OCS Study
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Ecological Function and Recovery of Biological Communities within Dredged Ridge-Swale Habitats in the South-Atlantic Bight

Volume 2: Final Report on the Primary Producers and Invertebrates of the Sand Shoals

U.S. Department of the Interior
Bureau of Ocean Energy Management
Sterling, VA

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Editors:
Debra Murie[1]
Jennifer Bucatari[2]
Deena Hansen[2]

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By
[1] University of Florida, School of Forest, Fisheries, and Geomatics Sciences, 7922 NW 71st Street, Gainesville, FL 32653
[2] BOEM, Marine Minerals Program, 45600 Woodland Rd, Sterling, Virginia 22209, USA

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ABOUT THE COVER

Trichodesmium (S. Badylak); *Dexaminella* sp. (L. Jennings); *Pagurus annulipes* (L. Jennings); *Latreutes parvulus* (L. Jennings); stomatopod *Squilla* sp. (P. Baker); lancelet *Branchiostoma virginiae* (C. Frank); haustoriid amphipod *Acanthohaustorius millsi* (C. Frank); free-living bryozoan *Reussirella doma* (C. Frank)

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List of Abbreviations and Acronyms

ANOVA	Analysis of Variance
APHA	American Public Health Association
BOEM	Bureau of Ocean Energy Management
CMECS	Coastal and Marine Ecological Classification Standard
CPUE	Catch-per-unit-effort
CSII	Canaveral Shoal II
CSII-BA	Canaveral Shoal II Borrow Area
GPS	Global Positioning System
HSD	honestly significant difference
LMM	Linear Mixed-Effects Models
$MgCl_2$	Magnesium chloride
NOAA	National Oceanic and Atmospheric Administration
SD	Standard Deviation
TED	Turtle Excluder Device
TN	Total Nitrogen
TP	Total Phosphorus
YSI	Yellow Springs Instruments

6 Water Quality Parameters

Edward Phlips, Susan Badylak, Leslie Landauer, Anne West-Valle, and Benjamin Stelling

Key Points

- Mean surface water temperatures were greater than the bottom water temperatures within each of the four shoals but did not differ among the four shoals over the study period and followed the same general temporal pattern; mean bottom water temperature was higher at CSII compared to Bull Shoal, with CSII-BA and Chester Shoals overlapping with both of those shoals.
- Overall mean salinity, dissolved oxygen concentration, and pH for surface and bottom waters were not different within each shoal, nor were they different among the four shoals over the study period.
- Overall mean Secchi disk depths (i.e., light attenuation) did not differ among the four shoals over the study period.
- Mean turbidity levels over the study period were generally lower in the surface than bottom water samples for all shoals.
- Post-dredge seasons (i.e., spring and summer of 2014 and 2018) showed no major differences among shoals, including the dredged shoal, CSII-BA, in the trends of mean surface and bottom turbidities, mean chlorophyll *a* in surface and bottom waters, and mean total phosphorus and total nitrogen in surface and bottom waters.

6.1 Introduction

The physical and chemical properties of the water column play an important role in the structure and function of biological communities (Parsons et al. 1984; Reynolds 2006; Day 2013). A number of key water quality parameters were investigated in this study, including temperature, salinity, dissolved oxygen concentration, pH, turbidity, light attenuation (i.e., as Secchi disk depth), chlorophyll *a* concentration, total phosphorus concentration and total nitrogen concentration.

- Temperature regulates the rate of important metabolic processes in aquatic organisms, thereby affecting key functions, such as growth and reproduction. Changing temperature regimes also affect the structure of biological communities based on the temperature preferences and tolerances of different species.
- Similarly, salinity levels can impact the structure and function of biological communities based on the preferences and tolerances of different species to variations in the salt content of the water.
- Oxygen is essential for metabolism of aerobic organisms, and hypoxic conditions (i.e., < 3 mg oxygen L^{-1}) can negatively impact the health of aquatic aerobic organisms.
- Water-column pH can affect a range of water chemistry characteristics, such as the character of inorganic carbon and nitrogen elements. However, the range of pH values encountered in open oceans environments is typically narrow due to the buffering capacity of seawater.
- Turbidity is a measure of water clarity in terms of the amount of suspended matter, which includes suspended sediments and planktonic organisms. Levels of turbidity affect light

availability in the water column and therefore can impact primary production. High levels of turbidity can also affect other functional components of the biological community, such as filter-feeding organisms and visual predators.

- Another parameter used to measure light availability in the water column was Secchi disk depth, which can be used to determine light extinction coefficients used for the estimation of the depth of the euphotic zone for photosynthesis.
- Chlorophyll *a* concentrations are frequently used as surrogates for phytoplankton biomass, with the recognition that physical (e.g., light intensity), chemical (i.e., nutrient levels) and biological (e.g., species-specific and life-history differences) can influence the relationship between cell chlorophyll *a* concentrations and cell biomass (Reynolds 2006).
- Phosphorus and nitrogen are two of the most important macronutrients for the growth of primary producers, in part because they are often found in more limiting quantities in aquatic ecosystems than many other nutrient elements (Reynolds 2006). As a result, total phosphorus (TP) and total nitrogen (TN) are often used as important trophic state indicators that reflect the potential productivity of ecosystems.

Taken together, these parameters provide an important view of the structure and dynamics of the physical and chemical environment of the study shoals off the east coast of Florida (Figure 6-1), which included three reference shoals (Canaveral Shoal II, Bull Shoal, and Chester Shoal) and the dredged shoal (CSII-BA). Physical details of the shoals and the timeline of dredging on CSII-BA are provided in Chapter 1.

The overall goal of this chapter was to examine the spatiotemporal variability of these water quality parameters on an annual, seasonal, and diurnal basis in both the surface water and bottom waters of the shoals. In addition, these water quality parameters were compared for the dredged shoal (CSII-BA), relative to the three reference (non-dredged) shoals (CSII, Chester, and Bull Shoals), before and after dredging events.

6.2 Methods

Data on basic water quality parameters were collected during seasonal, daytime sampling events from the fall of 2013 through the summer of 2019. Each of the daytime sampling events included the four study shoals, i.e., Bull, Chester, CSII-BA, and CSII (Figure 6-1). Each shoal included six stratified-random sampling sites, four in associated swale areas and two in ridge areas of each shoal. Seasons included spring (March–May), summer (June–September), fall (October–November), and winter (December through to the following February). In addition, a limited series of nighttime sampling events were carried out for daytime versus nighttime comparisons. Nighttime sampling was done on CSII-BA, CSII, and Chester Shoals in the winter and summer of 2014 and 2015. The nighttime sampling of each shoal was completed within the same week as the daytime sampling of the shoals. Details of the study shoals and sampling site selections are given in Chapter 1.

At each sampling site, basic water-column parameters (i.e., temperature, salinity, oxygen, pH, Secchi disk depth) and water samples for analysis of turbidity, chorophyll *a*, TN and TP were obtained from the surface and bottom (i.e., approximately 1 m from the bottom) of the water column. Surface-water column parameter measurements were made at 1 m below the surface and bottom measurements were made 1 m off the bottom (i.e., sondes were lowered to the bottom and raised by one meter for reading). In order to capture a representative water sample of the surface-water layer, an integrating tube was used to capture the top 2.5 m of the water column. Multiple tubes of water were poured into a bucket to obtain 10 L of water. Aliquots of water were removed from the bucket after stirring for the various analyses. Bottom-water samples were collected using a 5-L horizontal Niskin sampler. Two Niskin samples were combined into a bucket for a composite sample, from which aliquots were removed for the various analyses.

On-site measurements of water temperature, salinity, and oxygen concentrations were made with a Yellow Springs Instruments (YSI) environmental multi-probe at the surface of the water column and at 1 m from the bottom of the water column. Light attenuation in the water column was measured using a Secchi disk.

Turbidity was determined for surface- and bottom-water samples using a LaMotte meter (APHA 2005). Chlorophyll *a* and pheophytin concentrations were determined in the laboratory using filtered surface- and bottom-water samples extracted with solvent and measured using a dual beam scanning spectrophotometer (Sartory and Grobbelaar 1984; APHA 2005; Phlips et al. 2010). TN and TP concentrations were determined with standard (USEPA 1983; APHA 2005) methods.

Differences in water quality parameters were tested among shoals, between ridge versus swale habitats, surface- versus bottom-water samples, and among seasons and years using Duncan Multiple Range Tests ($P \leq 0.05$). For these comparisons, only daytime sampling events were used to ensure a balanced sample size. All analyses were done using statistical packages in SAS® (SAS Institute 2012).

In addition to this static spatiotemporal sampling, Hydrolab DS5X environmental multi-probe continuous-recording units were deployed at the different shoals to monitor water temperature, dissolved oxygen concentrations, salinity, turbidity and chlorophyll *a* concentrations (fluorometric). The units were set to record values at 30-min intervals. The units were mounted approximately 1 m from the sediment surface on metal A-frame structures anchored to the sea floor. Units were deployed for approximately a month at a time in association with moored acoustic doppler current profilers (see Chapter 2). The units were deployed at selected shoals in different seasons to examine short-term variability in the parameters listed above.

6.3 Results

6.3.1 Temperature

Mean water temperatures at the four shoals over the study period followed the same general temporal pattern (Figure 6-2). Individual sampling events of mean bottom-water temperatures were sometimes lower than mean surface-water temperatures, mostly in the summer (Figure 6-2), as further indicated by the lower mean water temperatures in the bottom than surface of the water column for the study period (Table 6-1).

6.3.2 Salinity

Mean salinities at the four shoals ranged from near 33 to 39 psu for both surface and bottom readings over the study period (Figure 6-3). Overall mean salinity for the study period was 35.9 psu (standard deviation, SD = 0.1 psu). No significant differences were observed between mean values for surface and bottom measurements or among the four shoals within the study (all $P \geq 0.05$).

6.3.3 Oxygen

Most mean dissolved oxygen concentrations at the four shoals ranged from near 6 to 9 mg L^{-1} for both surface and bottom readings over the study period (Figure 6-4). Two exceptions were the fall 2015 and summer 2016 sampling events, when mean dissolved oxygen concentrations were below saturation, i.e., near 3–4 mg L^{-1}. Overall mean value for the study period was 6.85 mg L^{-1} (SD = 0.07). No significant differences were observed between mean values for surface and bottom measurements or among the four shoals within the study (all $P \geq 0.05$).

6.3.4 pH

Mean pH values ranged from 8.0 to 8.5 for all four shoals and sampling dates in the study for both surface- and bottom-water measurements (Figure 6-5). Overall mean value for the study period was 8.18 (SD = 0.04). No significant differences were observed between surface and bottom measurements within each shoal or among shoals of the study (all $P \geq 0.05$).

6.3.5 Light Attenuation

Mean Secchi disk depths ranged from lows near 2–3 m in the fall and winter sampling events to peak values in the summer sampling events ranging from 6–12 m (Figure 6-6). Overall mean value for the study period was 5.0 m (SD = 0.5). There were no overall significant differences in mean Secchi disk depths among the four shoals over the study period, however, there were some modest differences among shoals within each season (Table 6-2).

6.3.6 Turbidity

Turbidity levels over the study period were generally lower in the surface- than bottom-water samples (Figure 6-7), as indicated by the mean values at the four shoals over the study period (Table 6-3). The latter effect on bottom water turbidity was illustrated in Figure 6-8, which shows the effect of the wind event on October 16–18 on turbidity, which reached up to 720 ntu based on continuous-recording Hydrolab sonde units located near the sediment surface. The continuous-recording sonde events showed peak turbidity values higher (Table 6-4) than the peak values observed during the in situ sampling events, demonstrating the importance of resuspension processes associated with strong wind events, during which in situ sampling by the research vessels available for this study was not possible.

Mean surface-water turbidity values for the four shoals ranged from near 0.2 to 4 ntu (Figure 6-7). No differences were observed in mean surface turbidity over the study period between ridge or swale habitats within each shoal, or in ridge habitats among shoals, but Bull Shoal had lower turbidity in its swales compared to Chester and CSII-BA Shoals, with CSII Shoal not different from the other three shoals (Table 6-5). Seasonally, the highest mean surface turbidities for the study period were in the fall and the lowest were in the summer at all four shoals (Table 6-6). In terms of interannual differences in mean surface-water turbidity, all four shoals exhibited a general upward trend in values, from lows in Year 1 to peak values in Years 4 or 5 (Table 6-7). The temporal patterns in mean surface turbidities at CSII-BA (the dredged shoal) did not differ significantly from the other three shoals in the post-dredge periods (i.e., spring and summer) in 2014 (Year 1) and 2018 (Year 2) (Figure 6-7). In 2014, no significant changes were observed in mean turbidity and in 2018 all shoals showed a decline in mean turbidity.

A large range of mean turbidity values was observed in the bottom-water samples (i.e., 0.2–16 ntu) (Figure 6-7). A comparison of ridge and swale habitats for mean bottom-water turbidity for the study period showed higher values at swale than ridge habitats at Chester and CSII (Table 6-8). Among shoals, the highest mean for the ridge habitat was in the dredged shoal (CSII-BA), but for swale habitat the highest mean was at CSII (Table 6-8). Seasonal differences in mean bottom-water turbidity were less defined than for surface-water samples (Table 6-9). Generally, fall and winter means were higher than summer means, and the dredged shoal (CSII-BA) and CSII had somewhat higher mean values than Bull and Chester Shoals, although the differences were not always significant (Table 6-9). Interannual patterns of mean bottom-water turbidity were different in the four shoals of the study (Table 6-10). Year 1 had the lowest mean annual turbidity values at all four shoals. After Year 1, peak mean values occurred in different years at the four shoals. Within year comparisons showed no differences in mean values among shoals in Years 1, 3 and 4. During Year 2, both CSII-BA and CSII had peak mean turbidities that were higher than mean turbidities on Bull and Chester Shoals but were not significantly different from one another. In Year 5 the mean bottom turbidity of CSII was higher than Bull and Chester Shoals but was not significantly higher than CSII-BA.

In terms of the post-dredge period events (i.e., spring and summer) of 2014 (Year 1) and 2018 (Year 5), no apparent major differences were observed among shoals in the trends of mean surface-water or mean bottom-water turbidity values, including the dredged shoal (CSII-BA) (Figure 6-7).

6.3.7 Chlorophyll *a*

Overall, mean surface chlorophyll *a* concentrations for the study period were lower than mean bottom chlorophyll *a* concentrations, but were similar among all four shoals with mean values ranging from 1.01 to 1.18 µg L^{-1} (Table 6-11). Mean chlorophyll *a* (pheophytin corrected) concentrations in surface-water samples over the study period ranged from near 0.2 µg L^{-1} in the summer of 2017 to near 4 µg L^{-1} in the fall of 2017 for all four shoals of the study (Figure 6-9). No differences in mean surface chlorophyll *a* concentrations were observed between ridge and swale habitats at any of the shoals (all $P > 0.05$). Mean surface-water pheophytin concentrations (degradation products of chlorophyll *a*) were low over the study period for all shoals, i.e., below 20% of corrected chlorophyll *a* (Figure 6-9).

All shoals had similar seasonal patterns in mean chlorophyll *a* concentrations for water samples. For the study period, seasonal mean corrected chlorophyll *a* concentrations were highest for the fall, followed by the winter, and lowest in the spring and summer (Table 6-12). Within each season, mean surface corrected chlorophyll *a* concentrations were similar across the four shoals, including the dredged shoal (CSII-BA) (Table 6-12).

Interannual differences in annual mean surface chlorophyll *a* concentrations were not significant at Bull Shoal during all 5 years, while showing some overlap in mean concentration at Chester Shoal between Year 1 and Years 2–5 (Table 6-13). Both CSII-BA and CSII had similar mean concentrations during Years 1–4, with Year 5 mean values were higher than the other 4 years. Within years, however, the shoals had similar mean chlorophyll *a* concentrations in Years 1 and 3–5, with means overlapping among the shoals in Year 2.

Overall, mean bottom chlorophyll *a* concentrations for the study period were similar among Bull, Chester, and CSII-BA Shoals, but lower than the overall mean for CSII (Table 6-11). Mean chlorophyll *a* concentrations in bottom-water samples over the study period ranged from less than 1 µg L^{-1} in the summer of 2017 to 8 µg L^{-1} in the fall of 2018 (Figure 6-10). Mean bottom pheophytin concentrations for the study period were a higher percentage of corrected chlorophyll *a* than in surface-water samples for all four shoals, i.e., up to 30–40%. Mean bottom chlorophyll *a* concentrations were not different between ridge versus swale habitats within each shoal except for CSII where the mean chlorophyll *a* concentration was lower in ridge habitat (Table 6-14). Within ridge habitat, however, the means were not different among the shoals, however, within swale habitat the mean chlorophyll *a* concentration in the swale of CSII was higher than the swales of all other shoals (Table 6-14).

Seasonal mean chlorophyll *a* concentrations in bottom-water samples showed few consistent differences (Table 6-15). The only somewhat consistent trend was lower mean values in the summer, which was also partly related to generally calmer wind conditions in the summer versus the rest of the year. Highest mean values occurred in different seasons for the four shoals.

Interannual differences in mean bottom-water chlorophyll *a* concentrations were relatively modest (Table 6-16). The only consistent trend was higher concentrations in Year 5 of the study than other years for all four shoals.

The results of continuous-recording sonde events showed higher mean bottom-water chlorophyll*a* (uncorrected) concentrations (Table 6-17) than mean values for bottom-water chlorophyll *a* concentrations based on all sampling events (Table 6-11), in part reflecting the importance of sediment resuspension in defining variability in bottom-water chlorophyll *a* levels (Figure 6-11).

In terms of the post-dredge period events (i.e., spring and summer) of 2014 (Year 1) and 2018 (Year 5), no apparent major differences were observed among shoals in the trends of mean surface or mean bottom-water chlorophyll *a* values, including the dredged shoal (CSII-BA) (Figures 6-9 and 6-10).

Another aspect of the study related to variability in phytoplankton biomass was a comparison of daytime versus nighttime sampling events. In 2014 and 2015, winter and summer sampling events were completed during daytime and nighttime within the same week. Mean surface-water chlorophyll *a* values in three sampling shoals (Chester, CSII-BA and CSII) used in the night versus day comparison showed no major differences per season for either ridge or swale habitats (Figures 6-12 and 6-13 respectively). Some differences in seasonal mean chlorophyll *a* concentrations in bottom-water samples were observed between daytime and nighttime sampling events within the same season. These differences were not unexpected based on the importance of sediment resuspension in defining chlorophyll *a* levels in near-bottom water layers, as discussed above. Therefore, separation of day and night sampling by days or even hours can result in different wind conditions and therefore different levels of resuspension.

6.3.8 TP and TN

Mean TP concentrations in surface water for individual sampling events ranged from 2 to 45 µg L^{-1} (Figure 6-14). The four shoals of the study had similar mean surface-water TP concentrations for the study period (Table 6-18). A comparison of mean surface-water TP concentrations in ridge and swale habitats showed no significant differences between or among the four shoals (all $P > 0.05$). Overall mean surface-water TP concentration for all shoals was 17.6 µg L^{-1} (SD = 1.4). A seasonal comparison of mean surface-water TP concentrations showed no differences among seasons for Bull, Chester, and CSII-BA Shoals, and small overlapping differences on CSII (Table 6-19); there were no differences among shoals within each season. Interannual comparison of mean TP concentrations in surface water showed consistently higher values in Year 2 for all four shoals (Table 6-20). The other years had relatively similar mean values. There were no differences in mean values among shoals within any year.

Mean TP concentrations in bottom-water samples were higher than surface-water samples in all four shoals (Table 6-18). Comparison of mean values among shoals showed higher bottom-water mean TP at CSII compared to the other three shoals (Table 6-18). A comparison of mean bottom-water TP concentrations in ridge and swale habitats showed no significant differences in Bull, Chester or CSII-BA, but the mean for swale habitat in CSII was higher than for ridge habitat (Table 6-21). Comparison of means among the four shoals showed no differences for ridge sites, but a higher mean value for CSII for swale habitat (Table 6-21). Seasonal patterns of mean bottom-water TP concentrations were different among shoals (Table 6-22). At Bull Shoal, the highest means were in the fall and winter, but at Chester Shoal there were no significant differences among seasons. At CSII-BA and CSII, the highest mean values were in the winter and spring. Within each season differences among shoals were limited to the winter and spring, when mean values for CSII were the highest. In terms of interannual patterns in mean bottom-water TP, Year 2 had the highest values for all four shoals, but the difference was not significant for Chester Shoal (Table 6-23). Within each year differences among shoals were only significant for Years 2 and 3. In Year 2, CSII-BA and CSII both had higher means than Bull and Chester Shoals, while in Year 3 there was a difference between CSII and Bull Shoal, but Chester Shoal and CSII-BA were not different from either Bull Shoal or CSII.

In terms of the post-dredge period events (i.e., spring and summer) of 2014 (Year 1) and 2018 (Year 5), no apparent major differences were observed among shoals in the trends of mean surface or mean bottom-water TP values, including the dredged shoal (CSII-BA) (Figure 6-14).

Mean surface-water TN concentrations mostly ranged from 100–200 µg L^{-1}, with a few exceptions, most prominently values in excess of 300 µg L^{-1} in the fall 2013 and winter 2013/14 at CSII-BA and CSII, and means less than 100 in the summer sampling events of 2014 and 2017 for all shoals (Figure 6-15). For the study period, mean surface-water TN concentration was lower at Bull Shoal than the other three shoals (Table 6-24). Within each shoal, mean surface-water TN concentrations at swale and ridge habitats were similar over the study period (Table 6-25). Among shoals, mean surface-water TN concentrations were similar for ridge habitat, but lower at Bull Shoal for swale habitat (Table 6-25).

From a seasonal perspective, mean surface-water TN concentrations were highest in the fall at all four shoals (Table 6-26). Within each season, Bull Shoal had the lowest mean TN concentrations in the fall and winter. In the spring, Chester and CSII-BA had higher mean values than Bull and CSII. Summer mean surface-water TN concentrations did not differ among the shoals. Interannual patterns in mean surface-water TN concentrations were different among shoals. Highest means were in Years 2, 3 and 5 at Bull and Chester Shoals, but in Years 1, 2 and 5 at CSII-BA and CSII Shoals (Table 6-27). Within each year, the relationships between means varied, i.e., in Year 1 CSII-BA and CSII had the highest means, in Year 2 CSII had a lower mean than Chester Shoal but similar to Bull and CSII-BA Shoals, and in Year 3 Chester Shoal had the highest mean value. There were no differences among shoals in Years 4 and 5.

The range and temporal patterns of mean bottom-water TN concentrations were generally similar to the surface values (Figure 6-15). Mean bottom-water TN concentrations over the study period were higher than surface values at Chester Shoal, but similar at Bull, CSII-BA, and CSII Shoals (Table 6-24). Mean bottom-water TN concentrations were not different between ridge and swale habitats within each shoal (Table 6-28). Within ridge habitat, however, Chester had a higher mean TN concentration compared to CSII, but CSII-BA and Bull Shoals were not different from either Chester or CSII Shoals (Table 6-28). Within swale habitats, Chester also had a higher mean TN concentration compared to CSII-BA, but Bull and CSII were not different than either Chester or CSII-BA Shoals.

From a seasonal perspective, fall and winter had the highest mean bottom-water TN concentrations at all four shoals, and the lowest means were in the spring and summer, except at Chester in the spring (Table 6-29). In the fall, all shoals had similar mean TN values (Table 6-29). In the winter, the mean value was lower at Bull Shoal than the other three shoals. In spring, Chester Shoal had a higher mean value than the other three shoals. In the summer, CSII-BA had a lower mean value than Bull Shoal, and Chester and CSII Shoals were not different from either Bull or CSII-BA Shoals.

Interannual patterns in mean bottom-water TN concentrations were different by shoal (Table 6-30). At Bull and Chester Shoals, mean values were lower in Year 1 than Years 2–5. At CSII-BA, mean TN value in Year 4 was lower than in Year 1, but neither of those years was different than Years 2, 3 and 5. At CSII, mean TN was higher in Year 1 than Years 2–5. Within Year 1, CSII had the highest mean TN value. In Year 2, Bull and Chester Shoals had the highest mean TN values. In Years 3 and 4, there were no differences in mean TN among shoals. In Year 5, CSII had a lower mean TN than the other three shoals.

In terms of the post-dredge period events (i.e., spring and summer) of 2014 (Year 1) and 2018 (Year 5), no apparent major differences were observed among shoals in the trends of mean surface-water or mean bottom-water TN values, including the dredged shoal (CSII-BA) (Figure 6-15).

6.4 Discussion

The physical and chemical parameters included in this study were selected because of their potential influence on the character and dynamics of planktonic and benthic organisms. Two of the parameters showed minimal variability, namely pH and dissolved oxygen concentration in the water column. pH values were consistently near 8.2, reflecting the buffering capacity of oceanic waters. Oxygen concentrations in the water column observed in this study did not reach hypoxic levels (i.e., <3 mg L^{-1}), and were generally near saturation concentrations. The relative stability of these two parameters also reflects the hydrologically dynamic polymictic character of the Canaveral shelf that minimizes vertical stratification and disrupts spatial patchiness.

The other parameters included in this study exhibited temporal variability, which help to explain the observed variability in key biological communities (see Chapters 7 and 9). Water temperatures exhibited the typical seasonal pattern but, because of the subtropical location of the Canaveral shelf, winter temperatures were predominantly above 20 ºC and summer temperatures were near 30 ºC. The narrow range compared to temperate regions reduces the impact of temperature on seasonal variability in biological communities. Spatially, there were no significant differences in either surface- or bottom-water temperatures among the four shoals, including the dredged shoal (CSII-BA) (Table 6-1). Bottom-water temperatures were sometimes modestly lower than surface temperatures, particularly in the summer, which is characterized by generally calmer wind conditions (excluding tropical storm events). This trend was illustrated by the seasonal monthly mean wind totals (i.e., in miles $month^{-1}$) for the study period (2013–2019) reported by the U.S. National Climate Center (www.ncdc.noaa.gov/IPS); i.e., fall = 1,277 (SD = 375); winter = 1,541 (SD = 204); spring = 1,867 (SD = 217); and summer = 1,106 (SD = 234).

Salinity values observed in the study region were similar to levels characteristic of the U.S. western Atlantic Ocean. No differences among shoals were observed, reflecting the high degree of wind- and current-based mixing of the water column within the study region, and the absence of any significant freshwater inflows that directly impact the study region. Temporally, salinities were modestly lower during the fall and winter than spring and summer. The difference reflects seasonal shifts in the sources of water influencing the Cape Canaveral region. In the fall and winter, the predominance of winds from the north drive coastal currents southward along the coast of Florida toward the shelf (AlYousif et al. 2021). These water masses are subject to inflows of low salinity water from rivers (e.g., St. Johns River) and inlets (e.g., St. Augustine, Sebastian, and Ponce Inlets) along eastern Florida, which appear to modestly depress seasonal salinities.

Turbidity was another parameter that exhibited the influences of spatial and temporal variability in wind and currents. The elevated bottom values relative to surface values reflects resuspension of bottom sediments due to current- and wind-driven circulation. In bottom waters, fall, winter and spring had the highest mean turbidities, which coincided with the seasons of highest mean monthly wind for the study period (2013–2019) in southeast Florida (reported above). In surface-water samples, turbidities were also lowest in the summer and spring, and highest in the fall, followed by winter.

The seasonal differences between the surface- and bottom-water turbidites indicated that factors other than just local wind speed govern the turbidities. One likely factor was the role of seasonal shifts in the direction from which coastal water masses reach the Cape Canaveral shelf (AlYousif et al. 2021). In the fall and winter, winds predominantly come from the north, as discussed in the previous section on salinity. These winds drive coastal water masses south along the coast, where they are influenced by introductions of turbidity from rivers and inlet inputs, as well as resuspended bottom sediments. The arrival of the water masses on the Canaveral shelf are therefore higher in turbidity than in the spring and summer, when southeasterly trade winds push water from the south into the Cape Canaveral shelf, and enhance the influence of Gulf Stream waters, which are low in turbidity (Stelling 2021). In addition to general seasonal patterns in turbidity, episodic events, such as tropical storms and dredging operations, have the potential to elevate turbidities in the water column. In all four shoals, the fall 2016 and fall 2017 were periods of elevated surface-water turbidity, possibly because both years were associated with major hurricanes in the early fall; however, this linkage was only speculative. In terms of the post-dredge period events (i.e., spring and summer) of 2014 and 2018, no apparent major differences in the trends of mean surface- or bottom-water turbidity were observed among shoals.

The effects of seasonal shifts in wind and current directions can also be seen in light attenuation expressed as Secchi disk depth. Seasonal mean Secchi disk depths had the opposite seasonal pattern as seasonal mean surface-water turbidity, i.e., highest in the summer and lowest in the fall. The latter relationship reflects the fact that tripton (non-algal suspended matter) is a major component of light attenuation in many coastal marine environments, along with phytoplankton biomass (Kirk 1994; Phlips et al. 1995).

Two other parameters examined in this study were chemical elements most commonly limiting for primary production in aquatic ecosystems, phosphorous and nitrogen (Parsons et al. 1984; Reynolds 2006). Mean TP and TN concentrations over the study period followed some of the same spatial and seasonal patterns as turbidity, which suggests that they may be under some of the same driving factors. In the case of TP, mean bottom-water concentrations were higher than mean surface concentrations at all four shoals. This indicates that resuspension of bottom sediments may contribute to TP levels in lower parts of the water column. There were no differences among shoals, except for a somewhat higher mean at CSII in bottom waters. Seasonally, mean TP concentrations in the fall and winter were marginally higher, or in some cases similar to levels in the spring and summer, but the means were for the most part not statistically different. In terms of the post-dredge period events (i.e., spring and summer) of 2014 and 2018, no apparent major differences in the trends of mean surface or bottom TP were observed among shoals.

In the case of TN, mean bottom-water concentrations were higher than mean surface concentrations at all four shoals. There were only minor differences among shoals, with the lower surface-water mean at Bull Shoal, and higher bottom-water mean at Chester Shoal. Seasonally, the highest mean TN concentrations were in the fall, followed by the winter, and lowest in the spring and summer. As discussed in previous sections on salinity and turbidity, these temporal patterns may reflect seasonal shifts in the sources of water influencing the Cape Canaveral region. In the fall and winter, the predominance of winds from the north drive coastal currents southward along the coast of Florida toward the shelf (AlYousif et al. 2021). These water masses are subject to inflows of nutrient enriched water from rivers (e.g., St. Johns River) and inlets (e.g., St. Augustine, Sebastian, and Ponce Inlets) along eastern Florida. Conversely, spring and summer southeasterly trade winds bring water masses from the south, including the Gulf Stream, which are characterized by low nitrogen concentrations. The exceptionally high mean TN values in the fall 2013 may be related to the presence of a bloom of the nitrogen-fixing cyanobacterium *Trichodesmium* at CSII-BA and CSII. *Trichodesmium* (see Figure 5-5) is a common bloom-forming cyanobacterium in coastal waters of Florida, and has been linked to the supply of nitrogen for red tide events in the Gulf of Mexico (Mulholland et al. 2014). In terms of the post-dredge period events (i.e., spring and summer) of 2014 and 2018, no apparent major differences were observed among shoals in the trends of mean surface- or bottom-water TN values.

The last water quality parameter in this study was chlorophyll *a*, a widely used measure of algal biomass in aquatic ecosystems (Parsons et al. 1984; Reynolds 2006). The mean surface-water concentration for the study period was 1.11 $\mu g\ L^{-1}$, which places the study region on the oligotrophic side of the trophic scale. The range of individual surface chlorophyll *a* concentrations ranged from 0.1 to 10 $\mu g\ L^{-1}$. The highest values observed in the study were associated with blooms of the cyanobacteria *Trichodesmium* in the fall of 2013. The range of values fall within the levels reported by the National Oceanic and Atmospheric Administration's (NOAA's) Coast Watch satellite imaging program for the same time period (http://coastwatch.chesapeakebay.noaa.gov/region_fg.php#k490) (Stelling et al. 2023). Based on satellite imagery, surface chlorophyll *a* concentrations in the nearshore fringe of the central and northeast shores of Florida commonly range from 0.3 to 3 $\mu g\ L^{-1}$, but can periodically exceed these levels during localized nearshore bloom events, such as the 2007 red tide event (Hart et al. 2015).

Mean bottom-water chlorophyll *a* concentration for the study period was 2.5 µg L^{-1}. The higher mean for bottom-water samples likely reflects the resuspension of microalgae located on or near the surface of the sediments. Chlorophyll *a* concentrations in the surface layer of the bottom can be substantial. In part, this reflects settling of diatoms out of the surface water, as indicated by the overall higher biomass of diatoms in bottom-water than surface-water samples (see Chapter 7) (Tate et al. 2020).

The greater mean bottom-water chlorophyll *a* observed via the continuous-recording sonde versus seasonal in situ sampling may be due to several factors. The sonde values are based on in situ fluorescence probe measurements, which are known to run on the high side relative to more precise extracted values, particularly in environments with elevated turbidity (Martins and Pelegri 2006). In addition, the sonde values include measurements during higher wind periods, i.e., 10/16/2014 and 10/18/2014 (Figure 6-11), demonstrating the importance of resuspension of benthic algae. In situ sampling during high wind events by the research vessels available for this study were not possible for safety reasons.

The seasonal pattern of surface chlorophyll *a* concentrations did not follow the traditional "spring bloom" pattern often associated with temperate environments, but rather reflects the subtropical climate in the region and the sources of water masses moving through the area (Stelling et al. 2023). Mean surface-water chlorophyll *a* concentrations were highest in the fall (followed by the winter) and lowest in the summer. The seasonal pattern is similar to that observed for both turbidity and TN concentrations, suggesting that some of the drivers for chlorophyll *a* are similar. As in the case of the former two parameters, wind-driven movement of water along the east coast of Florida toward Cape Canaveral, bringing in water with elevated levels of nutrient, particulate matter, and chlorophyll *a* to the Cape shelf. Conversely, southeasterly trade winds in the spring and summer bring in clearer waters from the south, including the Gulf Stream. The high TN levels observed in the fall season are noteworthy because nitrogen is a limiting factor for primary production in many marine environments (Parsons et al. 1984; Reynolds 2006), including coastal ecosystems in Florida (Phlips et al. 1999, 2002; Bledsoe et al. 2004; Dix et al. 2013). In terms of the post-dredge period events (i.e., spring and summer) of 2014 and 2018, no apparent major differences were observed among shoals in the trends of mean surface- or bottom-water chlorophyll *a* values.

The lack of major differences among shoals during post-dredge periods in the trends of mean values for the water quality parameters included in this study suggest that impacts of dredging on these factors are relatively short-lived (i.e., < 1–2 months). This observation also highlights the fact that the Cape Canaveral shelf is hydrologically dynamic, which makes water-column conditions on the shelf subject to strong allochthonous influences. In other words, the character of water masses passing through the Cape Canaveral region is strongly impacted by the origins and history of the passing water masses. This trend does not preclude major short-term impacts of local events, such as dredging and storms, on water-column characteristics, particularly factors like turbidity, resuspended benthic algae, and light attenuation.

6.5 References

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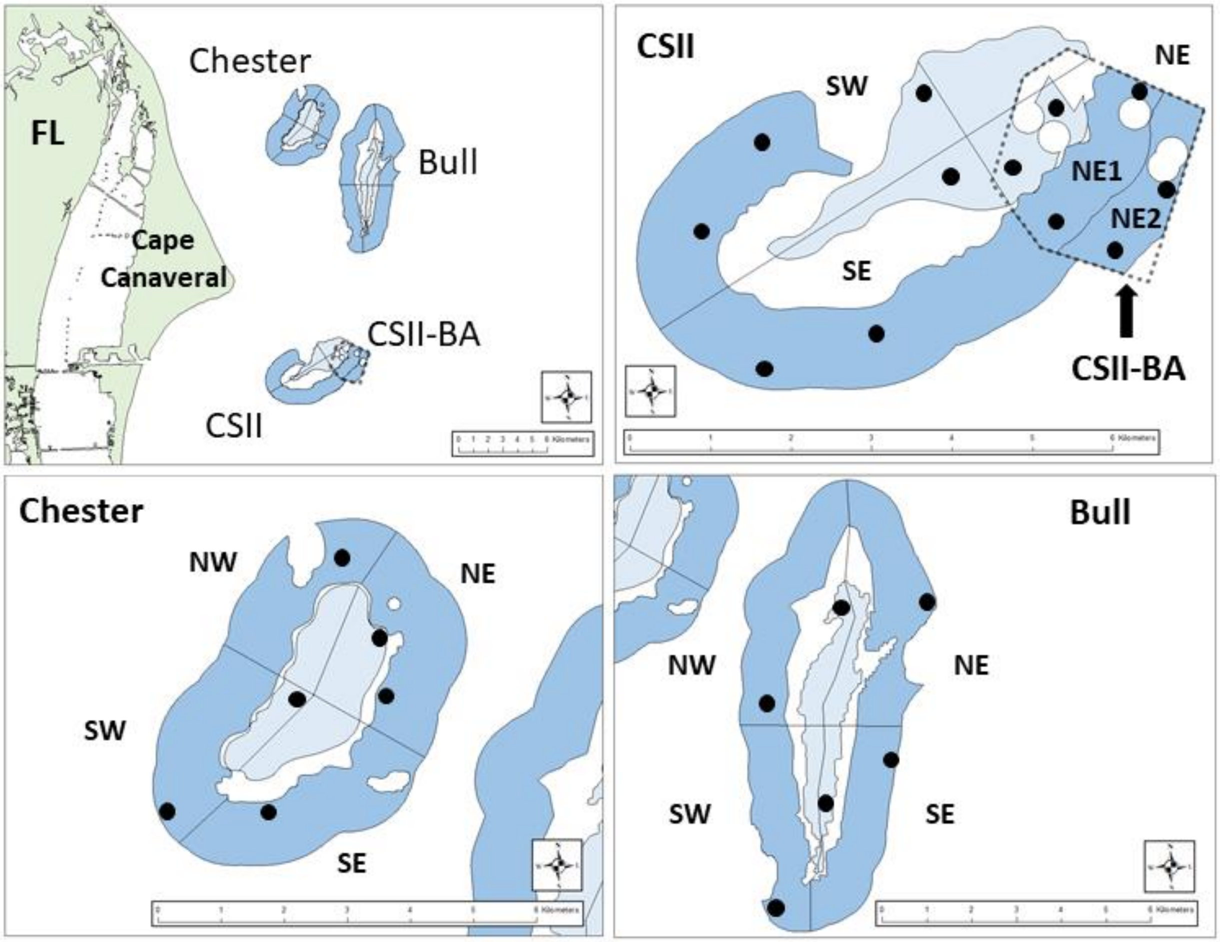

Figure 6-1. Location of water sampling sites on ridges (light blue) and in swales (dark blue) for study shoals.
Potential sampling sites (solid black dots) included four swale sites and two ridge sites, except for CSII-BA, which had four swale sites that covered the potential dredged area.

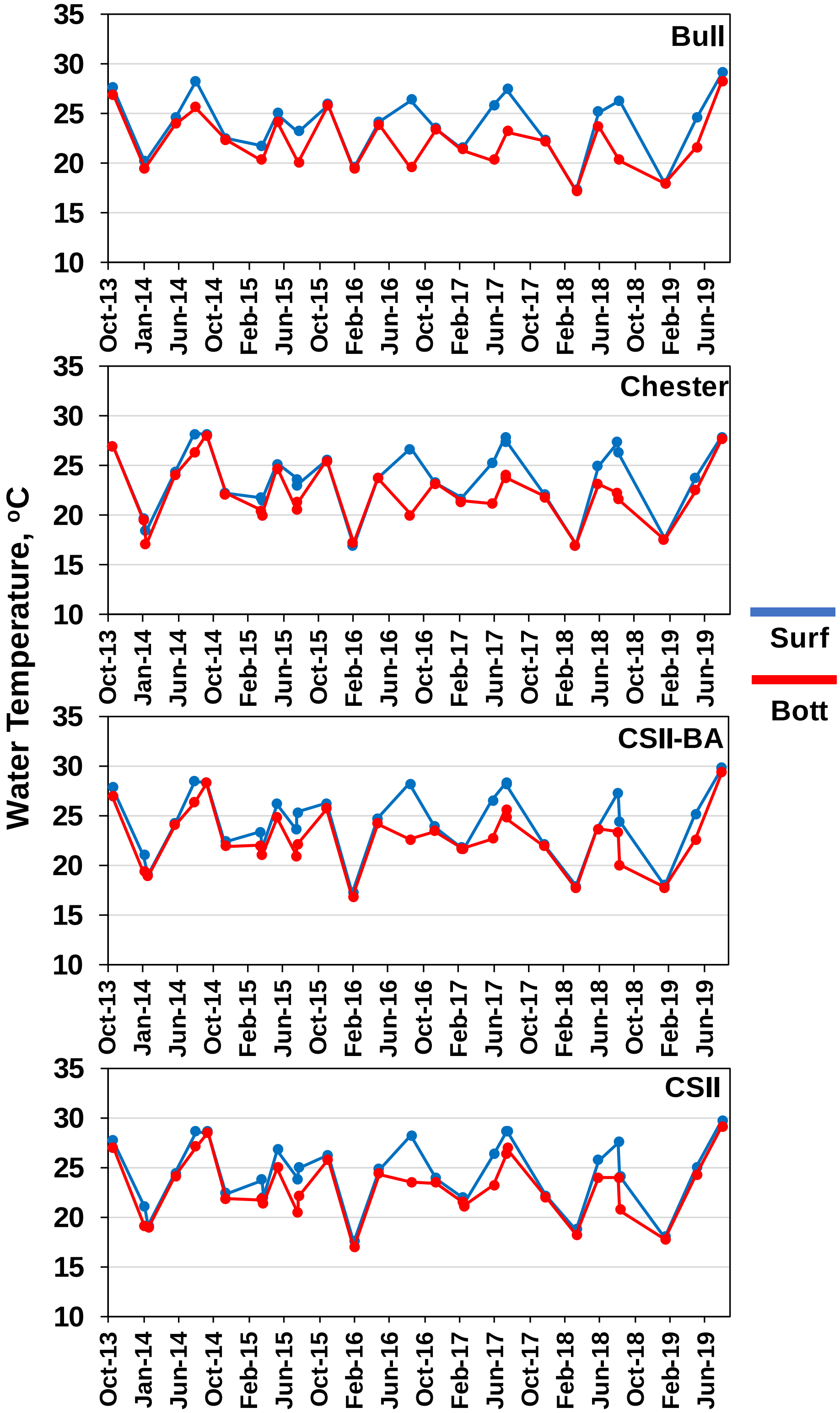

Figure 6-2. Mean surface- and bottom-water temperatures (°C) for the shoals.

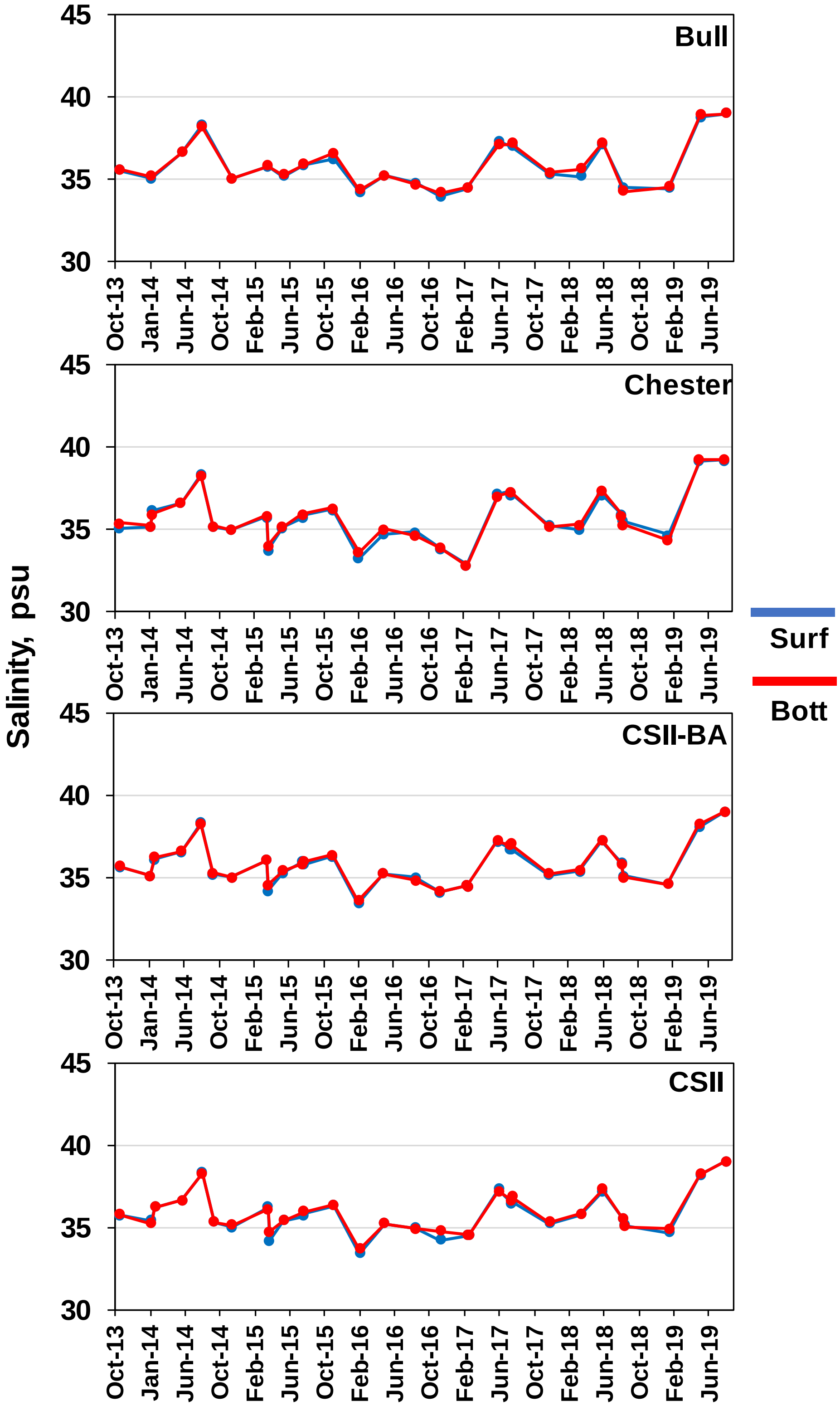

Figure 6-3. Mean surface- and bottom-water salinities (psu) for the shoals.

