported
Striped mullet	*Mugil cephalus*	Transient	Coen et al 1997; Wenner et al 1996
Summer flounder	*Paralichthys dentatus*	Transient	Luckenbach and Nestlerode (unpubl. data); Mann and Harding 1997; 1998; Coen et al. 1999; Harding and Mann 1999
Tripletail	*Lobotes surinamensis*	----------	None reported
Weakfish	*Cynoscion regalis*	Transient	Coen et al. 1999; Luckenbach and Nestlerode (unpubl. data); Mann and Harding 1997; 1998; Harding and Mann 1999
White perch	*Morone americana*	Transient	Coen et al. 1999; Luckenbach and Nestlerode (unpubl. data)

* Species whose relative abundances have been reported in the literature as being generally higher in shell bottom than in other habitats. A lack of information precludes the categorization of species not marked. Sources include Street et al. 2005, Breitburg 1999; Coen et al. 1999; Peterson et al. 2003; Grabowski 2005.

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Appendix I. Summary statistics for fish assemblages by tidal creek. Table abbreviations: TL=total length (cm), SD = standard deviation, Min= minimum, Max=maximum, Wt=weight (g), Av D = Average Density (#/100m^3).

Site No	Site	Species	Total	Ave TL	SD TL	Min TL	Max TL	Ave Wt	Beach Seine Av D	Beach Seine SD	Haul Seine Av D	Haul Seine SD
1	North; undredged	Atlantic menhaden	117	14.1	1.3	13.2	15.5	32.5	5.5	6.2	0.0	0.0
1	North; undredged	Bay anchovy	87	5.0	1.4	2.8	7.1	0.8	2.0	1.6	11.0	7.4
1	North; undredged	Atlantic silverside	73	7.4	1.3	5.4	8.5	17.1	0.3	0.1	18.5	15.6
1	North; undredged	Gizzard shad	69	31.5	16.7	10.3	47.2	339.0	0.6	0.3	4.6	0.0
1	North; undredged	Silver perch	29	8.4	2.1	6.0	11.9	6.2	1.0	0.4	1.4	0.0
1	North; undredged	Striped anchovy	10	7.3	1.4	6.0	8.9	2.0	0.4	0.1	4.3	0.0
1	North; undredged	Striped mullet	10	12.4	4.5	8.3	17.2	18.9	0.5	0.2	1.5	0.0
1	North; undredged	Atlantic croaker	7	13.7	16.6	3.2	34.0	177.0	0.4	0.0	1.4	0.0
1	North; undredged	Blue crab	6						0.2	0.0	0.0	0.0
1	North; undredged	Red drum	2	38.2		32.6	43.8	523.9	0.0	0.0	0.0	0.0
1	North; undredged	Summer flounder	2	43.9	8.7	37.7	50.0	1063.1	0.0	0.0	0.0	0.0
1	North; undredged	Hogchoker	1	14.8		14.8	14.8	6.5	0.0	0.0	0.0	0.0
1	North; undredged	Naked goby	1	4.4		4.4	4.4	1.4	0.2	0.0	0.0	0.0
1	North; undredged	Striped killifish	1	6.9		6.9	6.9	3.9	0.2	0.0	0.0	0.0
2	North; dredged	Bay anchovy	135	5.5	1.5	3.9	7.7	1.1	0.5	0.1	19.2	14.5
2	North; dredged	Gizzard shad	53	33.7	10.3	15.4	46.4	576.9	0.4	0.3	0.0	0.0
2	North; dredged	Silver perch	41	10.0	0.7	8.6	13.5	13.5	2.0	0.9	0.0	0.0
2	North; dredged	Atlantic menhaden	18	16.8	2.1	15.3	18.3	77.2	3.0	0.0	0.0	0.0
2	North; dredged	Mummichog	18	7.3	1.6	5.5	9.8	4.5	5.0	6.5	0.0	0.0
2	North; dredged	Atlantic silverside	9	8.4	0.5	7.4	9.9	4.4	0.6	0.7	1.0	0.0
2	North; dredged	Striped mullet	7	17.9	4.8	12.4	21.3	63.1	3.1	4.0	0.0	0.0
2	North; dredged	Atlantic croaker	4	15.0	15.2	4.1	28.5	238.9	1.5	0.0	0.0	0.0
2	North; dredged	Striped killifish	3	6.3	0.3	6.1	6.5	2.4	1.6	2.0	0.0	0.0
2	North; dredged	Blue crab	2						0.2	0.0	0.0	0.0
2	North; dredged	Striped anchovy	2	7.5		7.5	7.5	1.8	2.9	0.0	0.0	0.0
2	North; dredged	Ladyfish	1	11.7		11.7	11.7	8.6	0.2	0.0	0.0	0.0
2	North; dredged	Red drum	1	32.2		32.2	32.2	821.0	0.0	0.0	0.0	0.0
3	Hebden; undredged	Bay anchovy	325	4.6	0.6	3.0	6.1	0.7	0.3	0.1	42.4	43.2

Site No	Site	Species	Total	Ave TL	SD TL	Min TL	Max TL	Ave Wt	Beach Seine Av D	Beach Seine SD	Haul Seine Av D	Haul Seine SD
3	Hebden; undredged	Atlantic silverside	307	7.1	1.6	3.9	9.3	2.0	0.6	0.2	33.9	30.6
3	Hebden; undredged	Silver perch	157	10.8	4.5	5.8	19.8	56.1	4.8	5.0	2.1	0.3
3	Hebden; undredged	Gizzard shad	111	25.9	14.1	8.0	47.5	256.4	1.3	0.5	1.3	0.0
3	Hebden; undredged	Atlantic menhaden	36	13.8	1.0	12.7	17.1	37.6	1.5	0.2	0.0	0.0
3	Hebden; undredged	Spot	30	15.8	1.4	14.0	22.0	50.0	0.2	0.0	1.3	0.0
3	Hebden; undredged	Blue crab	18						0.4	0.1	0.0	0.0
3	Hebden; undredged	Striped anchovy	16	6.7	0.3	6.2	7.0	1.7	0.7	0.3	2.4	0.0
3	Hebden; undredged	Mummichog	12	7.4	0.7	6.9	8.3	12.1	0.6	0.5	0.0	0.0
3	Hebden; undredged	Atlantic croaker	9	18.9	12.1	5.5	29.0	102.6	0.4	0.0	0.0	0.0
3	Hebden; undredged	Red drum	9	35.9	2.6	31.0	39.5	520.4	0.2	0.0	0.0	0.0
3	Hebden; undredged	Striped mullet	8	21.0	1.6	19.9	23.0	76.1	0.9	0.0	0.0	0.0
3	Hebden; undredged	American eel	3	43.5	6.4	39.0	50.0	273.1	0.2	0.0	1.3	0.0
3	Hebden; undredged	Permit	2	6.4	0.8	5.8	7.0	3.2	0.2	0.0	1.3	0.0
3	Hebden; undredged	Spotfin mojarra	2	6.4		6.3	6.5	1.4	0.2	0.0	0.0	0.0
3	Hebden; undredged	Bluefish	1	14.1		14.1	14.1	25.8	0.2	0.0	0.0	0.0
3	Hebden; undredged	Spotted seatrout	1	43.0		43.0	43.0	739.4	0.0	0.0	0.0	0.0
3	Hebden; undredged	Striped killifish	1	6.0		6.0	6.0	2.4	0.2	0.0	0.0	0.0
3	Hebden; undredged	Tripletail	1	3.6		3.6	3.6	1.2	0.0	0.0	1.1	0.0
3	Hebden; undredged	Weakfish	1	8.0		8.0	8.0	3.7	0.2	0.0	0.0	0.0
4	Hebden; dredged	Atlantic silverside	509	5.8	2.0	4.1	8.7	2.3	0.7	0.0	42.3	13.8
4	Hebden; dredged	Bay anchovy	332	5.0	1.3	2.8	6.7	0.5	0.8	0.1	26.4	10.9
4	Hebden; dredged	Gizzard shad	65	28.4	15.6	11.2	48.0	233.7	6.4	0.0	1.1	0.0
4	Hebden; dredged	Silver perch	57	8.7	0.8	7.6	9.7	7.6	2.7	1.8	0.9	0.0
4	Hebden; dredged	Blue crab	45						2.2	0.7	0.0	0.0
4	Hebden; dredged	Mummichog	42	7.5	0.2	7.0	8.2	10.4	2.9	2.5	0.0	0.0
4	Hebden; dredged	Striped mullet	29	16.4	2.5	12.5	18.6	54.7	2.5	2.6	0.0	0.0
4	Hebden; dredged	Spot	12	15.5	2.0	11.5	17.5	65.5	0.7	0.3	0.0	0.0
4	Hebden; dredged	Striped killifish	7	5.3	0.4	5.0	5.5	1.6	1.0	1.0	0.0	0.0
4	Hebden; dredged	White perch	6	11.5	3.5	7.7	16.0	35.5	0.5	0.2	0.0	0.0
4	Hebden; dredged	Atlantic menhaden	5	12.8	1.1	11.2	13.5	20.8	0.5	0.3	0.0	0.0