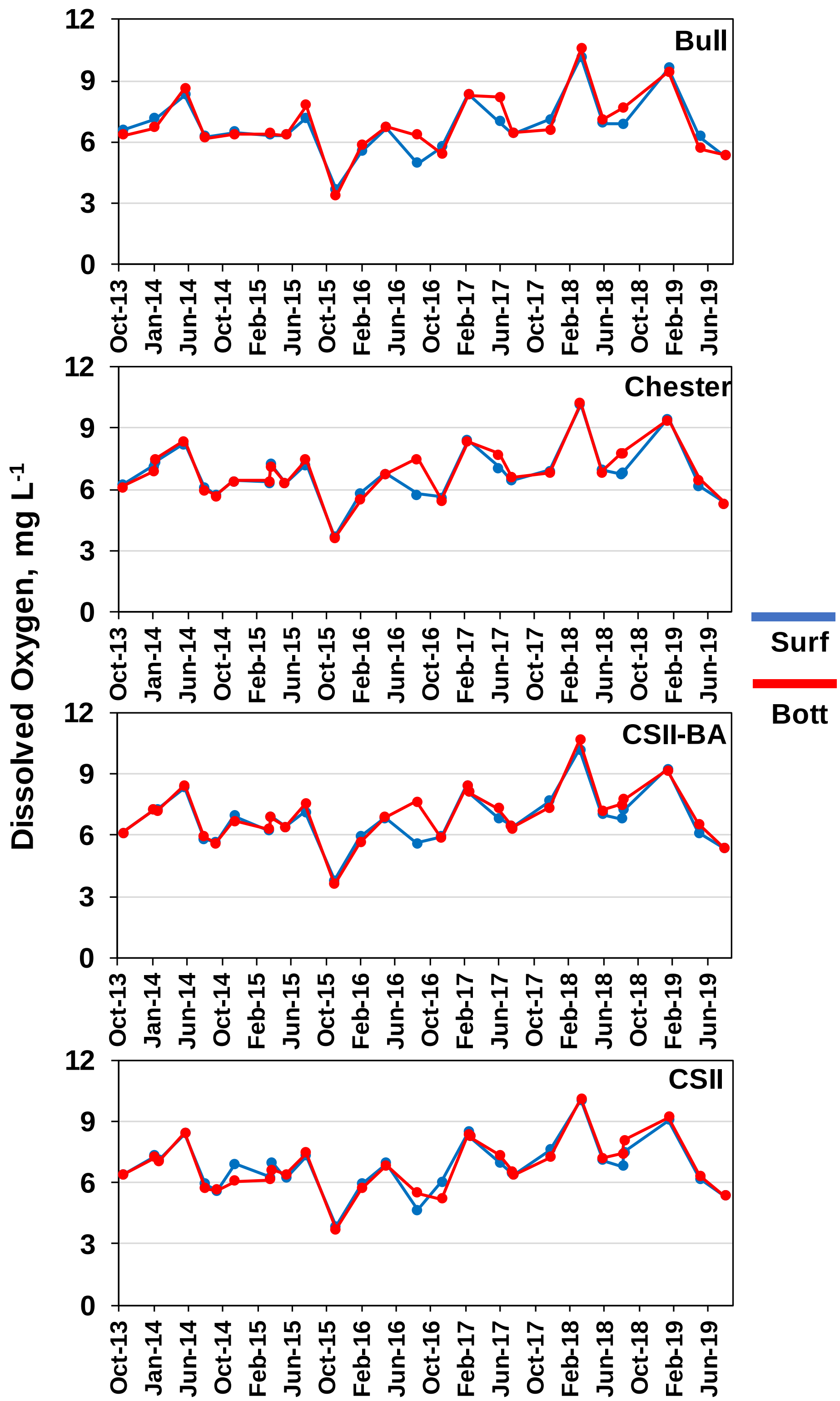

Figure 6-4. Mean surface- and bottom-water dissolved oxygen concentrations (mg L^{-1}) for the shoals.

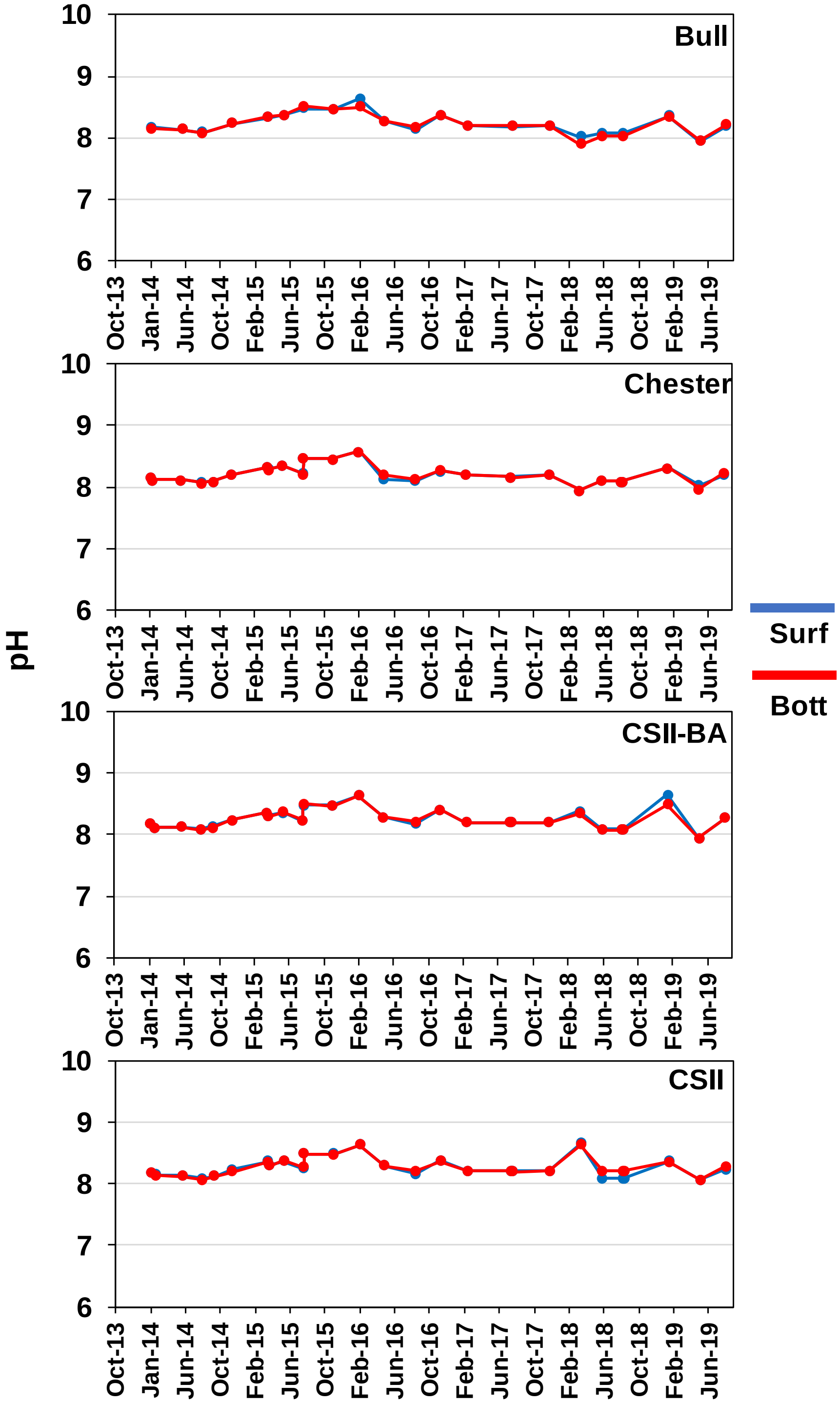

Figure 6-5. Mean pH in surface- and bottom-water for the shoals.

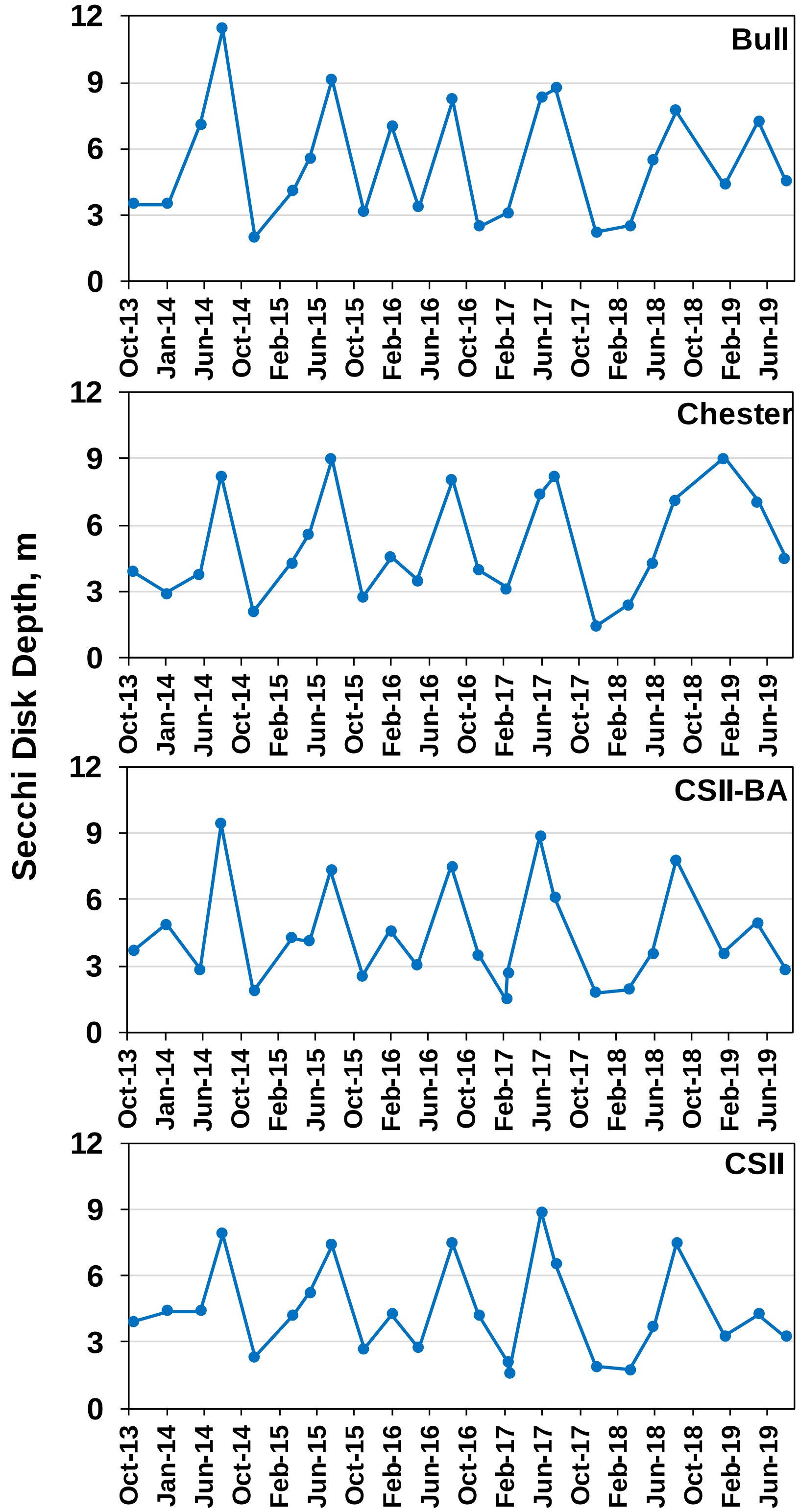

Figure 6-6. Mean Secchi disk depths (m) for the shoals.

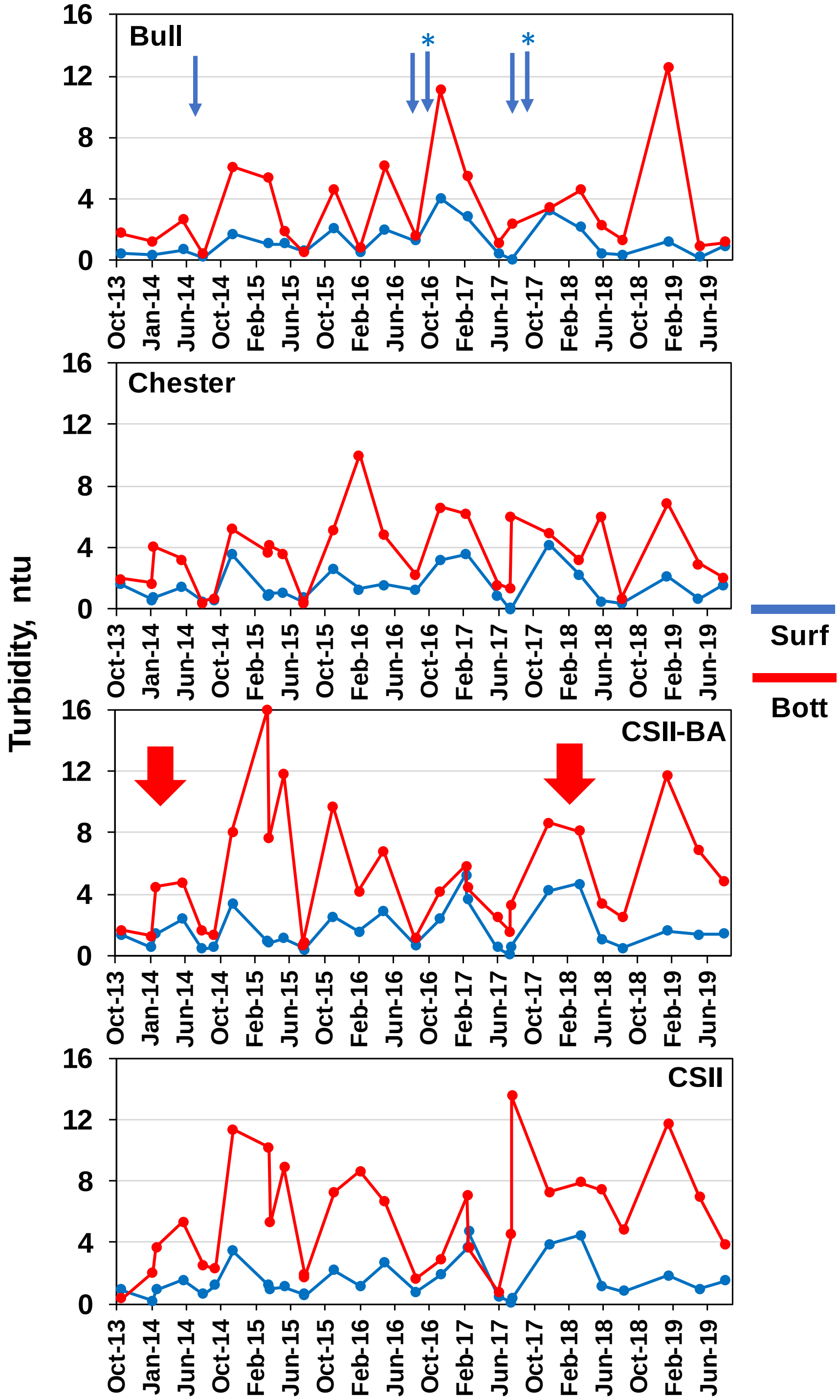

Figure 6-7. Mean surface- and bottom-water turbidity (ntu) for the shoals.
Red arrows mark the two periods of dredging activity at CSII-BA. Blue arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denotes Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

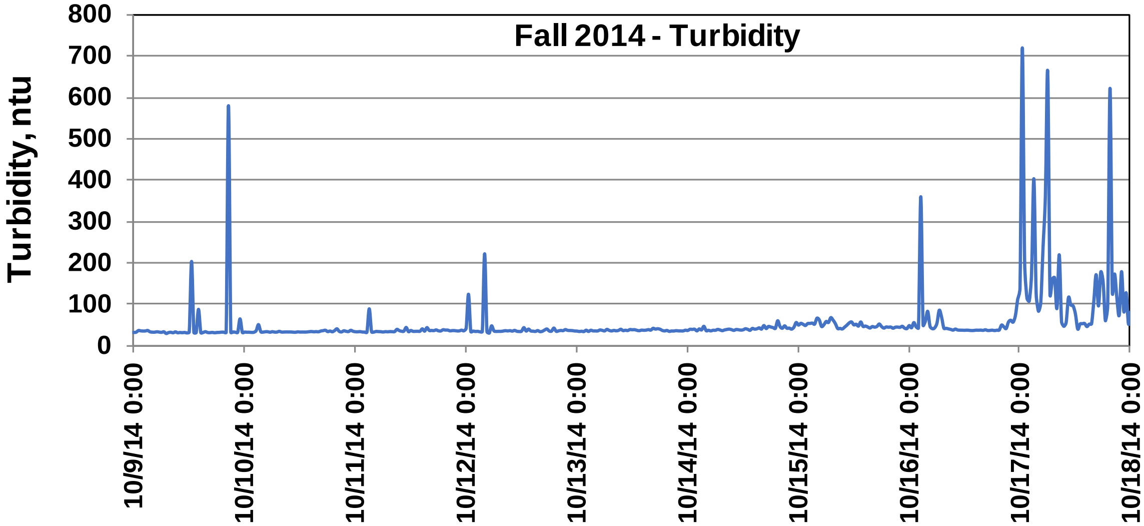

Figure 6-8. Example of continuous recording of bottom-water turbidity (ntu) from a Hydrolab sonde showing increased turbidity during a wind event on 17–18 October 2014.
Example was for Sonde #1 in fall 2014.

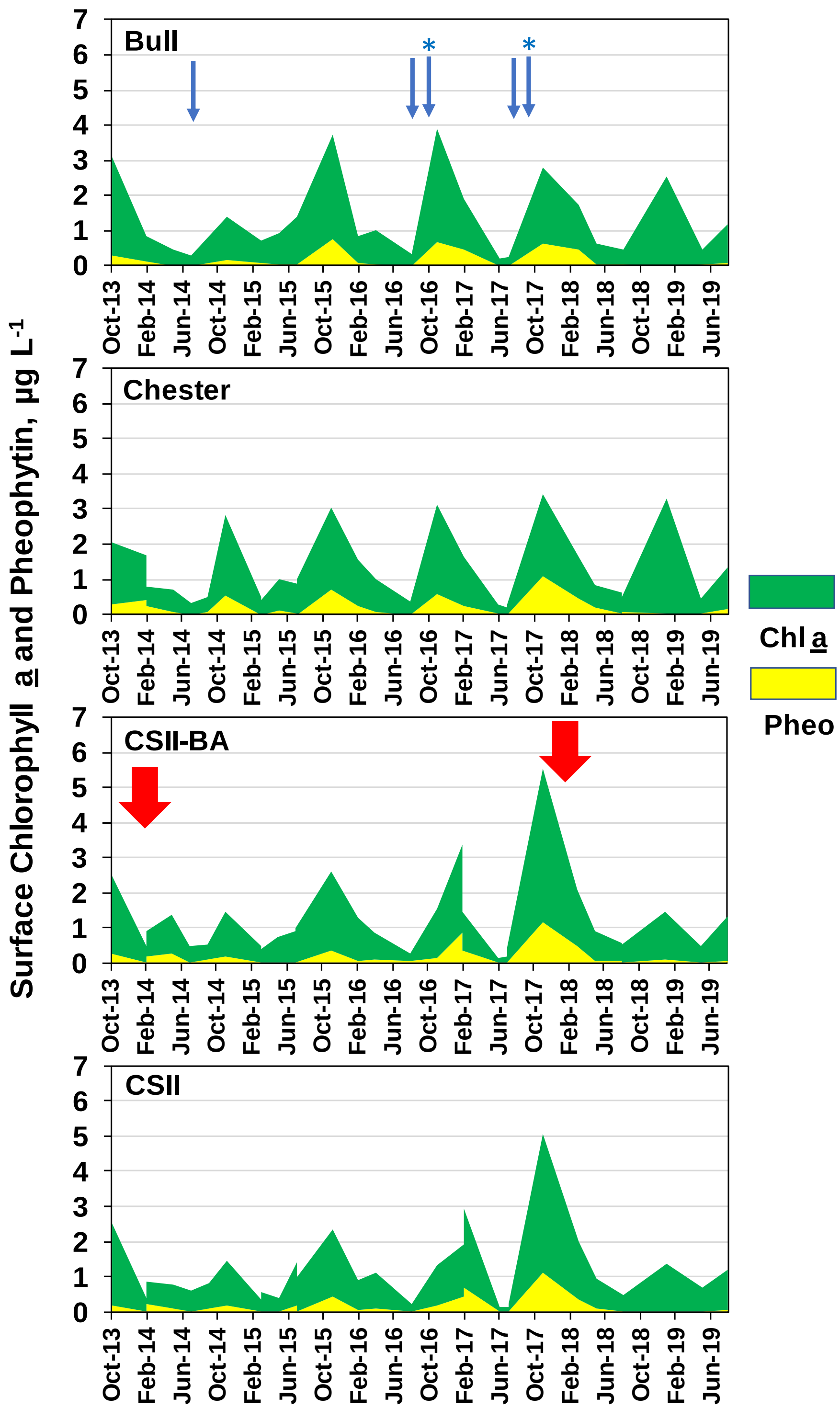

Figure 6-9. Mean corrected surface-water chlorophyll *a* and pheophytin concentrations (µg L^{-1}) at the four shoals.
Red arrows mark the two periods of dredging activity at CSII-BA. Blue arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denote Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

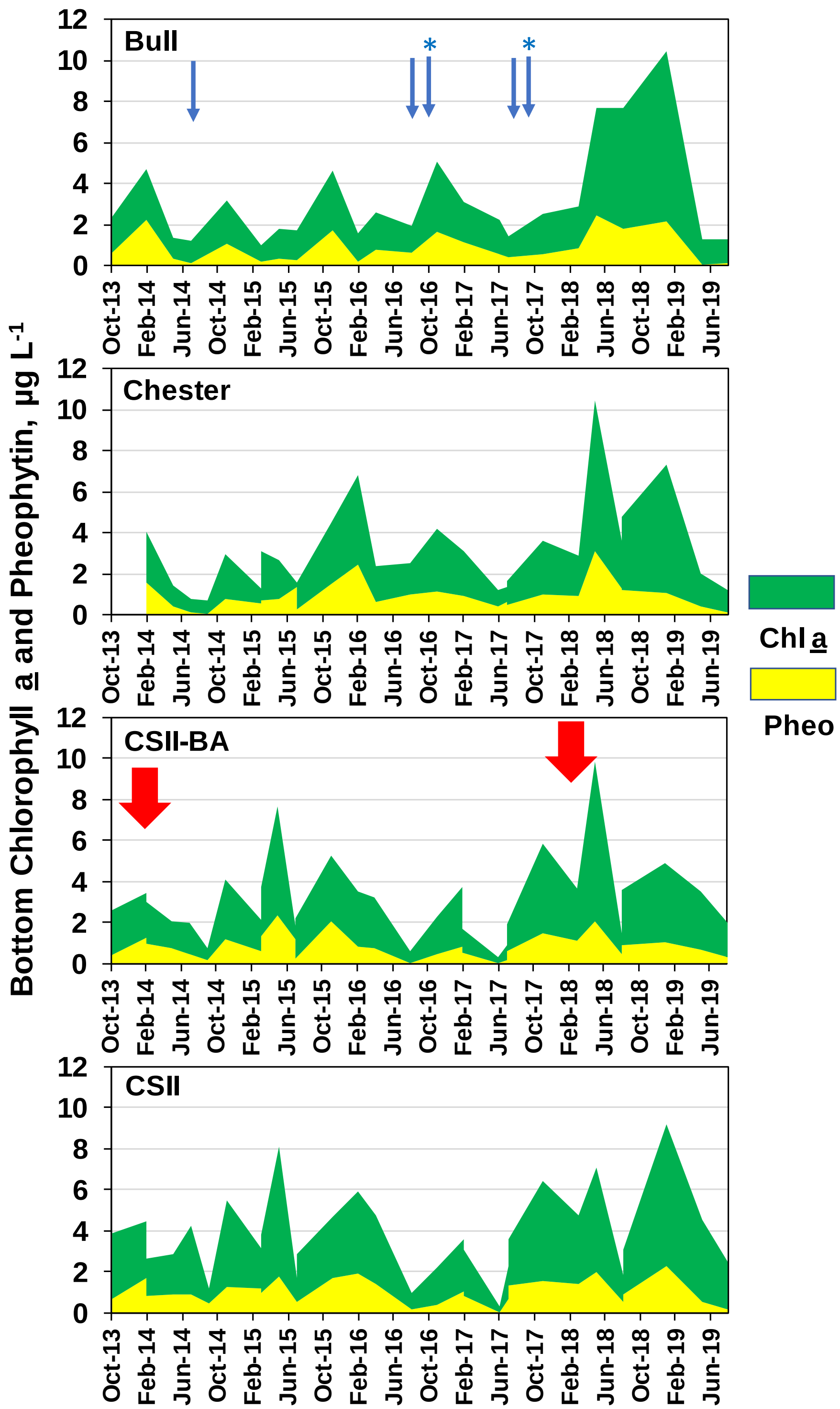

Figure 6-10. Mean corrected bottom-water chlorophyll *a* and pheophytin concentrations (µg L^{-1}) at the shoals.

Red arrows mark the two periods of dredging activity atCSII-BA. Blue arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denote Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

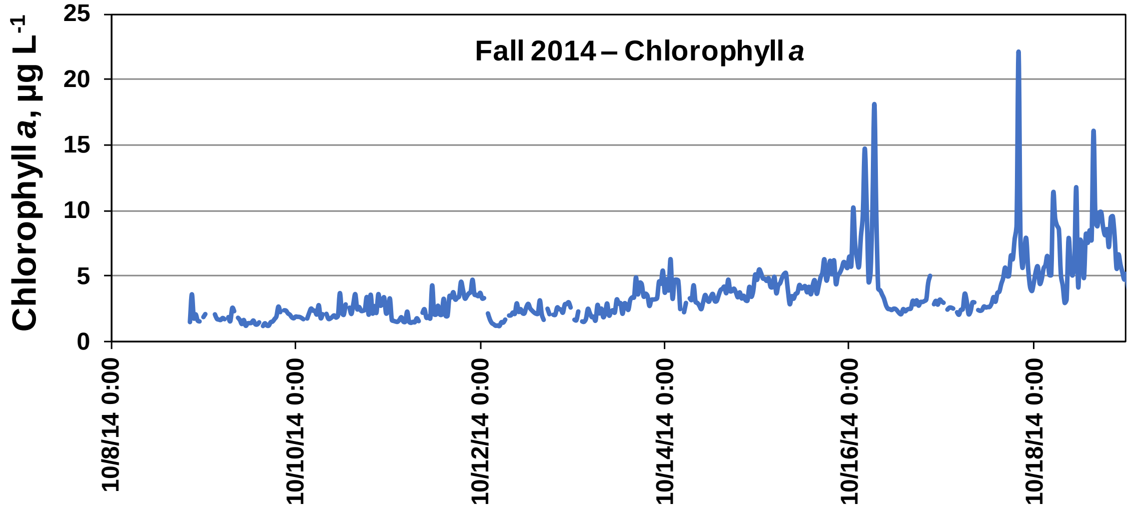

Figure 6-11. Example of continuous bottom-water chlorophyll a concentration (µg L^{-1}) data recorded from YSI in situ environmental monitors.
Example is for Sonde #1 in fall 2014.

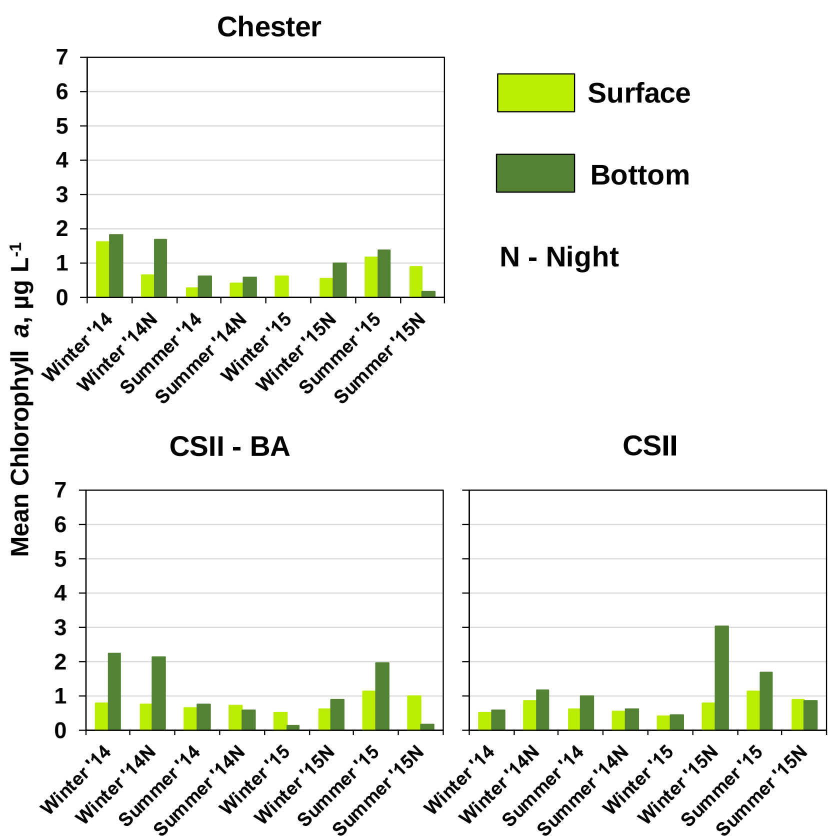

Figure 6-12. A comparison of mean corrected surface- and bottom-water chlorophyll *a* concentrations (µg L^{-1}) at the ridge habitat for day versus night sampling events.

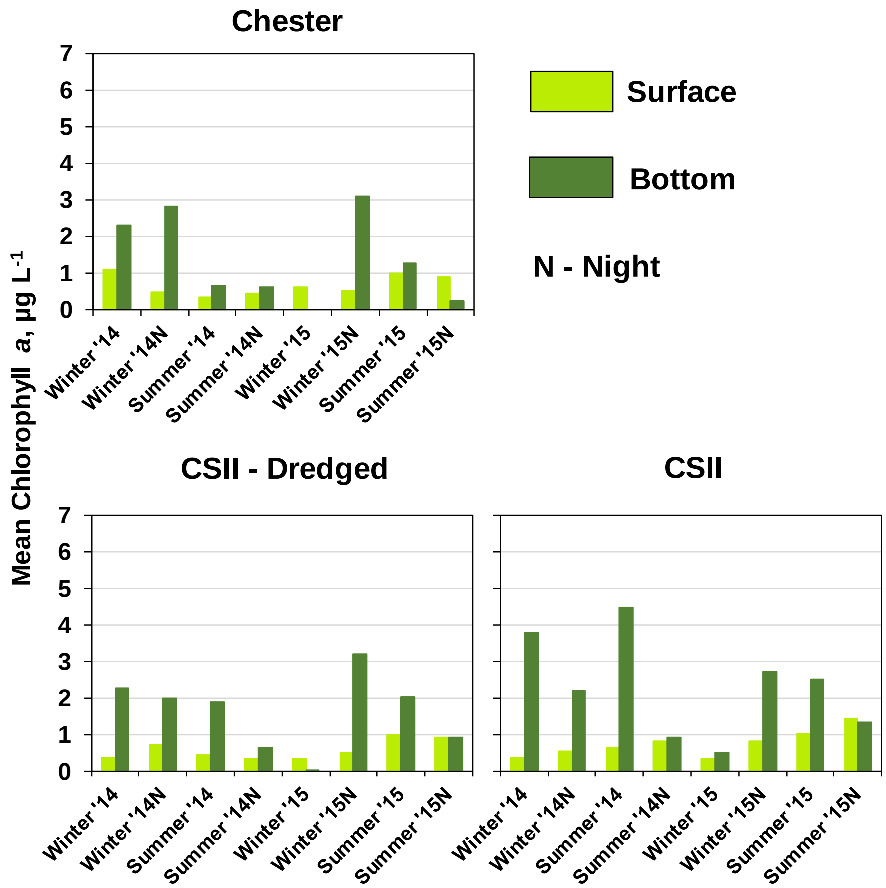

Figure 6-13. A comparison of mean corrected surface- and bottom-water chlorophyll *a* concentrations (µg L^{-1}) at the swale habitat for day versus night sampling events.

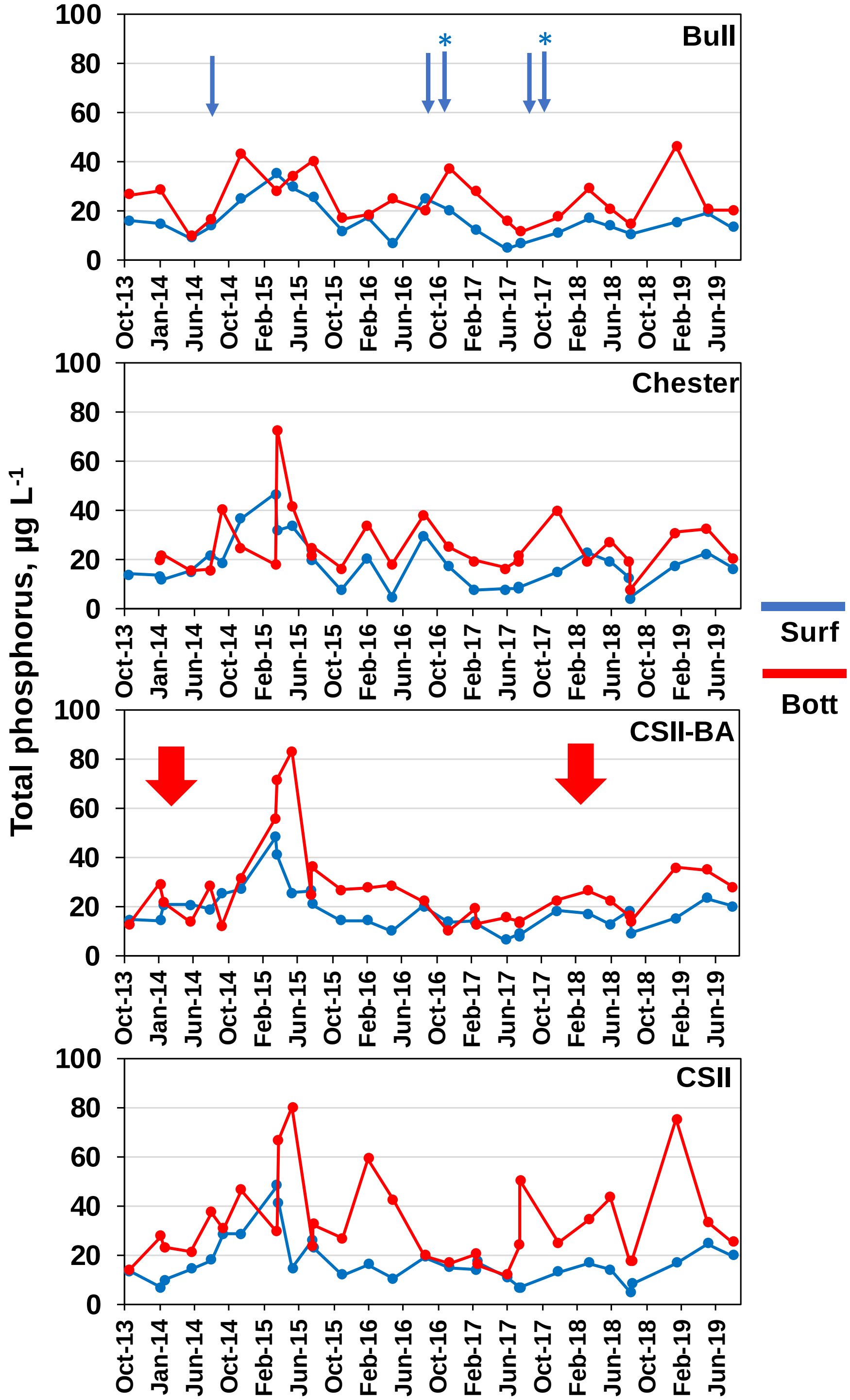

Figure 6-14. Mean surface- and bottom-water TP concentrations (µg L^{-1}) for the shoals over the study period.
Red arrows mark the two periods of dredging activity at CSII-BA. Blue arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denotes Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

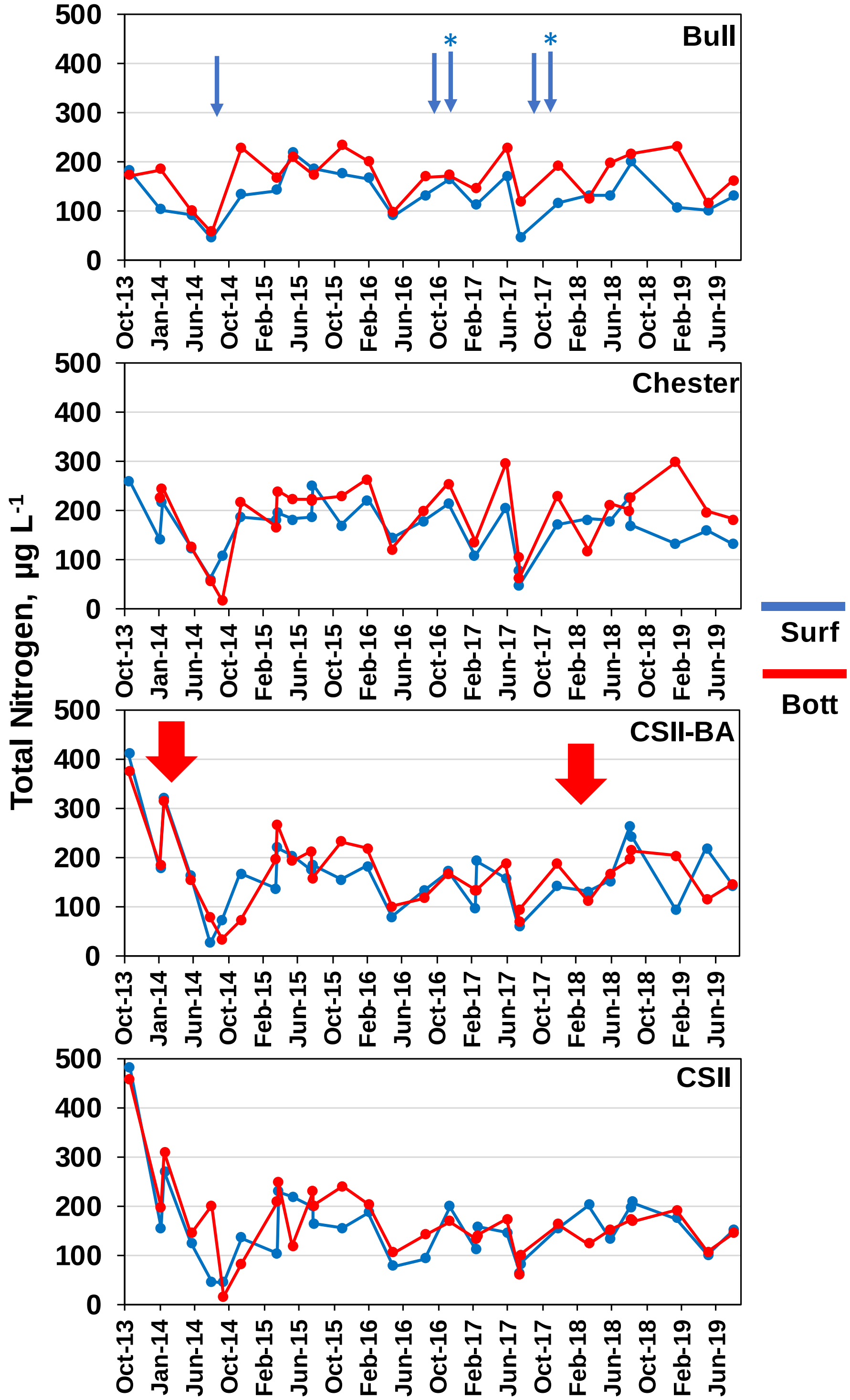

Figure 6-15. Mean surface- and bottom-water TN concentrations (µg L^{-1}) for the shoals over the study period.
Red arrows mark the two periods of dredging activity at CSII-BA. Blue arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denote Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

Table 6-1. Comparison of mean surface- and bottom-water temperatures (ºC) over the study period within each shoal and among all shoals.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between surface and bottom means within each shoal, and lower case letters are used to compare means among shoals.

Depth Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Surface	23.9 A	23.8 A	24.4 A	24.5 A
"	a	a	a	a
Bottom	22.2 B	22.4 B	22.8 B	23.1 B
"	b	ab	ab	a

Table 6-2. Comparison of mean Secchi depth (m) for the four seasons for the shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasonal means within each shoal, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	2.7 D	2.6 C	2.5 C	2.7 C
"	a	a	a	a
Winter	4.1 C	4.4 B	3.6 B	3.3 C
"	a	b	a	a
Spring	6.2 B	5.3 B	4.6 B	4.9 B
"	a	ab	b	b
Summer	8.3 A	7.6 A	6.8 A	6.6 A
"	a	ab	b	b

Table 6-3. Comparison of mean turbidity values (ntu) for the surface and bottom samples at the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between surface and bottom means within each shoal, and lowercase letters are used to compare means among shoals.

Depth Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Surface	1.25 A	1.56 A	1.68 A	1.54 A
"	b	ab	a	ab
Bottom	3.59 B	3.88 B	5.47 B	7.07 B
"	c	c	b	a

Table 6-4. Sonde data for turbidity (ntu) for CSII-BA, Bull and Chester Shoals.

Sondes were deployed in tandem with Acoustic Doppler Current Profilers (see Appendix Table A-1 for differences between summer I and II deployments). Cells with "-" have no data due to probe malfunction.

Shoal	Season and Year	Sonde ID #	Mean	SD	Median	Low	High
CSII-BA	Summer 2014	1	24.6	29.4	12.4	0.0	187.3
CSII-BA	Fall 2014	1	54.9	69.9	36.4	28.6	720.0
CSII-BA	Winter 2014-2015	1	-	-	-	-	-
CSII-BA	Spring 2015	1	34.0	7.8	34.3	19.6	129.6
CSII-BA	Summer I 2015	1	34.0	2.3	34.7	28.1	43.1
CSII-BA	Summer II 2015	1	27.2	3.8	26.5	20.8	42.0
CSII-BA	Fall 2015	1	-	-	-	-	-
CSII-BA	Winter 2016	1	-	-	-	-	-
Bull	Summer 2014	2	3.5	4.5	2.2	0.0	25.5
Bull	Fall 2014	2	-	-	-	-	-
Bull	Winter 2014-2015	2	49.5	13.6	44.4	36.5	120.4
Bull	Summer I 2015	2	27.1	11.0	24.1	0.0	43.3
Bull	Summer II 2015	2	40.9	4.8	40.8	31.5	67.5
Bull	Fall 2015	2	184.2	223.2	103.0	0.0	1,115.0
Chester	Summer 2014	3	-	-	-	-	-
Chester	Fall 2014	3	25.8	4.3	26.9	12.2	41.7
Chester	Summer I 2015	3	123.7	18.2	122.8	97.7	187.0
Chester	Summer II 2015	3	-	-	-	-	-
Chester	Fall 2015	3	-	-	-	-	-
Chester	Winter 2016	3	-	-	-	-	-

Table 6-5. Comparison of mean surface turbidity values (ntu) for the ridge and swale habitats at the four shoals over the study period.

Mean values which were not significantly different ($P > 0.05$) share the same letter value. Capital letters are used for the comparison between ridge and swale means within each shoal, and lowercase letters are used to compare means among shoals.

Habitat Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Ridge	1.31 A	1.62 A	1.93 A	1.92 A
"	a	a	a	a
Swale	1.21 A	1.63 A	1.65 A	1.46 A
"	b	a	a	ab

Table 6-6. Comparison of mean surface turbidity (ntu) for the four seasons for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between seasonal means within each shoal, and lowercase letters are used to compare seasonal means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	2.31 A	3.04 A	2.77 A	2.45 A
"	a	a	a	a
Winter	1.36 B	1.57 B	1.92 B	1.81 B
"	a	a	a	a
Spring	0.82 C	1.03 C	1.56 B	1.31 B
"	c	bc	a	ab
Summer	0.60 C	0.64 C	0.56 C	0.71 C
"	a	a	a	a

Table 6-7. Comparison of annual mean surface turbidity (ntu) for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means within each shoal, and lowercase letters are used to compare annual means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	0.44 D	1.06 B	1.18 B	0.80 C
"	b	b	a	ab
2	1.11 BC	1.59 AB	1.44 B	1.56 BC
"	a	a	a	a
3	1.46 AB	1.69 AB	1.91 AB	1.67 B
"	a	a	a	a
4	1.86 A	1.94 A	1.84 AB	1.61 BC
"	a	a	a	a
5	1.79 A	2.04 A	2.60 A	2.57 A
"	a	a	a	a

Table 6-8. Comparison of mean bottom turbidity values (ntu) for the ridge and swale habitats at the four shoals.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between ridge and swale means within each shoal, and lowercase letters are used to compare means among shoals.

Habitat Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Ridge	3.49 A	2.76 B	6.60 A	4.08 B
"	b	b	a	b
Swale	3.63 A	4.59 A	5.13 A	8.68 A
"	b	b	b	a

Table 6-9. Comparison of mean bottom-water turbidity (ntu) for the four seasons for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between seasonal means within each shoal, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	5.38 A	5.49 A	6.45 A	5.91 AB
"	a	a	a	a
Winter	5.50 A	5.00 A	7.38 A	10.13 A
"	b	b	ab	a
Spring	2.50 B	3.73 A	6.02 A	6.00 AB
"	b	b	a	a
Summer	1.25 B	1.60 B	1.96 B	4.07 B
"	b	b	b	a

Table 6-10. Comparison of annual mean bottom turbidity (ntu) for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means within each shoal, and lowercase letters are used to compare annual means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	1.52 C	1.80 B	2.32 C	2.52 B
"	b	a	a	a
2	3.45 ABC	3.26 AB	9.29 A	8.02 A
"	b	b	b	a
3	3.28 ABC	5.56 A	5.45 BC	6.03 B
"	a	a	a	a
4	5.01 AB	5.13 A	3.65 C	6.01 A
"	a	a	a	a
5	2.94 BC	3.72 AB	5.66 BC	6.85 A
"	c	bc	ab	a

Table 6-11. Comparison of mean corrected chlorophyll *a* concentrations (µg L^{-1}) for the surface- and bottom-water samples for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between surface and bottom means within each shoal, and lowercase letters are used to compare means among shoals.

Depth Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Surface	1.18 B	1.16 B	1.09 B	1.01 B
"	a	a	a	a
Bottom	2.32 A	2.39 A	2.47 A	3.02 A
"	b	b	b	a

Table 6-12. Comparison of mean corrected surface-water chlorophyll *a* concentrations (μg L^{-1}) for the four seasons for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasonal means within each shoal, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	2.47 A	2.25 A	2.32 A	2.16 A
"	a	a	a	a
Winter	1.24 B	1.24 B	0.95 B	0.93 B
"	a	a	a	a
Spring	0.59 C	0.65 C	0.68 C	0.62 C
"	a	a	a	a
Summer	0.63 C	0.56 C	0.59 C	0.62 C
"	a	a	a	a

Table 6-13. Comparison of annual mean corrected surface-water chlorophyll *a* concentrations (μg L^{-1}) for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means within each shoal, and lowercase letters are used to compare seasonal means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	1.08 A	1.00 B	1.08 B	1.03 B
"	a	a	a	a
2	1.05 A	1.18 AB	0.88 B	0.74 B
"	ab	a	ab	b
3	1.27 A	1.25 AB	1.11 B	1.00 B
"	a	a	a	a
4	1.27 A	1.12 AB	0.83 B	0.76 B
"	a	a	a	a
5	1.01 A	1.15 AB	1.83 A	1.72 A
"	a	a	a	a

Table 6-14. Comparison of mean corrected bottom-water chlorophyll *a* concentrations (µg L^{-1}) for the ridge and swale habitats for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between ridge and swale means within each shoal, and lowercase letters are used to compare means among shoals.

Habitat Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Ridge	2.36 A	2.13 A	2.45 A	2.25 B
"	a	a	a	a
Swale	2.30 A	2.62 A	2.60 A	3.48 A
"	b	b	b	a

Table 6-15. Comparison of mean corrected bottom-water chlorophyll *a* concentrations (µg L^{-1}) for the four seasons for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasonal means within each shoal, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	2.43 A	2.72 A	2.88 AB	3.48 A
"	b	b	b	a
Winter	2.82 A	2.82 A	2.37 B	3.02 A
"	a	a	a	a
Spring	2.07 A	2.46 AB	3.34 A	3.49 A
"	a	a	a	a
Summer	1.98 A	1.47 B	1.27 C	1.80 B
"	a	ab	b	ab

Table 6-16. Comparison of annual mean corrected bottom-water chlorophyll *a* concentrations (μg L^{-1}) for the four shoals over the study period.

Mean values which were not significantly different ($P > 0.05$) share the same letter value. Capital letters are used for the comparison among annual means witihn each shoal, and lowercase letters are used to compare means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	1.59 B	1.29 C	1.83 BC	2.79 BC
"	b	b	b	a
2	1.45 B	1.53 BC	2.90 B	3.38 AB
"	b	b	a	a
3	1.86 B	2.65 ABC	2.22 BC	2.78 BC
"	b	ab	ab	a
4	2.01 B	2.25 BC	1.23 C	1.71 C
"	ab	a	b	ab
5	3.79 A	3.89 A	4.32 A	3.89 AB
"	a	a	a	a

Table 6-17. Sonde data for chlorophyll *a* (μg L^{-1}) for CSII-BA, Bull, and Chester Shoals.

Sondes were deployed in tandem with Acoustic Doppler Current Profilers (see Appendix Table A-1 for differences between summer I and II deployments). Cells with "-" have no data due to probe malfunction. Values in italics are suspect.

Shoal	Season and Year	Sonde ID #	Mean	SD	Median	Low	High
CSII-BA	Summer 2014	1	*12.63*	*14.87*	*7.43*	0.71	*133.73*
CSII-BA	Fall 2014	1	4.09	2.18	3.74	1.22	23.81
CSII-BA	Winter 2014-2015	1	5.82	1.86	5.54	2.24	15.66
CSII-BA	Spring 2015	1	5.54	2.99	5.02	0.00	*28.41*
CSII-BA	Summer I 2015	1	3.89	2.25	3.49	1.50	*25.88*
CSII-BA	Summer II 2015	1	-	-	-	-	-
CSII-BA	Fall 2015	1	6.02	3.20	4.98	0.12	20.66
CSII-BA	Winter 2016	1	5.05	3.79	3.43	0.16	*33.95*
Bull	Summer 2014	2	1.79	1.86	1.46	0.00	15.51
Bull	Fall 2014	2	1.91	1.14	1.58	0.89	11.45
Bull	Winter 2014-2015	2	4.38	1.04	4.62	2.61	7.09
Bull	Summer I 2015	2	-	-	-	-	-
Bull	Summer II 2015	2	*20.20*	*8.81*	*19.20*	1.55	*57.07*
Bull	Fall 2015	2	4.64	2.72	3.88	1.45	21.51
Chester	Summer 2014	3	2.64	1.87	2.19	0.65	17.11
Chester	Fall 2014	3	4.38	2.04	3.84	2.06	23.49
Chester	Summer I 2015	3	3.45	1.41	3.43	0.97	14.28
Chester	Summer II 2015	3	5.93	2.69	6.27	0.37	14.96
Chester	Fall 2015	3	3.93	1.26	3.69	0.87	10.06
Chester	Winter 2016	3	5.67	2.52	5.06	2.21	21.54

Table 6-18. Comparison of mean TP concentrations (µg L^{-1}) for the surface and bottom samples for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between surface and bottom means within each shoal, and lowercase letters are used to compare means among shoals.

Depth Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Surface	16 B	19 B	17 B	16 B
"	a	a	a	a
Bottom	25 A	24 A	27 A	34 A
"	b	b	b	a

Table 6-19. Comparison of mean surface-water TP concentrations (µg L^{-1}) for the four seasons for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasonal means within each shoal, and lowercase letters are used to compare seasonal means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	17 A	18 A	18 A	16 AB
"	a	a	a	a
Winter	19 A	24 A	23 A	21 A
"	a	a	a	a
Spring	14 A	17 A	16 A	15 B
"	a	a	a	a
Summer	16 A	17 A	18 A	16 AB
"	a	a	a	a

Table 6-20. Comparison of annual mean surface-water TP concentrations (µg L^{-1}) for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means witihn each shoal, and lowercase letters are used to compare means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	14 B	16 B	17 B	13 B
"	a	a	a	a
2	29 A	38 A	30 A	29 A
"	a	a	a	a
3	15 B	16 B	15 BC	14 B
"	a	a	a	a
4	11 B	11 B	10 C	12 B
"	a	a	a	a
5	13 B	15 B	14 BC	13 B
"	a	a	a	a

Table 6-21. Comparison of mean bottom-water TP concentrations (µg L-1) for the ridge and swale samples in the four sampling regions over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between ridge and swale means within each shoal, and lowercase letters are used to compare means among shoals.

Habitat Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Ridge	24 A	22 A	29 A	24 B
"	a	a	a	a
Swale	25 A	25 A	27 A	41 A
"	b	b	b	a

Table 6-22. Comparison of mean bottom-water TP concentrations (µg L^{-1}) for the four seasons for four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasonal means within each shoal, and lowercase are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	29 A	27 A	21 B	26 B
"	a	a	a	a
Winter	30 A	30 A	35 A	44 A
"	b	b	ab	a
Spring	21 B	26 A	33 A	39 AB
"	b	b	ab	a
Summer	21 B	23 A	21 B	28 B
"	a	a	a	a

Table 6-23. Comparison of annual mean bottom-water TP concentrations (µg L^{-1}) for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means within each shoal, and lowercase letters are used to compare means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	21 B	17 B	21 DC	25 B
"	a	a	a	a
2	37 A	28 AB	52 A	47 A
"	b	b	a	a
3	20 B	27 AB	26 BC	37 B
"	b	ab	ab	a
4	23 B	21 AB	13 D	24 B
"	a	a	a	a
5	21 B	24 AB	21 DC	30 B
"	a	a	a	a

Table 6-24. Comparison of mean TN concentrations (µg L^{-1}) for the surface and bottom samples for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between surface and bottom means within shoal, and lowercase letters are used to compare means among shoals.

Depth Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Surface	135 B	163 A	156 A	152 A
"	b	a	a	ab
Bottom	171 A	191 A	161 A	165 A
"	b	a	b	b

Table 6-25. Comparison of mean surface-water TN concentrations (µg L^{-1}) for the ridge and swale habitats for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between ridge and swale means for within each shoal, and lowercase are used to compare means among shoals.

Habitat Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Ridge	139 A	156 A	149 A	161 A
"	a	a	a	a
Swale	132 A	171 A	166 A	153 A
"	b	a	a	ab

Table 6-26. Comparison of mean surface-water TN concentrations (µg L^{-1}) for the four seasons for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasonal means within each region, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	155 A	201 A	210 A	224 A
"	b	ab	ab	a
Winter	128 B	173 B	178 AB	179 B
"	b	a	a	a
Spring	135 B	167 B	162 B	132 C
"	b	a	a	b
Summer	124 B	145 B	136 B	124 C
"	a	a	a	a

Table 6-27. Comparison of annual mean surface-water TN concentrations (µg L^{-1}) for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means within each shoal, and lowercase letters are used to compare means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	106 C	147 B	194 A	201 A
"	c	b	a	a
2	171 A	202 A	173 A	154 AB
"	ab	a	ab	b
3	142 AB	179 AB	137 B	127 B
"	b	a	b	b
4	125 BC	145 B	140 B	136 B
"	a	a	a	a
5	145 AB	176 AB	166 AB	173 AB
"	a	a	a	a

Table 6-28. Comparison of mean bottom-water TN concentrations (µg L^{-1}) for the ridge and swale habitats for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between ridge and swale means within shoal, and lowercase letters are used to compare means among shoals.

Habitat Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Ridge	161 A	195 A	159 A	155 A
"	ab	a	ab	b
Swale	175 A	195 A	169 A	177 A
"	ab	a	b	ab

Table 6-29. Comparison of mean bottom-water TN concentrations (µg L^{-1}) for the four seasons for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasonal means within each shoal, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	201 A	234 A	208 A	221 A
"	a	a	a	a
Winter	177 AB	213 A	203 A	201 A
"	b	a	ab	ab
Spring	160 B	197 A	153 B	132 B
"	b	a	b	b
Summer	151 B	151 B	131 B	142 B
"	a	ab	b	ab

Table 6-30. Comparison of annual mean bottom-water TN concentrations (µg L^{-1}) for the four shoals over the study period.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means within each shoal, and lowercase letters are used to compare means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	130 B	138 B	198 A	249 A
"	b	b	ab	a
2	196 A	208 A	154 AB	151 B
"	a	a	b	b
3	176 A	205 A	167 AB	172 B
"	a	a	a	a
4	167 A	189 A	145 B	143 B
"	a	a	a	a
5	184 A	198 A	169 AB	151 B
"	a	a	ab	b

7 Phytoplankton and Bacterioplankton

Ed Phlips, Susan Badylak, Leslie Landauer, Anne West-Valle, and Benjamin Stelling

Key Points

- There were no consistent significant differences in total mean phytoplankton biomass among shoals for surface or bottom water.
- Diatoms, dinoflagellates, and cyanobacteria were regular major contributors to total phytoplankton biomass throughout the study. Dinoflagellates generally had higher mean biomass in surface-water than bottom-water samples, in part reflecting their ability to move up in the water column via flagellar motility. By contrast, diatoms generally had higher mean biomass in bottom-water than surface-water samples, in part reflecting a combination of sinking of cells in the water column and re-suspension of sedimented cells from the benthos into the lower layers of the water column.
- Small-sized phytoplankton was found to be important in terms of both abundance and biomass. Together, picoplanktonic cyanobacteria and nanoplanktonic eukaryotes often represented over 50% of total phytoplankton biomass. This observation highlights the importance of the microbial loop in the Cape Canaveral shelf.
- Seasonally, the highest mean total phytoplankton biomass levels over the study period were observed in the fall (followed by winter), and lowest levels were observed in the spring and summer. Seasonal differences were in part attributable to shifts in predominant seasonal wind directions, which drive water along the coast from the north in the fall and winter, but from the south in the spring and summer, including eddies and upwelling from the Gulf Stream.
- In terms of the comparison of post-dredge periods (i.e., spring and summer of 2014 and 2018) and similar seasons in other years, no reproducible differences were observed at any of the shoals. These observations suggest that the any impacts of dredging on phytoplankton composition and biomass are comparatively short-lived (i.e., not extending beyond a few months).

7.1 Introduction

The focus of most biological research on the impacts of dredging on coastal ecosystems has been on the faunal assemblage, but it is also essential to understand potential effects on primary producers that form the base of the food web. The principal planktonic primary producers in most coastal ecosystems are bacteria and phytoplankton (Valiela 1984). The character, productivity, and abundance of these organisms play central roles in the structure and integrity of coastal ecosystems. Planktonic primary producers, including phytoplankton and bacterioplankton, are the major source of carbon for zooplankton as well as benthic filter-feeding animals and deposit feeders. The character of plankton communities in shelf environments along the southern and central east coast of the U.S. are influenced by inputs from the Gulf Stream and local estuaries, with strong representation of diatoms, dinoflagellates, picoplanktonic cyanobacteria, and a range of nanoplanktonic eukaryotic species (Phlips et al. 1999, 2006, 2010, 2011, 2012; Badylak and Phlips 2004, 2007). The main goal of this component of the research program was to quantify the composition and biomass of the primary producers to help define the impacts of dredging on primary producers within the affected local coastal zone, and determine the temporal/spatial scales of recovery from the disturbances caused by the dredging.

7.2 Methods

The composition, abundance, biovolume and carbon content of phytoplankton and bacterioplankton were determined from collections of water at stratified-random locations within ridge and swale habitats of reference/control shoals (CSII, Bull, and Chester Shoals) and the dredged shoal (CSII-BA Shoal). Specific details of the location and overall sampling design for the phytoplankton is outlined in Chapter 6. In summary, the dredged shoal and three reference shoals were sampled at six sites each on a seasonal basis. Water was collected from 1 m off the bottom using multiple samples of messenger-driven closing water bottles. The multiple samples from each site were pooled and mixed before aliquots for analyses were taken and preserved, in accordance with standard operating procedures (Phlips et al. 1999, 2010). In addition, surface water was collected using integrating poles that collected the top 3 m of the water column. Multiple pole samples from each site were pooled and mixed before aliquots for analyses were taken and preserved.

Bacterioplankton densities were determined using fluorescence microscopy of acridine orange stained samples (Hobbie et al. 1977; Crisman et al. 1995). Autofluorescence microscopy was used to enumerate picoplanktonic cyanobacteria (Phlips et al. 1999). General phytoplankton composition was determined using the Utermöhl method (Utermöhl 1958; Phlips et al. 2010). The principal references used for identification included both general taxonomic guides and primary journal references (Cupp 1943; Hasle 1978; Sournia 1986; Ricard 1987; Round et al. 1990; Throndsen and Heimdal 1993; Hasle and Syvertsen 1996; Steidinger and Tangen 1996; Thomas 1997; Horner 2002; Quiroga and Chretiennot 2004; Krayesky et al. 2009; Steidinger et al. 2009; Chung et al. 2010; Sar et al. 2010). Samples preserved in Lugol's were settled in 19-mm diameter cylindrical chambers. Phytoplankton cells were identified and counted at 400× and 100× with a Leica phase-contrast inverted microscope. At 400×, a minimum of 100 cells of a single taxon and 30 grids were counted. If 100 cells of a single taxon were not counted by 30 grids, up to a maximum of 100 grids were counted until 100 cells of a single taxon were reached. At 100×, a total bottom count was completed for taxa >30 µm in size. Cell biovolumes were estimated by assigning combinations of geometric shapes to fit the characteristics of individual taxa (Smayda 1978; Sun and Liu 2003). Phytoplankton biomass as carbon values (i.e., µg carbon ml^{-1}) were estimated by using conversion factors for different taxonomic groups applied to biovolume estimates based on the power function relationships described by Menden-Deuer and Lessard (2000), with modifications for preservative biovolume effects described in various literature resources (Strathmann 1967; Ahlgren 1983; Sicko-Goad et al. 1984; Verity et al. 1992; Work et al. 2005).

Mean biomass values were based on relevant site values within each shoal of the study. Duncan Multiple Range Tests were used to test for differences among shoals ($P \leq 0.5$), between ridge versus swale habitats, surface-water versus bottom-water samples, and among seasons and years. For these comparisons, only daytime sampling events were used to ensure a balanced sample size. All analyses were done using statistical packages in SAS® (SAS Institute 2012).

7.3 Results

7.3.1 Phytoplankton Biomass

Mean surface-water phytoplankton biomass levels (i.e., in terms of estimated carbon content of phytoplankton per sampling event) ranged from 0.02 mg carbon L^{-1} to 0.45 mg carbon L^{-1} (Figure 7-1). For the study period (2013–2019), mean surface biomass levels were similar for all four shoals (Table 7-1). The highest mean surface biomass levels in all four shoals of the study were observed in the fall 2013 sampling event, principally related to a strong surface bloom of the nitrogen-fixing cyanobacterium *Trichodesmium*, which reached biomass levels in individual samples up to near 0.3 mg carbon L^{-1}. For the remainder of the study period, peak mean biomass levels were near 0.2 mg carbon L^{-1}. No significant differences were observed for total mean surface biomass levels between ridge and swale habitats at the four shoals (all $P > 0.05$). The overall mean biomass for the study period was 0.119 mg carbon L^{-1}.

Seasonal patterns of mean surface biomass concentrations over the study period were similar for all four shoals (Table 7-2). The highest mean biomass values in all four shoals over the study period were in the fall, followed by the winter, and the lowest levels were in the spring and summer.

Interannual patterns of mean surface-water biomass were similar for all four shoals of the study (Table 7-3). The highest annual mean values were in Years 1 and 5 of the study for all shoals. The Year 5 peaks followed the intense hurricane season of 2017 (Figure 7-1) and reflected high phytoplankton biomass in the fall of 2017 and winter of 2017-18.

In terms of the post-dredge period events (i.e., spring and summer) of 2014 and 2018, no apparent major differences were observed among shoals in the trends of mean surface-water phytoplankton biomass, including the dredged shoal (CSII-BA) (Figure 7-1). Both years showed declines in biomass means in the post-dredge period in all four shoals.

Mean bottom-water phytoplankton biomass levels over the study period were higher than surface-water means at all four shoals of the study (Table 7-1). Mean bottom-water phytoplankton biomass ranged from 0.05 mg carbon L^{-1} to 0.45 mg carbon L^{-1} (Figure 7-2). A comparison of total mean bottom biomass at ridge and swale habitats of the four shoals showed no differences between ridge and swale habitats (Table 7-4). There were relatively small differences among shoals, with modestly lower mean values for both ridges and swales for Bull Shoal (Table 7-4).

A comparison of mean bottom-water phytoplankton biomass levels over the study period showed few significant differences both among seasons and among shoals within each season (Table 7-5).

Interannual patterns of mean bottom-water biomass were similar at all four shoals of the study (Table 7-6). The highest annual mean value was in Year 5 of the study at all shoals.

In terms of the post-dredge period events (i.e., spring and summer) of 2014 and 2018, no apparent major differences were observed among shoals in the trends of mean bottom-water phytoplankton biomass values, including the dredged shoal (CSII-BA) (Figure 7-2). In 2014, all shoals had declines in mean values in the post-dredge period, while in 2018 all shoals had increases in mean values.

7.3.2 Phytoplankton Composition

Phytoplankton composition varied spatially and temporally, including differences between surface-water and bottom-water samples. The phytoplankton community in the study region included a diverse array of species from a wide range of major taxonomic groups (i.e., based on divisional breakdowns described in Reynolds 2006), including cyanobacteria, Prochlorobacteria, Bacillariophyta (i.e., diatoms), Dinophyta (i.e., dinoflagellates), Chlorophyta (i.e., green algae), Euglenophyta (i.e., euglena), Cryptophyta (i.e., Cryptophytes), Raphidophyta, Chrysophyta (i.e., golden algae) and Haptophyta.

In order to provide a broad view of spatial and temporal variability in composition, the data set was grouped into four major categories, dinoflagellates, diatoms, cyanobacteria, and all “other” groups (typically dominated by smaller unicellular taxa, such as cryptophytes, euglenophytes, chlorophytes, raphidophytes, haptophytes, and chrysophytes). Each of the four groups were major contributors to mean total phytoplankton biomass (mg carbon L^{-1}) for the four shoals in both surface and bottom-water samples (Figures 7-1 and 7-2).

In surface-water samples, cyanobacteria had the highest mean biomass over the study period, followed by dinoflagellates, and diatom and other taxa had the lowest mean biomass (Table 7-7). In bottom-water samples, diatoms had the highest mean biomass over the study period, followed by cyanobacteria, and dinoflagellates and other taxa had the lowest mean biomass (Table 7-7). The differences between surface and bottom-water biomass patterns for the four groups were further reflected in the significant differences between the two for dinoflagellates and diatoms, the former being greater in surface samples and the latter in bottom samples. The patterns were relatively consistent among the four shoals of the study area (Table 7-8).

From a seasonal perspective, mean surface biomass levels of cyanobacteria were highest in the fall and summer (Table 7-9). Mean biomass (µg carbon L^{-1}) levels of dinoflagellates, diatoms and other taxa were highest in the fall, matching the overall pattern of peak total phytoplankton biomass discussed in the previous section. The seasonal pattern was somewhat more complex in bottom-water samples (Table 7-10). Similar to surface samples, cyanobacteria had the highest mean biomass in the summer and dinoflagellates had the highest mean biomass in the fall. By contrast, diatoms had the highest biomass in the winter and spring. Other taxa had similar mean biomass levels in the fall, winter, and spring.

From another functionally important perspective, a comparison was made of the relative contribution of three size classes of phytoplankton to total phytoplankton in surface- and bottom-water samples (Figures 7-3 and 7-4). The first size class was defined as small-celled taxa, including picoplanktonic phytoplankton (i.e., up to 2 µ), nanoplanktonic phytoplankton (> 2–20 µ), and micro-planktonic phytoplankton (> 20–200+ µ). The first size class was primarily dominated by unicellular cyanobacteria, and some very small dinoflagellates, diatoms, and other micro-flagellates. Many of these smaller-celled taxa play an important role in the microbial loop and are key primary producers in open-ocean ecosystems. In surface-water samples, picoplanktonic taxa had the highest mean biomass levels among the three size classes (Table 7-11). A similar pattern was observed for all four shoals of the study (Table 7-12). In bottom-water samples, all three size classes had the same mean biomass values in three of the four shoals (Table 7-13), again in part reflecting the importance of resuspension and diatom sinking processes, which elevate the importance of larger cells.

In order to identify some of the individual taxa that were major contributors to total biomass in the study area, the top 500 (Top-500) biomass values for individual taxa observed over the study period were identified for surface-water (Table 7-14) and bottom-water (Table 7-15) samples. The results were ordered by major taxonomic groups and frequency of occurrence in the Top-500 list. The highest observed individual biomass levels (mg carbon L^{-1}) and cell densities (cells ml^{-1}) within each taxon were also noted.

In surface-water samples, a large number of dinoflagellate genera were on the Top-500 list, including, *Cochlodinium, Protoperidinium*, *Azadinium, Gyrodinium*, *Prorocentrum*, *Kapelodinium, Karenia*, *Karlodinium, Torodinium, Amphidinium,* and *Scrippsiella* (Table 7-14). Bottom-water samples contained a shorter and less frequent representation of dinoflagellate taxa in the Top-500, including *Azadinium, Cochlodinium, Prorocentrum* and *Protoperidinium* (Table 7-15).

Surface-water samples contained seven centric diatom genera in the Top-500 list, including *Guinardia*, *Dactyliosolen*, *Paralia, Skeletonema, Bellerochea*, *Brockmanniella*, and *Leptocylindrus* (Table 7-14). Bottom-water samples had a greater presence of diatoms in the Top-500 list, both in terms of frequency and peak biomass, including the aforementioned genera, plus *Cyclotella, Thalassiosira, Cylindrotheca, Coscinodiscus, Navicula, Odontella, Pseudo-nitzschia, Rhizosolenia* and undefined picoplanktonic pennate taxa (Table 7-15).

In terms of post-dredge periods, surface-water biomass levels declined at all four shoals (Figure 7.1). However, the pattern of decline in the winter-spring was also observed in the non-dredge years. The biomass declines in spring coincided with a proportional increase in the relative importance of picoplanktonic cyanobacteria biomass (Figure 7-1). In bottom-water samples, the post-dredge periods exhibited different patterns (Figure 7-2), with declines in biomass in 2013/2014 at all four shoals but increases in biomass in 2017/2018. In the latter period, the increase was principally associated with increases in diatom biomass. A similar increase in diatom biomass was observed in the following year (2018/2019).

7.3.3 Bacterioplankton

Total mean non-photosynthetic bacterioplankton densities ranged from 0.1 x 10^9 cells L^{-1} to 6 x 10^9 cells L^{-1} per sampling event (Figure 7-5). Estimated mean non-photosynthetic bacterioplankton biomass as carbon ranged from 0.002 to 0.12 mg carbon L^{-1} (Figure 7-6). The highest peaks in both mean cell densities and biomass were observed in the summer of 2015 in surface and bottom-water samples at all four shoals of the study (Figures 7-5 and 7-6). The period from the summer of 2016 through fall of 2017 also had comparatively high cell densities and biomass, particularly at Bull and Chester Shoals.

Mean bottom-water, non-photosynthetic bacterioplankton densities were higher than mean surface-water, non-photosynthetic bacterioplankton densities over the study period at all four shoals (Table 7-16). There were no differences between shoals for surface-water samples, and only minor differences between shoals for bottom-water samples. (Table 7-16).

From a seasonal perspective, mean surface-water, non-photosynthetic bacterioplankton biomass values were generally highest in the summer and fall for the study period (Table 7-17). In bottom-water samples, the highest mean values were in the summer (Table 7-18).

From an interannual perspective, mean surface-water, non-photosynthetic bacterioplankton biomass values were highest in Year 2 of the study (Table 7-19), reflecting the exceptionally high peaks in the summer of 2015 (Figure 7-6). The second highest mean values were in Year 4 at Bull and Chester Shoals. In bottom-water samples, Years 2 and 4 had the highest mean biomass values (Table 7-20), reflecting the elevated peaks in bottom-water, non-photosynthetic bacterioplankton biomass (Figure 7-6).

In terms of the post-dredge period events (i.e., spring and summer) of 2014 and 2018, no apparent major differences were observed among shoals in the trends of mean surface or bottom-water, non-photosynthetic bacterioplankton cell densities or biomass, including the dredged shoal (CSII-BA) (Figures 7-5 and 7-6). Both years showed declines in biomass means in the post-dredge period at all four shoals.

7.4 Discussion

Mean total surface-water phytoplankton carbon biomass in the Cape Canaveral shelf over the study period was 0.118 mg L^{-1}, with no significant differences among shoals. Mean total bottom-water phytoplankton biomass was higher than for surface water, i.e., 0.164 mg L^{-1}. The higher biomass in bottom-water samples likely reflects resuspension of algae residing on the sediment surface, as indicated by the high chlorophyll *a* levels observed in surface sediment samples (see Chapter 8). There is no other published information on the range of phytoplankton carbon biomass values for the east central coastline of Florida, precluding any direct comparisons with other research results. For comparison, in the eutrophic northern Indian River Lagoon, located within the barrier island system of eastern Florida, mean total phytoplankton carbon biomass was 2.5 mg L^{-1} over the same time period (Phlips et al. 2021), demonstrating the oligotrophic character of the Cape Canaveral shelf.

While there was little spatial variation in total mean phytoplankton biomass among shoals for either surface or bottom water, there was significant seasonal variability in phytoplankton biomass. At all four shoals the highest mean biomass levels were observed in the fall, followed by winter, and lowest levels were in the spring and summer. This was the same pattern described for chlorophyll *a* levels (see Chapter 6). The pattern was different than the spring-summer peaks in phytoplankton biomass observed in many ecosystems (Winder and Cloern 2010), and was best viewed from a hydrologic perspective. It is important to keep in mind that surface phytoplankton composition and abundance in the hydrologically dynamic environment of the Cape Canaveral shelf region are strongly influenced by the introduction and rapid passage of external water masses. The origins of these water masses depend on wind and circulation patterns. Persistent northerly winds in fall and winter can bring in water masses from along the eastern coast of Florida north of the Cape, over which they are influenced by inputs from rivers (e.g., St. Johns River) and major inlets to the intra-coastal waterway (i.e., St. Augustine, Matanzas and Ponce de Leon Inlets). The inputs have elevated levels of nutrients, turbidity, and phytoplankton. The summer/fall wet season (including tropical storms) in Florida generate higher discharges from these inputs in the fall (Srifa et al. 2016). The exceptionally high phytoplankton biomass observed in the fall and winter of 2017 may in part reflect the impact of Hurricane Irma along the east coast of Florida in September (Phlips et al. 2020).

In the spring and summer trade winds coming from the south-east can bring in water masses into the Cape shelf, including eddies off the nearby Gulf Stream, which bring in water masses of Caribbean origin, with typically lower nutrient, turbidity and phytoplankton levels. It is also possible that elevated top-down pressure on phytoplankton communities in the spring and summer by zooplankton restrict phytoplankton standing crops. The latter hypothesis is not supported by the observation that total zooplankton biomass in the study region had the same seasonal pattern as total phytoplankton (see Chapter 9). However, further research on the dynamics of key zooplankton taxa is needed to further test this hypothesis.

The relative absence of seasonal differences in mean bottom-water total phytoplankton levels likely reflects the importance of resuspension of algae from the surface of sediments, and sinking of diatoms, in elevating biomass in the bottom-water layer. These processes are more closely linked to local short-term wind patterns than seasonal variability in temperature, light and nutrient availability.

In terms of the comparison of post-dredge periods (i.e., spring and summer of 2014 and 2018), both showed a decline in surface-water phytoplankton biomass levels, which was the same pattern for the other years of the study. The patterns were consistent among shoals. For bottom-water biomass there was no consistent pattern, with declines in 2014 and some increases in 2018. The lack of consistent patterns was also observed in other years of the study for bottom water.

Beyond the general spatial and temporal patterns of total phytoplankton biomass, there were noteworthy trends in the biomass distributions of the major taxonomic groups and size classes of phytoplankton. The higher mean biomass levels of dinoflagellates in surface samples than bottom samples may in part reflect their ability to move up in the water column via flagellar motility. The higher mean biomass levels of diatoms in bottom-water than surface-water samples in part reflects a combination of sinking of cells in the water column and resuspension of sedimented cells from the benthos into the lower layers of the water column. The greater relative abundance of diatoms in bottom than surface water, and opposite pattern in dinoflagellates, may result in differences in the utilization of phytoplankton carbon by higher trophic levels at different depths in the water column. Many of the dinoflagellate species observed in the study were mixotrophic (i.e., capable of photosynthesis and growth using organic carbon), and some were heterotrophic. The ability of these dinoflagellates to consume bacteria and small-sized phytoplankton means they are an important part of the microbial loop, which impacts the efficiency of carbon and energy transfer up the food web (Pomeroy et al. 2007; Fenchel 2008). At the same time, sedimentation of phytoplankton on to the sediment surface is a major source of carbon for benthic microbial and faunal communities.

Seasonally, in surface-water samples, dinoflagellates, diatoms, and "other" taxa (e.g., chlorophytes) had the highest mean biomass in the fall, followed by the winter, and the lowest mean values were for spring and summer. By contrast, mean cyanobacteria biomass was highest in the fall and summer, likely reflecting the general preference of the group for higher temperatures (Paerl and Huisman 2008). The seasonal patterns in bottom-water samples were more mixed. Diatoms had the highest biomass in the winter and spring, perhaps reflecting greater wind mixing of algae from the benthos during these windy seasons. Cyanobacteria had the highest mean biomass in the summer, again reflecting their temperature preference. Dinoflagellates and "other" taxa had the lowest mean biomass in the summer, which reflects the overall trend in carbon availability for mixotrophic taxa, which are common in both of these groups.

Another important observation of this study was the importance of small-sized phytoplankton in terms of both abundance and biomass. The smallest size class of phytoplankton, picoplankton (≤ 2 µm), was primarily dominated by unicellular cyanobacteria. In both surface and bottom samples, picoplanktonic cyanobacteria (including spherical forms and *Synechococcus* spp.) were the largest contributors to the Top-500 lists. This reflects the great importance of this size class in open-ocean environments around the world (Flombaum et al. 2013). Another important component of the picoplankton was non-photosynthetic bacteria, which represented roughly near half as much biomass as picoplankton cyanobacteria. Mean values fell within the range commonly observed in nearshore coastal ecosystems (Day 2013). Nanoplanktonic species (> 2 to 20 µm) were also a major component of total biomass and included unicellular cyanobacteria and small-sized diatoms and micro-flagellates. Together, pico- and nanoplanktonic primary producers represented near 70% of total phytoplankton biomass. This observation further highlights the importance of the microbial loop in the Cape Canaveral shelf, as discussed above.

7.5 References

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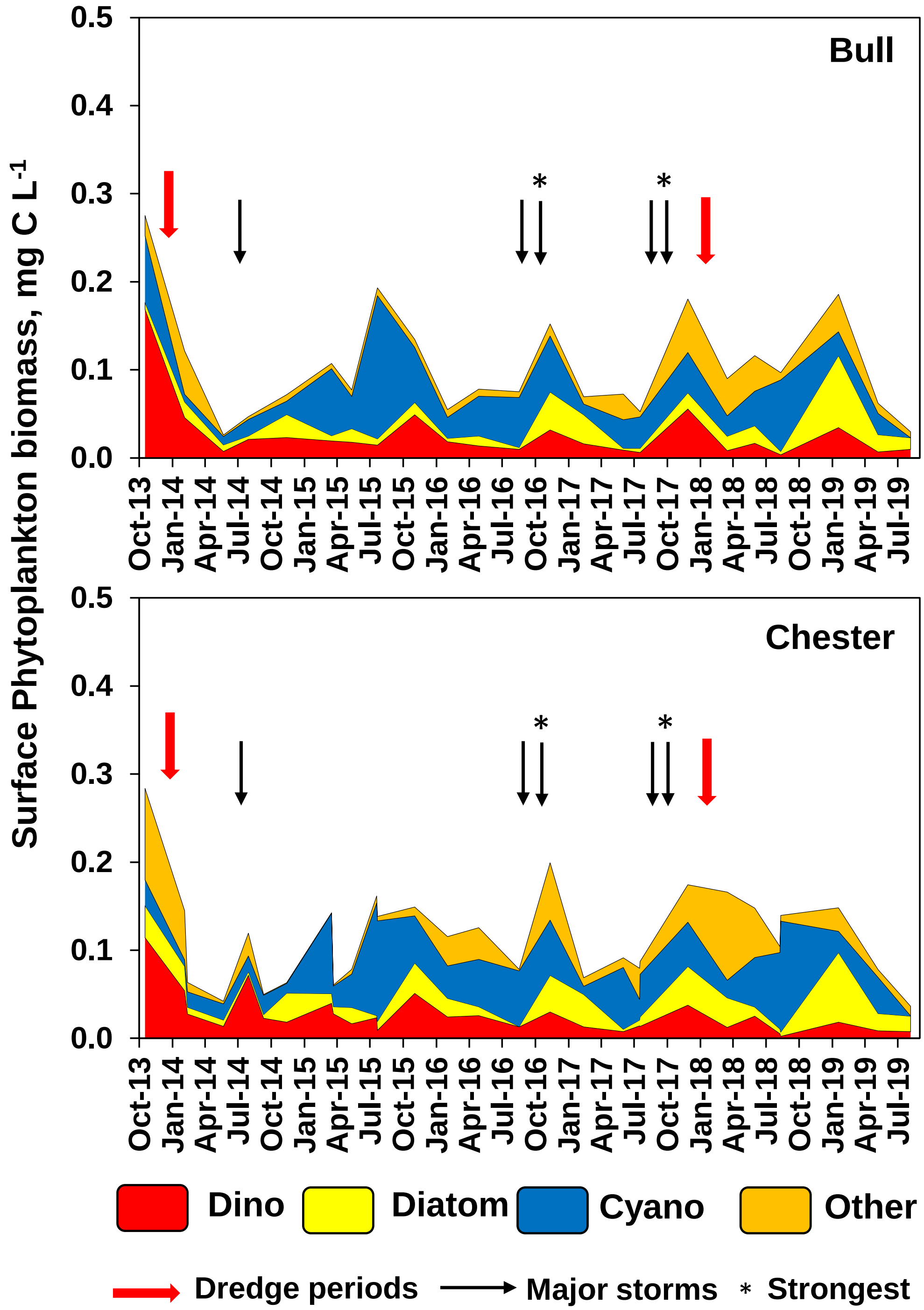

Figure 7-1. Mean surface-water phytoplankton biomass (mg carbon L^{-1}) at the four sampling shoals over the study period.

Biomass is subdivided into four categories: dinoflagellates (red), diatoms (yellow), cyanobacteria (blue), and all other taxa (orange). Red arrows mark the two periods of dredging activity at CSII-BA. Black arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denotes Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

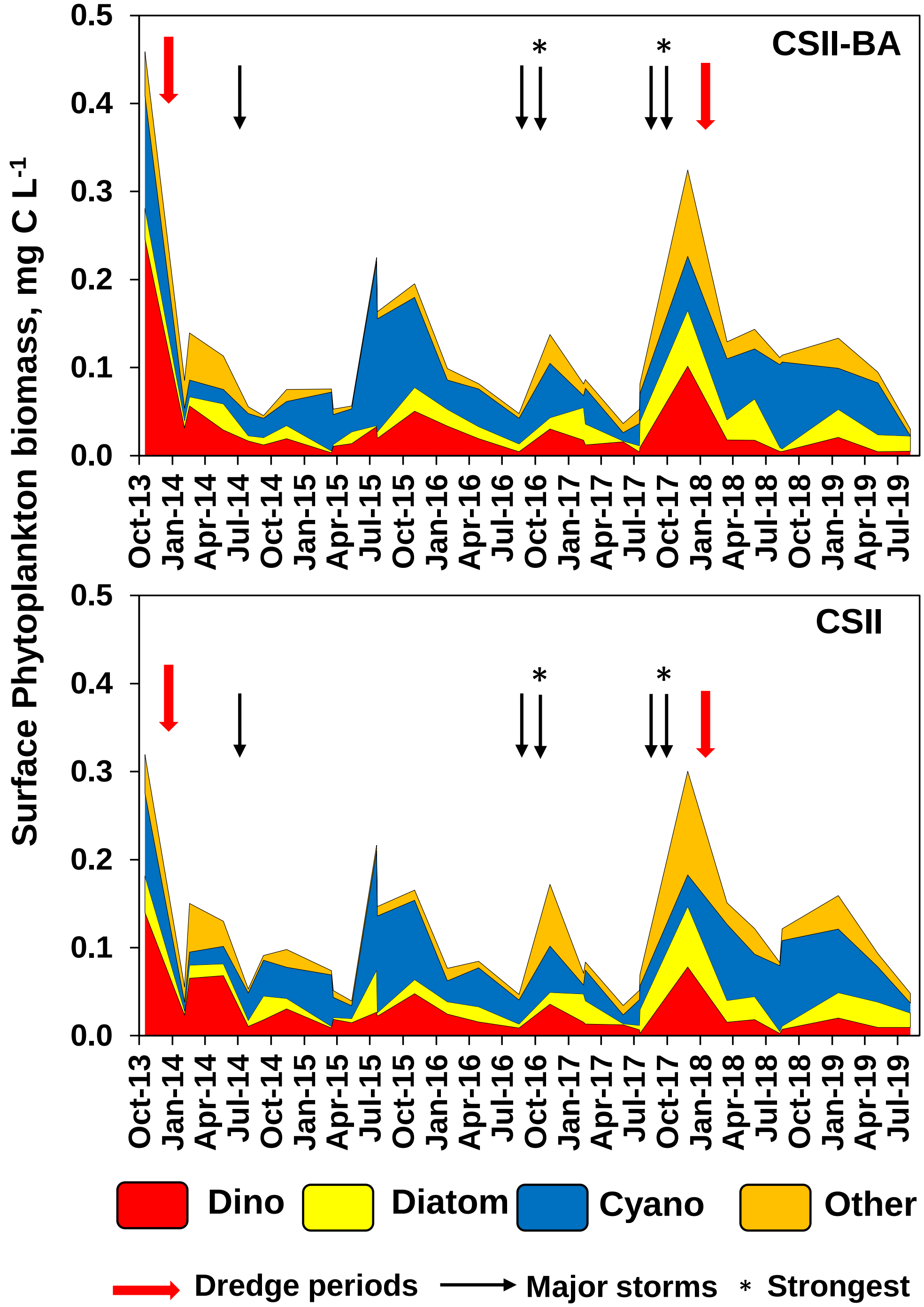

Figure 7-1 (Cont'd). Mean surface-water phytoplankton biomass (mg carbon L^{-1}) at the four sampling shoals over the study period.

Biomass is subdivided into four categories: dinoflagellates (red), diatoms (yellow), cyanobacteria (blue), and all other taxa (orange). Red arrows mark the two periods of dredging activity at CSII-BA. Black arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denotes Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

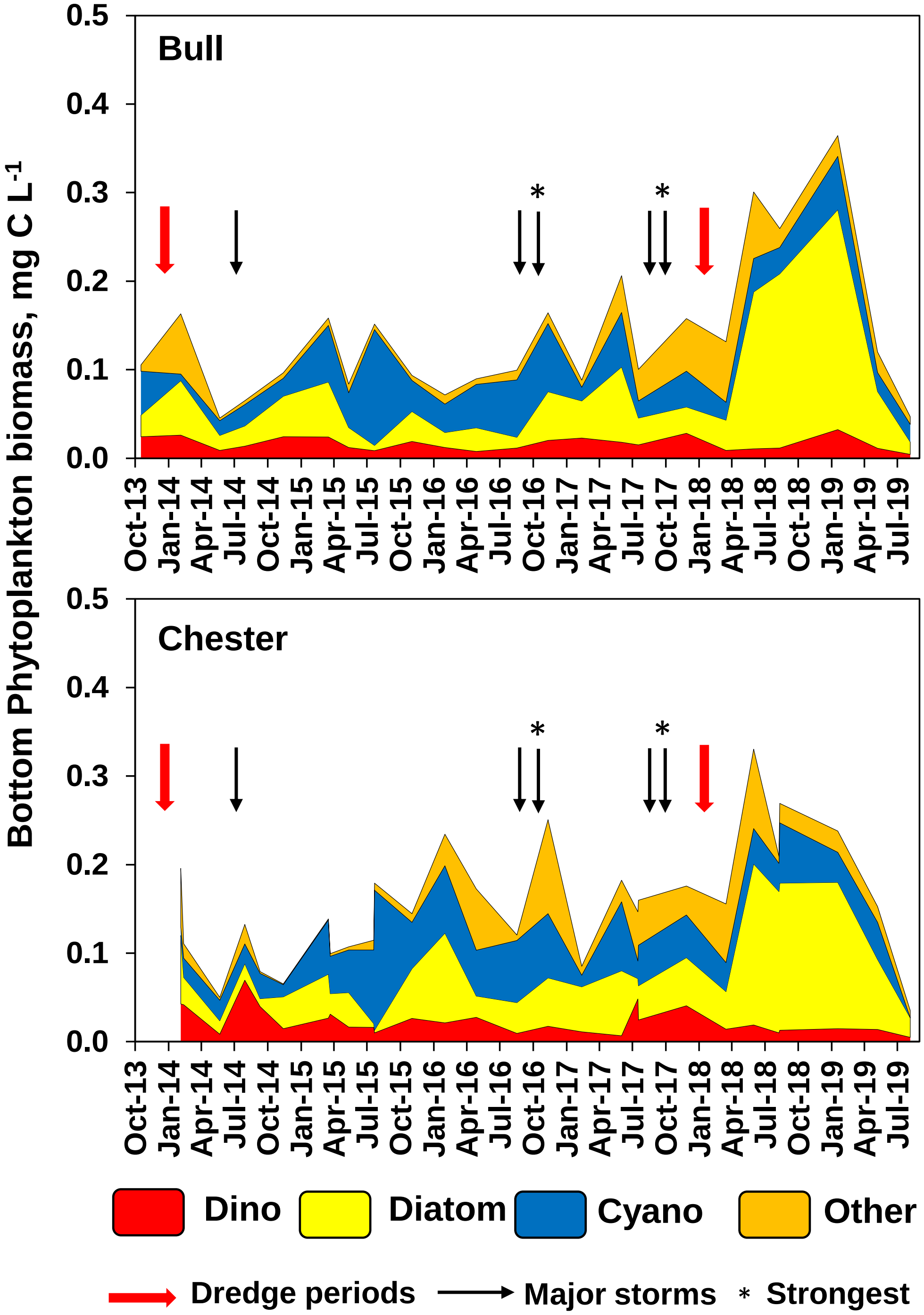

Figure 7-2. Mean bottom-water phytoplankton biomass (mg carbon L-1) for the four shoals over the study period.