Site No	Site	Species	Total	Ave TL	SD TL	Min TL	Max TL	Ave Wt	Beach Seine Av D	Beach Seine SD	Haul Seine Av D	Haul Seine SD
4	Hebden; dredged	Striped bass	3	5.7		2.3	9.0	6.1	0.4	0.0	0.0	0.0
4	Hebden; dredged	Striped anchovy	2	5.9		5.6	6.2	1.2	0.0	0.0	1.0	0.0
4	Hebden; dredged	Red drum	1	30.8		30.8	30.8	368.5	0.0	0.0	0.0	0.0
4	Hebden; dredged	Sheepshead minnow	1	5.0		5.0	5.0		0.3	0.0	0.0	0.0
4	Hebden; dredged	Summer flounder	1	29.3		29.3	29.3	252.3	0.7	0.0	0.0	0.0
5	Buchanan; undredged	Bay anchovy	402	4.7	0.6	2.8	5.5	1.8	0.9	0.0	33.3	51.7
5	Buchanan; undredged	Atlantic silverside	316	6.3	1.7	3.8	8.6	3.1	0.9	0.0	24.4	20.5
5	Buchanan; undredged	Silver perch	115	10.5	1.3	8.4	12.0	9.0	9.7	15.6	0.0	0.0
5	Buchanan; undredged	Gizzard shad	47	27.5	14.8	10.5	47.3	236.2	2.1	0.1	0.8	0.0
5	Buchanan; undredged	Atlantic menhaden	24	15.5	0.4	15.0	16.0	35.5	3.2	0.0	0.0	0.0
5	Buchanan; undredged	Mummichog	15	6.4	0.2	6.2	6.5	3.8	6.8	9.0	0.0	0.0
5	Buchanan; undredged	White perch	13	10.4	1.2	9.0	11.4	12.8	1.7	2.4	0.0	0.0
5	Buchanan; undredged	Blue crab	12						2.4	3.6	0.0	0.0
5	Buchanan; undredged	Red drum	6	37.0	5.0	31.0	41.4	600.1	0.0	0.0	0.0	0.0
5	Buchanan; undredged	Spotfin mojarra	5	6.7		6.7	6.7	3.9	4.7	0.0	0.0	0.0
5	Buchanan; undredged	Striped anchovy	3	6.2		6.0	6.4	3.3	0.6	0.0	0.0	0.0
5	Buchanan; undredged	Striped mullet	3	18.9	5.8	14.8	23.0	22.3	1.9	0.0	0.0	0.0
5	Buchanan; undredged	Naked goby	2	2.3		2.3	2.3		0.6	0.0	0.0	0.0
5	Buchanan; undredged	American eel	1	21.0		21.0	21.0		0.0	0.0	0.9	0.0
5	Buchanan; undredged	Atlantic croaker	1	4.1		4.1	4.1	0.9	0.4	0.0	0.0	0.0
5	Buchanan; undredged	Bluefish	1	29.9		29.9	29.9	226.8	0.0	0.0	0.0	0.0
5	Buchanan; undredged	Crevalle jack	1	10.5		10.5	10.5		0.3	0.0	0.0	0.0
5	Buchanan; undredged	Spot	1	14.8		14.8	14.8	42.3	0.9	0.0	0.0	0.0
6	Buchanan; dredged	Atlantic silverside	1153	6.5	1.4	4.0	8.5	1.4	4.3	1.6	180.2	221.4
6	Buchanan; dredged	Bay anchovy	452	5.4	1.1	3.4	7.0	0.9	4.6	5.6	45.0	28.8
6	Buchanan; dredged	Atlantic menhaden	191	13.1	2.3	9.5	16.8	24.7	18.6	19.8	1.0	0.0
6	Buchanan; dredged	Gizzard shad	107	25.1	13.5	9.0	47.5	245.0	9.4	6.9	1.9	0.9
6	Buchanan; dredged	Mummichog	94	5.8	0.8	4.6	7.1	1.9	12.5	0.3	35.2	0.0
6	Buchanan; dredged	Silver perch	66	9.8	2.2	5.8	13.0	9.2	12.6	20.0	1.4	0.4
6	Buchanan; dredged	Spot	22	15.2	0.8	13.0	17.4	50.0	7.0	0.0	0.0	0.0