Biomass is subdivided into four categories: dinoflagellates (red), diatoms (yellow), cyanobacteria (blue), and all other taxa (orange). Red arrows mark the two periods of dredging activity at CSII-BA. Black arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denotes Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

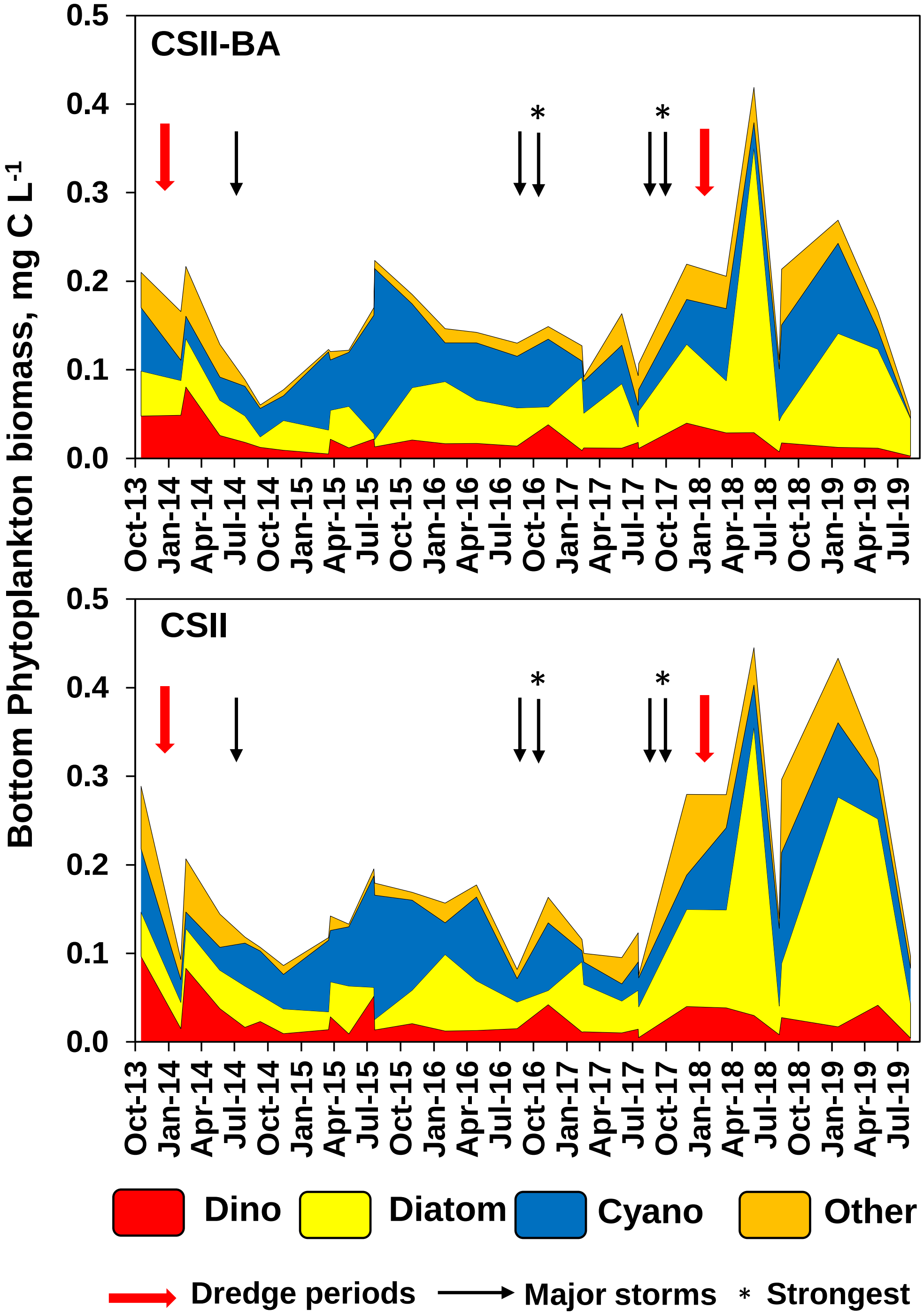

Figure 7-2 (Cont'd). Mean bottom-water phytoplankton biomass (mg carbon L-1) for the four shoals over the study period.

Biomass is subdivided into four categories: dinoflagellates (red), diatoms (yellow), cyanobacteria (blue), and all other taxa (orange). Red arrows mark the two periods of dredging activity at CSII-BA. Black arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denotes Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

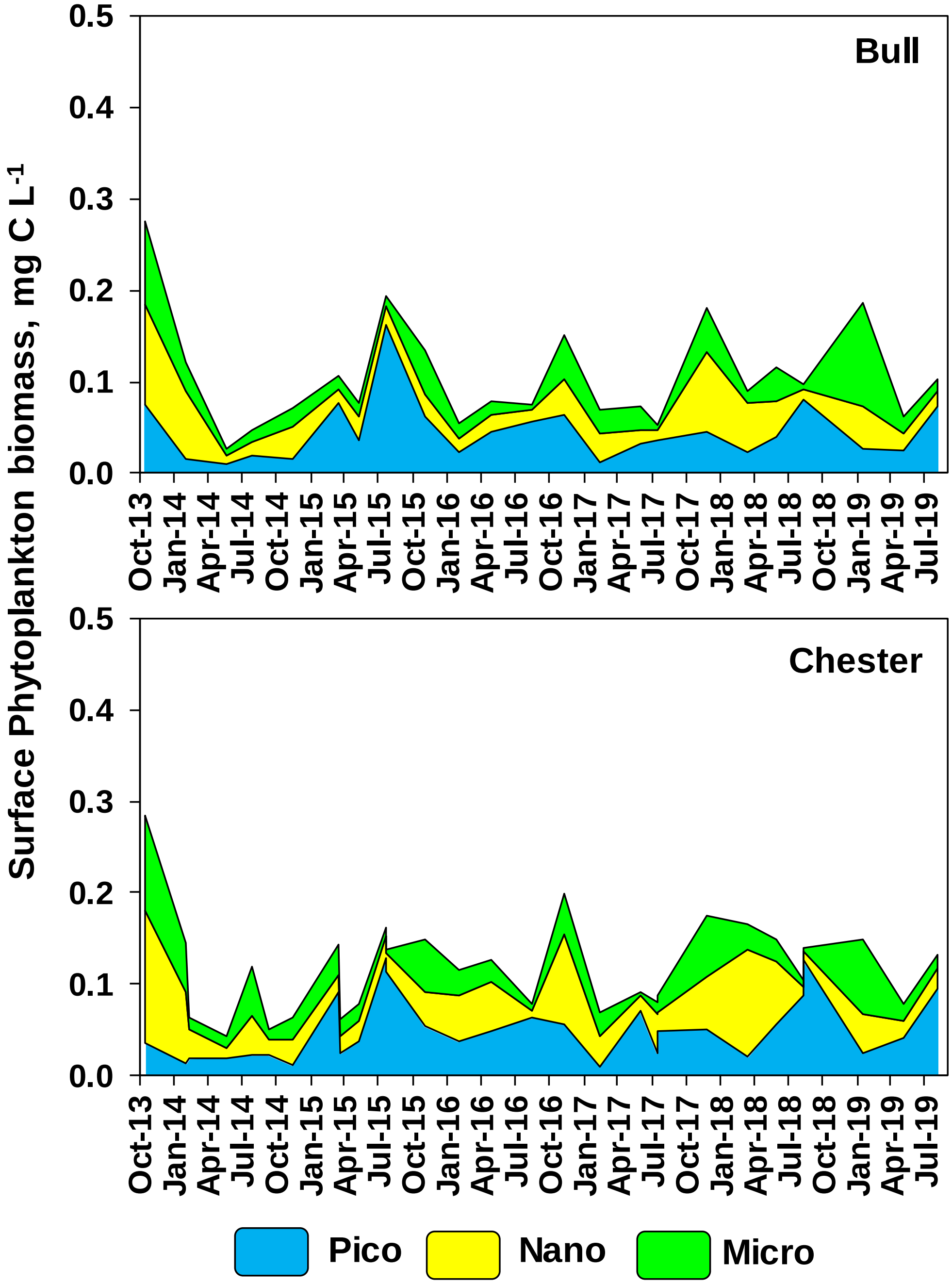

Figure 7-3. Contributions of picoplanktonic phytoplankton (i.e., up to 2 µm), nanoplanktonic phytoplankton (i.e., > 2–20 µm), and microplanktonic phytoplankton (i.e., > 20–200+ µm) to mean total surface-water phytoplankton biomass (mg carbon L^{-1}) at the four shoals.

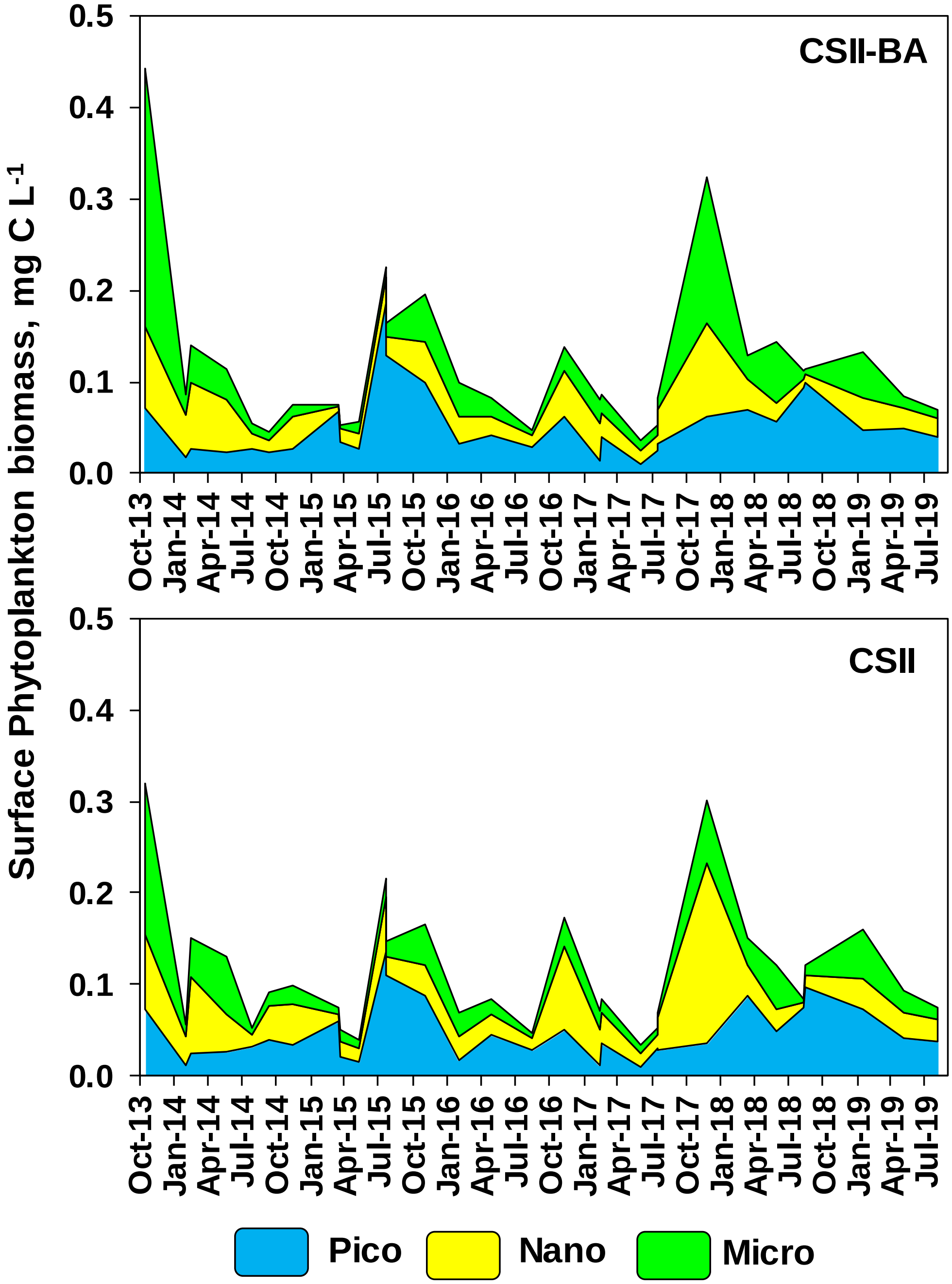

Figure 7-3 (Cont'd). Contributions of picoplanktonic phytoplankton (i.e., up to 2 µm), nanoplanktonic phytoplankton (i.e., > 2–20 µm), and microplanktonic phytoplankton (i.e., > 20–200+ µm) to mean total surface-water phytoplankton biomass (mg carbon L^{-1}) at the four shoals.

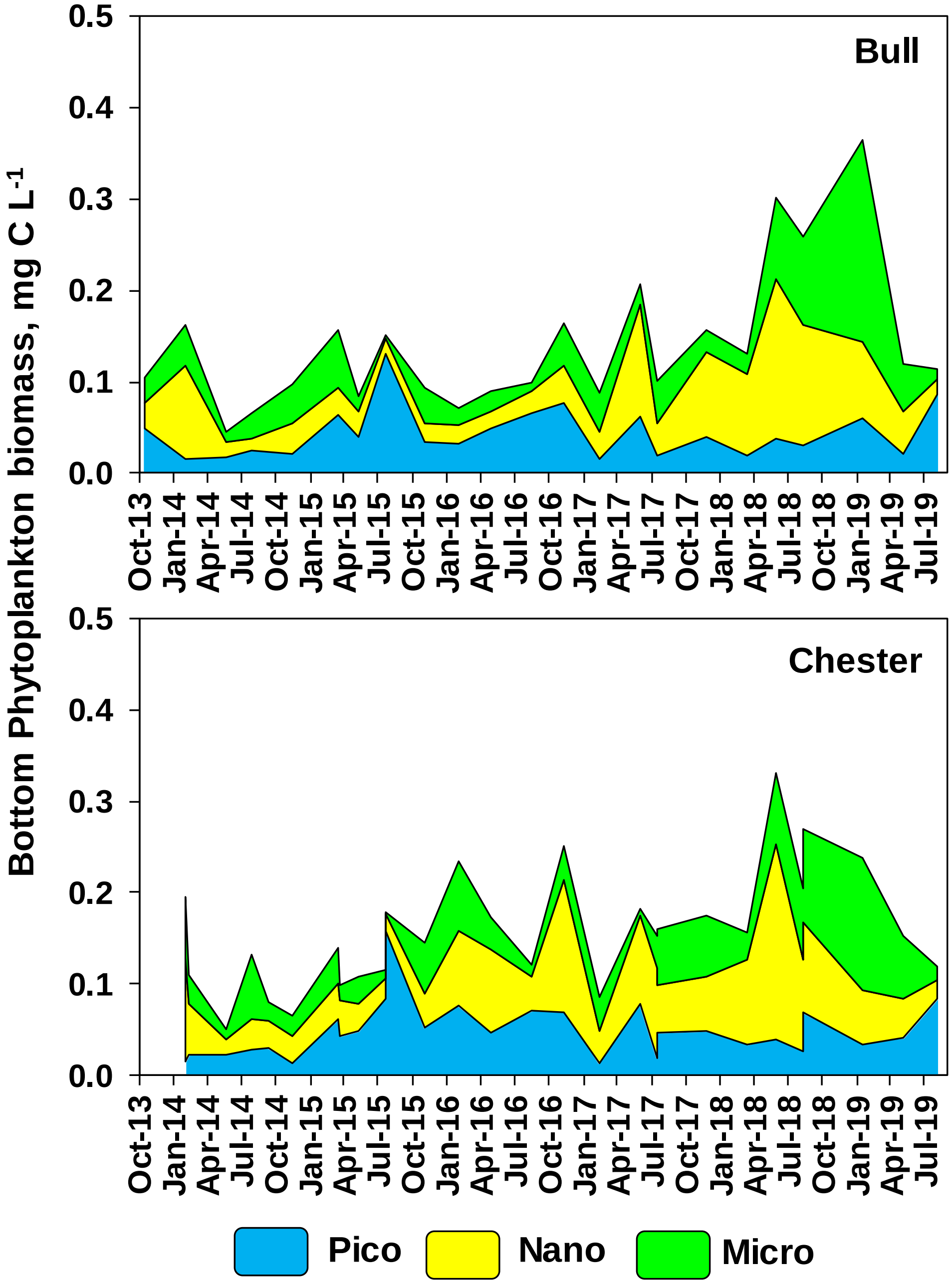

Figure 7-4. Contributions of picoplanktonic phytoplankton (i.e., up to 2 µm), nanoplanktonic phytoplankton (i.e., > 2–20 µm), and microplanktonic phytoplankton (i.e., > 20–200+ µm) to mean total bottom-water phytoplankton biomass (mg carbon L-1) of the four shoals.

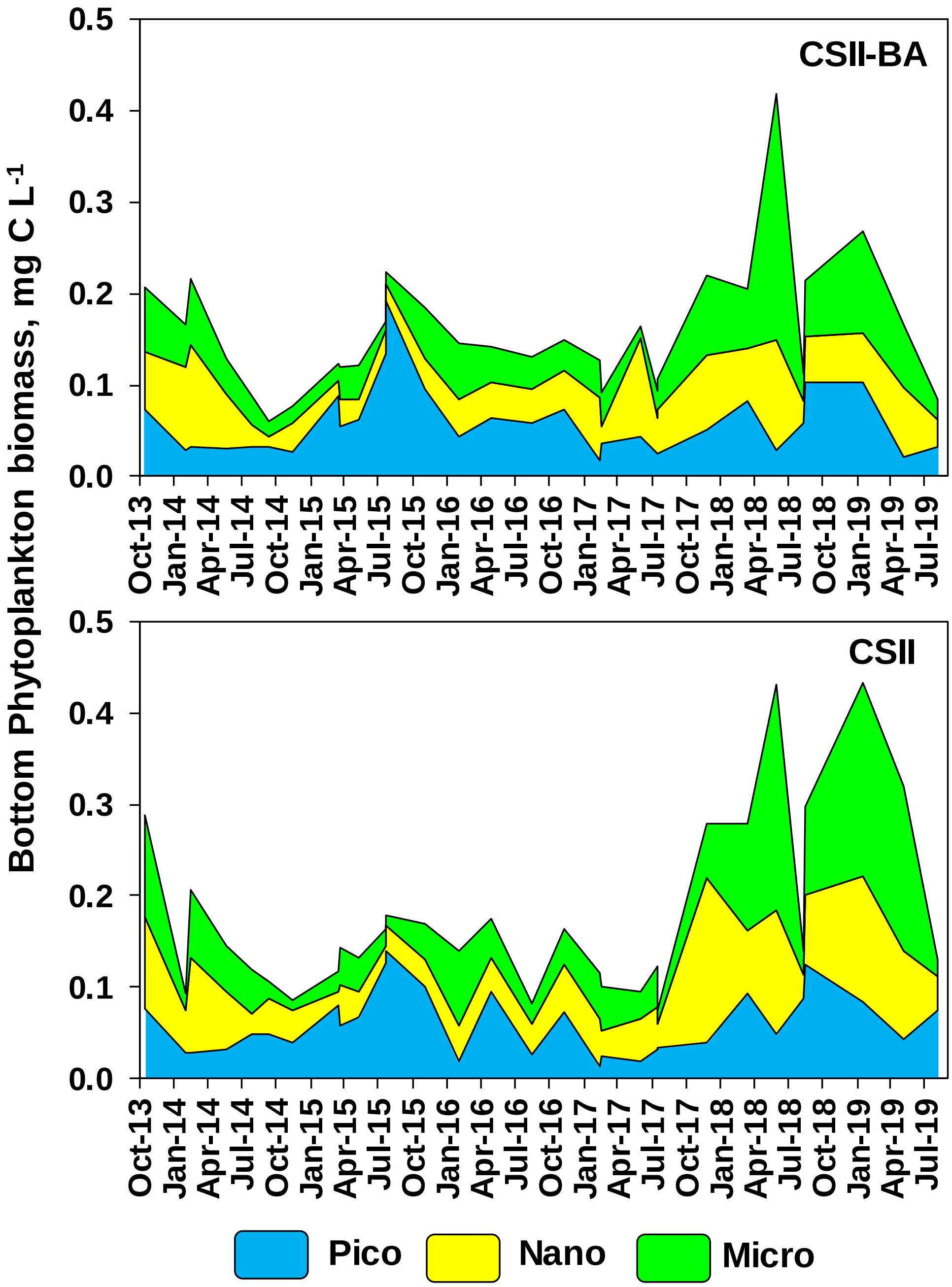

Figure 7-4 (Cont'd). Contributions of picoplanktonic phytoplankton (i.e., up to 2 µm), nanoplanktonic phytoplankton (i.e., > 2–20 µm), and microplanktonic phytoplankton (i.e., > 20–200+ µm) to mean total bottom-water phytoplankton biomass (mg carbon L-1) of the four shoals.

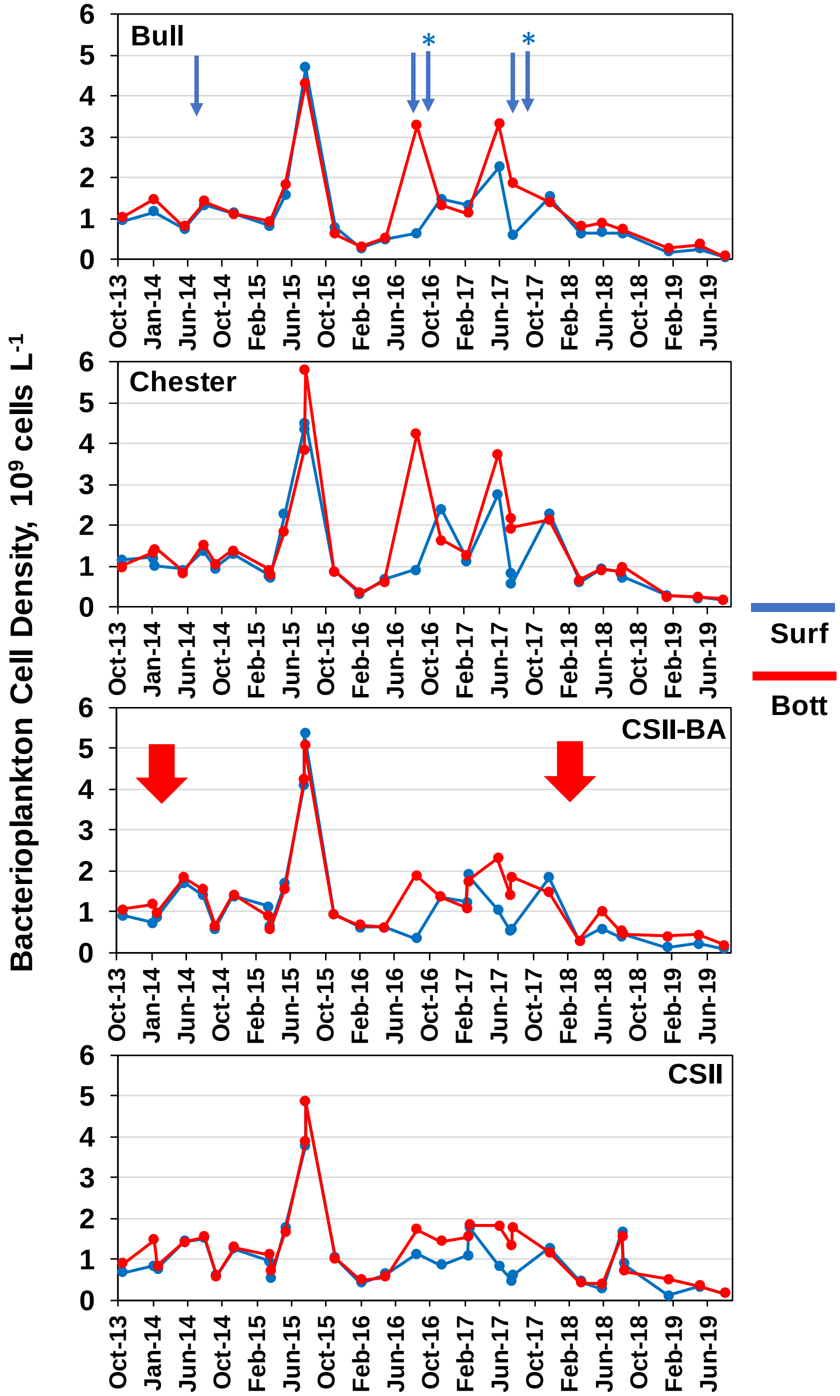

Figure 7-5. Mean non-photosynthetic bacterioplankton densities (10^9 cells L^{-1}) for surface and bottom-water samples for the four shoals over the study period.
Red arrows mark the two periods of dredging activity at CSII-BA. Blue arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denotes Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

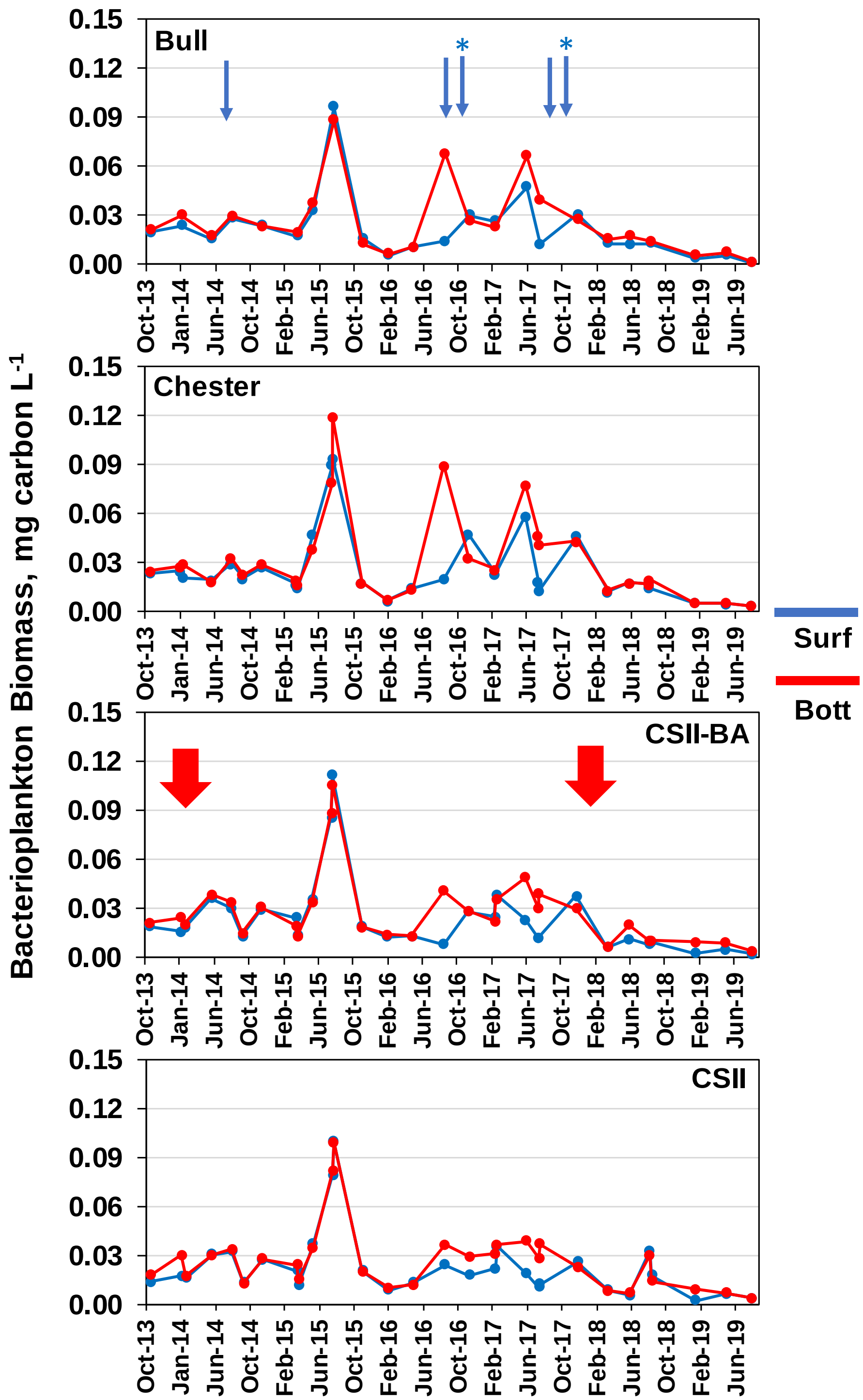

Figure 7-6. Mean non-photosynthetic bacterioplankton biomass (mg carbon L^{-1}) for surface and bottom-water samples for the four shoals over the study period.

Red arrows mark the two periods of dredging activity at CSII-BA. Blue arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denotes Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

Table 7-1. Comparison of mean total phytoplankton biomass (mg carbon L^{-1}) for surface and bottom-water samples for the four shoals of the study.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between surface and bottom means within each shoal, and lowercase letters are used to compare means among shoals.

Depth Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Surface	0.106 A	0.127 A	0.123 A	0.116 A
"	a	a	a	a
Bottom	0.141 B	0.160 B	0.168 B	0.188 B
"	b	a	a	a

Table 7-2. Seasonal comparison of mean total phytoplankton biomass (mg carbon L^{-1}) in surface-water samples for the four shoals of the study.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasonal means within each shoal, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	0.163 A	0.174 A	0.235 A	0.212 A
"	b	b	a	ab
Winter	0.105 B	0.131 B	0.102 B	0.098 B
"	b	a	b	b
Spring	0.072 C	0.094 C	0.086 C	0.084 C
"	b	a	ab	ab
Summer	0.095 C	0.116 C	0.089 C	0.085 C
"	ab	a	b	b

Table 7-3. Comparison of annual mean total phytoplankton biomass (mg carbon L^{-1}) in surface-water samples for the four shoals of the study.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means within each shoal, and lowercase letters are used to compare annual means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	0.118 A	0.148 AB	0.176 A	0.140 AB
"	a	a	a	a
2	0.112 A	0.106 C	0.093 B	0.089 B
"	a	a	a	a
3	0.086 A	0.117 BC	0.106 B	0.095 BC
"	b	a	ab	ab
4	0.087 A	0.112 BC	0.085 B	0.084 C
"	a	a	a	a
5	0.121 A	0.157 A	0.178 A	0.174 A
"	b	ab	a	a

Table 7-4. Comparison of mean bottom-water total phytoplankton biomass (mg carbon L^{-1}) at ridge and swale habitats for the four shoal of the study.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between ridge and swale means within each shoal, and lowercase letters are used to compare means among shoals.

Habitat	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Ridge	0.134 A	0.159 A	0.172 A	0.163 A
"	b	ab	a	ab
Swale	0.144 A	0.170 A	0.166 A	0.199 A
"	b	ab	b	a

Table 7-5. Seasonal comparison of mean total phytoplankton biomass (mg carbon L^{-1}) in bottom-water samples for the four shoals of the study.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasonal means within each shoal, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	0.124 A	0.159 A	0.169 AB	0.199 AB
"	b	ab	a	a
Winter	0.162 A	0.175 A	0.171 AB	0.195 AB
"	a	a	a	a
Spring	0.141 A	0.166 A	0.190 A	0.213 A
"	b	ab	ab	a
Summer	0.132 A	0.163 A	0.141 B	0.147 B
"	a	a	a	a

Table 7-6. Comparison of annual mean total phytoplankton biomass (mg carbon L^{-1}) in bottom-water samples for the four shoals of the study.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means within each shoal, and lowercase are used to compare means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	0.095 BC	0.126 B	0.149 B	0.161 B
"	b	ab	a	a
2	0.123 BC	0.123 B	0.137 B	0.129 B
"	a	a	a	a
3	0.089 C	0.168 B	0.151 B	0.150 B
"	b	a	a	a
4	0.140 B	0.170 B	0.129 B	0.110 B
"	ab	a	b	b
5	0.212 A	0.223 A	0.264 A	0.317 A
"	b	b	ab	a

Table 7-7. Comparison of mean phytoplankton biomass (mg carbon L^{-1}) of four major phytoplankton groups in surface-water and bottom-water samples over the entire study area.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between surface and bottom means within each group, and lowercase letters are used to compare means among groups.

Depth Sampled	Dinoflagellates	Diatoms	Cyanobacteria	Other
Surface	0.028 A	0.019 B	0.049 B	0.022 B
"	b	c	a	c
Bottom	0.021 B	0.065 A	0.054 A	0.026 A
"	c	a	b	c

Table 7-8. Comparison of mean phytoplankton biomass (mg carbon L^{-1}) of four major phytoplankton groups in surface-water and bottom-water samples by shoal.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between surface and bottom means within each shoal, and lowercase letters are used to compare means among shoals.

Group	Depth Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII
Dinoflagellates	Surface	0.026 A	0.027 A	0.031 A	0.028 A
"	"	a	a	a	a
"	Bottom	0.016 B	0.021 B	0.020 B	0.024 B
"	"	b	ab	ab	a
Diatoms	Surface	0.016 B	0.022 B	0.020 B	0.018 B
"	"	b	a	ab	ab
"	Bottom	0.058 A	0.063 A	0.064 A	0.075 A
"	"	a	a	a	a
Cyanobacteria	Surface	0.046 A	0.050 A	0.052 A	0.047 A
"	"	a	a	a	a
"	Bottom	0.044 A	0.052 A	0.060 A	0.061 A
"	"	b	ab	a	a
Other	Surface	0.018 A	0.028 A	0.020 A	0.024 A
"	"	b	a	b	ab
"	Bottom	0.023 A	0.031 A	0.023 A	0.028 A
"	"	b	a	b	ab

Table 7-9. Seasonal comparison of mean phytoplankton biomass (mg carbon L^{-1}) of four major phytoplankton groups in surface-water samples over the entire study area.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasons within each group, and lowercase letters are used to compare seasonal means among groups.

Season	Dinoflagellates	Diatoms	Cyanobacteria	Other
Fall	0.068 A	0.030 A	0.058 A	0.040 A
"	a	b	a	b
Winter	0.022 B	0.024 B	0.037 B	0.025 B
"	b	b	a	b
Spring	0.017 BC	0.015 C	0.035 B	0.017 C
"	b	b	a	b
Summer	0.012 C	0.009 D	0.066 A	0.009 D
"	b	b	a	b

Table 7-10. Seasonal comparison of mean phytoplankton biomass (mg carbon L^{-1}) of four major phytoplankton groups in bottom-water samples over the entire study area.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasons within each group, and lowercase letters are used to compare seasonal means among groups.

Season	Dinoflagellates	Diatoms	Cyanobacteria	Other
Fall	0.031 A	0.047 B	0.056 B	0.030 A
"	c	b	a	c
Winter	0.020 B	0.078 A	0.048 B	0.029 A
"	c	a	b	c
Spring	0.017 BC	0.089 A	0.044 B	0.028 A
"	c	a	b	c
Summer	0.015 C	0.041 B	0.071 A	0.019 B
"	c	b	a	c

Table 7-11. Comparison of mean phytoplankton biomass (mg carbon L^{-1}) of three size classes of phytoplankton groups in surface-water and bottom-water samples over the entire study area.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between surface and bottom means within each size class group, and lowercase letters are used to compare means among size class groups.

Depth Sampled	Picoplankton	Nanoplankton	Microplankton
Surface	0.049 B	0.037 B	0.033 B
"	a	b	b
Bottom	0.054 A	0.057 A	0.054 A
"	a	a	a

Table 7-12. Shoal comparisons of mean phytoplankton biomass (mg carbon L^{-1}) of three size classes of phytoplankton groups in surface-water samples over the study period.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among means for size classes within each shoal, and lowercase letters are used to compare size class means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Picoplankton	0.047 A	0.052 A	0.051 A	0.046 A
"	a	a	a	a
Nanoplankton	0.032 B	0.045 A	0.033 B	0.038 AB
"	b	a	b	ab
Microplankton	0.028 B	0.033 B	0.041 AB	0.031 B
"	b	ab	a	ab

Table 7-13. Shoal comparisons of mean phytoplankton biomass (mg carbon L^{-1}) of three size classes of phytoplankton groups in bottom-water samples over the study period.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among means for size classes within each shoal, and lowercase letters are used to compare size class means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Picoplankton	0.044 A	0.052 AB	0.061 A	0.061 A
"	b	ab	a	a
Nanoplankton	0.053 A	0.066 A	0.051 A	0.059 A
"	a	a	a	a
Microplankton	0.043 A	0.048 B	0.055 A	0.067 A
"	b	b	ab	a

Table 7-14. Frequency of observation of taxa in the Top-500 by biomass and highest cell density observed for each taxa for surface-water samples over the study period.

Taxa	Scientific Name or Group	Frequency	Highest Biomass (mg carbon m^{-3})	Highest Density (cells ml^{-1})
Cyanophyta (Blue-green Algae)	Spherical picocyanobacteria	334	0.217	945,690
"	*Synechococcus* spp.	10	0.074	168,610
"	*Trichodesmium erythraeum*	3	0.286	44
Bacillariophyta (Diatoms)	*Guinardia delicatula*	12	0.062	225
"	*Guinardia flaccida*	5	0.032	32
"	*Dactyliosolen fragilissimus*	2	0.040	340
"	*Paralia sulcate*	2	0.032	131
"	*Skeletonema cf. costatum*	2	0.079	1,300
"	*Bellerochea horologicalis*	1	0.031	12
"	*Brockmanniella brockmannii*	1	0.076	770
"	Centric diatom (350-400 µ)	1	0.038	<1
"	*Leptocylindrus danicus*	1	0.031	149
Dinophyta (Dinoflagellates)	*Cochlodinium* sp.	9	0.092	20
"	*Protoperidinium* sp.	9	0.078	32
"	*Azadinium caudatum*	4	0.164	135
"	*Gyrodinium* sp.	4	0.054	713
"	Gymnoid sp.	3	0.062	831
"	*Gyrodinium spirale*	3	0.047	6
"	*Prorocentrum triestinum*	3	0.092	81
"	*Kapelodinium vestifici*	2	0.053	181
"	*Karenia mikimoto*	2	0.032	9
"	*Karlodinium veneficum*	2	0.045	181
"	*Torodinium robustum*	2	0.043	45
"	*Amphidinium* spp.	1	0.045	54
"	*Protoperidinium bipes*	1	0.041	60
"	*Scrippsiella* sp.	1	0.076	50
Chlorophyta (Green Algae)	Prasinophyte sp.	45	0.102	15,525
Prymnesiophyta	Prymnesium sp.	1	0.034	4,621
Nanoplanktonic Eukaryotic Phytoplankton (Undefined)	Eukaryotic nanoplankton spp.	24	0.310	32,918
"	Spherical phytoflagellate sp.	10	0.170	14,691

Table 7-15. Frequency of observation of taxa in the Top-500 by biomass and highest cell density bserved for each taxa for bottom-water samples over the study period.

Taxa	Scientific Name or Group	Frequency	Highest Biomass (mg carbon m^{-3})	Highest Density (cells ml^{-1})
Cyanophyta (Blue-green Algae)	Spherical picocyanobacteria	281	0.240	1,049,634
"	*Synechococcus spp.*	6	0.149	340,445
Bacillariophyta (Diatoms)	*Guinardia delicatula*	26	0.217	795
"	*Cyclotella choctawhatcheeana*	25	0.246	9,342
"	*Guinardia flaccida*	22	0.309	98
"	Pennate diatom spp. (1-5 µ)	13	0.000	5
"	*Thalassiosira* spp. (10 µ)	9	0.176	6,704
"	*Paralia sulcate*	6	0.076	386
"	*Cylindrotheca closterium*	5	0.000	5
"	*Leptocylindrus danicus*	4	0.061	291
"	Centric diatom (10 µ)	3	0.084	3,201
"	*Brockmanniella brockmannii*	2	0.084	861
"	Pennate diatom chain	2	0.049	1,105
"	*Skeletonema cf. costatum*	2	0.113	4,938
"	Centric diatom (350-400 µ)	1	0.036	<1
"	*Coscinodiscus* sp.	1	0.035	45
"	*Dactyliosolen fragilissimus*	1	0.068	182
"	*Navicula* sp.	1	0.037	136
"	*Odontella rhombus*	1	0.041	151
"	*Odontella sinensis*	1	0.038	10
"	*Pseudo-nitzschia sp.*	1	0.076	3,467
"	*Rhizosolenia* sp.	1	0.048	21
Dinophyta (Dinoflagellates)	*Azadinium caudatum*	5	0.049	41
"	*Cochlodinium* sp.	2	0.133	29
"	*Prorocentrum micans*	1	0.038	9
"	*Prorocentrum texanum*	1	0.059	16
"	*Protoperidinium* sp.	1	0.037	15
Chlorophyta (Green Algae)	Prasinophyte sp.	38	0.321	48,967
Prymnesiophyta	Prymnesium sp.	2	0.053	7,139
Nanoplanktonic Eukaryot Phytoplankton (Undefined)	Eukaryotic nanoplankton spp.	25	0.127	13,514
"	Spherical phytoflagellate sp.	11	0.131	11,335

Table 7-16. Comparison of mean non-photosynthetic bacterioplankton densities (10^9 cells L^{-1}) for surface-water and bottom-water samples for the four shoals of the study.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between surface and bottom means within each shoal, and lowercase letters are used to compare means among shoals.

Depth Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Surface	1.05 A	1.25 A	1.10 A	1.02 A
"	a	a	a	a
Bottom	1.30 B	1.54 B	1.31 B	1.23 B
"	ab	a	ab	b

Table 7-17. Seasonal comparison of mean non-photosynthetic bacterioplankton biomass (mg carbon L^{-1}) in surface-water samples for the four shoals of the study.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasonal means within each shoal, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	0.024 AB	0.032 A	0.026 AB	0.021 B
"	ab	a	ab	b
Winter	0.015 B	0.015 B	0.016 B	0.014 B
"	a	a	a	a
Spring	0.020 AB	0.027 A	0.021 AB	0.018 B
"	ab	a	ab	b
Summer	0.028 A	0.029 A	0.029 A	0.031 A
"	a	a	a	a

Table 7-18. Seasonal comparison of mean non-photosynthetic bacterioplankton biomass (mg carbon L^{-1}) in bottom-water samples for the four shoals of the study.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasonal means within each shoal, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	0.022 B	0.031 B	0.025 BC	0.023 B
"	b	a	b	b
Winter	0.017 B	0.017 C	0.017 C	0.019 B
"	a	a	a	a
Spring	0.026 B	0.028 BC	0.027 B	0.022 B
"	a	a	a	b
Summer	0.040 A	0.051 A	0.039 A	0.037 A
"	a	a	a	a

Table 7-19. Comparison of annual mean non-photosynthetic bacterioplankton biomass (mg carbon L^{-1}) in surface-water samples for the four shoals of the study.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means within each shoal, and lowercase letters are used to compare means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	0.022 BC	0.024 BC	0.025 B	0.023 B
"	a	a	a	a
2	0.043 A	0.046 A	0.050 A	0.046 A
"	a	a	a	a
3	0.012 D	0.015 C	0.013 C	0.016 B
"	a	a	a	a
4	0.029 B	0.035 AB	0.025 B	0.018 B
"	ab	a	ab	b
5	0.017 DC	0.023 BC	0.016 BC	0.014 B
"	ab	a	ab	b

Table 7-20. Comparison of annual mean non-photosynthetic bacterioplankton biomass (mg carbon L^{-1}) in bottom-water samples in the four regions of the study.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means within each shoal, and lowercase letters are used to compare means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	0.025 B	0.026 C	0.029 BC	0.027 BC
"	a	a	a	a
2	0.042 A	0.052 A	0.047 A	0.046 A
"	a	a	a	a
3	0.024 B	0.032 BC	0.021 DC	0.020 DC
"	a	a	a	a
4	0.039 A	0.044 AB	0.037 AB	0.034 B
"	ab	a	ab	b
5	0.019 B	0.023 C	0.016 D	0.013 D
"	ab	a	b	b

8 Microphytobenthos

Ed Phlips, Susan Badylak, Leslie Landauer, Anne West-Valle, and Benjamin Stelling

Key Points

- The range of microphytobenthos chlorophyll *a* levels observed in this study (i.e., 1–202 mg m^{-2}) were in line with the range of values observed in other shallow ecosystems on the east and west coasts of Florida.
- Spatial and temporal differences in microphytobenthos chlorophyll *a* concentrations were observed in this study. The highest mean chlorophyll *a* concentrations were observed at CSII Shoal (followed by Bull Shoal), and the lowest concentrations were at Chester and CSII-BA Shoals. Seasonally, chlorophyll *a* concentrations generally peaked in the summer.
- A comparison of microphytobenthos chlorophyll *a* concentrations in the pre- to post-dredge sediment samples showed no major differences in concentrations, and patterns observed for the post-dredge period were generally similar at all the shoals.

8.1 Introduction

Microalgae residing on the surface of sediments, often referred to as microphytobenthos, can represent a significant component of primary production in shallow ecosystems (MacIntyre et al. 1996). Along with macroalgae and seagrasses, it represents one of the principal benthic primary producers in most coastal ecosystems (Valiela 1984). Microphytobenthos also represents a potential source of carbon for benthic deposit-feeding organisms.

The main goal of this component of the research program was to quantify the biomass of microphytobenthic algae to help define the impacts of dredging on these potentially important primary producers within the affected local coastal zone, and determine the temporal/spatial scales of recovery from the disturbances caused by the dredging.

8.2 Methods

Microphytobenthos samples were obtained by subsampling benthic grabs collected in Chapter 11. In brief, three replicate subsamples of the sediment were taken from each benthic grab using 20-mm diameter coring tubes. The sediments for each grab were categorized for sand size as part of the analysis in Chapter 11. This was based on the CMECS guidelines and included four broad categories of sand, i.e., coarse sand, medium sand, fine sand, and muddy-sand (see Chapter 11 sand metrics methodology).

All benthic grabs collected from CSII and CSII-BA were sampled for microphytobenthos; half of the grabs from Chester and Bull Shoals were sampled. In total, 24 grabs were sampled during each event (72 coring tubes in total). All samples were transported to the laboratory on ice for analysis.

For microphytobenthos analysis, the top centimeter of the sediment core was removed for analysis. Chlorophyll *a* and pheophytin concentrations were determined using sediment samples extracted with solvent and measured using spectrophotometric methods (APHA 2005; Phlips et al. 2010). For estimation of biomass levels in terms of carbon, corrected chlorophyll *a* values were converted into algal carbon by multiplying by 40, based on the broad assumption that chlorophyll *a* is about 1% of dry wet of microalgae and carbon is about 40% of dry weight of microalgae (Reynolds 2006).

Mean biomass values were based on relevant site values within each shoal of the study. Duncan Multiple Range Tests were used to test for differences among shoals ($P \leq 0.5$), between ridge versus swale habitats, surface- versus bottom-water samples, among seasons and years, and between the dredged shoal (CSII-BA) and the reference shoals (CSII, Bull, and Chester). All analyses were done using statistical packages in SAS® (SAS Institute 2012).

8.3 Results

8.3.1 Sediment Surface Microalgae Biomass

Mean corrected chlorophyll *a* concentrations on the sediment surface (i.e., top 1 cm) ranged from <1 mg m^{-2} to 78 mg m^{-2} (Figure 8-1). Mean chlorophyll *a* concentrations were generally higher at swale than ridge habitats (Figure 8-1, Table 8-1). The highest mean corrected chlorophyll *a* concentrations over the study period were observed in both ridge and swale habitats at CSII, followed by Bull Shoal. The CSII-BA Shoal had the lowest mean values (Table 8.1). Estimated mean sediment surface algal biomass values (i.e., carbon values based on corrected chlorophyll *a* concentrations) ranged from 0.21 to 1.27 g carbon m^{-2}, with the same spatial and temporal pattern as chlorophyll *a* (Table 8-2).

Seasonally, the highest mean corrected chlorophyll *a* values were different among shoals (Table 8-3). At Bull Shoal the highest values were in the summer and fall, at Chester Shoal the highest values were in the spring and summer, and at CSII-BA the highest value was in the summer. There were no significant seasonal differences in CSII. Interannually, mean corrected chlorophyll *a* was high in Year 3 in the four shoals of the study, although differences among years within each shoal were not drastic (Table 8-4).

Mean corrected chlorophyll *a* concentrations were highest in muddy-sand sediments (43.5 mg m^{-2}), followed by fine sand (15.6 mg m^{-2}), and the lowest values were for coarse (11.3 mg m^{-2}) and medium (10.1 mg m^{-2}) sands. By shoal, mean microphytobenthic chlorophyll *a* levels were highest at CSII and lowest at CII-BA for all sediment types (Table 8-5).

8.4 Discussion

The importance of microphytobenthic algae in the Cape Canaveral shelf is illustrated by a comparison of chlorophyll *a* levels in the water column versus the surface sediments (top 1 cm). The mean chlorophyll *a* levels in the water column in this study was 1.2 µg L^{-1}, which equates to 12 mg m^{-2} at a water-column depth of 10 m. The mean concentration of chlorophyll *a* observed in the top 1 cm of surface sediments was 9 mg m^{-2} for ridge sites and 20 mg m^{-2} for swale sites. The similarity of the chlorophyll *a* values for the water-column microphytobenthos highlight the need to incorporate the latter group in overall considerations of primary production and carbon availability in the Cape Canaveral shelf, as pointed out by other researchers of coastal ecosystems (MacIntyre et al. 1996; Underwood 2001; Hope et al. 2020). The range of microphytobenthic chlorophyll *a* levels observed in this study (i.e., 1–202 mg m^{-2}) were in line with the range of values observed in other shallow ecosystems on the East and Gulf Coasts of the United States, such as Long Island Sound, New York (i.e., 2–225 mg m^{-2}) (Sun et al. 1994); Delaware Estuary, Delaware (79–166 mg m^{-2}) (Sullivan and Daiber 1975); Chesapeake Bay, Maryland (i.e., 5–65 mg m^{-2}) (Rizzo and Wetzel 1985); San Antonio Bay, Texas (i.e., Macintyre and Cullen 1996), and Mobile Bay, Alabama (i.e., 2–42 mg m^{-2}) (Deleon et al. 2019).

Spatial and temporal differences in microphytobenthos chlorophyll *a* concentrations were observed in this study. The highest mean chlorophyll *a* concentrations were observed at CSII Shoal (followed by Bull

Shoal), and the lowest concentrations were at Chester and CSII-BA Shoals. The differences may be related to differences in mean chlorophyll *a* concentrations associated with the four major sediment types. Mud/sand type sediment had higher mean chlorophyll *a* concentrations than fine, medium, or coarse sand types. A number of studies of microphytobenthos chlorophyll *a* concentrations in other ecosystems have observed differences in concentrations between sediment types (Underwood 2001; Janousek 2009; Deleon et al. 2019; Morelle et al. 2020). For example, a study of the Seine River estuary in France similarly showed higher average microphytobenthos chlorophyll *a* concentrations in muddy than sand sediments (Morelle et al. 2020).

From a temporal perspective, microphytobenthos chlorophyll *a* concentrations were highest in the summer at all four shoals, although the seasonal differences were not significant at CSII Shoal. Many studies of microphytobenthos chlorophyll *a* concentrations in other ecosystems have reported seasonal differences in concentrations (Colijn and de Jonge 1984; Macintyre and Cullen 1996; Morelle et al. 2020), most often with peaks in the summer. For example, microphytobenthos chlorophyll *a* concentrations at six sites in the Ems-Dollard estuary in the Netherlands peaked in summer (Colijn and de Jonge 1984). It was likely that the seasonal trend in microphytobenthos chlorophyll *a* concentrations in the Cape Canaveral shelf was at least in part due to higher incident irradiance levels and lower light attenuation in the water column during the summer.

A comparison of microphytobenthos chlorophyll *a* concentrations in the pre- to post-dredge sediment samples showed no major shifts in concentrations, and patterns observed for the post-dredge period were generally similar at all four shoals. The exceptions were the observation of peaks at swale sites in the winter of 2014 at Bull Shoal and in the spring 2014 sampling at CSII Shoal (both non-dredged shoals).

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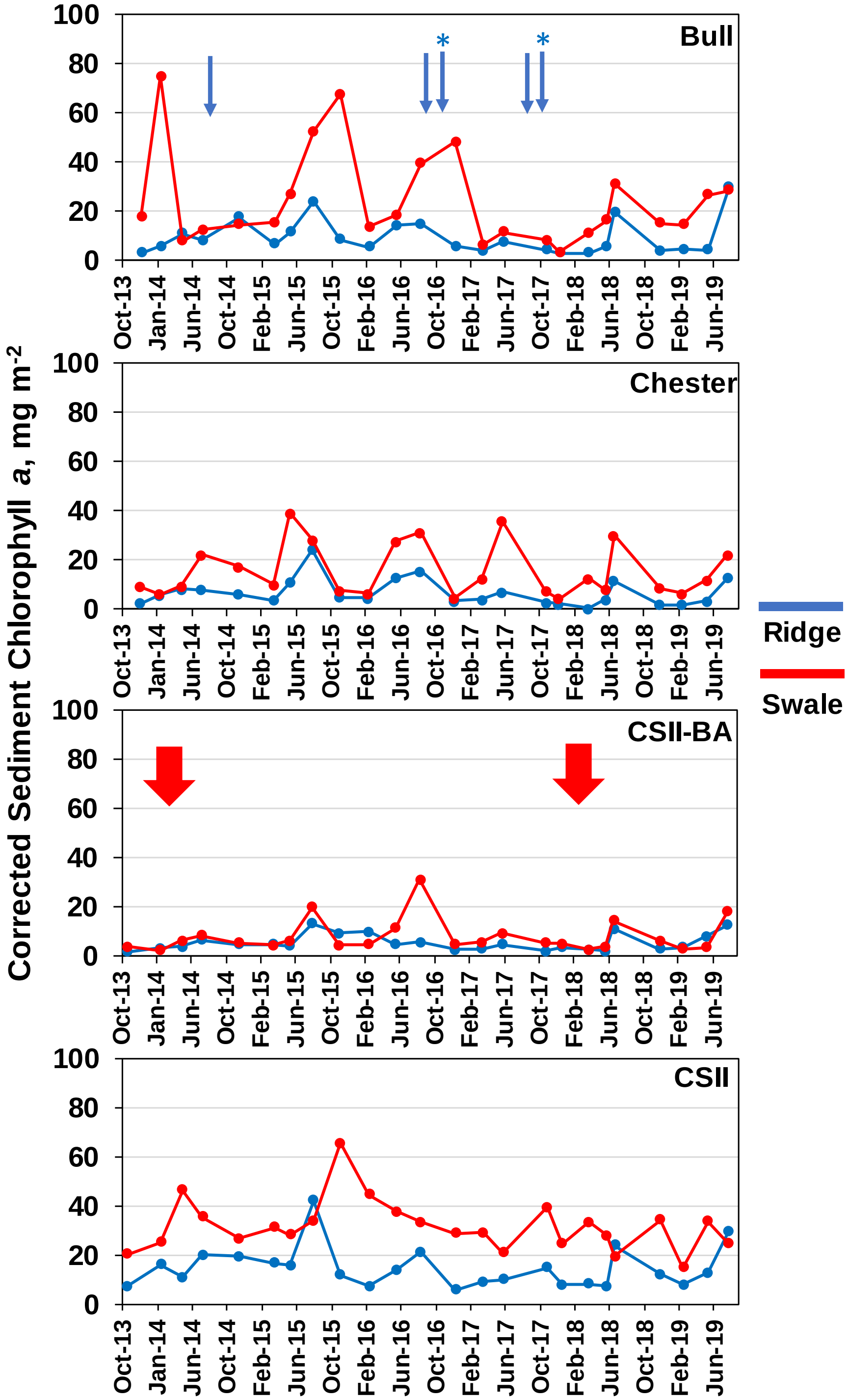

Figure 8-1. Mean surface sediment (i.e., top 1 cm) corrected chlorophyll *a* (mg carbon m^{-2}) in the four shoals of the study.

Red arrows mark the two periods of dredging activity at CSII-BA. Blue arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denotes Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

Table 8-1. Comparison of mean sediment surface corrected chlorophyll *a* concentrations (mg m^{-2}) for ridge and swale habitats for the four shoals.

Mean values which are not significantly different ($P > 0.05$) share the same letter value. Capital letters are used for the comparison between ridge and swale means within each shoal, and lowercase letters are used to compare means among shoals.

Habitat	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Ridge	9.2 B	5.2 B	5.2 B	14.6 B
"	b	c	c	a
Swale	23.9 A	15.8 A	7.9 A	31.7 A
"	b	c	d	a

Table 8-2. Comparison of mean sediment surface biomass concentrations (g carbon m^{-2}) for ridge and swale habitats for the four shoals.

Mean values which are not significantly different ($P > 0.05$) share the same letter value. Capital letters are used for the comparison between ridge and swale means within each shoal, and lowercase letters are used to compare means among shoals.

Habitat	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Ridge	0.37 B	0.21 B	0.21 B	0.58 B
"	b	c	c	a
Swale	0.96 A	0.63 A	0.32 A	1.27 A
"	b	c	d	a

Table 8-3. Seasonal comparison of mean sediment surface corrected chlorophyll *a* (mg m^{-2}) in the four shoals of the study.

Mean values which are not significantly different ($P > 0.05$) share the same letter value. Capital letters are used for the comparison among seasonal means within each shoal, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	21.3 AB	6.8 B	4.5 B	25.7 A
"	a	b	b	a
Winter	15.2 B	7.1 B	3.9 B	23.9 A
"	b	c	c	a
Spring	15.0 B	17.1 A	5.9 B	25.4 A
"	b	b	c	a
Summer	24.9 A	19.9 A	13.5 A	28.9 A
"	a	b	c	a

Table 8-4. Comparison of annual mean sediment surface corrected chlorophyll *a* (mg m^{-2}) for the four shoals of the study.

Mean values which are not significantly different ($P > 0.05$) share the same letter value. Capital letters are used for the comparison among annual means within each region, and lowercase letters are used to compare means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	18.9 ABC	9.8 B	4.5 D	25.6 B
"	b	c	c	a
2	23.3 AB	19.6 A	8.1 B	27.6 B
"	ab	b	c	a
3	27.7 A	14.5 AB	10.9 A	34.6 A
"	a	b	b	a
4	14.3 BC	11.3 B	5.0 DC	22.9 B
"	b	bc	c	a
5	12.9 C	10.4 B	5.8 BCD	21.3 B
"	b	bc	c	a
6	17.8 BC	9.7 B	7.5 BC	23.9 B
"	b	c	c	a

Table 8-5. Mean sediment surface corrected chlorophyll *a* and pheophytin concentrations (mg m^{-2}) in samples of different sediment composition, i.e., coarse sand, medium sand, fine sand, and muddy-sand sediment.

Mean values for sediment types within each shoal that were not significantly different ($P > 0.05$) share the same letter value.

Sediment	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Coarse Sand	10.7 B	13.8 B	5.1 A	18.2 B
Medium Sand	11.2 B	8.8 B	6.9 A	18.3 B
Fine Sand	17.1 B	13.9 B	10.4 A	19.9 B
Muddy Sand	57.8 A	37.2 A	4.0 A	40.9 A

9 Zooplankton

Ed Phlips, Susan Badylak, Leslie Landauer, Anne West-Valle, and Benjamin Stelling

Key Points

- The two most important zooplankton groups in terms of biomass (mg carbon L^{-1}) throughout the study period and shoals were arthropods and protozoans.
- The high biomass levels of small-sized ciliates highlights the important role the microbial loop plays in food webs of the Cape Canaveral shelf.
- In terms of the influence of dredging activity on the zooplankton community, no major differences in trends in biomass or composition among the four shoals were observed in post-dredge seasons (i.e., spring and summer of 2014 and 2018) compared to similar seasons in other years, suggesting that any impacts of dredging were relatively short-lived.

9.1 Introduction

Zooplankton are critical links in marine food webs that connect planktonic primary producers to higher level consumers. In this chapter, we focus on nano- (i.e., 5–20 μ size class), micro- (i.e., 20–200 μ), and smaller mesozooplankton (200–1000 μ) components of the zooplankton community. This group includes elements of the microbial loop (Pomeroy et al. 2007; Fenchel 2008), which are known to play a large role in food web structure and function in many oligotrophic coastal ocean environments (Calbet 2008; Glibert and Mitra 2022), including the Cape Canaveral shelf. For example, ciliates, which are mostly less than 100 μ in size, are numerically the dominant zooplankton group on the shelf, and are major consumers of picoplanktonic cyanobacteria and bacterioplankton. Zooplankton was included in this study to examine possible impacts of disruptions of the benthic filter-feeding community associated with dredging within the context of overall top-down pressures on plankton abundance, since benthic filter-feeders consume both phytoplankton and zooplankton.

Our primary objective was to compare the abundance and composition of zooplankton among shoals, years, and seasons. In addition, the abundance and composition was specifically compared within and outside of years subject to dredging.

9.2 Methods

Zooplankton water samples were collected concomitantly with water samples for phytoplankton analysis, as outlined in Chapter 7. In summary, water samples were collected at stratified-random sites within ridge and swale habitats of reference/control shoals (CSII, Bull, and Chester Shoals) and the dredged shoal (CSII-BA Shoal) from fall 2013 to summer 2019. Each shoal was sampled at six sites each on a seasonal basis. Details of the study shoals and sampling site selections are given in Chapter 1. In addition, nighttime sampling was done on CSII-BA, CSII, and Chester Shoals in the winter and summer of 2014 and 2015. The nighttime sampling of each shoal was completed within the same week as the daytime sampling of the shoals.

Zooplankton analysis was carried out in accordance with previously defined methods (Harris et al. 2000; Badylak and Phlips 2008). At each sampling site, water was collected at the surface and bottom of the water column using a 3-m vertical, water-column integrating pole and a Niskin bottle, respectively. These water samples were preserved in the field with Lugol's. Aliquots of 10 L of the Lugol's-preserved sample water were filtered through a 41µ pore size mesh filter. Zooplankton on the filter were rinsed into a scintillation vial and adjusted to a final volume of 20 ml. Zooplankton were then counted using the Utermöhl method (Utermöhl 1958). Cylindrical chambers with a 19-mm inner diameter were used to settle aliquots of samples. Settling time was a minimum of 4 hours. Zooplankton (< 1,000 µ) were identified and counted at 100X magnification with a Leica phase-contrast inverted microscope. A minimum of 3 ml was counted. If 100 individuals of a single taxon were not reached after 3 ml were counted, then counting continued until 100 individuals of a single taxon were reached, or the entire 20 ml aliquot was counted, whichever came first. For the purpose of presentation, zooplankton were categorized into three broad groups, protozoans (e.g., ciliates), arthropods (e.g., copepods, crustacean nauplii), and other taxa (e.g., cnidarians, mollusk, and echinoderm larvae). Small-celled protozoans (i.e., < 41 µ) (e.g., *Myrionecta rubra*) were enumerated during the phytoplankton counts (Chapter 7) and then added to the total zooplankton counts. A collection of peer-reviewed journal literature, and several reference texts (e.g., Smith and Johnson 1996; Lee et al. 2000; Young et al. 2002; Johnson and Allen 2012; Dolan et al. 2013) were used to aid in identification of taxa.

Biovolumes of zooplankton were estimated by assigning combinations of geometric shapes and dimensional measurements to fit the characteristics of individual taxa (Postel et al. 2000). Specific dimensions were measured for at least 30 randomly selected cells. Species which vary substantially in size were placed into size categories. Zooplankton carbon values (as µg carbon L^{-1}) were estimated by using conversion factors for different taxonomic groups applied to biovolume estimates (expressed as 10^6 μm^3 ml^{-1}): i.e., 0.099 x biovolume of arthropods, 0.19 x biovolume of protozoans, and 0.052 x biovolume of other taxa, except cnidarians (0.005 x biovolume) and *Sagitta* (0.036 x biovolume) (Putt and Stoecker 1989; Postel et al. 2000; Kiørboe 2013).

The core descriptions of total biomass trends include all zooplankton taxa within the nanoplankton (< 20 µ), microplankton (20–200 µ), and lower mesoplankton (200–1,000 µ) size ranges, plus all copepods. All other taxa larger than 1,000 µ were not included in the biomass comparison analyses, since it was determined that the method of collection was not appropriate for quantitative comparisons of these larger taxa.

Differences in mean biomass values were tested among shoals, between ridge versus swale habitats, surface- versus bottom-water samples, and among seasons and years using Duncan Multiple Range Tests ($P \leq 0.05$). For these comparisons, only daytime sampling events were used to ensure a balanced sample size. Day versus night zooplankton abundance was also compared between winter and summer seasons in 2014 and 2015 using Duncan Multiple Range Tests ($P \leq 0.05$). All analyses were done using statistical packages in SAS® (SAS Institute 2012).

9.3 Results

9.3.1 Zooplankton Biomass

Total mean zooplankton biomass (i.e., µg carbon L^{-1}) for surface-water samples ranged from 0.005 to 0.11 mg carbon L^{-1} (Figure 9-1). For the study period (2013–2019), mean surface zooplankton biomass levels were similar for all four shoals, with only a minor but statistically lower abundance on Bull Shoal compared to both CSII and CSII-BA, with Chester Shoal not different than any of the shoals (Table 9-1). A comparison of total mean surface biomass levels at ridge and swale habitats at the four shoals showed no significant differences (all $P > 0.05$), with an overall mean value of 0.03.

Seasonal patterns of mean surface biomass concentrations over the study period were similar for all four shoals (Table 9-2). The highest mean biomass values in all four shoals over the study period were in the fall, followed by the winter, and the lowest levels were in the spring and summer. Interannual patterns of mean surface-water biomass were similar for all four shoals of the study (Table 9-3). The highest annual mean values were in Year 5 of the study at all shoals. Comparisons of night and day sampling events showed a pattern of higher surface biomass means in night compared to day samples, primarily due to differences in arthropod biomass (Figure 9-2).

In terms of the post-dredge period events (i.e., spring and summer) of 2014 and 2018, no apparent major differences were observed among shoals in the trends of mean surface-water zooplankton biomass, including the dredged region (CSII-BA) (Figure 9-1). Both years showed declines in biomass means in the post-dredge period at all four shoals.

Mean bottom-water zooplankton biomass levels over the study period were higher than surface-water means at all four shoals of the study (Table 9-1). Mean bottom-water zooplankton biomass levels ranged from 0.01 mg carbon L^{-1} to 0.18 mg carbon L^{-1} (Figure 9-3). A comparison of total mean bottom-water biomass levels at ridge and swale habitats at the four shoals showed some differences at CSII and CSII-BA (Table 9-4). Small differences among shoals, with modestly lower mean values for Bull and Chester Shoals compared to CSII-BA and CSII.

A comparison of seasonal mean bottom-water zooplankton biomass levels over the study period showed no significant differences in Chester Shoal and CSII (Table 9-5). At Bull and CSII-BA Shoals the mean biomass levels were highest in the summer. Interannual patterns of mean bottom-water zooplankton biomass showed only minor shoalspecific differences and were similar in all four shoals of the study (Table 9-6). At Bull and CSII-BA Shoals, Year 1 means were lower than Years 2–5. At Chester Shoal, Years 2, 3 and 5 had the highest mean values, while at CSII Year 2 had a higher mean value than the other 4 years. Day-night comparison for bottom-water were less distinct or consistent than for surface samples (Figure 9-4). The only major difference was in the 2015 winter sampling events, when day values were higher than night values.

In terms of the post-dredge period events (i.e., spring and summer) of 2014 and 2018, no apparent major differences were observed among shoals in the trends of mean bottom-water zooplankton biomass values, including the dredged region (CSII-BA) (Figure 9-3). In 2014, all shoals had declines in mean values in the post-dredge period, while in 2018 all shoals had increases in mean values.

9.3.2 Zooplankton Composition

The two most important zooplankton groups in terms of biomass (mg carbon L^{-1}) throughout the study period and shoals were arthropods and protozoans (Figures 9-1 and 9-3). For the entire study period, mean arthropod biomass was approximately twice as high as protozoan biomass, and ten times higher than all 'other' taxa (Table 9-7). Mean biomass values were higher in bottom than surface-water samples (Table 9-7). Similar patterns were observed for the three major groups (i.e., protozoans, arthropods, and 'other' taxa) in all four shoals of the study (Table 9-8). In terms of comparisons between day and night samplings, surface-water samples frequently had higher zooplankton biomass during the night due to higher levels of arthropods (Figure 9-2). In the case of bottom-water samples, major differences were only observed in 2015, during which daytime values were higher than night values, again due to differences in arthropod biomass (Figure 9-4).

Seasonal patterns of mean surface-water biomass for the three major zooplankton groups (Table 9-9) were similar to the observations for total zooplankton biomass (Table 9-2). Mean values were highest in the fall (followed by winter) and lowest in the spring and summer. Seasonal patterns for bottom-water samples were not as clear-cut (Table 9-10). For protozoans, mean biomass was lower in the spring than the other three seasons, while for arthropods the summer season was higher than the other three seasons. For all 'other' taxa, winter had lower mean biomass than the other three seasons.

In terms of taxa within the major groupings, copepods were the dominant taxa within the Arthropoda, as reflected by the composition of the Top-500 list of individual observations based on carbon biomass for both surface-water and bottom-water samples (Tables 9-11 and 9-12, respectively).

Ciliate species (Protozoa, Phylum Ciliophora) dominated the Top-500 list, reflecting their importance to overall zooplankton biomass (Tables 9-11 and 9-12). All protozoans in the Top-500 lists were ciliates. The dominant taxa within the ciliates were small-sized species (i.e., < 50 µ).

9.4 Discussion

The microzooplankton/small mesozooplankton community of the shoals was dominated by protists in terms of numerical abundance. Even in terms of biomass (i.e., carbon equivalence) protozoans represented an average of 35% of total zooplankton biomass. Within the protozoa, ciliates were always the dominant group, and small-sized taxa (i.e., < 40 µ) were on average equal or higher in biomass than larger ciliate taxa. The high biomass levels of small-sized ciliates highlights the important role the microbial loop plays in food webs of the Cape Canaveral shelf. Small ciliates play a major role in grazing activity on pico- and nano-planktonic phytoplankton and bacterioplankton, making them an important component of the microbial loop (Pierce and Turner 1992; Calbet 2008; Fenchel 2008; Flynn et al. 2019). Many ciliate species are also capable of retaining the phytoplankton they consume, taking advantage of the photosynthetic activity of the incorporated cells (i.e., sometimes referred to as kleptoplasty, a form of symbiosis). In this sense, these ciliate species are functionally both primary producers and secondary consumers (Stoecker et al. 1987; McManus et al. 2012; Flynn et al. 2019).

The importance of the microbial loop is also indicated by two features of the phytoplankton community, i.e., the major role played by picoplanktonic cyanobacteria and the strong representation of mixotrophic and heterotrophic dinoflagellates (Chapter 7). It is well documented that the microbial loop is an important component in many ocean environments that strongly influences carbon, nutrient and energy transfer to higher trophic levels (Flynn et al. 2019; Glibert and Mitra 2022). The other major zooplankton group observed in the Cape Canaveral shelf in terms of average biomass was Arthropoda, principally copepods. The most frequent copepod contributors to the Top-500 fell within the mesozooplankton size category (i.e., > 200 µ). The latter observation conforms to the observation that copepods are often the numerically most abundant mesozooplankton taxa (Paffenhöfer 1983; Schminke 2006).

The seasonal pattern for mean total zooplankton biomass followed the same general pattern observed for phytoplankton biomass (Table 7-6), largely based on trophic relationships observed in most marine ecosystems (Valiela 1984). It is important to keep in mind that surface zooplankton composition and abundance in the hydrologically dynamic environment of the Cape Canaveral shelf region are strongly influenced by the constant introduction and rapid passage of external water masses. The origins of these water masses depend on wind and circulation patterns (Stelling et al. 2023). For example, persistent northerly winds can bring in water from along the eastern coast of Florida north of the Cape, while the opposite wind direction can bring in water masses from south of the Cape (Chapter 2; AlYousif et al. 2021). In addition, eddies from the nearby Gulf Stream can bring in water masses of Caribbean and Gulf of Mexico origins (Atkinson 1977). The relatively minor seasonal differences in bottom-water zooplankton biomass, compared to surface samples, likely reflects the importance of resuspension of zooplankton from the surface of sediments.

In terms of the influence of dredging activity on the zooplankton community, no major differences were observed in post-dredge (i.e., spring and summer 2014 and 2018) trends in biomass or composition among the four shoals, suggesting that any impacts of dredging were relatively short-lived.

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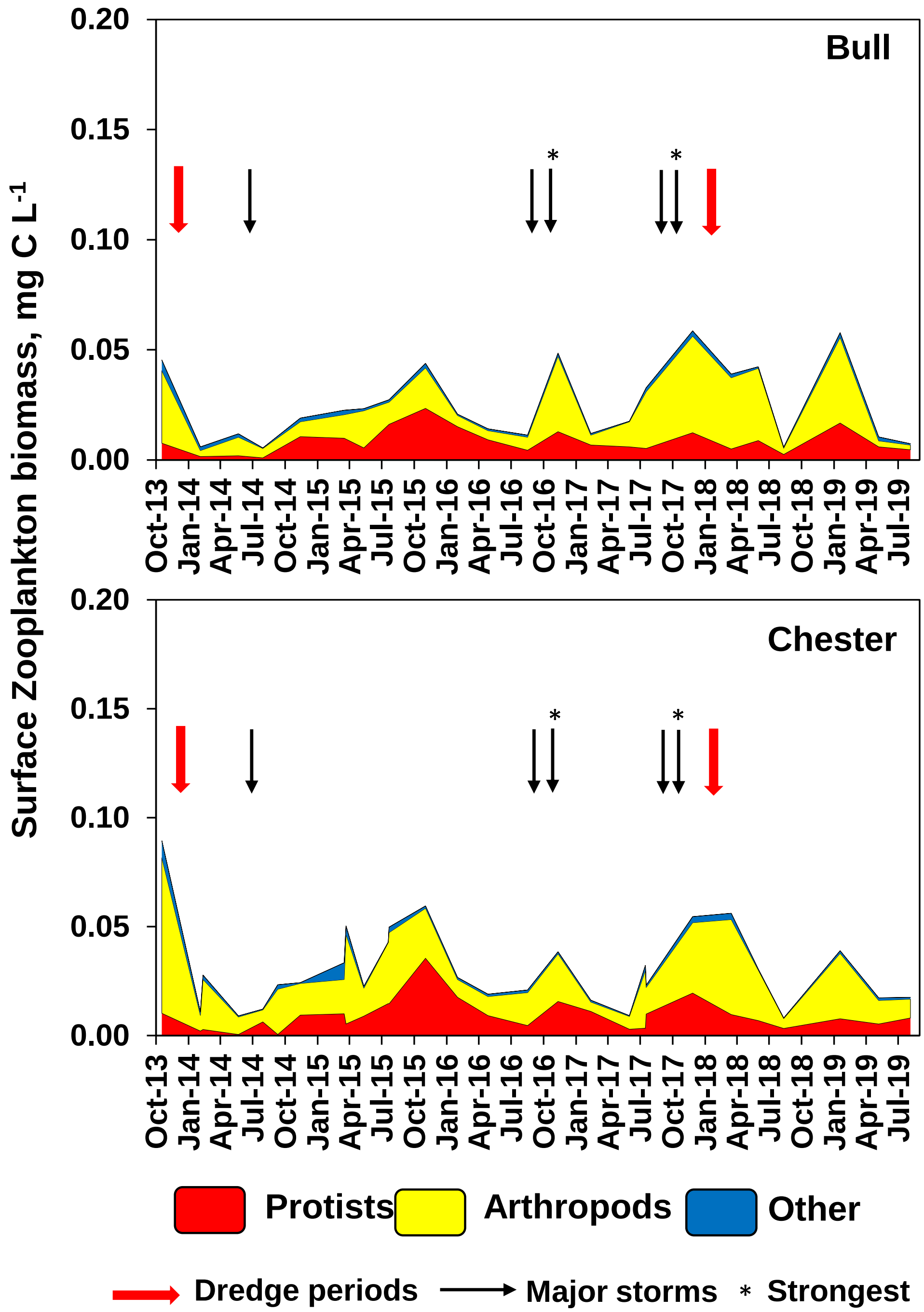

Figure 9-1. Mean surface-water zooplankton biomass (mg carbon L-1) at the four shoals over the study period.
Biomass was subdivided into three categories: protozoans (red), arthropods (yellow), and others (blue). Red arrows mark the two periods of dredging activity at CSII-BA. Black arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denotes Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

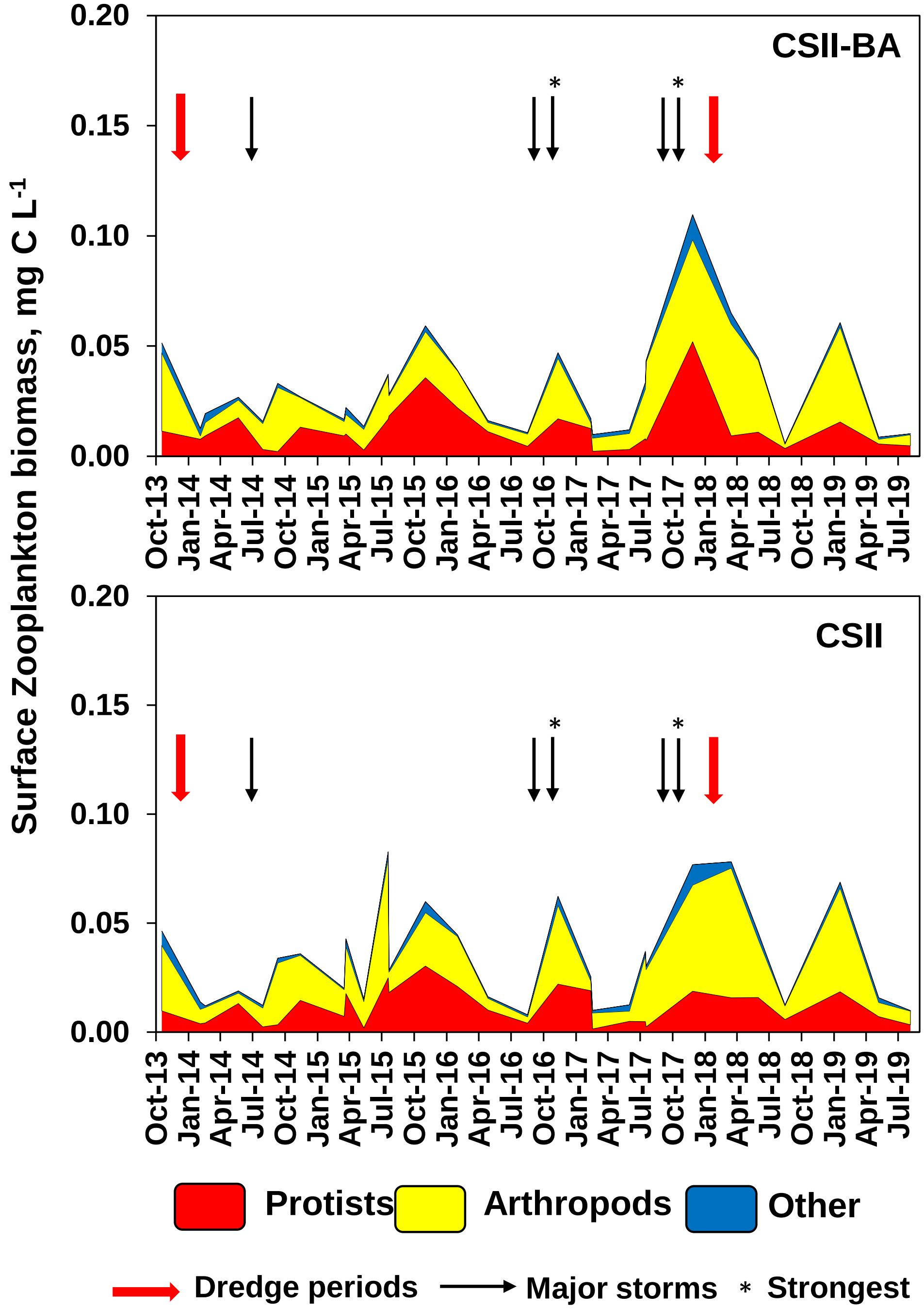

Figure 9-1 (Cont'd). Mean surface-water zooplankton biomass (mg carbon L-1) at the four shoals over the study period.

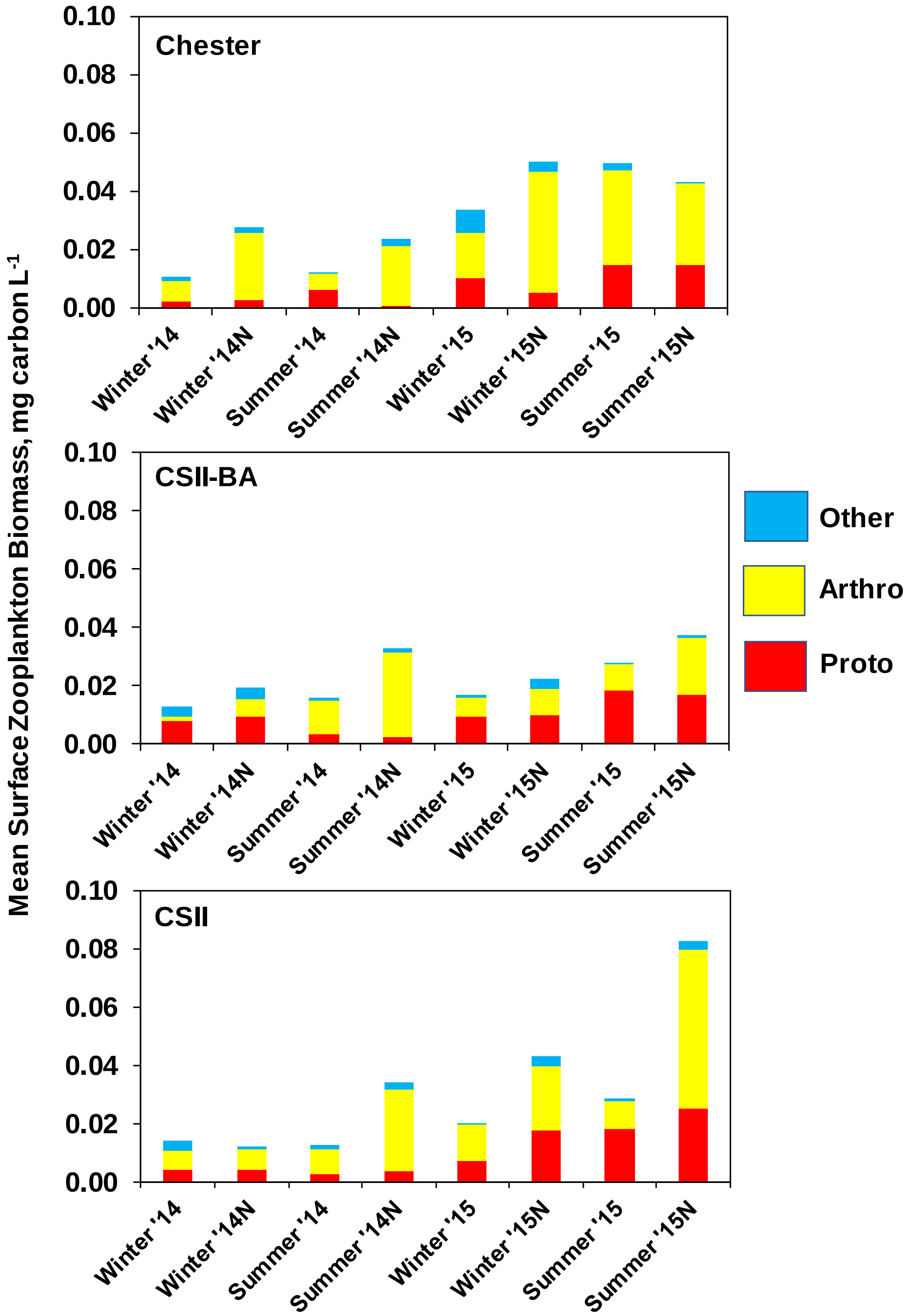

Figure 9-2. Comparison of day and night mean surface-water zooplankton biomass (mg carbon L^{-1}) at the four shoals.
Biomass was subdivided into three categories: protozoans (red), arthropods (yellow), and others (blue). 'N' in the Season-Year labels refers to night sampling events.

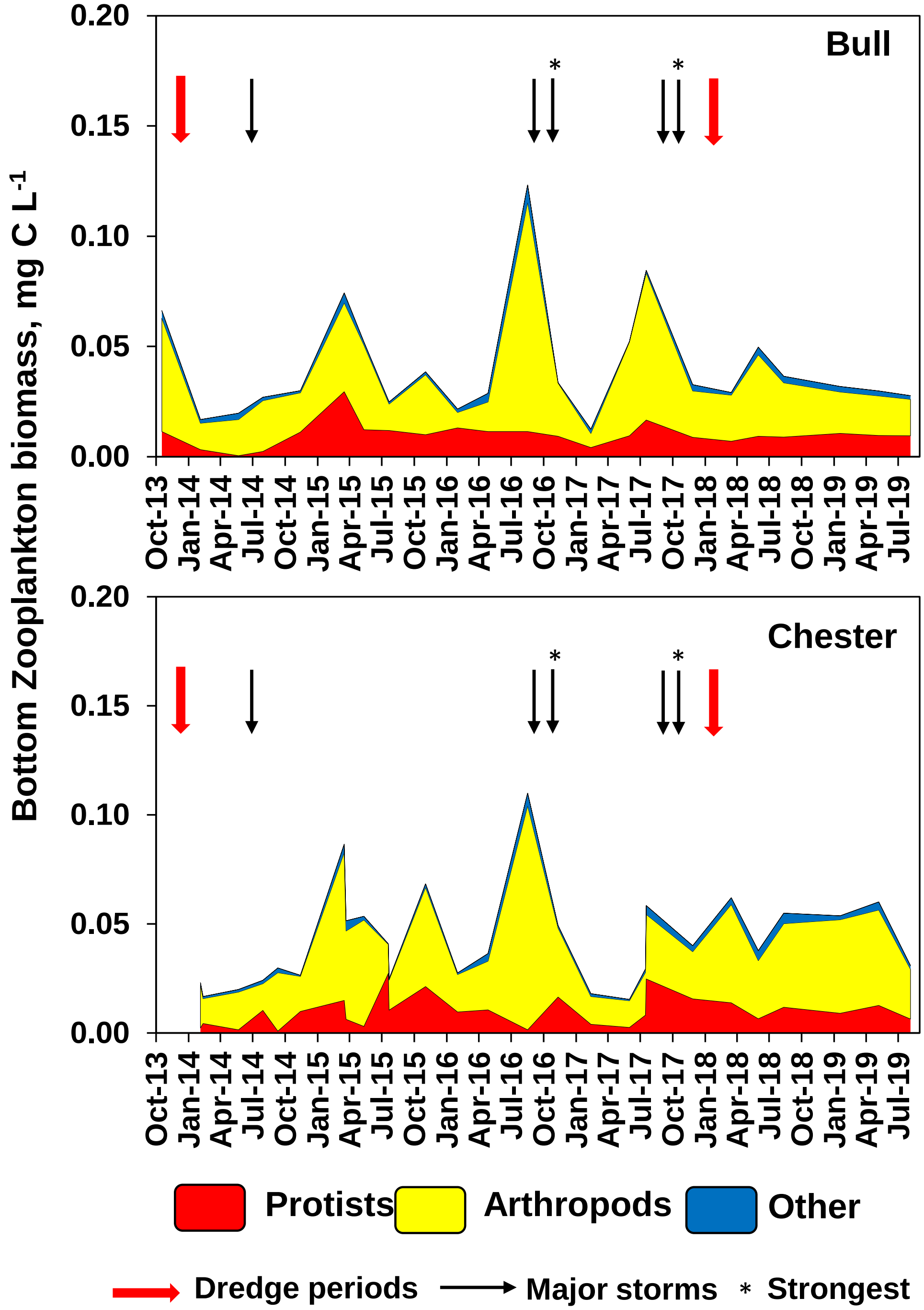

Figure 9-3. Mean bottom-water zooplankton biomass (mg carbon L-1) at the four shoals.
Biomass was subdivided into three categories: protozoans (red), arthropods (yellow), and others (blue). Red arrows mark the two periods of dredging activity at CSII-BA. Black arrows indicate the timing of hurricane events that impacted the Cape Canaveral area. * denotes Hurricanes Mathew (2016) and Irma (2017), which were major hurricanes impacting the area.

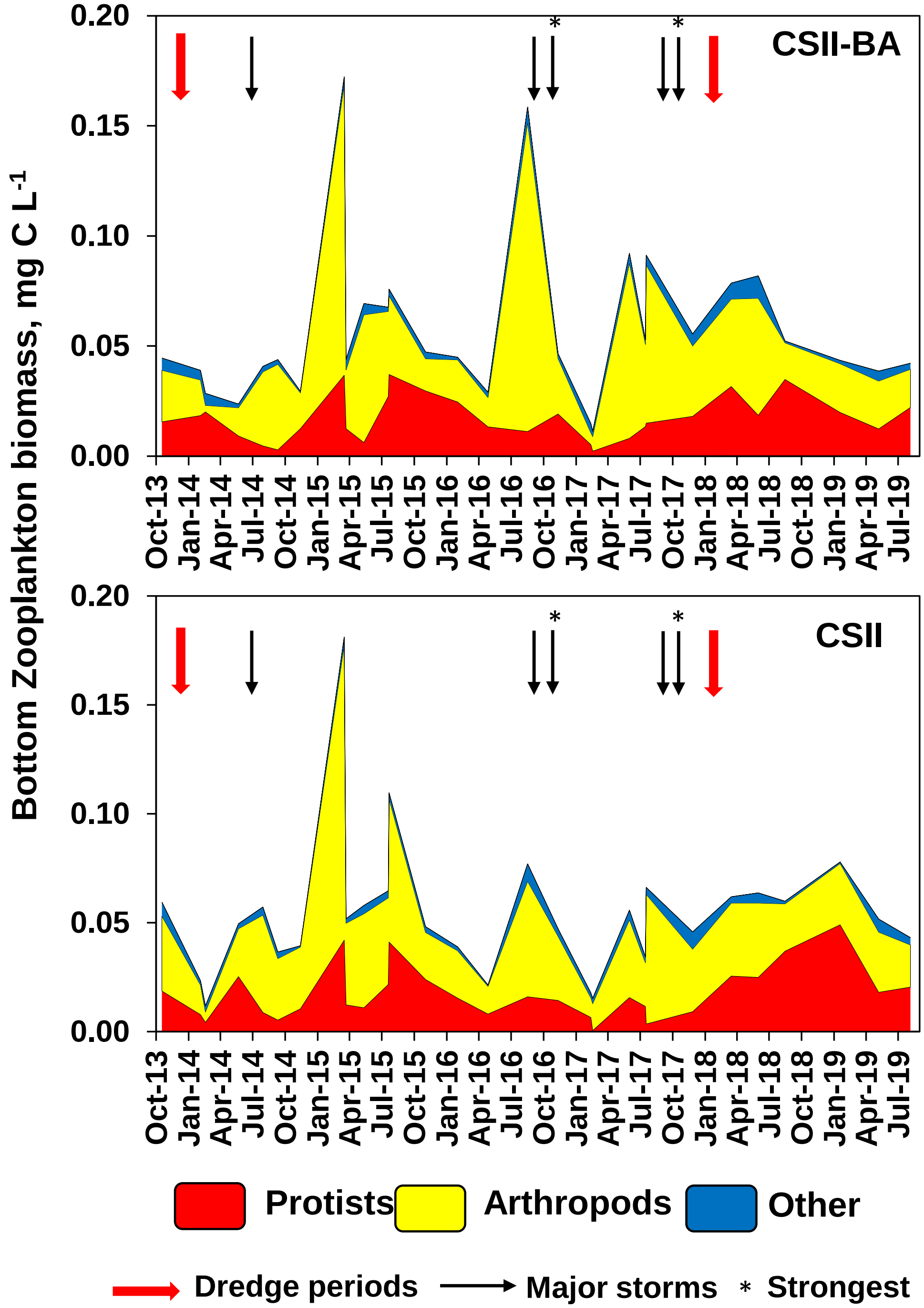

Figure 9-3 (Cont'd). Mean bottom-water zooplankton biomass (mg carbon L-1) at the four shoals.