Site No	Site	Species	Total	Ave TL	SD TL	Min TL	Max TL	Ave Wt	Beach Seine Av D	Beach Seine SD	Haul Seine Av D	Haul Seine SD
6	Buchanan; dredged	Atlantic croaker	11	5.1		3.7	6.5	0.8	3.3	0.0	0.0	0.0
6	Buchanan; dredged	Blue crab	10						2.0	0.2	0.0	0.0
6	Buchanan; dredged	Striped anchovy	6	6.5	0.5	5.8	6.9	1.7	1.3	0.0	2.3	0.0
6	Buchanan; dredged	Striped mullet	6	15.7	1.2	14.5	18.2	38.9	2.4	2.6	1.0	0.0
6	Buchanan; dredged	Red drum	4	31.8	2.6	26.0	35.0	311.8	0.0	0.0	0.0	0.0
6	Buchanan; dredged	Blackcheek tonguefish	2	7.7		7.7	7.7	2.8	1.3	0.0	0.0	0.0
6	Buchanan; dredged	Sheepshead minnow	1	4.1		4.1	4.1	2.0	2.7	0.0	0.0	0.0
6	Buchanan; dredged	Striped bass	1	20.5		20.5	20.5	85.0	0.0	0.0	0.0	0.0
6	Buchanan; dredged	Summer flounder	1	12.8		12.8	12.8	19.5	1.7	0.0	0.0	0.0
6	Buchanan; dredged	Sharptail goby	1	13.0		13.0	13.0	11.3	0.6	0.0	0.0	0.0
6	Buchanan; dredged	White perch	1	9.0		9.0	9.0	8.7	0.2	0.0	0.0	0.0

	Species Count	Abu	Ave TL	SD TL	Min TL	Max TL	Ave Wt	Beach Seine Av D	Beach Seine SD	Haul Seine Av D	Haul Seine SD
All Sites Combined	***30***	***5973***	***14.1***	***3.8***	***11.2***	***17.2***	***103.9***	***1.9***	***1.3***	***5.5***	***4.6***
Site 1: North; undredged	14	415	16.0	6.0	11.7	20.8	168.6	0.8	0.6	3.1	1.6
Site 2: North; dredged	13	294	14.4	4.1	10.8	17.8	151.1	1.6	1.1	1.6	1.1
Site 3: Hebden; undredged	20	1050	15.7	3.7	12.8	19.3	114.0	0.7	0.4	4.4	3.7
Site 4: Hebden; dredged	16	1117	12.9	2.9	10.2	15.5	75.8	1.4	0.6	4.5	1.5
Site 5: Buchanan; undredged	18	968	13.7	3.5	11.6	15.7	85.8	2.1	1.7	3.3	4.0
Site 6: Buchanan; dredged	18	2129	12.2	2.6	9.8	14.8	48.0	4.7	3.2	14.9	14.0