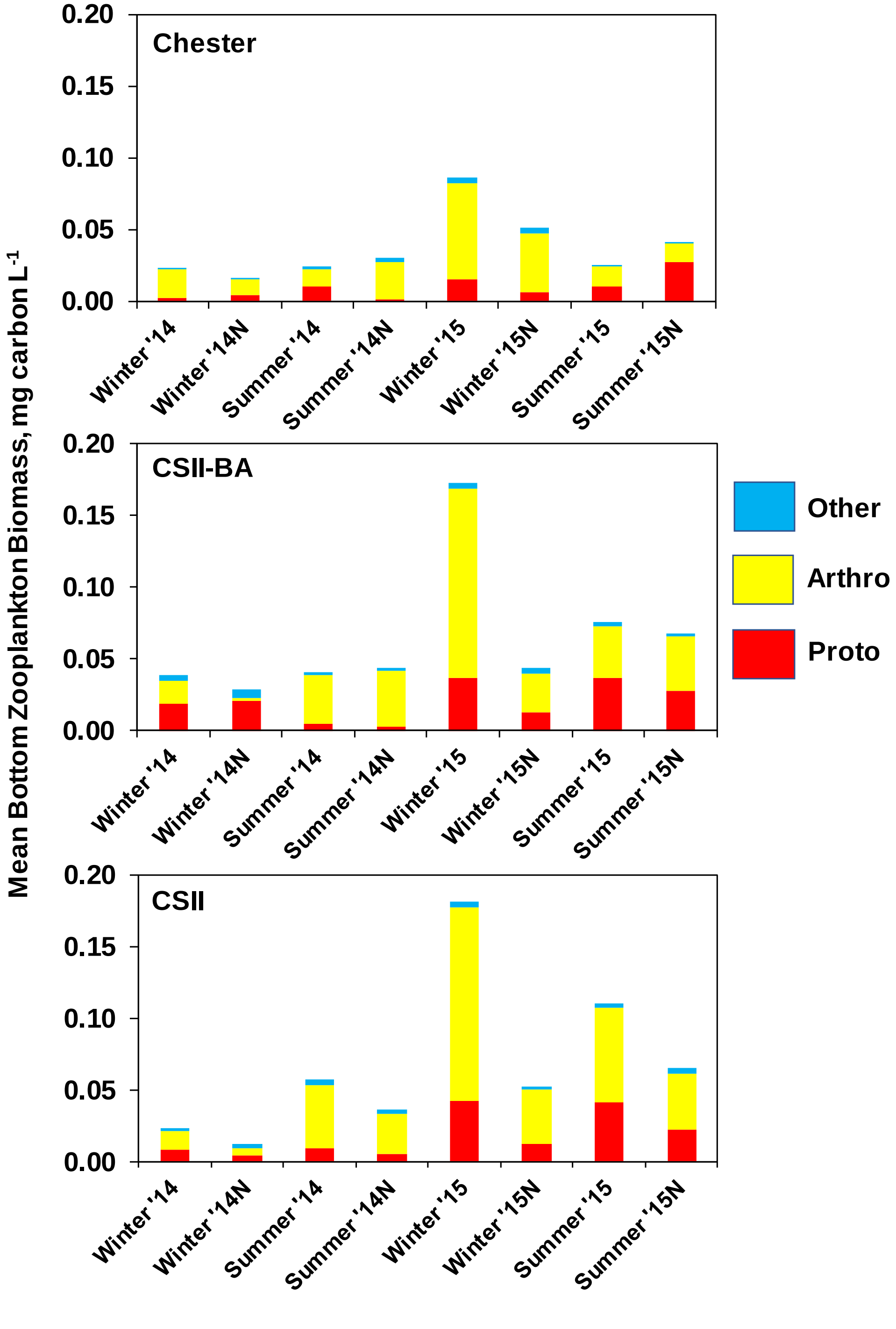

Figure 9-4. Comparison of day and night mean bottom-water zooplankton biomass (mg carbon L^{-1}) for the four shoals.
Biomass was subdivided into three categories: protozoans (red), arthropods (yellow), and others (blue). 'N' in the Season-Year labels refers to night sampling events.

Table 9-1. Comparison of mean total zooplankton biomass (mg carbon L^{-1}) for surface- and bottom-water samples at the four shoals of the study.

Mean values which were not significantly different ($P > 0.05$) share the same letter value. Capital letters are used for the comparison between surface and bottom means within each shoal, and lowercase letters are used to compare means among shoals.

Depth Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Surface	0.026 B	0.030 B	0.032 B	0.032 B
"	b	ab	a	a
Bottom	0.041 A	0.045 A	0.061 A	0.058 A
"	b	b	a	a

Table 9-2. Seasonal comparison of mean total zooplankton biomass (mg carbon L^{-1}) in surface-water samples for the four shoals of the study.

Mean values which are not significantly different ($P > 0.05$) share the same letter value. Capital letters are used for the comparison among seasonal means for each shoal, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	0.044 A	0.053 A	0.058 A	0.056 A
"	b	a	a	a
Winter	0.026 B	0.030 B	0.034 B	0.039 B
"	a	ab	ab	a
Spring	0.020 BC	0.018 C	0.020 C	0.020 C
"	a	a	a	a
Summer	0.015 C	0.022 BC	0.019 C	0.017 C
"	a	a	a	a

Table 9-3. Comparison of annual mean total zooplankton biomass (mg carbon L^{-1}) in surface-water samples for the four shoals of the study.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means within each region, and lowercase letters are used to compare means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	0.018 B	0.030 AB	0.027 B	0.023 B
"	a	a	a	a
2	0.023 B	0.033 AB	0.021 B	0.025 B
"	b	a	b	b
3	0.022 B	0.032 AB	0.031 B	0.032 B
"	b	a	a	a
4	0.028 AB	0.022 B	0.028 B	0.031 B
"	a	a	a	a
5	0.036 A	0.037 A	0.056 A	0.050 A
"	a	a	a	a

Table 9-4. Comparison of mean bottom-water total zooplankton biomass (mg carbon L-1) at ridge and swale habitats in the four shoals of the study.

Mean values which were not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between ridge and swale means within each shoal, and lowercase letters are used to compare means among shoals.

Habitat	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Ridge	0.045 A	0.041 A	0.067 A	0.050 B
"	b	b	a	ab
Swale	0.039 A	0.046 A	0.057 B	0.062 A
"	c	bc	ab	a

Table 9-5. Seasonal comparison of mean total zooplankton biomass (mg carbon L^{-1}) in bottom-water samples for the four shoals of the study.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among seasonal annual means within each region, and lowercase letters are used to compare means among shoals.

Season	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
Fall	0.040 AB	0.046 A	0.045 B	0.048 A
"	a	a	a	a
Winter	0.031 B	0.045 A	0.064 AB	0.066 A
"	b	ab	a	a
Spring	0.039 B	0.038 A	0.053 B	0.049 A
"	bc	c	a	ab
Summer	0.054 A	0.050 A	0.078 A	0.067 A
"	b	b	a	ab

Table 9-6. Comparison of annual mean total zooplankton biomass (mg carbon L^{-1}) in bottom-water samples for the four shoals of the study.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison among annual means within each region, and lowercase letters are used to compare means among shoals.

Year	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII Shoal
1	0.033 B	0.023 C	0.037 C	0.047 B
"	bc	c	ab	a
2	0.045 AB	0.047 AB	0.086 A	0.097 A
"	b	b	a	a
3	0.053 A	0.061 A	0.070 AB	0.046 B
"	a	a	a	a
4	0.045 AB	0.035 BC	0.057 ABC	0.044 B
"	ab	b	a	ab
5	0.037 AB	0.048 AB	0.067 ABC	0.058 B
"	c	b	a	ab

Table 9-7. Comparison of mean biomass (mg carbon L^{-1}) of three major zooplankton groups in surface-water and bottom-water samples over the entire study area.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between surface and bottom means for group, and lowe case letters are used to compare means among groups.

Depth Sampled	Protozoans	Arthropods	Other
Surface	0.011 B	0.017 B	0.002 B
"	b	a	c
Bottom	0.015 A	0.034 A	0.003 A
"	b	a	c

Table 9-8. Comparison of mean biomass (mg carbon L^{-1}) of three major zooplankton groups in surface-water and bottom-water samples by shoal.

Mean values which are not significantly different (P > 0.05) share the same letter value. Capital letters are used for the comparison between surface and bottom means within each shoal, and lowercase letters are used to compare means among shoals.

Group	Depth Sampled	Bull Shoal	Chester Shoal	CSII-BA Shoal	CSII
Protozoans	Surface	0.008 B	0.010 A	0.013 B	0.011 B
"	"	c	bc	a	ab
"	Bottom	0.010 A	0.010 A	0.018 A	0.019 A
"	"	b	b	a	a
Arthropods	Surface	0.016 B	0.018 B	0.017 B	0.018 B
"	"	a	a	a	a
"	Bottom	0.029 A	0.032 A	0.038 A	0.035 A
"	"	b	ab	a	ab
Other	Surface	0.001 B	0.001 B	0.002 B	0.002 B
"	"	b	b	a	a
"	Bottom	0.002 A	0.002 A	0.004 A	0.004 A
"	"	b	b	a	a

Table 9-9. Seasonal comparison of mean biomass (mg carbon L^{-1}) of three major zooplankton groups in surface-water samples over the entire study area.

Mean values which are not significantly different ($P > 0.05$) share the same letter value. Capital letters are used for the comparison among seasons for each group, and lowercase letters are used to compare means among groups.

Season	Protozoans	Arthropods	Other
Fall	0.019 A	0.030 A	0.004 A
"	b	a	c
Winter	0.011 B	0.019 B	0.002 B
"	b	a	c
Spring	0.007 C	0.011 C	0.001 C
"	b	a	c
Summer	0.007 C	0.011 C	0.001 C
"	b	a	c

Table 9-10. Seasonal comparison of mean zooplankton biomass (mg carbon L-1) of three major zooplankton groups in bottom-water samples over the entire study area.

Mean values which are not significantly different ($P > 0.05$) share the same letter value. Capital letters are used for the comparison among seasons for each group, and lowercase letters are used to compare means among groups.

Season	Protozoans	Arthropods	Other
Fall	0.015 A	0.027 B	0.003 AB
"	b	a	c
Winter	0.017 A	0.033 B	0.002 B
"	b	a	c
Spring	0.011 B	0.031 B	0.003 A
"	b	a	c
Summer	0.016 A	0.043 A	0.003 A
"	b	a	c

Table 9-11. Frequency of observation of zooplankton taxa in the Top-500 by biomass (mg carbon L^{-1}) and highest biomass and individual densities observed for each taxa for surface-water samples over the study period.

Group	Taxa	Frequency in Top-500	Highest Biomass (mg carbon L^{-1})	Highest Density (Individuals L^{-1})
Protozoa	Ciliate spp. 20-40 µ	85	0.073	22,900
"	Ciliate spp. <20 µ	33	0.017	49,500
"	*Tontonia* sp.	13	0.018	796
"	Tintinnid spp.	7	0.013	22,500
"	*Myrionecta rubra*	6	0.009	36,400
"	*Stenosomella* sp.	6	0.013	1,102
"	*Codonellopsis* sp.	5	0.019	418
"	*Tintinnopsis* sp.	5	0.016	1,394
"	*Wangiella* sp.	4	0.010	847
"	Ciliate spp. >40 µ	1	0.009	4
"	*Tintinnidium* sp.	1	0.008	178
Arthropoda	Calanoid copepod spp. >700 µ	19	0.662	84
"	Calanoid copepod spp. <700 µ	72	0.061	112
"	*Penilia avirostris*	27	0.048	14
"	Cyclopoid copepod spp.	11	0.014	59
"	Ostracod spp.	9	0.025	29
"	Crab zoea <1,000 µ	7	0.012	3
"	Crustacean nauplii	6	0.027	246
"	Harpacticoid copepod spp.	4	0.015	15
Other Taxa	Actinotroch sp.	2	0.011	8
"	Oikopleura spp.	2	0.019	23
"	*Polygordius* larvae	1	0.010	6
"	Trochophore larvae	1	0.008	113
"	Pluteus larvae 299-449 µ	1	0.011	31

Table 9-12. Frequency of observation of zooplankton taxa in the Top-500 by biomass (mg carbon L^{-1}) and highest biomass and individual densities observed for each taxa for bottom-water samples over the study period.

Group	Taxa	Frequency in Top-500	Highest Biomass (mg carbon L^{-1})	Highest Density (Individuals L^{-1})
Protozoa	Ciliate spp. 20-40 µ	69	0.056	32,400
"	*Stenosomella* sp.	34	0.071	6,229
"	Ciliate spp. <20 µ	30	0.025	74,200
"	*Codonellopsis* sp.	11	0.029	636
"	*Myrionecta rubra*	7	0.014	54,600
"	*Tontonia* sp.	7	0.021	930
"	*Tintinnidium* sp.	5	0.025	540
"	Tintinnid spp.	4	0.022	36,400
"	*Wangiella* sp.	4	0.012	1,093
"	*Carchesium* sp.	2	0.015	19,062
"	Ciliate spp. >40 µ	1	0.026	162
"	*Strombidinopsis* sp.	1	0.050	2,197
Arthropoda	Calanoid copepod spp. >700 µ	110	0.192	32
"	Calanoid copepod spp. <700 µ	97	0.162	479
"	*Penilia avirostris*	72	0.279	84
"	Cyclopoid copepod spp.	23	0.072	441
"	Ostracod spp.	7	0.022	25
"	Crustacean nauplii	6	0.026	1,055
"	Barnacle cyprid	1	0.013	15
"	Cladoceran sp.	1	0.027	18
"	Crab zoea <1,000 µ	1	0.012	3
"	*Evadne* sp.	1	0.019	10
Other Taxa	Harpacticoid copepod spp.	1	0.012	5
"	Oikopleura spp.	2	0.015	21
"	Actinotroch sp.	1	0.010	7
"	Lancelet sp.	1	0.012	10
"	Molluscan trochophore	1	0.014	119

10 Meroplankton

Patrick Baker, Colin Frank, and Ed Phlips

Key Points

- Meroplankton over the sand shoals off the east coast of Florida was dominated by bivalve and polychaete larvae.
- Overall, there were significant differences in meroplankton among seasons and habitat (ridge versus swale) but not shoals, therefore none of the differences could be attributed to dredging impacts.
- Season had the strongest impact, affecting all functional groups of meroplankton except molluscan larvae, while habitat showed the opposite, affecting only molluscan larvae.
- Echinoderm and polychaete larvae showed limited shoal effects but were not different between the dredged shoal (CSII-BA) and the non-dredged shoal (CSII).
- Lack of any dredging impacts on meroplankton were consistent with prior research on zooplankton overall showing that effects of spoil removal were transient.

10.1 Introduction

Meroplankton are early planktonic life stages of animals that will grow or metamorphose to a non-planktonic existence, such as a benthic clam or a sea urchin. They comprise a functional class of zooplankton, distinct from holoplankton, which complete their entire life cycles as plankton. The majority of meroplankton are in the size range of mesozooplankton (i.e., 200–2,000 μ), but also include macrozooplankton (> 2,000 μ). Definitions of meroplankton have been reviewed by Harris et al. (2000), Nybakken and Bertness (2005), and Johnson and Allen (2012) but it is important to stress that these size ranges, while widely used (Harris et al. 2000; Johnson and Allen 2012), are necessarily artificial. Bivalve molluscan larvae, for example, range from well under 100 μ in diameter to over 300 μ, and thus span the micro-mesoplankton division (Chanley and Andrews 1971; Goodsell et al. 1992). Chapter 9 analyzed and discussed the abundance and composition of zooplankton ranging from nanoplankton (< 40 μ) to lower-end mesoplankton (i.e., < 1,000 μ), in which the vast majority are holoplanktonic and important primary consumers (e.g., copepods). Meroplankton analyzed in the current chapter are also important primary consumers in the food web but, as the disperal stage of benthic and demersal invertebrates, they are also inextricably linked to benthic invertebrate populations and ecosystems (Butman 1987).

Few studies have attempted to examine the effects of sand removal during dredging on open-ocean zooplankton (including meroplankton) communities, which are usually not endemic to a particular area, but drift with ocean currents past or through dredged sites (Sullivan and Hancock 1977). Physical factors associated with dredging, including turbidity, changes in dissolved oxygen, and pollutants, could potentially affect meroplankton. Turbidity is known to alter or negatively correlate with zooplanktonic distribution and behavior in lakes and estuaries (Sherk et al. 1976; Hart 1988; Roman et al. 2001; Lohrer and Wetz 2003; Dejen et al. 2004; David et al. 2005), and is known to suppress feeding by zooplankton in those ecosystems (Hart 1988; David et al. 2005), so it is reasonable to consider turbidity a factor for marine plankton as well. Turbidity usually increases during dredging but is generally short-lived, on the order of an hour or less (Windom and Stickney 1976; Sullivan and Hancock 1977; Hitchcock et al. 1999; Duclos et al. 2013; Fisher et al. 2015; Spearman 2015; Van Lancker and Baeye 2015). The focus of most studies is on the resultant deposition from the plume, with potential benthic impacts, rather than affecting the plankton. Impacts of dredging on dissolved oxygen levels in the water are variable; the strongest effects are visible in the deposition zone, not the removal zone (Windom and Stickney 1976; Lohrer and Wetz 2003). In addition, toxic pollutants in the sediments, if present, may be resuspended during dredging and have been shown to increase zooplankton mortality (DeCoursey and Vernberg 1975; Johnston 1981). Even within an estuary, however, the transient nature of the plankton itself means that water-column impacts from point-source dredging can dissipate in a single tidal cycle (Sullivan and Hancock 1977). It could therefore be expected that the effects may be even more short-lived in an open coastal environment and difficult to detect, especially against strong seasonal and interannual variations common to plankton communities (Benedetti et al. 2019; Giering et al. 2019).

10.1.1 Goals and Objectives

The goal of the meroplankton study was to describe and quantify the diversity and abundance of meroplankton among shoals, seasons, and between ridge versus swale habitats for CSII-BA (the dredged shoal) relative to CSII, Bull, and Chester Shoals (the references shoals). Specific objectives included:

1. Identify and numerically quantify meroplankton to the lowest feasible taxonomic level, across study shoals and seasons.
2. Develop estimates of species (form) richness and numerical abundance of functional groups of meroplankton (as defined in Table 10-1).
3. Compare meroplankton species (form) richness and functional group abundance:
    a. spatially among the dredged shoal (CSII-BA) and undredged (reference) shoals (CSII, Bull and Chester Shoals), and between ridge and swale habitats.
    b. temporally among seasons and years.
4. Determine whether there were discernable effects of dredging disturbance on meroplankton species richness or functional group abundance.

10.2 Methods

10.2.1 Site Description

Meroplankton samples were collected at the same sampling sites and times as water samples for phytoplankton (Chapter 7) and zooplankton (Chapter 9) (Figure 10-1). In summary, meroplankton was sampled at stratified-random sites within ridge and swale habitats of reference shoals (CSII, Bull, and Chester Shoals) and the dredged shoal (CSII-BA Shoal) from fall 2013 to summer 2017. Each shoal was sampled at six sites on a seasonal basis (2 and 4 sites in ridge versus swale habitat, respectively), for a total of 96 samples per year. Seasons were defined as winter (December through February), spring (March through May), summer (June through September), and fall (October and November). Details of the study shoals and sampling site selections are given in Chapter 1. One fall season of sampling was completed at the shoals prior to the first dredging event on CSII-BA, which occurred in winter 2013/14 to spring 2014. Meroplankton was analyzed over a subsequent 4-year period of time.

10.2.2 Meroplankton Samples

The WP2 (Wisconsin plankton net – type 2, designed for vertical tows) zooplankton net used in this study had an opening diameter of 0.5 m and a length of 2.0 m, with a mesh size of 104 μ (Harris et al. 2000). The net was manually lowered to the benthos at each sample location and then hauled straight up (vertical tow) one time per site, at an approximate rate of 1.0 $m \cdot s^{-1}$. The depth of the vertical tow was recorded to the nearest 0.1 m. Depth was measured during sampling, taking into account the hull of the vessel (0.5 m below the surface). A sprayer was used on the outside of the net to rinse plankton into the sample bucket, which was then transferred to a carboy containing Lugol's solution.

For the first 2 years of the study, samples were preserved in the field in 2 L of 2% acidic Lugol's solution, an iodine-based stain and preservative (Anderson and Karlson 2017). It was observed, however, that some calcareous invertebrate skeletons were imperfectly preserved using this solution and so, in later seasons, meroplankton were preserved in alkaline Lugol's solution (Anderson and Karlson 2017).

In the laboratory, meroplankton samples were subsampled using the Huntsman Marine Laboratory beaker method for splitting into 1/8th samples (van Guelpen et al. 1982). Samples were then separated into size fractions by sequentially pouring the samples over nylon mesh of specific grid size affixed to modified beakers. To facilitate sorting for counting and identification, samples were split into size fractions of > 500 µm, 243–500 µm, and < 243 µm (i.e., 104–243 µ based on mesh of zooplankton net). A plankton counting wheel (Ward 1955) was used to accurately count taxa in each size fraction using a zoom stereomicroscope. Analyses focused on functional groups (discussed below), which could span several size classes.

Taxa were identified to the lowest level possible. Identification resources included the following general sources: Newell and Newell (1977), Smith (1977), Yamaji (1991), Todd et al. (1996), Shanks (2001), Young et al. (2002), and Johnson and Allen (2012). Taxon-specific resources included Plate and Husemann (1994) for Polychaeta; Rees (1950), Chanley and Andrews (1971), and Goodsell et al. (1992) for Bivalvia; Lalli and Conover (1973) for Gastropoda; and Cook (1966) and Naomi et al. (2006) for Crustacea. Taxonomic data were updated using the World Register of Marine Species (WoRMS 2019). Damage to specimens, especially soft-bodied larvae of Platyhelminthes and Nemertea, and lack of identification resources for other specific taxa and life stages, introduced some uncertainty into identification but was minor compared to the vast majority of specimens in the major functional groups.

Species richness, a measurement of diversity, is defined as a total count of all species in a sample (Cox1996). In some cases in the present study, such as meroplankton from Phylum Nemertea, specimens could not be identified to the species level, but could be distinguished from other taxonomic groups. The concept *identifiable form* (just *form* herafter) was used to refer to the lowest possible distinct taxon, which might be individual species for some groups but some broader taxon for other groups, each which might include several related species. Form richness, therefore, became a proxy for meroplankton species richness. Whereas form richness would not be comparable across multiple studies due to varying levels of species identification, it was comparable on a relative scale among the shoals, season, habitats, and years within the current study.

To facilitate comparisons, meroplankton were also categorized into functional groups that were collections of species formed primarily along phylogenetic groupings, but within which uncommon taxa were placed within larger groups based on comparable body features. Functional groups used in this study are summarized in Table 10-1.

Meroplankton subsample counts (n_c) were standardized to abundance·m^{-3} (n) using the following formula (Equation 1):

$$n = \frac{8n_c}{0.196y} \qquad (1)$$

where 8 = the subsampling factor, 0.196 = the cross section (m^2) of the area sampled by the zooplankton net, and y = sample depth (m).

An analysis of variance (ANOVA) was used to test for significant differences in mean abundance of functional groups among shoals, seasons, and between ridge and swale habitats. Specific differences in abundance of functional groups related to dredging impact was also compared between the dredged shoal (CSII-BA) relative to the reference shoals (CSII, Chester, and Bull Shoals). When the overall ANOVA was significant ($P \leq 0.05$) then *a posteriori* Tukey multiple comparison tests were done to determine where the differences occurred. Several tropical storms impacted the study area during the sampling timeframe (see Chapter 1, Table 1-3) and these were noted when relevant.

10.3 Results

10.3.1 Meroplankton Composition

In total, 150,218 meroplankters were counted in the 104–243 μ mesh, 81,785 in the 243–500 μ mesh, and 23,246 in the > 500 μ mesh. These were counts from the subsampled fractions so total sample abundances were eight times higher. There was a total of 383 net samples collected from all sites, fall 2013 to summer 2017; one sample from CSII in fall 2016 was lost.

Numerical abundance for functional groups, and for a few abundant taxa within functional groups, are summarized in Table 10-2. Molluscan and brachiopod larvae comprised the most common functional group, with 43.6% of all meroplankton sampled. Of this group, the vast majority (85.9%) were bivalve larvae, mainly in the smallest size fraction and poorly preserved; brachiopod larvae (probably all *Glottidia pyramidata*), comprised only 0.1% of this group. Polychaete and other worm larvae, of which 94.1% were meroplanktonic larvae of polychaete annelids, were nearly as abundent, at 41.3% of meroplankton. The only other functional group to comprise more than 5% was crustacean larvae, making up 7.2% of all meroplankton. Some examples of common meroplankton are shown in Figure 10-2.

For meroplanktonic crustaceans and bivalve molluscs, the great majority of counts were in either the largest size class (most taxa) or the smallest (bivalves). Among abundant groups, larvae of polychaetes and echinoderms were well-distributed across size fractions. Size fractions were therefore combined in further analyses.

10.3.2 Meroplankton Form (Species) Richness

Shoal had no detectable effect on meroplankton form richness (P = 0.396), with a mean among all shoals of 18.45 forms (taxa); this included no difference between dredged and non-dredged shoals. Form richness was significantly different among seasons (P < 0.0001). The mean number of taxa in the summer (23.0) was significantly greater than in the spring (20.9), with both summer and spring greater than fall and winter (15.4 and 14.3 taxa, respectively), which were not different from one another. Form richness was significantly higher over swale habitat (19.4 taxa) compared to ridge habitat (16.5) (P < 0.0001).

10.3.3 Meroplankton Abundance

None of the shoals differed significantly (P > 0.05) for total meroplankton densities or for any of the functional groups (Table 10-3). Season had a much broader effect on meroplankton abundance than the shoal factor (Table 10-4). Total meroplankton abundance differed significantly among seasons, with highest counts in summer and lowest in fall (Figure 10-3). Crustacean larvae had low counts in both winter and fall, and were higher in summer and spring (Figure 10-4). Echinoderm larvae abundance peaked in summer and was relatively low in the other seasons (Figure 10-5). Molluscan larvae were consistently abundant across all seasons, with no significant differences (Figure 10-6). Lancelets were abundant in summer but scarce the rest of the year (Figure 10-7). Polychaetes and worm larvae showed stronger differences with a spring minimum and large peaks in other seasons (Figure 10-8).

Meroplankton abundance was not different between ridge versus swale habitats for most functional groups (Table 10-5). The exceptions were molluscan larvae (mainly Bivalvia), which was significantly more abundant over ridges than swales (Table 10-5). The abundance for the functional group for amphipods and isopods was also higher at ridges than swales, although their overall abundance was low.

10.4 Discussion

Season was a significant factor for abundance differences for every meroplankton functional group tested, except molluscan larvae. The lack of differences for molluscan larvae was not the result of low numbers or unusually high variance; as a group, molluscan larvae were just similarly abundant in every season (Table 10-4, Figure 10-6). There might have been species-specific seasonal differences masked by the overall functional group, as most bivalve larvae could not be reliably identified to lower taxonomic level. Gastropod larvae were usually present but in low numbers, as were lamp shells *Glottidia pyramidata*, so the overall pattern of high abundance among all seasons was being driven primarily by bivalves, which made up 85.9% of specimens in that functional group. For all other functional groups, season had a strong effect on abundance (Table 10-4).

Habitat type showed almost the opposite trend relative to the season effect and the only meroplankton group that showed an effect was molluscan larvae, which were more abundant over ridge habitats. It was unknown why that would be true uniquely for molluscs. The diversity (richness) of forms sampled also differed, with a modest but significant diversity increase in swale habitat samples. This was most likely a consequence of sample size, which was larger than at ridge sites, and was, therefore, affected by species-area effects (Cox 1996).

Meroplankton, either as a whole or by functional group, did not differ among shoals, including dredged and undredged sites (Table 10-3), inferring that the entire sample region functioned as a continuous and well-mixed water mass, with respect to plankton. These findings were also consistent with predictions by Sullivan and Hancock (1977) that oceanic planktonic communities are too transient to detect impacts from sand removal, and with findings by Windom and Stickney (1976) that detectable impacts are mostly found in spoil deposition areas, not spoil removal areas. This does not mean there were no impacts, but that—if they occurred—they dissipated before they could be detected by seasonal sampling (i.e., within 3 months). It is possible that plankton surveys would have to be conducted simultaneously in time and place with active dredging to detect even a short-term impact.

Several tropical storms occurred during the sampling period, as noted in the figures showing meroplankton abundance over time (Figures 10-3 through 10-8). While meroplankton values did change for some groups following a storm, there was no consistent effect of storms on any meroplankton functional group over time, and most changes were related to season more so than storm events; nor was any one storm followed by similar changes across most meroplankton groups.

10.5 Conclusions

Meroplankton at Cape Canaveral was dominated by molluscan larvae (mainly bivalves) and polychaete larvae, collectively accounting for 85% of all specimens collected. Meroplankton data were robust enough to detect significant differences among seasons, and between habitat types, but none of these differences could be attributed to dredging impacts. Season had the strongest impact, affecting all functional groups of meroplankton except molluscan larvae, while habitat (ridge versus swale) showed the opposite trend, with only molluscan larvae showing an effect. Echinoderm and polychaete larvae showed limited shoal effects, but they were not driven or mirrored by differences between the dredged and non-dredged shoals. These findings were consistent with other studies on spoil removal impacts on zooplankton in that effects are, at most, transient and dissipate quickly.

10.6 References

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Figure 10-1. All meroplankton sampling stations from fall 2013 to summer 2017.
Locations and areas are indicated for sampling stations (dots), ridges (green) and swales (beige), and the dredged area (CSII-BA) (pink). Depth contours are in meters.

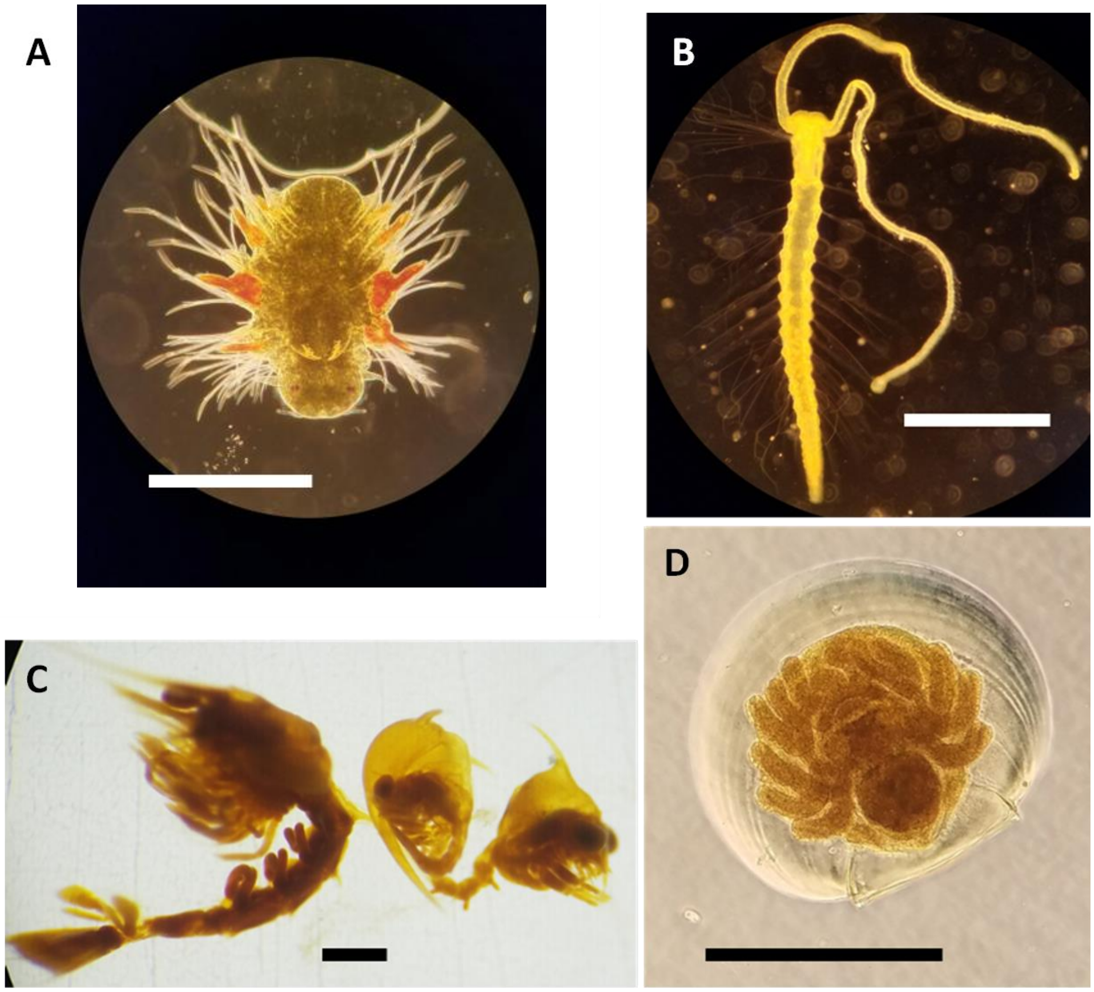

Figure 10-2. Examples of common meroplankton collected from study shoals.
A) Nereidae (Annelida: Polychaeta), B) Magelona (Annelida: Polychaeta), C) three species of decapod crustacean larvae (Arthropoda: Crustacea: Decapoda), and D) *Glottidia* (Brachiopoda: Lingulata). Scale bar = 200 µm.

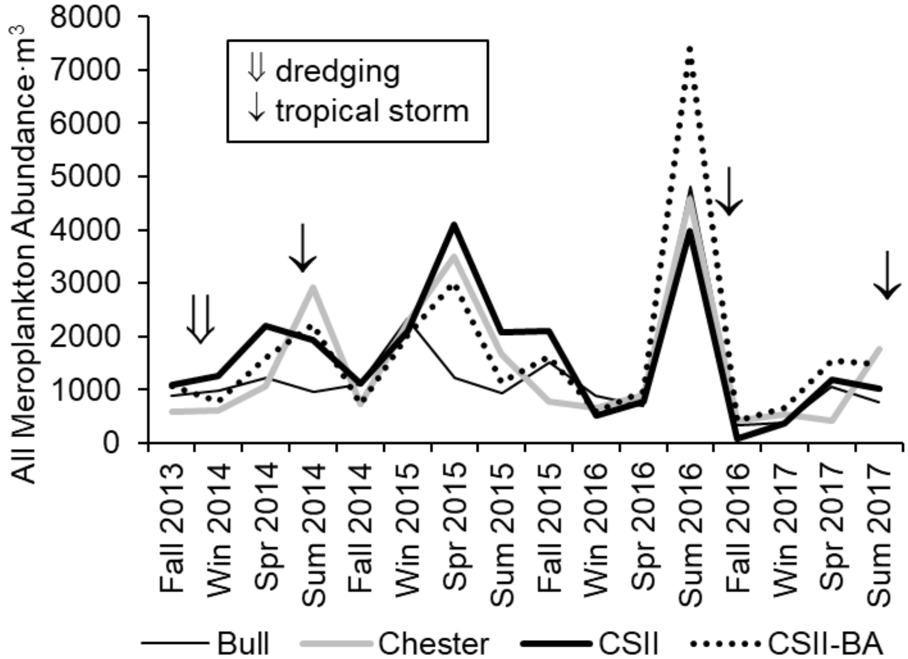

Figure 10-3. Seasonal mean abundance of all meroplankton (all size classes) from fall 2013 to summer 2017, by shoal.
Functional groups are defined in Table 10-1.

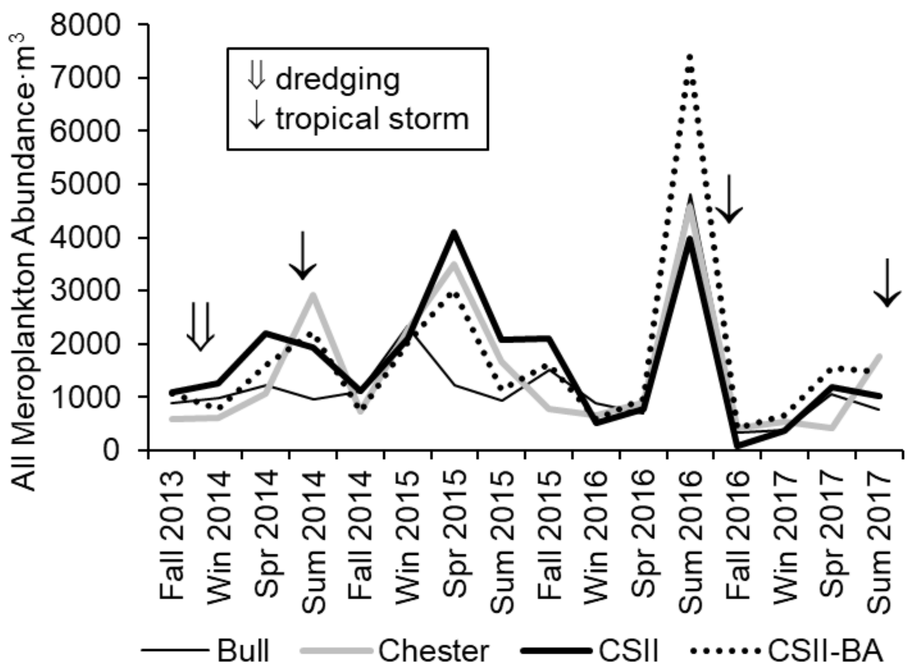

Figure 10-4. Mean seasonal abundance of crustacean larvae, all size classes, from fall 2013 to summer 2017, by shoal.
Functional groups are defined in Table 10-1.

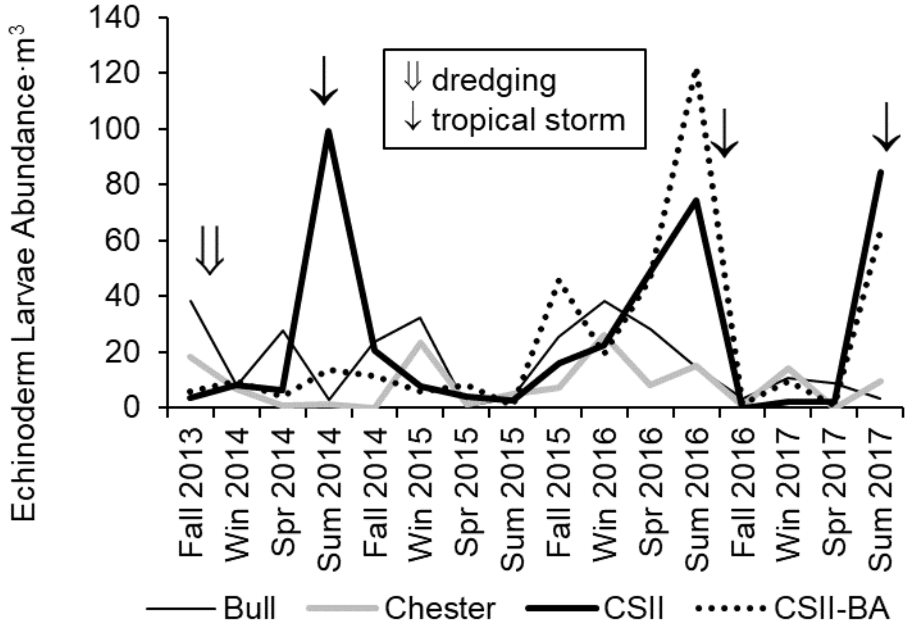

Figure 10-5. Abundance of echinoderm larvae, all size classes, from fall 2013 to summer 2017, by shoal.
Functional groups are defined in Table 10-1.

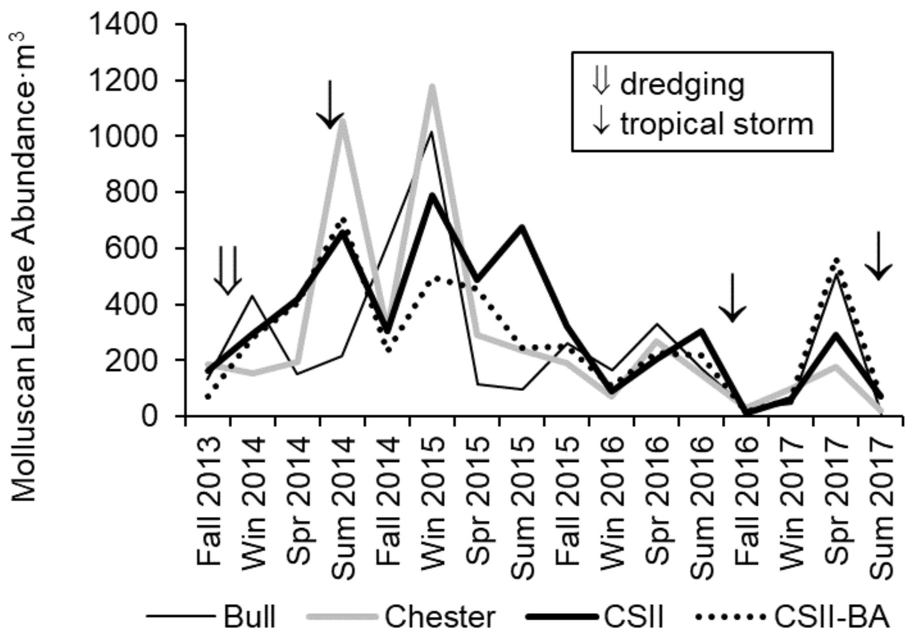

Figure 10-6. Mean seasonal abundance of molluscan larvae, all size classes, from fall 2013 to summer 2017, by shoal.
Functional groups are defined in Table 10-1. Lamp shell larvae (Brachiopoda) were also included but most of the molluscan larvae were Bivalvia.

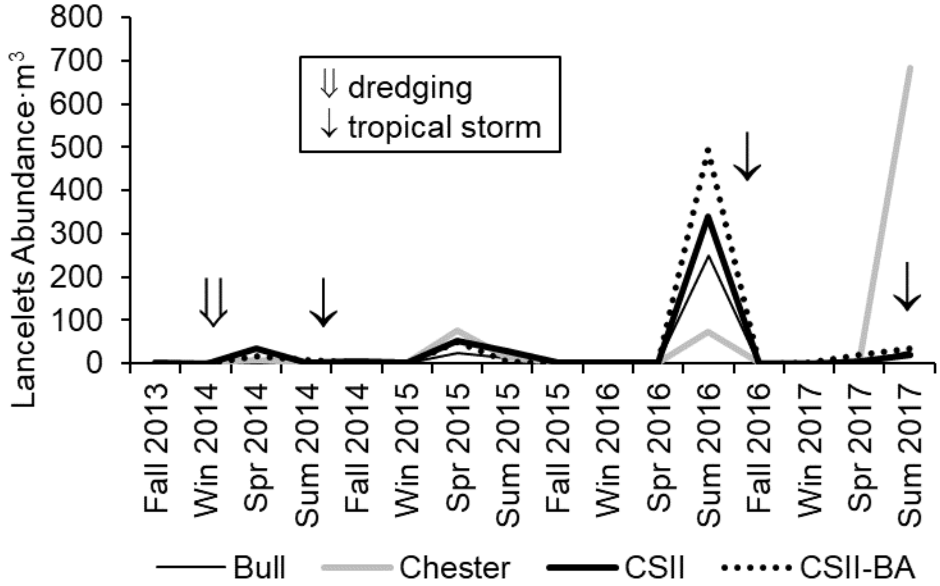

Figure 10-7. Mean seasonal abundance of lancelets (Cephalochordata), all size classes, from fall 2013 to summer 2017, by shoal.
Functional groups are defined in Table 10-1.

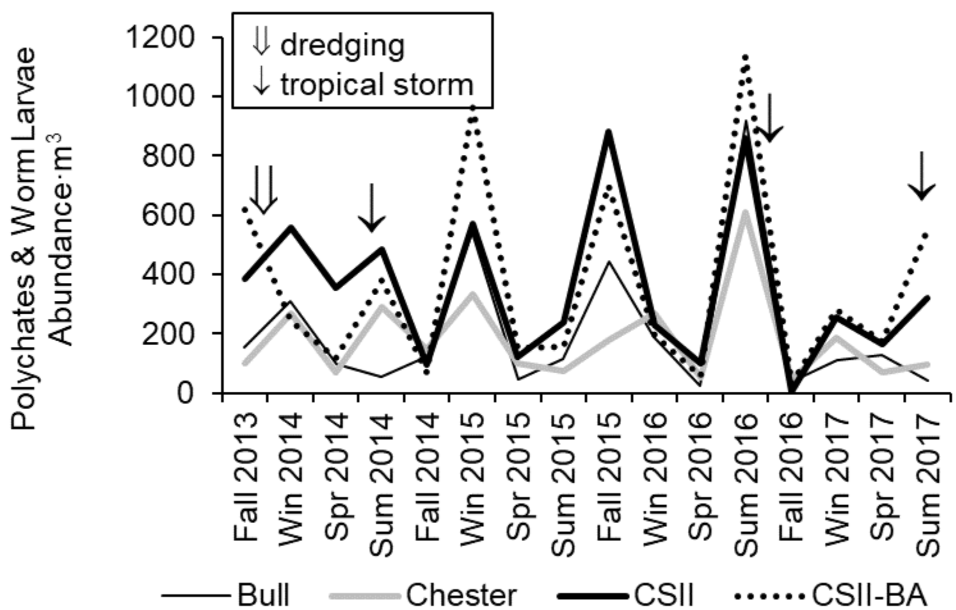

Figure 10-8. Mean seasonal abundance of polychaetes and other worm larvae, all size classes, from fall 2013 to summer 2017, by shoal.
Functional groups are defined in Table 10-1.

Table 10-1. Functional groups of meroplankton.

Functional Group	Definition
Amphipods and Isopods	Crustacea: Peracarida in Amphipoda, Isopoda, and Tanaidacea, except for holopelagic groups such as Amphipoda: Hyperiidae.
Crustacean Larvae	Larvae and post-larvae of otherwise benthic crustaceans in Decapoda, plus barnacles (Maxillopoda: Thecostraca).
Echinoderm Larvae	All planktonic stages of Echinodermata, including a few newly metamorphosed brittle stars (Ophiuroidea).
Molluscan and Brachiopod Larvae	Shelled larvae of Bivalvia, Gastropoda, and Brachiopoda (a lamp shell, *Glottidia pyramidata*).
Lancelets	Planktonic larval stages of lancelets (Chordata: Cephalochordata).
Polychaetes and Worm Larvae	Annelida (excluding horoplanktonic species), plus larvae of Bryozoan, Nemertea, Phoronida, Platyhelminthes, and Sipuncula. All were soft-bodied and used cilia for locomotion.

Table 10-2. Total abundance of functional meroplankton groups, including selected subsets of functional groups, 2013–2017.

Functional groups of meroplankton are defined in Table 10-1. The total from which abundance percentages are calculated is 255,249 plankters.

Functional Group	Subset of Functional Group	Abundance (count)	Abundance (% of total)
Amphipods and Isopods	All	1,170	0.5
Crustacean Larvae	All	18,492	7.2
"	Decapoda: Pinnotheridae	2,937	0.1
Echinoderm Larvae	All	7,049	2.8
"	Echinoidea Larvae	3,634	1.4
Molluscan and Brachiopod Larvae	All	111,353	43.6
"	Mollusca: Bivalvia	95,683	37.3
"	Brachiopods	223	0.0009
Lancelets	All	12,228	4.8
Polychaetes and Worm Larvae	All	105,923	41.3
"	Larval Polychaetes	99,642	38.9

Table 10-3. Differences in mean abundance (number per m^3) of meroplankton among shoals, fall 2013 to summer 2017.

Functional groups are defined in Table 10-1.

Functional Group	Bull Shoal	Chester Shoal	CSII Shoal	CSII-BA Shoal	P
All Meroplankton	3,320.4	3,444.1	4,771.5	4,477.5	0.350
Amphipods and Isopods	21.5	19.2	18.7	13.8	0.824
Crustacean Larvae	228.4	256.9	406.5	263.9	0.512
Echinoderm Larvae	100.7	51.1	151.0	137.7	0.225
Molluscan Larvae	1,608.1	1,724.7	1,975.3	1,651.4	0.912
Lancelets	115.0	313.9	133.0	202.4	0.830
Polychaetes and Worm Larvae	1,246.6	1,078.3	2087.0	2,208.3	0.091

Table 10-4. Differences in mean abundance (number per m^3) of meroplankton, among seasons, fall 2013 to summer 2017.

Functional groups are defined in Table 10-1. Significant differences among seasons within each functional group based on an overall analysis of variance are given by P-values in bold, followed by an a posteriori Tukey multiple comparisons test where mean values that are not significantly different (P > 0.05) among seasons within each functional group share the same letter value.

Functional Group	Winter	Spring	Summer	Fall	P
All Meroplankton	4,288.3 B	3,073.8 C	5,631.0 A	3,020.4 C	**0.019**
Amphipods and Isopods	19.6	27.2	17.1	9.3	0.193
Crustacean Larvae	116.1 C	310.8 AB	533.5 A	195.3 BC	**0.005**
Echinoderm Larvae	91.1	73.2	193.4	82.9	0.073
Molluscan Larvae	2,000.9	1,899.3	1,840.0	1,219.4	0.475
Lancelets	0.2 D	80.0 B	680.7 A	3.4 C	**0.005**
Polychaetes and Worm Larvae	2,060.4 AB	683.4 C	2,366.6 A	1,510.1 B	**0.011**

Table 10-5. Differences in mean meroplankton abundance (number per m^3), between ridge and swale habitats, fall 2013 to summer 2017.

Functional groups are defined in Table 10-1. P-values given for t-tests for mean abundance between ridge and swale habitats within each functional group, with significant differences in bold text.

Functional Group	Ridge	Swale	P
All Meroplankton	1,709.6	1,432.5	0.097
Amphipods and Isopods	3.9	2.6	**0.020**
Crustacean Larvae	48.8	48.0	0.937
Echinoderm Larvae	17.9	18.7	0.852
Molluscan Larvae	389.9	241.5	**< 0.001**
Lancelets	31.6	32.1	0.980
Polychaetes and Worm Larvae	283.0	273.4	0.784

11 Benthic Infaunal and Epifaunal Invertebrates from Benthic Grabs

Patrick Baker and Colin Frank

Key Points

- Across all shoals, ridge sediments were significantly coarser and had lower organic content than swale sediments. Significant changes in sediment grain size and organic content at the dredged shoal (CSII-BA) were matched by similar changes at the reference shoals (CSII, Chester, and Bull) at the same time, so could not be attributed to dredging.
- Shoals, habitat (ridge versus swale), and seasons all significantly affected abundance of benthic invertebrates, including at dredged (CSII-BA) and non-dredged (CSII) portions of Canaveral Shoal II, Chester Shoal, and Bull Shoal. However, most of these were unrelated to dredging events.
- No general biological factors—including invertebrate abundance, biomass, species richness, or Simpson's Index of Diversity—changed following dredging events at any of the shoals.
- The only taxon for which abundance clearly changed at CSII-BA following dredging were amphipods (small crustaceans) in the Family Haustoriidae, which increased in the year following the second dredging event relative to the year preceding it. This specific change was not observed at CSII, Chester, or Bull Shoals. No changes were observed during the first dredging event at any of the shoals.
- The most abundant taxa, such as amphipods, sand dollars, lancelets, and even colonial bryozoans, were motile, and thus able to quickly recolonize any disturbed area.
- Benthic invertebrates were potentially the most directly impacted biota by the dredging events, but they were, with limited exceptions, either not impacted or recovered from dredging too quickly for seasonal sampling to detect an effect.

11.1 Introduction

Benthic infaunal invertebrates live within the bottom sediments, and epifaunal invertebrates live on or attached to the surface of the bottom sediments. As such, they form a dynamic coupling between the benthic and the pelagic realms in coastal waters. They are also an important potential prey source for higher trophic levels, such as fishes. Newell et al. (1998) and Boyd et al. (2005) have reviewed dredging impacts on benthic invertebrates in the North Atlantic. Newell et al. (1998) divided impacts into removal of invertebrates, complete burial of invertebrates, and partial burial by sedimentation. Most work has focused on invertebrate removal impacts because they were the most severe, clearly quantifiable, yet ultimately gave way to recovery. Initial benthic biological impacts of removal were severe; a loss of 80% of invertebrate biodiversity and 90% of biomass, including almost all bivalves, was described for some sites (Desprez 2000; van Dalfsen et al. 2000). Those impacts could affect at least three ecosystem services: a fishery itself (e.g., harvesting molluscs), a community sustaining a different fishery (e.g., benthic invertebrates fed upon by commercial crustaceans or fishes), and water filtration by mollusks and other benthic invertebrates (van der Schatte Olivier et al. 2018). The importance of these ecosystem services costs would be modified by their duration (i.e., a rapid versus a prolonged recovery).

As noted in Chapter 1, one definition of the term *recovery* refers to return to a former state, as indicated by the presence of specific organisms or species assemblages; this is probably the most cited definition for invertebrates recovering from a perturbation. Recovery of benthic communities from dredging, reviewed in studies of European sites, varied with site productivity, current regime, the magnitude of the disturbance, and the taxonomic group considered, among other factors (Van Der Veer et al. 1985; van Dalfsen et al. 2000; Boyd et al. 2005). Sediment grain size itself did not necessarily limit recovery; assemblages in a fine-sediment site with strong currents recovered in 1–3 years, but took 5–10 years in a site with low currents (Van Der Veer et al. 1985).

Pre-dredging communities may sometimes be incapable of recovery, if recovery is defined as a return to a prior state. Desprez (2000) documented long-term changes in a polychaete community as a result of dredging; although species richness recovered, the post-dredging community, on altered substratum, was not the same as the community before dredging. Climate change may also alter the ranges of species enough that, if a community is severely disturbed, it cannot replace itself (Hiscock et al. 2001; Hawkins et al. 2008).

Not all studies on dredging document significant impacts. A high-energy sand area, at the mouth of Biscayne Bay, Florida, was commercially dredged using a suction pump without a cutter head (Iversen and Beardsley 1974). The area lacked macrophytes and was dominated by mostly small taxa; a prior study recorded 354 animal species in adjacent areas (Bader and Roessler 1971). The study by Iversen and Beardsley (1974) looked only at two sample periods, pre- and post-dredging, and the researchers concluded that ecological recovery had occurred before the final sample period, about 6 months following the dredging.

11.1.1 Goals and Objectives

The broad goal of this study was to describe the taxonomic diversity and quantify the abundance and biomass of benthic invertebrates in offshore sand shoals, in relation to dredging events. Specific objectives included:

1. Identify to the lowest feasible taxonomic level, and quantify abundance and biomass of benthic invertebrates collected with a benthic grab across all study shoals and years.
2. Compare benthic invertebrate diversity, abundance, and biomass:
    c. spatially among the dredged shoal (CSII-BA) and undredged (reference) shoals (CSII, Bull, and Chester Shoals), and among ridge and swale habitats.
    d. temporally among sampling years (6 years) and seasons (four seasons).
3. Determine whether dredging events resulted in significant changes in benthic invertebrates relative to any changes attributed to naturally occurring spatial or temporal changes in invertebrates on the reference shoals.

11.2 Methods

11.2.1 Site Description

Benthic invertebrates were sampled offshore of Cape Canaveral at CSII-BA (the dredged portion of Canaveral Shoal II) and CSII (the reference or non-dredged portion of Canaveral Shoal II), as well as Chester and Bull Shoals (two reference shoals). Details of the study shoals and sampling site selections are given in Chapter 1; Figure 11-1 shows the location of all invertebrate sampling stations. The sampling times and locations were the same as for other biological samples, as outlined in Chapter 1, Section 1.5. The dredged area and timeline are shown in Chapter 1, Table 1-1. Timing of hurricanes and major tropical storms that occurred during the study are noted in Table 1-3. Each of the three shoals sampled included shallow habitat (ridge) and comparatively deeper surrounding habitat (swale), as outlined in

Chapter 1. In summary, samples were taken from stratified-random sites within ridge and swale habitats of the shoals on a seasonal basis from fall 2013 to summer 2019. Seasons were defined as winter (December through February), spring (March through May), summer (June through September), and fall (October and November). Chester and Bull Shoals were each sampled at 12 sites per season (four and eight sites in ridge versus swale habitat, respectively). At Canaveral Shoal II, six samples were collected in each season in the dredged area (CSII-BA) and six were collected in the non-dredged area (CSII) (two and four sites in ridge versus swale habitat, respectively). Depth was measured at each sampling site, taking into account the hull of the vessel (0.5 m below the surface). Safe and effective sampling conditions for benthic grabs required wave heights of less than 2 m which, on several occasions, pushed sampling dates into the beginning of the following season, although sample dates were always at least 60 days apart. All samples were collected during the day.

Dredging events occurred twice during the study, one from November 2013 to April 2014 and another in January to March 2018, as outlined in Table 1-1. There was only one data collection in the fall (October 2013) prior to the first dredging event. For the second dredging event, samples were taken four seasons prior to the dredging event and for four sequential seasons following the dredging event. The timing of these dredging events, especially the first dredging, constrained some comparative analyses.

11.2.2 Young Grab Sampling Procedures

The Young grab, sometimes called a Young Modified Van Veen grab, was a van Veen grab surrounded by an open-frame circular base 1 m in diameter to increase sample precision, and suspended by a pyramidal frame that protects the closing arms of the grab (Figure 11-2). Surface area sampled was normally 338 cm^2. This design and its use has been described previously by Lie and Pamatmat (1965), Cutter et al. (2000), Dauer and Lane (2005), and Flexner (2013).

The Young grab was deployed from a research vessel, with the aid of a power winch (Figure 11-3). Following deployment, the grab rested on a frame into which a bin was placed to collect the sample when the jaws were opened. Sample failures, for example when the jaws did not close or debris in the jaws allowed material to fall out, were redone. In some instances, the substrate type and form sampled by the grab could affect the total sample area and volume. At some of the sampling stations, the sand was rippled or mounded on a scale smaller than the diameter of the Young grab (1 m) so that the jaws could not fully reach into the sediment or were at an angle to the sediment, resulting in a sloped or uneven sample interface. Very coarse sediment (i.e., shell debris) also prevented the jaws from digging into the substrate as deeply as possible. If, in these circumstances, repeat sampling efforts did not produce full grab samples then the sample was accepted but the surface area of the sample was adjusted to 303 cm^3, about a 10% reduction in surface area, and noted on the data sheet. There were no samples during this study for which we could not collect a sample with a surface area of at least 303 cm^3.

Prior to being emptied, the grab sample was accessed through the top of the grab jaws via hinged doors (Figure 11-4), which enabled smaller sediment subsamples to be taken prior to processing the entire grab for larger invertebrates. First, three shallow sediment cores were collected from the surface of a subsample of the grabs, placed on ice, and analyzed for benthic chlorophyll *a* as part of Chapter 8. For benthic invertebrates (this chapter), sediment cores were collected from all grab samples using a 3.81 cm (1.5 inch) diameter (area = 0.00114 m^2) by 15-cm long core pushed its full length into the grab sample. The sediment core was stored in 95% ethanol but, as noted below in Section 11.2.3, sediment cores were examined for invertebrate taxa prior to processing for sediment grain size.

The Young grab jaws were opened after the cores were removed, allowing the remaining sample to fall into a sample tub. The sample was then rinsed through a brass 1.4 mm (ϕ = -0.5) sieve into a separate tub using a seawater hose. The 1.4 mm sieve was the smallest standard sieve through which the majority of the sediment would pass. Living organisms and all sediment retained on the 1.4 mm sieve were placed into specimen jars and immersed in 7.5% magnesium chloride ($MgCl_2$) to relax any soft-bodied specimens to assist with their identification. After 1 hour, the $MgCl_2$ was decanted through a 0.5 mm sieve and replaced with 95% ethanol (Williams and van Syoc 2007).

Some samples had small lancelets (Cephalochordata: *Branchiostoma*), which were sometimes observed to pass through the 1.4 mm sieve, despite an overall size larger than 1.4 mm, because they had smooth, eel-like bodies. Lancelets were readily observed swimming in the water of the sieving tub, if present, which would be followed by modified sampling to collect them. The sediment and seawater that went through the 1.4 mm sieve into the tub was vigorously agitated, and the seawater then immediately decanted through a 0.5 mm sieve; this was repeated until no more lancelets were observed when the sediments were agitated.

11.2.3 Sediment Processing

Sediment samples were collected from the grab samples as described in Section 11.2.2.1 and were preserved in ethanol while on the research vessel, and subsequently examined as below (Section 11.2.4) for small invertebrates. This meant it was not necessary to subtract the area of the core (11.4 cm^2) from the benthic grab sample for the purpose of invertebrate counts.

After invertebrates were removed, samples were wet-sieved on a standard sediment sieve set (U.S. sieve sizes 5, 10, 35, 60, 120, and 230). Sediment fractions were oven dried for 24 hours and weighed to the nearest 0.001 g. Sediment fractions were then ashed at 500 °C for 3 hours to remove organic matter, cooled in a desiccator, and reweighed to obtain ash-free dry weights, following Poppe et al. (2000). Ash content of some of these sediment fractions was below the instrument margin of error, with the result that some organic matter weights were small negative values. In these cases, ash weights were converted to zero for the purpose of analysis. Sediment sizes were converted to the negative exponent of the diameter in millimeters, ϕ (phi) (Krumbein 1937; Griffiths 1967) for parametric statistical analysis, but some analyses were also performed using untransformed mean particle diameter (measured in mm). In both cases, sediment grain size per sample were expressed as weighted means (Strömgren 1974). Sediments were classified according to the Coastal and Marine Ecological Classification Standard, or CMECS (FGDC 2012), which were non-numerical categorical data (see Tables 4-1 and 4-2 for substrate type and grain sizes).

11.2.4 Specimen Quantification and Identification

Samples were sorted in the laboratory at the University of Florida and stored in 95% ethanol (except for lancelets, which were stored in 70% ethanol) in vials, one vial per taxon per grab, and stored for the duration of the project. If the ethanol in a sample appeared clouded or strongly discolored within a few weeks, it was replaced with fresh 95% ethanol. Lancelets were stored in 70% ethanol because 95% ethanol deformed their shape and size (*per. obs.*), making potential morphological studies difficult.

All samples contained two components: sediment core and sieve fraction (>1.4 mm, $\phi = -0.5$). Both the sediment core and the sieve fraction were sorted twice by hand. Specimens were identified to the lowest possible taxon possible within a reasonable amount of time (i.e., hours were not spent attempting to identify small, rare taxa to species). An example of the complexity of invertebrate identification is illustrated by Figure 11-5, showing a polychaete annelid and the numerous parts used for identification. Important identification resources included: for general invertebrates, Ruppert and Fox (1988); for polychaete annelids, Uebelacker and Johnson (1984) and Rouse and Pleijel (2001); for molluscs, Abbott (1974), Mikkelsen and Bieler (2008), Lee (2009), and Tunnell et al. (2010); for crustaceans, Menzies and Kruczynski (1983), Williams (1984), and LeCroy (2000-2011); and for echinoderms, Thomas (1962) and Hendler et al. (1995). Other specimen identification resources are too numerous to list here and are listed by taxonomic group in Appendix F. Taxonomic information was based on the World Registry of Marine

Species (WoRMS 2019). This database is updated continuously, and it is therefore possible additional taxonomic changes have occurred.

Very small invertebrates could, on occasion, adhere to or be trapped between sediment particles despite being small enough to go through the 1.4 mm sieve. In most cases (e.g., copepods and free-living nematodes) such instances were obvious sampling artifacts and were not included but, if they were marginal (in terms of size) specimens of otherwise commonly sampled taxa, they were counted. Internal parasites could come out of damaged specimens and, if identified as such, were not counted, but free-living stages of otherwise parasitic or commensal groups, such as male or juvenile parasitic amphipods (Bopyridae) and pea crabs (Pinnotheridae) were counted (Williams 1984; Markham 1985).

Biomass was calculated as wet weight. Specimens were kept intact for museum collections and future research, so dry weight—a destructive technique—was not feasible. Specimens were removed from tubes, or from shells they did not themselves produce in the case of hermit crabs (Arthropoda: Paguridae) or certain peanut worms (Sipuncula: Phascolionidae), but mineralized portions of shells or tests produced by and attached to tissues (e.g., mollusk shells and bryozoan tests) were considered biomass. Organisms were removed from the preservation fluid, blotted for several seconds on a dry tissue, and then weighed to the nearest 0.0001 gram. All specimens of a single lowest identified taxon from a single sample were weighed together, although the number of specimens was recorded separately.

Specimens of the polychaete *Owenia fusiformis* (Oweniidae) were too small and fragile to remove in a cost-effective manner from their tubes, a problem noted by other researchers (Ménard et al. 1989). A sample of 15 specimens were weighed in their tubes (tube weight), then removed from their tubes and reweighed (tissue weight). The tissue weights were regressed against tube weights to produce a linear relationship that was used to estimate tissue weight of specimens from tube weights alone. When tube weight was less than the y-intercept of the regression then the mean tissue weight of the samples expressed as a fraction of the tube weight was used to predict tissue weight of *O. fusiformis.*

11.2.5 Data Treatments

Abundance and biomass data were converted to individuals (invertebrates) per square meter or biomass (g) per square meter for some analyses, by multiplying values by a factor of 29.58 (1 m^2 divided by the surface area of the grab, which was 0.0388 m^2). Some samples were smaller as a result of grab sampling difficulties (see Section 11.2.2 above); for such samples, the conversion factor was increased to 33.0 (1 m^2 divided by 0.0303 m^2). These changes did not affect statistical analyses other than to correct for differing sample areas. Untransformed abundance (count) data were used in some goodness-of-fit analyses.

A large number of unidentified specimens complicated estimates of species richness so a conservative approach was adopted, addressed in the Discussion (Section 11.4). Multiple specimens within a genus or family that could not be identified to lower taxonomic levels were considered a single taxon for the purposes of species richness. Simpson's Index of Diversity (D), which calculates evenness (an inverse function of diversity), was used as an alternative indicator of sample diversity (Cox 1996; Brower et al. 1998) and calculated as

$$D = 1 - \frac{\sum n_i(n_i - 1)}{N(N-1)} \tag{11-1}$$

Where n_i = the number of individuals of taxon i, and N = all specimens of all taxa in the sample. D ranges from 1 (high evenness, or low diversity) to 0 (highly uneven, or high diversity), and 1 – D can be used as an index of dominance by the most common taxon.

Abundances of specific taxa (count data) were compared to expected frequency using Chi-square (χ^2) analysis. For a given test, the expected frequency was based on the relative number of samples in a treatment. For example, when comparing all ridge sites (288 samples) versus all swale sites (576 samples), the expected frequencies for a given taxon would be one third in ridge sites and two thirds in swale sites. When more than two frequencies were tested and resulted in a rejection of the null hypothesis of no difference from expected distributions, subdivided Chi-square analysis was used to estimate which frequencies accounted for the significant Chi-square value (Zar 1996).

Comparisons among shoals, seasons, sample years (fall to summer, since the study began in fall 2013), and habitat (ridge versus swale), were conducted using sediment (particle size and organic content), total species richness and total biomass, and select taxonomic groups for which there were sufficient numbers for analysis. For Canaveral Shoal II only, comparisons were made between CSII-BA (the shoal area that was dredged) and CSII (the non-dredged shoal). The selected taxonomic groups could be species (e.g., Chordata: *Branchiostoma virginiae*) but were more commonly family, class, or even phylum, based on the relative abundance of the taxon. A list of taxa used in analyses is provided in Table 11-1. Statistical significance was indicated as $P \leq 0.05$; Chi-square analyses reported the critical value associated with $\alpha = 0.05$.

Only one season of samples (fall 2013) was collected prior to the first dredging event (Chapter 1, Table 1.1), so it was compared to the first samples immediately following the end of the first year of sampling (summer 2014), as well as fall 2014, the season matching the first season, at both dredged (CSII-BA) and non-dredged (CSII) portions of Canaveral Shoals II. One year of data (spring 2018 to winter 2018–19) with all four seasons following the second dredging event were compared to the preceding year (fall 2016 to summer 2017). The sequence of seasons did not match, but all four seasons were represented in each data set. When significant differences were detected at either CSII or CSII-BA, the same parameters for the sample periods were examined at Bull and Chester Shoals.

Trends in physical data (depth, weighted mean sediment size expressed as phi, and proportional organic content of the sediment), and biotic data (total invertebrate abundance and biomass, species richness and Simpson's Index of Diversity, and major taxon counts) were also examined across the inter-dredging period. The inter-dredging period was defined as starting with the end of the event itself (i.e., spring 2014 for the first dredging event) to the final sample before the second dredging event (summer 2017), or a total of 14 sampling seasons. The spring 2014 sample, at the end of the dredging (April 28) was assigned the value of Day 1, and all subsequent sample dates were expressed as days since April 27, 2014.

11.3 Results

Six full years of data, from fall 2013 to summer 2019, were collected, with 12 samples at each of three shoals, four times per year. One sediment sample from CSII in fall 2017) and one sediment organic content sample from Chester Shoal in summer 2019 were lost (accidental spills), but no biological samples were lost. Surface-water temperatures ranged from a low of 13.9 ºC in February 2016 (winter sample) to a high of 27.8 ºC in July 2014 (summer sample), with seasonal means of 23.6 ºC in spring samples, 24.5 ºC in summer samples, 20.5 ºC in fall samples, and 17.7 ºC in winter samples.

11.3.1 Physical and General Biotic Factors

Coastal and Marine Ecological Classification Standards (CMECS) for sediments (FGDC 2012) were applied to all samples, although weighted mean sediment sizes (below) were used in data analyses. One sediment sample (Bull Shoal swale, winter 2019) was lost in a lab mishap (the invertebrates from that sample were not lost). Most sediments were sand with varying amounts of gravel or sand mixed in. However, the "gravel" (denoted by g or G) was composed exclusively of marine invertebrate shell fragments (i.e., biogenic instead of geologic), much of it apparently fossil material of species never recorded alive in the samples. Gravel designations were therefore replaced by shell designations (i.e., “slightly gravelly” was replaced with “slightly shelly”). Sand, indicated by S, comprised a plurality of 400 out of 863 samples, followed by (g)S (slightly shelly sand) (288 sites), gS (shelly sand) (117 sites), and mS (muddy sand) (42 sites). There were ten sG (sandy shell) sites, four (g)mS (slightly shelly muddy sand) sites, and one each msG (muddy sandy shell) and sM (sandy mud) sites.

Weighted mean sediment size, expressed as ϕ, decreased significantly with depth, but depth accounted for a small part of the variation ($r^2 = 0.111$, $P < 0.0001$). Phi (ϕ) is a negative exponent, such that as grain size decreases, phi increases, so the slope of a linear relationship was positive:

$$y = 0.081x + 0.212 \tag{11-2}$$

where y = ϕ and x = water depth in meters. A logarithmic relationship accounted for about the same amount of variability ($r^2 = 0.112$), with the relationship:

$$y = 0.351log_e(x) + 0.0742 \tag{11-3}$$

Proportional organic content showed a significant positive relationship with depth but explained <5% of the variation in the relationship ($r^2 = 0.042$, $P < 0.0001$).

Abiotic and general biotic parameters were compared between ridge and swale habitats (Table 11-2), seasons (Table 11-3), shoals (Table 11-4), and dredged and non-dredged parts of Canaveral Shoal II (Table 11-5). Physical parameters included depth, sediment size (expressed both as untransformed grain size and as ϕ), and proportional organic content. Biotic parameters included total invertebrate abundance (converted to numbers per m^2), invertebrate biomass (converted to $g \cdot m^{-2}$), species richness, and Simpson’s Index of Diversity.

Sample depth was significantly deeper in swale than ridge habitats (Table 11-2) but also varied significantly between all three shoals and the dredged (CSII-BA) and non-dredged (CSII) parts of Canaveral Shoal II. CSII was the shallowest with CSII-BA significantly deeper (Table 11-5), and Bull Shoal was the deepest of the shoals (Table 11-4). There was no seasonal signal for depth (Table 11-3).

Both untransformed weighted mean sediment size (in mm) and the weighted mean ϕ (negative exponent of size in mm) differed between ridge and swale habitat, with sediments significantly coarser on ridges than swales (Table 11-2). There was no seasonal effect on sediment size (Table 11-3). Bull Shoal had significantly coarser sediment than the other two shoals (which did not differ from each other) (Table 11-4), and CSII-BA had significantly coarser sediment than CSII (Table 11-5).

Invertebrate density was calculated by converting sample counts to values per unit area (m^2), as was invertebrate biomass. Invertebrate abundance, calculated as density, was not significantly different between ridge and swale habitat (Table 11-2). Abundance was significantly different among seasons (Table 11-3, Figure 11-6) and was significantly higher in summer compared to the other seasons. Abundance was significantly lower at the pooled CSII sites (CSII-All) compared to Bull and Chester Shoals, which did not differ from each other, but CSII-BA and CSII were not different from one another (Table 11-5). Invertebrate biomass was also not significantly different between ridge and swale habitat (Table 11-2) or among seasons (Table 11-3, Figure 11-7). It was not different among shoals when CSII-BA and CSII were pooled (CSII-All) (Table 11-4), but biomass was lower at CSII-BA when compared to CSII (Table 11-5).

Species richness, for which sequential sampling means are illustrated by shoal in Figure 11-8, was higher in swale habitat than ridge habitat (Table 11-2) and in summer samples compared to other seasons (Table 11-3). Chester and Bull Shoals had the highest species richness compared to CSII-All (Table 11-4), but CSII (non-dredged shoal) had higher species richness than CSII-BA (dredged portion) (Table 11-5). A significant difference in Simpson's Index of Diversity was detected only between ridge and swale habitats (Table 11-2); swale diversity was higher, as it was for species richness (Table 11-2). Simpson's Index of Diversity (Figure 11-9) was not different among seasons (Table 11-3) or shoals (Table 11-4).

Selected taxonomic groups were regressed as dependent variables against sample depth (m), log-transformed weighted mean sediment size (ϕ), and proportional organic content of sediments. None of the relationships, which were dominated by zero counts, had an r^2 value above 0.12 and therefore explained little of the variation (Table 11-6).

11.3.2 Taxon Abundance and Diversity

At least 500 unique taxa were identified from benthic grab samples. Of these, 92 specimens or groups of similar specimens could not be identified to at least genus and were treated as taxa. All Nemertea (ribbon worms), for example, were treated as a single taxon because of the poor condition (auto-fragmentation) of specimens and the lack of parts to identify them to lower taxonomic levels. Annelida was the most diverse benthic infaunal phylum in the study with 178 taxa, followed by Arthropoda with 134 taxa, and Mollusca with 123 taxa.

The most abundant individual taxon was the lancelet, *Branchiostoma virginiae* (Figure 11-10), of which there were 1,994 specimens (13.0% of all invertebrate specimens) recorded from 214 samples, with a combined wet-weight biomass of 37.12 g (1.3% of all biomass) (Table 11-7). That was followed by the amphipod *Acanthohaustorius millsi* (Figure 11-10), with 1,248 specimens (8.1%) across 348 samples and a combined biomass of 7.32 g (0.2%); and the free-living bryozoan *Reussirella doma* (Figure 11-10), with 1,010 specimens (6.6%) across 164 samples and a combined biomass of 16.73 g (0.6%). The amphipod family Haustoriidae, of which *A. millsi* was the most common representative, had 2,168 individuals (14.2% of all invertebrate specimens) with a collective wet weight of 10.72 g (0.4% of all biomass).

Biomass included living tissue and skeletons directly attached to living tissue (as opposed to worm tubes, for example); variations associated with this are addressed in the Discussion (Section 11.4). The largest individual specimens were sand dollars in Family Mellitidae (Figure 11-11). Total counts and summed weights of other abundant species or taxa, as collected in the field (not converted to units per square meter) are summarized in Table 11-7. Some taxa accounted for a disproportionate proportion of biomass. There were 659 bivalves other than Tellinidae, accounting for 4.3% of specimens but with a combined biomass of 154.9 g, or 5.6% of biomass. Sand dollars included 727 specimens, or 4.7% of specimens, but had a combined biomass of 358.6 grams, 13.0% of all invertebrate biomass in the sample. Mellitidae acted as an important source of variance in biomass data; both data peaks in biomass in Figure 11-7 were the result of adult sand dollars in the grab samples.

Tissue weight of the polychaete *Owenia fusiformis* was strongly related to tube weight, or specimen weight including the tube. A linear relationship, based on methods in Section 11.2.4, provided the strongest relationship ($r^2 = 0.759$, $P < 0.0001$), which was:

$$y = 8.3523x + 0.0024 \tag{11-4}$$

where y = tube weight and x = tissue weight. The mean (± 1SD) ratio of tissue weight to tube weight was 0.1132 ± 0.0371, which was used to estimate tissue weight of specimens when tube weight was equal to or less than 0.0024 g (the y-intercept in Equation 11-4).

Sample count data for abundant taxa (a subset of taxa in Table 11-7) were used to examine differences between treatments by goodness-of-fit analysis, with counts corrected for differing sample size. Results of Chi-square analyses are summarized for ridge versus swale habitats (Table 11-8), seasons (Table 11-9), all three study shoals (Table 11-10), and dredged versus non-dredged areas of CSII (Table 11-11).

Most taxon groups examined showed differences between ridge and swale habitats (Table 11-8, Figures 11-12 to 11-16). Those that did not included ribbon worms (Nemertea), the bloodworms (Polychaeta: Glyceridae), the abundant amphipods Haustoriidae, and the free-living bryozoan *Reussirella doma*. Swale samples tended to have higher abundance (after correcting for a larger number of samples); the exceptions to this were the amphipod *Metharpina floridana*, sand dollars (Echinoidea: Mellitidae), isopods, and lancelets, *Branchiostoma virginiae*), all of which were significantly more abundant in ridge samples.

Chi-square analysis detected seasonal differences in relative abundance for all taxa compared (Table 11-9, Figures 11-12 to 11-16) when all four seasons were considered. Among seasons, however, there were many pairwise comparisons that did not show a significant difference, based on subdivided Chi-square analysis. Summer and winter drove the strongest patterns, with most peak abundances in summer and most minimum abundances in winter, but there were a few notable exceptions: spionid polychaetes (Spionidae) were significantly more abundant in spring (Figure 11-13) and gastropods and other bivalves were significantly more abundant in fall (Figure 11-14). Spring and summer were the most common seasons (among seven taxa) to be similar, followed by fall and winter (five taxa). Highly abundant taxa did not all exhibit similar patterns: the amphipod family Haustoriidae and the free-living bryozoans, *R. doma*, were significantly more abundant in spring but did not differ significantly across other seasons, while lancelets, *B. virginiae*, were most abundant in summer and differed significantly across all seasons.

Chi-square analysis also detected significant differences across shoals for all taxa (Table 11-10, Figures 11-17 to 11-21), but not all shoals differed from each other for all taxa. Bull Shoal had no significant differences in densities of shovelnose worms (Polychaeta: Magelonidae) from CSII, while Chester Shoal had no significant differences in densities of tellin clams (Bivalvia: Tellinidae) and dwarf olive snails (Gastropoda: Olivellidae) from CSII. With the exception of auger snails (Terebridae), Bull and Chester Shoals were significantly different from each other across all taxa analyzed.

Dredged (CSII-BA) and non-dredged (CSII) portions of Canaveral Shoal II exhibited some differences among taxa, based on Chi-square analysis (Table 11-11, Figures 11-17 to 11-21), although not as many as for other comparisons. Ribbon worms (Nemertea), bloodworms (Glyceridae), predatory tubeworms (Onuphidae), lancelet worms (Opheliidae), spionid polychaetes (Spionidae) and isopods did not differ significantly between CSII-BA and CSII. Shovelnose worms (Magelonidae), amphipods (Haustoriidae and *M. floridana*), and sand dollars were all significantly more abundant on CSII-BA, but other taxa that exhibited significant differences were more abundant on CSII.

11.3.3 Comparisons of Pre- and Post-Dredging Canaveral Shoal II

Abiotic parameters (depth, weighted mean sediment size expressed as ϕ, and sediment proportional organic content) and general biotic (invertebrate abundance$\cdot$m^{-2}, invertebrate biomass$\cdot$m^{-2}, species richness, and Simpson's diversity index) data were compared between before-and-after dredging events, separately for the dredged (CSII-BA) and non-dredged (CSII) portions of Canaveral Shoal II. Sampling data were taken from the first dredging event (fall 2013) compared to the first period post dredging, summer 2014 (N=6); and for spring-summer 2017 before the second dredging event compared to spring-summer 2018 following dredging (N=12).

Weighted mean sediment size increased in CSII-BA samples after the first dredging event but not in CSII (Table 11-12). Bull Shoal also showed no significant change in sediment size following the first dredging event but Chester Shoal exhibited an increase in sediment size (significant decrease in ϕ) following the first dredging event (Table 11-12) Mean sediment size did not change in CSII-BA, CSII, or Bull Shoals after the second dredging event (Table 11-13), but did increase on Chester Shoal following the second dredging event.

Sediment organic content decreased significantly on CSII-BA, CSII, and Chester Shoal following the second dredging event (Table 11-13), but not following the first dredging event (Table 11-12). Bull Shoal showed no significant change in sediment organic content for either of the dredging events.

Depth did not change significantly at any shoals following either of the dredging events (Tables 11-12 and 11-13), and general biotic parameters (abundance, biomass, species richness, and Simpson's Index of Diversity) showed no change across either dredging event for either CSII-BA or CSII, so were not analyzed for other shoals.

Comparisons of individual taxon groups did not show significant differences before and after the first dredging event. There were only six samples (one season, fall 2013) before dredging within CSII-BA. Comparisons with the season after dredging (summer 2014) and the first fall season post dredging (fall 2014) mostly did not provide sufficient counts or biomass to conduct analyses and, for those that did, none were significantly different (all $P > 0.05$).

The second dredging event in fall 2017 to spring 2018 allowed for longer before-and-after comparisons for CSII-BA, so data from one full year—all four seasons—were compared from fall 2016 to summer 2017, and summer 2018 to winter 2019 (Table 11-14). Haustoriid amphipods were significantly more abundant post dredging than before the second dredging event, but no other taxon differences were detected. The same tests for the same periods at CSII did not show a change in haustoriid abundance (P = 0.3240), nor at Bull Shoal (P = 0.288) or Chester Shoal (P = 0.948). Haustoriid amphipods were the only taxon in the CSII-BA samples for which mean abundance per sample was greater than one, aside from lancelets, *B. virginiae*, in pre-dredging samples, but high variability precluded detecting a difference for lancelets. The polychaete family Oweniidae, dwarf olive snails (Olivellidae) and auger snails (Terebridae) were all present in the post-dredging event and not prior, but no meaningful statistical tests could be performed, and densities were all below 1 per sample. Replacing count data with biomass did not produce different results.

Sediment size in CSII-BA, expressed as weighted mean phi, decreased significantly over the inter-dredging sample period, spring 2014 to summer 2017, but the regression accounted for only a small part of the variability ($r^2 = 0.129$, Table 11-15), and the slope was negligible, with a linear relationship providing the best fit. Since phi is a negative exponent of size, the mathematical relationship was positive:

$$y = 0.0003x + 0.607 \tag{11-5}$$

where y = weighted mean sediment size phi and x = days since the last dredge event. If seasons (1 through 14) were used as an interval instead of days, the r^2 was nearly the same (0.127).

Sediment size expressed as phi did not change significantly at CSII for spring 2014 to summer 2017, but a weak negative trend (increase in mean phi) was detected for the same time period at both Bull and Chester Shoals (Table 11-15). These results matched the CSII-BA trend in direction but explained even less of the variability.

Sediment proportional organic content increased over the same spring 2014 to summer 2017 period at CSII-BA, again with the linear relationship providing the best fit, albeit still low ($r^2 = 0.181$, Table 11-15):

$$y = 5 \cdot 10^{-6}x + 0.006 \tag{11-6}$$

where y = mean sediment proportional organic content and x = days since the last dredge event (Table 11-15). The same increase was observed at all other shoals, including CSII (Table 11-15), but the regression coefficient r^2 was below 0.1 for CSII and Bull Shoals. At Chester Shoal, an exponential model provided the best fit to the data (r^2 = 0.161):

$$y = 0.0063log_e(x) \tag{11-7}$$

Depth, general biotic parameters (invertebrate abundance and biomass, species richness and Simpson's Index of Diversity), and abundance of most major taxa showed no significant trends with time in CSII-BA for the same interval (Tables 11-15, 11-16). The regression coefficient (r^2) was statistically significant for the bloodworms (Glyceridae), spaghetti worms (Terebellidae), and dwarf olive snails (Olivellidae), but were based on scant data and was extremely weak, i.e., below 0.1 (Table 11-16). For all other taxa, including amphipods and lancelets, for which n > 100, no significant trends were detected. Changing the independent variable from sequential day to sequential season did not affect which relationships were significant.

11.4 Discussion

11.4.1 Physical and General Biotic Factors

Depth characteristics of the study shoals were consistent: ridges were significantly shallower than swales (Table 11-2); the most seaward shoal (Bull Shoal) was the deepest (Table 11-4); CSII-BA (the dredged borrow area) was about a meter deeper than CSII (the non-dredged portion) (Table 11-5); and season had no effect on depth of these features (Table 11-3). Effects of depth on biota (or the lack thereof) are discussed below in Section 11.4.2.

The Krumbein ϕ (phi) log transformation of sediment size is designed to make statistical comparisons possible when considering unsorted sediments ranging from clay to boulders (Krumbein 1937). The sediments offshore from Cape Canaveral tended to be well-sorted and were mostly sand with moderate levels of mud or gravel-sized biogenic material (shell fragments). Using the CMECS system (FGDC 2012), most sediments were classified as sand (S) or muddy sand (mS), sometimes with biogenic material. This provided only a narrow range of categorical data to analyze functional relationships against (e.g., invertebrate density as a function of sediment classification), and the continuous data provided by weighted mean sediment size (Strömgren 1974) provided a greater and therefore more useful range of values for analyzing these relationships.

Both measures of sediment size (untransformed and log-transformed) showed a significant decrease in swales compared to ridges (Table 11-2) but, since ϕ is a negative exponent, it visually appeared to increase with depth. This was born out by the linear relationship between depth and sediment size (Figure 11-6), but the relationship had high variability and therefore had little predictive value (r^2 = 0.111). Neither measure of sediment size differed across seasons (Table 11-3), but sediments were significantly larger at Bull Shoal than either of the other two sites, and ϕ values were the highest (indicating the finest sediments) at CSII (Table 11-4). Sediments were significantly coarser in the dredged area of CSII despite it being slightly deeper (Table 11-5).

Abundance and biomass (converted to values·m^2) of all benthic and infaunal invertebrate taxa combined showed no significant differences between ridges and swales (Table 11-2), but specific taxa did differ (Table 11-8). Season had a strong effect on abundance (Table 11-3), and abundance also differed across shoals. Canaveral II-All had significantly lower abundance compared to Bull or Chester Shoals; however, CSII and CSII-BA were not different (Tables 11-4 and 11-5). In contrast, invertebrate biomass did not differ among seasons or shoals, most likely due to the high degree of variability observed. The only exception was CSII-BA, which had lower biomass than CSII when summarized shoal-wide (Table 11-5).

Species richness—a count of all taxa—is the simplest index of species diversity. Simpson's Index of Diversity is one of the most widely used and least likely to be criticized (Cox 1996; Brower et al. 1998), and it attempts to incorporate evenness, or the relative abundance of species, into the diversity. Two samples might share a species richness of 10 species, but if one sample has 82 of Species A and only 2 each of species B through J, it will exhibit high dominance by Species A and have a low Simpson's Index *D*. The samples in this study tended to be dominated by low numbers—often single individuals—of each taxon, so *D* was usually high. This result led to species richness often being a more sensitive index of species diversity in these samples than Simpson's Index. The latter was able to detect a greater diversity in swales than ridges (Table 11-2), but not between seasons, shoals, or dredged and non-dredged parts of Canaveral Shoal II. In contrast, species richness not only showed higher diversity in swales (a mean of 8.8 species versus 6.3 on ridge) but also detected highest diversity in summer (Table 11-3) and lowest on CSII-All (Table 11-4), with the dredged portion (CSII-BA) lower than the non-dredged portion (CSII) (Table 11-5).

11.4.1.1 Summary of Physical and General Biotic Factors

Overall, the entirety of Canaveral Shoal II (CSII-All) was shallower than the other shoals and had finer sediments, with lower benthic invertebrate abundance, biomass, and species diversity (richness or Simpson's Index) than the other shoals. Within CSII-All, the dredged area (CSII-BA) was significantly deeper and had significantly coarser sediments, significantly lower sediment organic content, significantly lower invertebrate biomass, and significantly lower species richness than the non-dredged portion (CSII). These findings indicated that CSII-BA had some overall differences compared to CSII. Whether these differences could be directly ascribed to dredging events is assessed in Section 11.4.3 below.

11.4.1.2 Physical and General Biotic Factors: Biomass Considerations

Biomass in this study was estimated using blotted wet weight, because dry weight or ash-free dry weight would require destruction of the samples. Wet weights could have been converted to dry weight using previously developed broad taxon estimates (Ricciardi and Bourget 1998), based on reviews of 42 earlier sources (many of which are difficult to track down), but even those did not approach the diversity observed in the samples in this study. Moreover, broad summaries for groups of taxa, even those in the same phylum and feeding on the same material, can result in different conversion factors. For example, Oweniidae, a small but common suspension-feeding polychaete in this study, consumes seston from the water column, but Magelonidae feeds on deposited material (mostly seston that has dropped out of the water column) by ingesting the sediment (Rouse and Pleijel 2001). The latter will have, in addition to plankton in its gut, sand grains, which would result in a different ash-free dry weight than a similar-sized Oweniidae. Eighty-two taxa across 24 Bivalvia families and 34 taxa across 16 Gastropoda were collected, most of which have not been examined for shell-tissue ratios, but Tellinidae and Semelidae, for example, have thin shells and long siphons, while Arcidae and Glycymeridae have thick shells and short siphons (Mikkelsen and Bieler 2008). Few of these groups have been examined for ash-free dry weights and biomass conversion; in particular, biomass conversion studies conducted on free-living bryozoans (Cupuladriidae) that were the most abundant taxa in this study (Table 11-7) were not available.

Ash-free dry weight as an index of biomass is not without its own bias. Mineralized skeletons are unavailable as a source of nutrition to most predators, but they still represent a measurable part of the energy budgets of the organisms that produce them (Wu and Levings 1978; Vahl 1981). Eliminating mineralized skeletons from biomass estimates would, therefore, underestimate energy flow from primary producers to consumers.

Wet-weight conversions of small benthic invertebrates were beyond the scope and budget of the present study but would make a worthwhile additional project for use by future researchers, and they should, ideally, be accompanied by energy budgets that include the metabolic cost of the skeleton. More samples would need to be collected; however, in many cases, the sample sizes collected in the present study were insufficient to produce repeated ash-free dry weight estimates. For example, 467 specimens of Oweniidae (mainly *Owenia fusiformis*) were collected in 164 samples but their combined wet weight across 6 years of the study was under 4 grams, while 684 specimens of the amphipod *M. floridana* across 307 samples had a collective wet weight of less than 2 grams (Table 11-7). At those masses, dry weights and ash-free dry weights would be below the precision thresholds of standard methods (Cox 1996) and would require specialized techniques and equipment.

11.4.2 Taxon Abundance and Diversity

Depth, sediment grain size (ϕ), and sediment organic content all predicted abundance (count data) of at least some benthic invertebrate species or groups (Table 11-6). Depth and sediment size each predicted about the same number of taxa, which was to be expected given that sediment size was related to depth. Every single taxon, in fact, showed a significant relationship to at least one of those two factors. On the other hand, the majority of these relationships were so weak (r^2 usually below 0.1) as to lack any useful predictive value, and the few relationships above that threshold for the molluscan families Tellinidae, Nassariidae, and Terebridae exhibited only modest slopes (Equations 11-4, 11-5, and 11-6). Sediment proportional organic content had even less predictive value, with fewer significant regressions than for depth or sediment size, and none with $r^2 > 0.1$. These low values were not for lack of data as over 1,000 individuals of lancelets (*B. virginiae*), amphipods (Haustoriidae), and free-living bryozoans (*R. doma*) were collected, but none of them exhibited a relationship with depth, sediment size, or organic content of $r^2 > 0.1$.

Chi-square goodness-of-fit analysis proved an effective way to test smaller subsets of count data, for which there were sometimes low values. Most groups differed between ridge and swale samples, and abundance was usually higher in swales, but the amphipod *Metharpina*, isopods, sand dollars, and lancelets—the latter being the single most abundant species in the study—were higher in swales (Table 11-8, Figures 11-12 to 11-16). Winter was usually the season of lowest abundance and was, at the very least, never the season of high abundance (Table 11-9, Figures 11-12 to 11-16). Summer was the season of highest abundance for several suspension- or deposit-feeding polychaete families (Opheliidae, Oweniidae, and Terebellidae), the amphipod *M. floridana*, isopods, brittle stars, and lancelets, but the suspension-feeding Spionidae (polychaetes) and Haustoriidae (amphipods) were both most abundant in spring, while all snail groups (Nassariidae, Olivellidae, and Terebridae) and sand dollars were most abundant in fall. Season, therefore, likely reflected the various life cycles and growth rates of different taxa.

Bull Shoal had the highest abundance of 10 out of the 21 taxa tested by goodness of fit, followed by Chester Shoal with 5 taxa (Table 11-10, Figures 11-17 to 11-21). Spaghetti worms (Terebellidae), bivalves other than Tellinidae, and auger snails (Terebridae) were all more abundant at CSII-All than at the other shoals. CSII-All had the lowest abundance for seven taxa, but that was comparable to Bull Shoal, while Chester Shoal had the lowest abundance of four taxa. There were taxon and abundance differences between CSII-BA (dredged) and CSII (non-dredged), even though they were unaffected by dredging events (see Section 11.4.4). When data were combined across all 6 years of sampling, 15 out of 21 taxa had significantly different abundances between CSII-BA and CSII. Of those differences, amphipods (Haustoriidae and *M. floridana*), sand dollars (Mellitidae), and lancelets (*B. virginiae*) were all more abundant at CSII-BA (Table 11-11, Figures 11-17 to 11-21).

11.4.2.1 Summary of Taxon Abundance and Diversity

There were no broad generalizations that could be made about taxon diversity across shoals, unlike for physical factors or general biotic factors. For some taxa, abundance was highest at CSII-All and, even within that shoal, several taxa—amphipods, sand dollars, and lancelets—were more abundant at CSII-BA (dredged) compared to CSII (non-dredged). It is possible, therefore, that no single benthic invertebrate taxon, or even group of taxa, is a reliable indicator of dredging impacts. If there was any invertebrate group that could be used as an indicator, the case was strongest for haustoriid amphipods, which, in addition to being more abundant at CSII-BA (dredged) relative to CSII (non-dredged), showed an increase post-dredge in 2018 (Table 11-14).

11.4.2.2 Taxon Abundance and Diversity: Taxon Diversity Considerations

Species richness is defined simply as the number of species in a given area (Cox 1996). The measure used in this study was more properly *taxon richness*, because it represents the diversity of the lowest taxonomic level to which we were able to identify an organism. Ideally, the two terms meant the same thing, but there were potential errors that could either inflate or deflate richness values, the most common of which were uncertainty in identification and cryptic taxa.

Uncertainty in species identification may inflate apparent species richness in some cases and deflate it in others. Several species of sand dollars (Mellitidae) are reported for the study area (Hendler et al. 1995), but small juveniles in the present study could not be resolved past genus and, sometimes, family. All adults were either *Mellita isometra* or an *Encope* species, but the possibility that the juveniles were of a different species (which subsequently died out or migrated out of the sample area) could not be ruled out. A sample with a range of sizes, therefore, would be recorded as *M. isometra* plus *Mellita* sp., even if all of them were the former. This was an example of potential species richness inflation. In the same example, a lack of reliable characters to separate *Encope aberrans* and *E. michelini* could result in species richness deflation.

The phylum Nemertea represents the most difficult case of the above problem with species identification. Ruppert and Fox (1988) list more than a dozen nemertean species for the study area, but identification was based mainly on characters that did not survive collection. Most specimens fragmented rapidly when collected, even if we obtained the whole specimen to start with and, given their small diameters, small fragments may not have been retained by collection sieves. On rare occasions, what appeared to be stylets were observed, but, given that we did not have all parts of most specimens, the possibility that all specimens possessed stylets could not be ruled out. No cost-effective means (i.e., not hiring outside consultants or developing a molecular genetic database) could be found within the scope of this project, so Nemertea, which were collected in 185 out of 864 samples, probably resulted in a slight decrease in species richness estimates.

Cryptic taxa are species that cannot not be differentiated from similar, closely related species, either because there are no morphological characters separating them, or because known or suspected species differences have not been resolved. Juvenile mysids (Crustacea: Mysidae) were an example of the former during this study, and the scorched mussel *Brachidontes* c.f. *B. exustus* provides a well-documented example of the latter. *Brachidontes* c.f. *B. exustus*, a common east Florida marine bivalve mollusk (although it did not occur in benthic grab samples) is now known to comprise multiple undescribed and poorly resolved species (Lee and Ó Foighil 2004). The result of cryptic species is a potential decrease in species richness values.

Taxonomic changes published or that became accepted during the project were common; for example, the genus *Angulus* (Bivalvia: Tellinidae) used in Mikkelsen and Bieler (2008) was suppressed in the Western

Atlantic in favor of *Ameritella* (WoRMS 2019). These changes, however, would exchange species-for-species and therefore did not affect species richness estimates.

11.4.2.3 Taxon Abundance and Diversity: Taxon Count Considerations

The definition of benthic and infaunal invertebrates in the present study included a size constraint, defined by the 1.4 mm (ϕ = -0.5) sieve. Early efforts to use a 0.5 mm sieve (ϕ = 1) resulted in retaining nearly all sediments, which was prohibitive for sorting. Invertebrates that passed through the 1.4-mm sieve as a result of small size were therefore not included in the study.

Lancelets created a problem that was resolved (see Section 11.2.2), but the solution relied on sampling teams observing lancelets in the sample at the outset. This was feasible if the lancelets were large (> 1 cm), but small lancelets might not have been observed if there were no larger lancelets present. It was also possible some small lancelets passed through even the 0.5-mm sieve, and lancelets may have been even more abundant than our high counts determined. Polychaete annelids and ribbon worms (Nemertea) were frequently smaller in diameter but were usually caught in the first sieve, even when additional sieving was required; this was probably because their bodies were softer and rougher than lancelets. Most other invertebrates had rigid bodies, and sampling them would be a direct function of sieve size.

Small invertebrates posed a potential source of count error if they would normally pass through a sieve but adhered to or were trapped between sediment particles that were retained. Some taxonomic groups (e.g., harpacticoid copepods) clearly fell outside the size range of interest and the occasional individual in samples was not included in counts. For other taxa, it was harder to make that determination, such as juvenile instars of abundant amphipods, so it is possible some were counted that would have normally gone through the sieve. Epifauna were not common in this study but could occur; examples of very small taxa included *Polydora* worms (Spionidae) that bored into shells and ectoprocts (Phylum Ectoprocta) attached to shells.

11.4.3 Discussion of Dredging Events

11.4.3.1 Comparisons of Sediment Around Dredging Events

There were changes in sediment particle size on CSII-BA around the time of dredging, but it could not be linked to dredging. Sampling was able to detect a significant increase in mean sediment particle size (decrease in ϕ) in the dredged area (CSII-BA) in the summer following dredging, compared to fall before dredging in 2013–2014 (Table 11-12), but not in the adjacent CSII (non-dredged) (Table 11-13). The post-dredging increase in sediment size in CSII-BA was consistent with results of between-shoal comparisons, showing coarser sediment at CSII-All overall (Table 11-4) and coarser sediments within dredged (CSII-BA) compared to non-dredged portions (CSII) (Table 11-5). Bull Shoal also did not see a change in sediment size after either dredging event, but Chester Shoal (a reference shoal) did show an increase in sediment size, comparable to CSII-BA, after the 2013–14 dredging events (Table 11-12). This indicated that there were changes in sediment size that were occurring naturally on the shoals and that these changes could therefore not be directly attributed to a dredging event. Moreover, Chester Shoal showed a similar increase in sediment size after the 2017–18 dredging event, even though none of the other shoals, including CSII-BA, showed a change in sediment size. Fall and summer were different seasons with potentially different wave energy and therefore sediment sorting regimes (see Chapter 2) (although CSII and Bull Shoal did not show a fall-to-summer change), but the 2017–18 sample periods matched spring-summer seasons. The most parsimonious conclusion was that sediment grain size did change, but it did so locally and independently of dredging. Whatever changes occurred on CSII-BA, moreover, did not spill over to the adjacent non-dredged CSII.

Sediment organic content, like sediment mean grain size, sometimes changed before and after dredging events, but could not be linked to dredging. A change in sediment proportional organic content was not detected after the first dredge event, but sediment organic content decreased significantly following the second dredging event in samples from CSII-BA, CSII, and Chester Shoal (Table 11-13). No significant changes in sediment organic content occurred after the first dredging event at any shoal (Table 11-12), or at Bull Shoal after either dredging event. The logical conclusion was, again, that sediment organic content could change but did so locally and independently of dredging. This inference was strengthened by the fact that shortening the test interval to a single season before-and-after dredging (which should have made the data more responsive to the dredging event) or lengthening the test interval to a full year to increase data did not result in any changes to the above before-and-after dredging comparisons.

The interval between dredging events, treated as a continuous recovery period (return to a prior state) showed results for sediment size and organic content comparable to before- and post-dredging comparisons, in that trends could occur but they were independent of dredging. The between-dredging period allowed for 1,297 days (spring 2014 to summer 2017, or 14 seasons) for change in physical characteristics if there was to be a return to a prior state at CSII-BA. Depth did not change at CSII-BA, but sediment size calculated as ϕ slowly decreased over time (Table 11-15). A small amount of the variability was accounted for by the relationship ($r^2 = 0.129$), but the results were consistent with the finding that sediments in CSII-BA (dredged) tended to be coarser than in CSII (non-dredged) (Table 11-5), and that sediment particle size increased following the first dredging event (Table 11-12). Sediment grain size at the non-dredge portion (CSII) did not change significantly over the same time period, but it decreased at both Bull and Chester shoals (Table 11-15). Sediment organic content increased significantly over the inter-dredge period at all shoals, although the r^2 exceeded 0.1 at only CSII-BA and Chester Shoal (Table 11-15). Sediment size and sediment organic content results for the inter-dredging period were consistent with the finding for before- and post-dredging comparisons of sediment size (discussed above), in which patterns at CSII-BA are matched at shoals physically distant from the dredging.

11.4.3.2 Comparisons of Biotic Factors Around Dredging Events

No general biological factors—including invertebrate abundance, biomass, species richness, or Simpson's Index of Diversity—differed before or after either dredging event at either CSII-BA or CSII (Tables 11-12, 11-13). Changing the sample period from two matching seasons before and after the second dredging event to four seasons before and after did not change any results.

Taxonomic data before and after dredging events were seldom able to indicate an impact from dredging, although this was sometimes a consequence of sampling limits. There were insufficient count data for most taxa for before-and-after comparison tests for the first dredging event (2013–14), and the few taxa for which there were—amphipods and sand dollars—did not show an effect. Season affected species biological factors (Tables 11-3, 11-9), so fall 2013 was also compared to fall 2014 (the first fall sampling event after dredging), but this was similarly unable to detect any differences for any taxa. One full year of CSII-BA species count data before (fall 2016 to summer 2017) and after (spring 2018 to winter 2018/19) the second dredging event were compared in order to get sufficient count data for statistical analysis. Most taxa had sufficient counts for statistical analysis, but only one—the amphipod family Haustoriidae—showed a significant effect, being higher following the second dredging event than before (Table 11-14). The Haustoriidae result was consistent with haustoriid amphipods generally being more abundant in CSII-BA than in CSII (Table 11-11, Figure 11-20). Moreover, comparisons of the same time periods at the non-dredged portion of Canaveral Shoal II (CSII) and both Bull and Chester Shoals showed no comparable change in haustoriid amphipods. Therefore, if there was a taxonomic indicator for dredging impacts, it was found in haustoriid amphipods. These amphipods were small, abundant, and fast-moving, and could have responded rapidly to disturbance.

Biological data for the inter-dredge period proved amenable to regression analysis, but it did not follow that the trends detected were meaningful. Bloodworms (Glyceridae), spaghetti worms (Terebellidae), and dwarf olive snails all showed significant trends (increases for bloodworms and spaghetti worms but a decrease for dwarf olive snails); however, in all cases, sample sizes were very small and $r^2 < 0.1$, indicating that a high degree of variability in the relationship. The lack of trends among other taxa was not for lack of data, however, because abundant taxa such as amphipods and lancelets ($n > 100$, Table 11-16) did not show trends over the between-dredging period.

Several hurricanes and tropical storms passed near Cape Canaveral during the study (Chapter 1, Table 1-3). The timing of these are indicated along with temporal trends in benthic and infaunal invertebrate abundance, biomass, species richness, and Simpson's diversity index (Figures 11-6 to 11-9, respectively). There were no visible trends or tendencies in any of the above factors following storm events. Storm events, like dredging, may displace benthic invertebrates, but they do not remove them entirely, so storm effects may be even more transitory than for dredging.

11.4.3.3 Summary of Analysis of Dredging Events

Physical factors (depth, sediment grain size, and sediment organic content) sometimes showed effects around the time of dredging, but there were no effects that were limited to the dredged area (CSII-BA). Sediment size changed in the dredged area following the first dredging event and sediment organic content changed after the second dredging event, but both were matched by similar trends at other reference shoals, including shoals well away from the dredge area. Chester Shoal most closely mimicked the dredged area (CSII-BA) in most changes, but was so far distant from CSII-BA that dredging impacts are highly improbable. Olsen Associates (2014) noted that sediment grain size distributions at CSII-BA did not change over more than a decade of dredging, so neither sediment size nor organic content could be used as an indicator of dredging impacts.

Biological factors, like physical factors, showed little or no effect from dredging by the next sampling season. General biotic parameters (invertebrate abundance and biomass, species diversity) did not differ at either dredged or non-dredged portions of Canaveral Shoal II before and after dredging events, even though they all were more broadly affected by ridge versus swale, season, and shoal. Likewise, most taxonomic groups showed no measurable before-and-after dredge effects, even though ridge versus swale, season, and shoal all significantly affected them. The one exception to the lack of dredge effects was the amphipod family Haustoriidae, which increased significantly in dredged areas following the second dredge event. Some degree of dredging impact was expected to occur—more than a million cubic meters of sand cannot be removed without displacing invertebrates—but unconsolidated, high-energy sandy environments in Florida are inhabited by species that rapidly reassert themselves in dredged areas (Iversen and Beardsley 1974). In addition, the dynamic nature of the sand shoals off the east coast of Florida increase the natural variability of both physical and biotic factors, as evidenced by the relative comparisons with the reference shoals that were not dredged during the study period.

11.5 Conclusions

The term *recovery* in most post-dredging citations refers to return to a former state, as indicated by the presence of specific benthic invertebrate species or species assemblages. Other studies on industrial dredging or comparable disturbance have reported a range of recovery times, attributed to various factors. High water current regimes were more associated with rapid recovery (Iversen and Beardsley 1974; van Dalfsen et al. 2000) than sediment grain size; a fine-grained site in high currents recovered in 1–3 years, but benthic invertebrate communities in comparable sediments with low currents took 5–10 years (Van Der Veer et al. 1985). Benthic invertebrate productivity was also associated with recovery; a Mediterranean site (low productivity) took 4 years to recover while a North Sea site (high productivity) recovered in 2 years (van Dalfsen et al. 2000). The duration of the disturbance—that is, the tendency for physical parameters to return to a prior state—was also associated with benthic invertebrate recovery. A strongly disturbed site in the English Channel (which had high productivity) was not fully recovered even in 4 years, but less disturbed sites elsewhere in the North Atlantic recovered in 2 years (Boyd et al. 2005). Different groups of benthic invertebrate organisms were reported to recover differently; polychaete annelids recovered faster than bivalves (van Dalfsen et al. 2000). Climate change could also affect recovery; if water temperatures or other climate-affected patterns were changing around the time of a dredging disturbance, return to the former benthic invertebrate species was inhibited under otherwise favorable environmental conditions (Hiscock et al. 2001; Hawkins et al. 2008).

The Cape Canaveral study area, as an ecosystem, clearly fits into the high-energy end of the spectrum of prior studies. Shoals were shallow—with most depths under 20 meters and ridges sometimes within 4 meters of the surface—and had no protection from ocean waves or storms. Wave energy was sufficient in that there were fewer days when sampling was possible than when it was not, even in summer. There were measurable changes in sediment grain size and proportional sediment organic content around the location and times of dredging events but, as they were matched by similar changes on reference shoals well away from the dredging, these changes could not be attributed to dredging. They did, however, infer highly dynamic shoal surfaces.

Based on water energy alone, one would predict rapid benthic and infaunal invertebrate community recovery from dredging impacts at Canaveral Shoal II, also reported for another Florida high-energy site (Iversen and Beardsley 1974). Biological primary productivity from the study area was poorly described prior to this study, and all that can be said for certain is that it was higher than regions further offshore (Chapter 6). The impacts of climate change on this area are unknown and complicated by the fact that Cape Canaveral has been described as a biogeographic transition zone for some invertebrates (Saunders et al. 1986; Sarver et al. 1992; Arnold et al. 1996; Lee and Ó Foighil 2004); the presence of various species may therefore change at or around Cape Canaveral for reasons having nothing to do with human impacts or climate change.

There were measurable effects of habitats (ridge versus swale), seasons, and shoals on benthic and infaunal invertebrates. There were differences between the dredged and non-dredged portions of Canaveral Shoals II; amphipods, lancelets, and sand dollars were all more abundant in dredged than non-dredged portions, but 10 other taxon groups showed an opposite trend. The only taxon for which a response to dredging could be inferred, however, was the amphipod family Haustoriidae, which increased in CSII-BA following a dredging event.

All Canaveral benthic and infaunal invertebrate samples in this portion of the study were taken in unconsolidated sand or some sand-gravel or muddy-sand combination, which was the intent since that was the habitat primarily impact by dredging. Sessile invertebrates were small and uncommon; most taxa—from small amphipods to large echinoderms—were mobile and adapted for sandy environments. Even Bryozoa, a phylum for which the vast majority of species are sessile (Ruppert and Fox 1988), was represented in this study mostly by small, mobile colonies. There were infaunal tubeworms, but sessile tubeworms with fixed tubes (e.g., Sabellariidae) were rare in the samples. Most sampled invertebrates, therefore, were likely to be able to reinvade a nearby disturbed area well before the next seasonal sampling event. Thus, while it was highly likely that there were immediate and strong dredging impacts on benthic invertebrates (i.e., localized complete removal), the effects were transient and recovery was rapid.

Lifespan and modes of recruitment may play into dredging impacts in ways the present study was unable to capture. The small size of sand-dwelling benthic invertebrates does not infer short lifespan; if there are dredging impacts, the life of a small species may well span the dredging event and subsequent recovery. In the present study, for example, the most abundant infaunal tubeworm was the small *Owenia fusiformis*, while the most abundant highly mobile species was the lancelet, *Branchiostoma virginiae*, but both can live up to 4 years (Ménard et al. 1989; Stokes and Holland 1995; Stokes and Holland 1996). Lancelets are highly mobile and can recruit (relocate) to a different area at any point during their life, but *O. fusiformis* have lower motility and recruit primarily by larval settlement, not relocation. Most of our *O. fusiformis* specimens were extremely small, so likely represented 0-year-class individuals (Ménard et al. 1989), but some lancelets exceeded 20 mm (Figure 11-10), in the upper size range for that species (Stokes and Holland 1995). In the present study, *O. fusiformis* were significantly more abundant in non-dredged than dredged portions of Canaveral Shoal II, but lancelets showed the reverse. Those patterns were not reflected in before-dredging versus post-dredging comparisons, but specific traits like the timing of recruitment versus individual mobility could complicate impact detection.

Cape Canaveral is a dynamic system, both in terms of physical characteristics and benthic and infaunal invertebrate communities. Few impacts from dredging on benthic and infaunal invertebrates appear to exist, with most changes falling within the natural variability seen across the shoals of the entire Cape Canaveral ecosystem, or recovery occurring too rapidly to be detected by even a robust seasonal sampling design.

11.6 References

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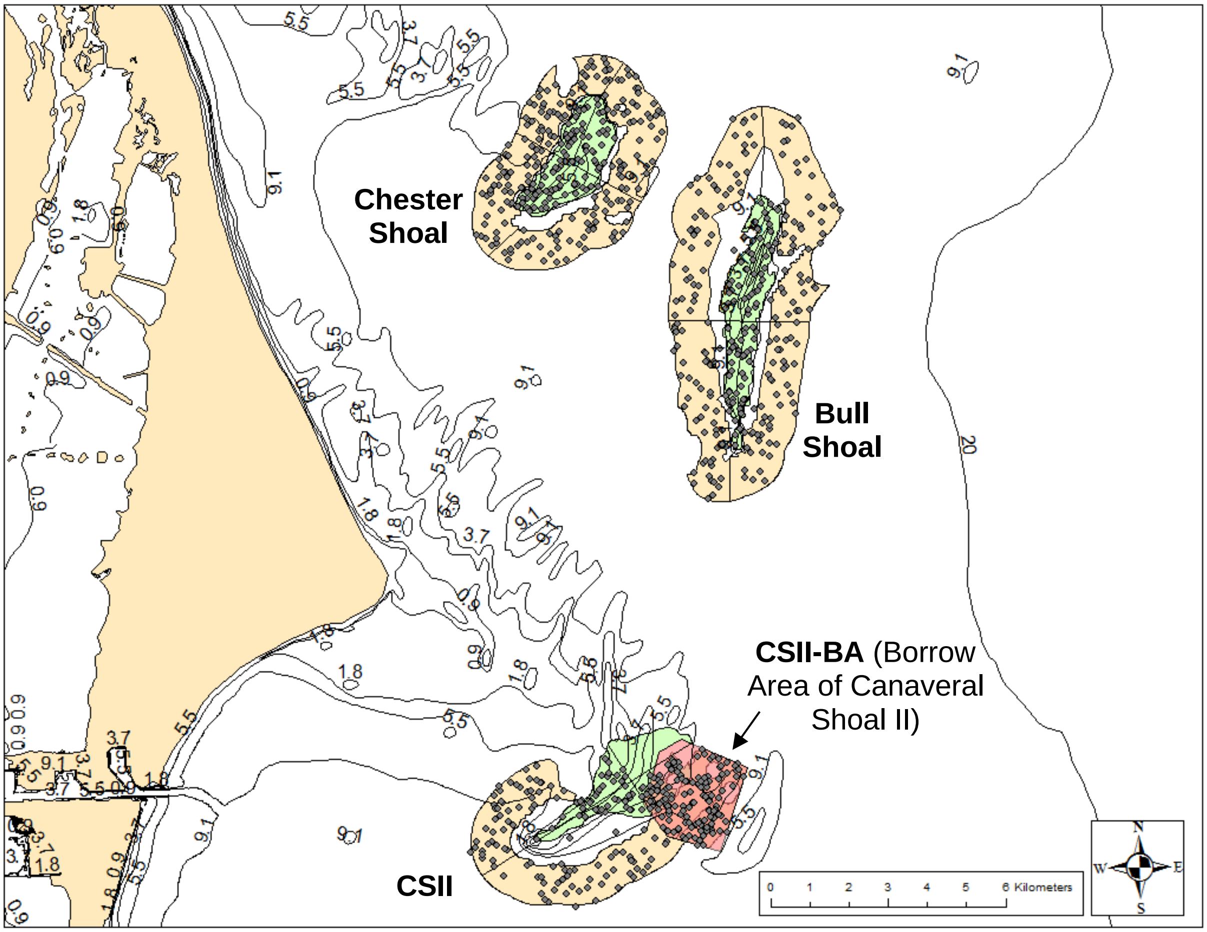

Figure 11-1. Young grab (quantitative benthic grab) sample stations for the study shoals off the east coast of Florida.
Depth contours are in meters.

Figure 11-2. Young grab.
The stabilizing frame diameter is 1 m, and a standard 5-gallon (20 L) bucket is included for scale. The van Veen grab is in the center, attached to a deployment line, with flat weights on either side. Photo: P. Baker.

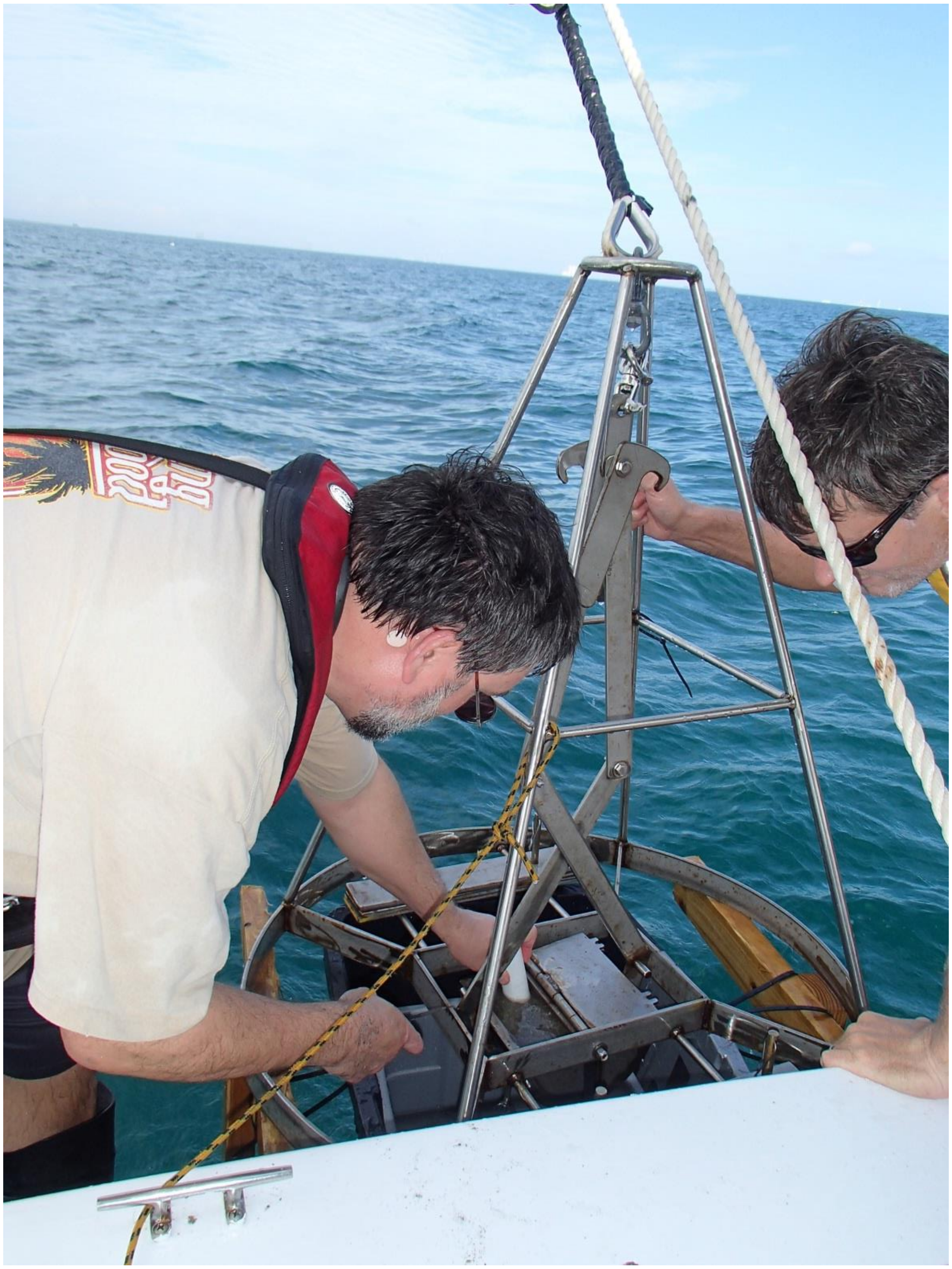

Figure 11-3. Young grab in operation at Canaveral Shoal II in summer 2016.
Photo: C. Frank.

Figure 11-4. Young grab with doors of the van Veen grab open, showing sediment capture.
This is an example of a sample that was rejected because the jaws failed to bite deeply enough into the sediments to capture the full possible surface area. Photo: P. Baker.

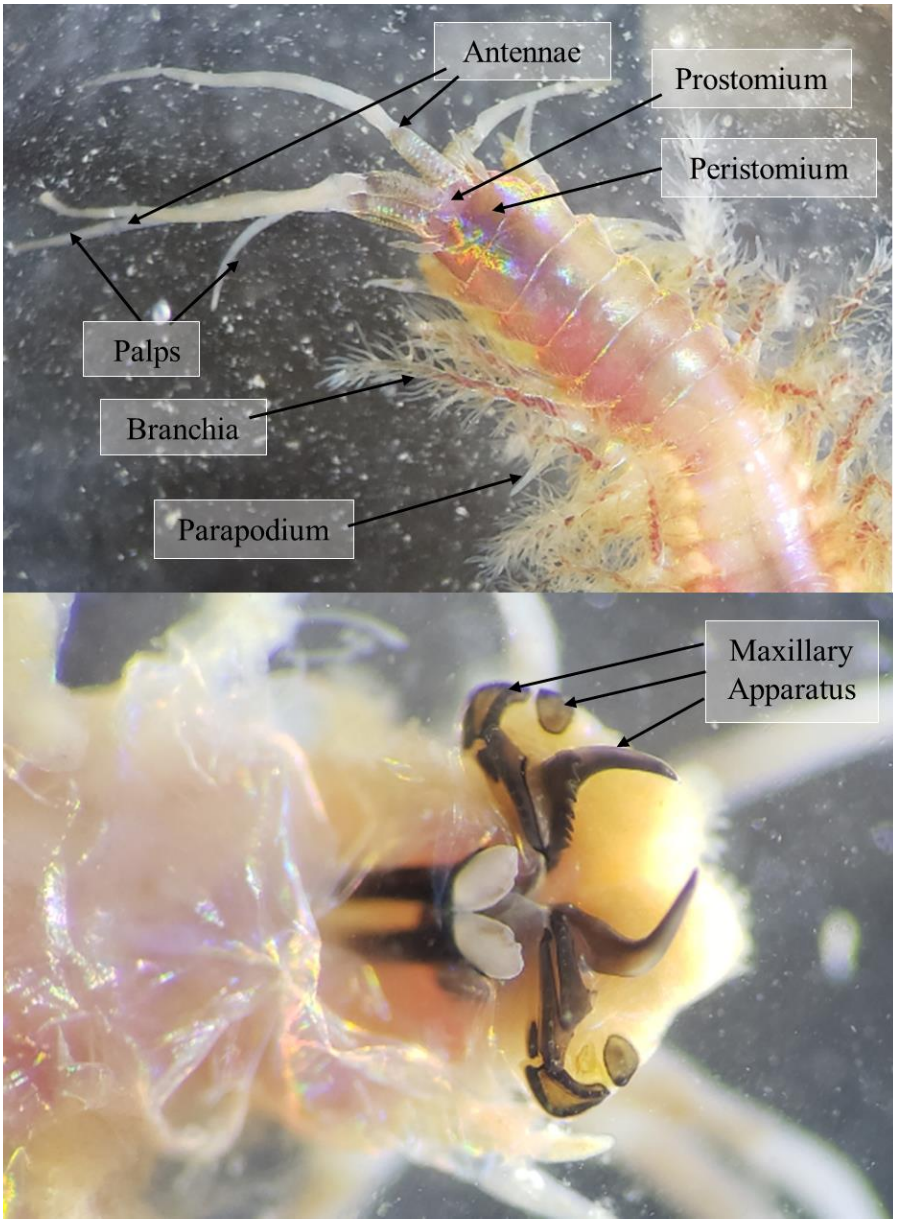

Figure 11-5. Example of a polychaete worm (Onuphidae: *Diopatra cuprea*) from the study (Bull Shoal, swale habitat, spring 2018), showing dorsal side with head and thoracic appendages (top) and ventral view of mouthparts (bottom), all used for identification.
This specimen had been frozen prior to the photograph; diameter of specimen = 4 mm. Photos: C. Frank.

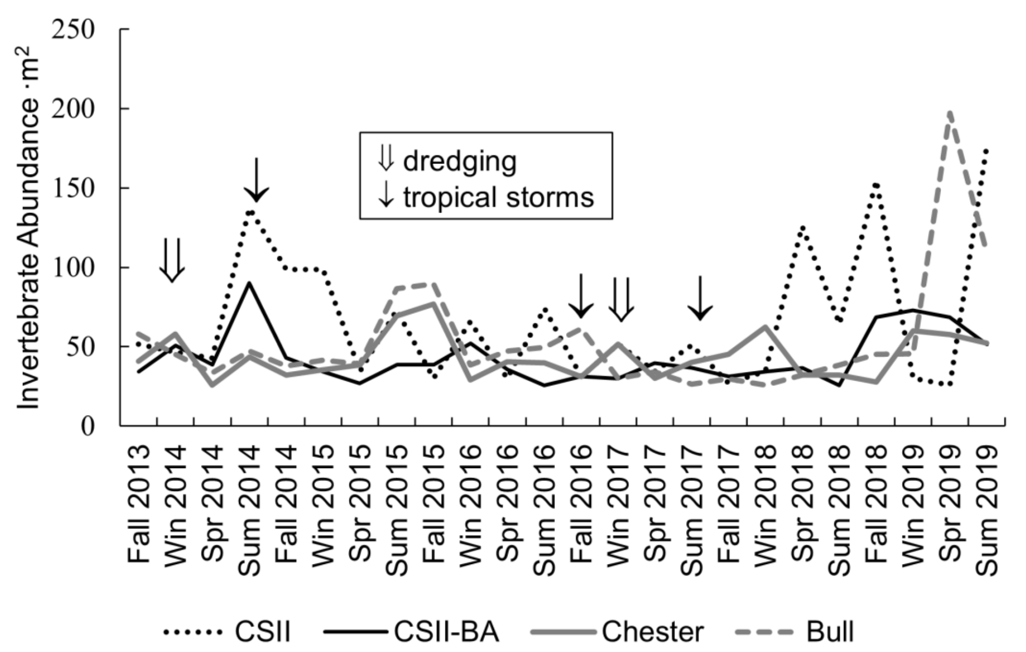

Figure 11-6. Seasonal means for sample invertebrate abundance (individuals·m²), fall 2013 to summer 2019, by shoal.

Values for Canaveral Shoal II (CSII) are divided into non-dredged (CSII) and dredged (CSII-BA). Arrows indicating tropical storms include multiple closely-spaced storms in 2016 and 2017.

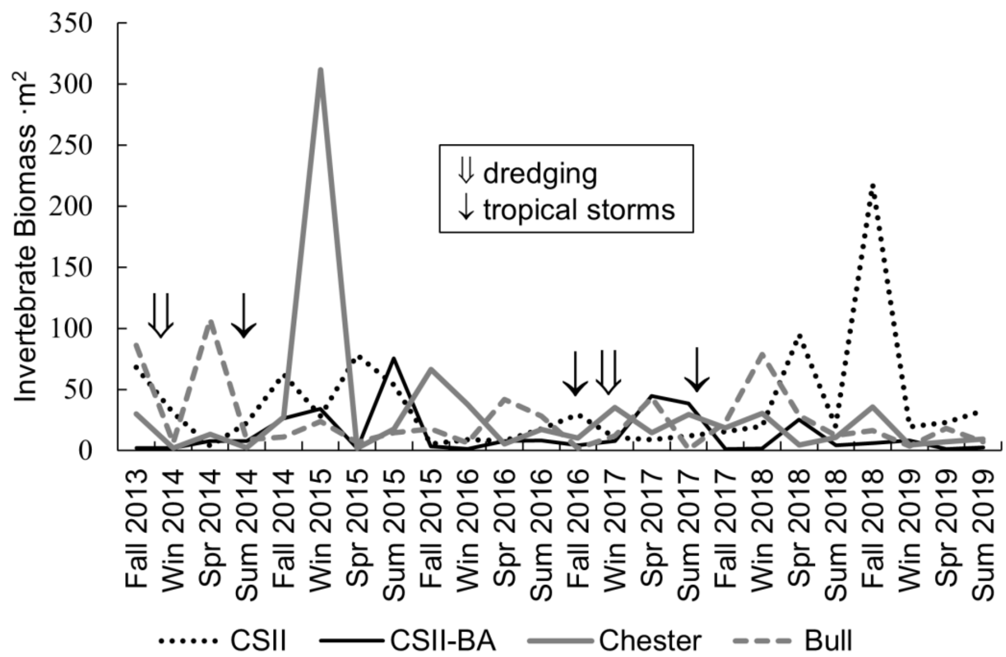

Figure 11-7. Seasonal means for sample invertebrate biomass, fall 2013 to summer 2019, by shoal.

Values for Canaveral Shoal II (CSII) are divided into non-dredged (CSII) and dredged (CSII-BA). Arrows indicating tropical storms include multiple closely-spaced storms in 2016 and 2017.

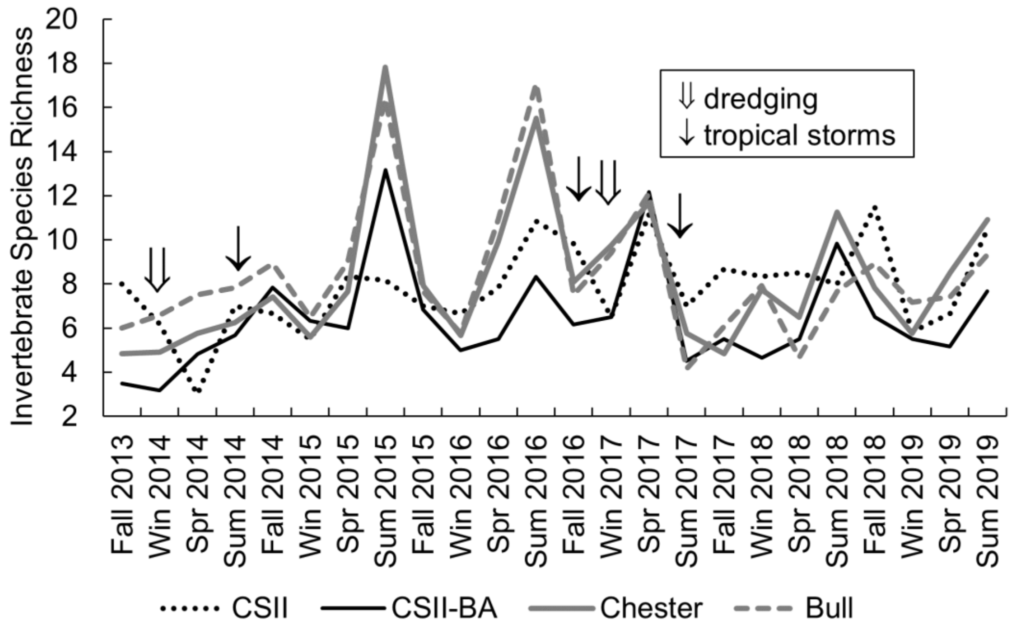

Figure 11-8. Seasonal means for sample species richness, fall 2013 to summer 2019, by shoal.
Values for Canaveral Shoal II (CSII) are divided into non-dredged (CSII) and dredged (CSII-BA). Arrows indicating tropical storms include multiple closely-spaced storms in 2016 and 2017.

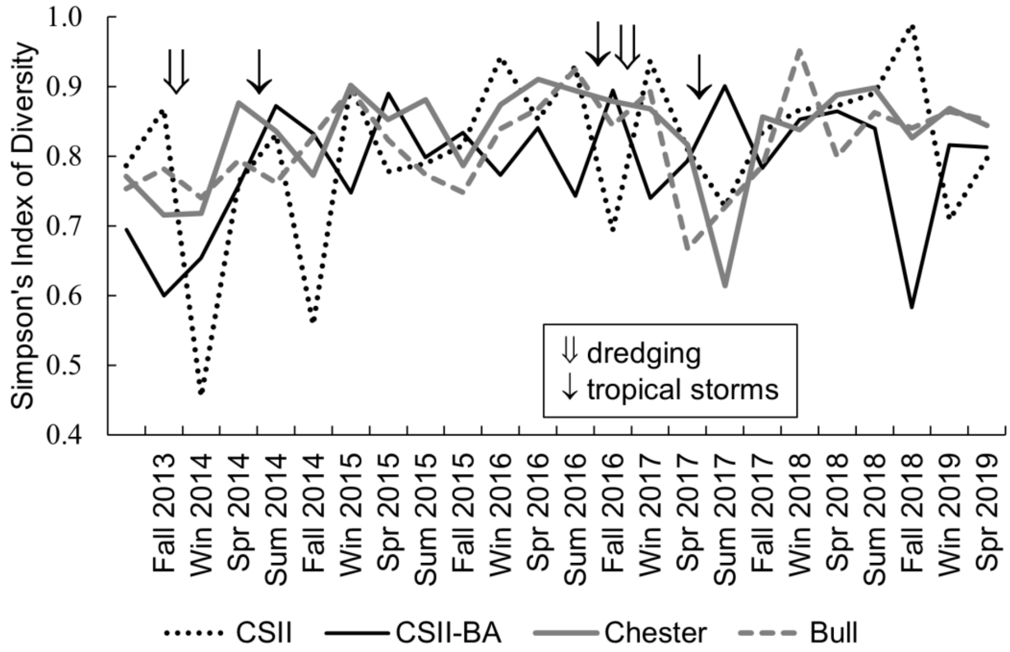

Figure 11-9. Seasonal means for sample Simpson's Index of Diversity, fall 2013 to summer 2019, by shoal.
Values for Canaveral Shoal II (CSII) are divided into non-dredged (CSII) and dredged (CSII-BA). Arrows indicating tropical storms include multiple closely-spaced storms in 2016 and 2017.

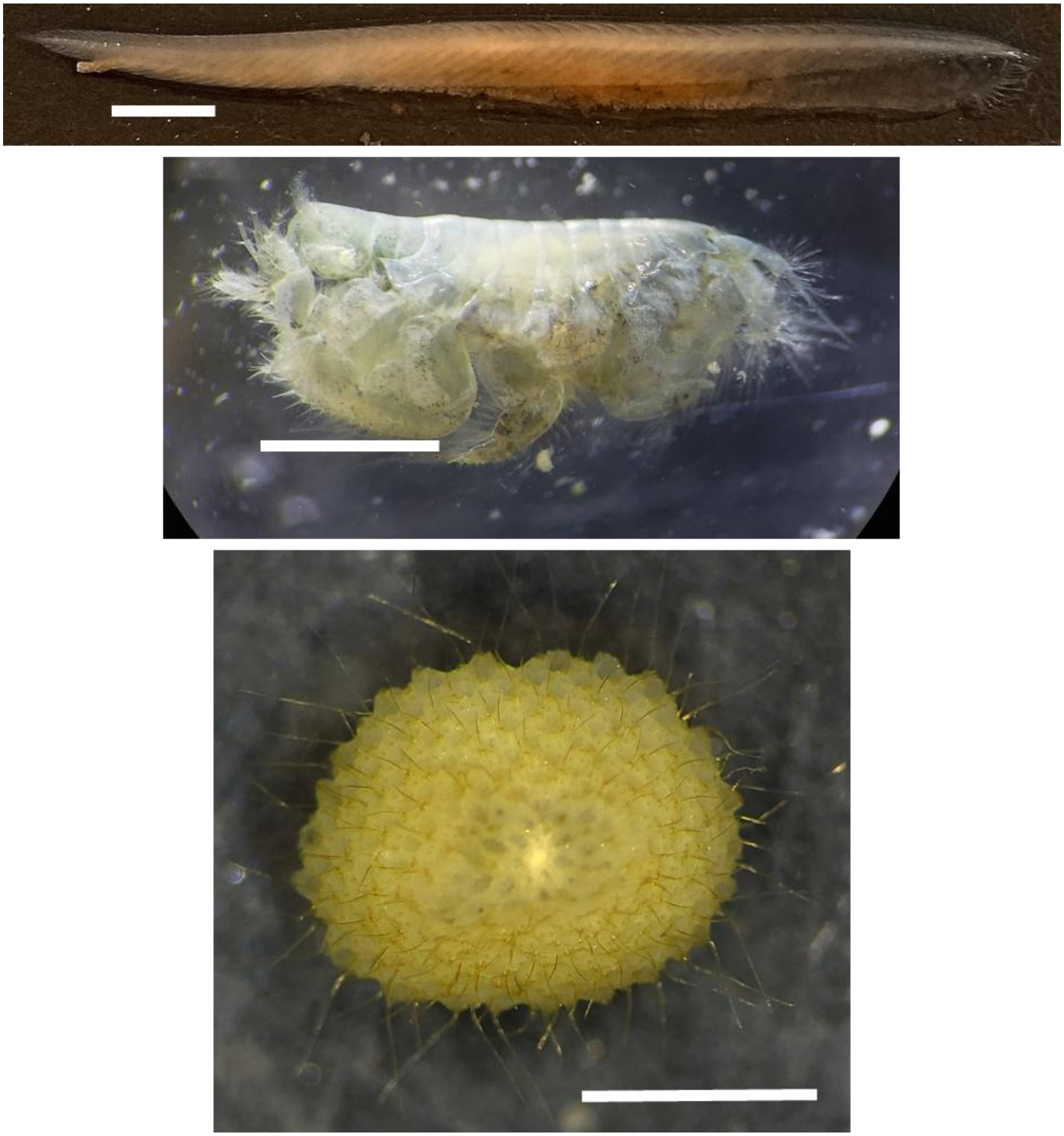

Figure 11-10. The abundant benthic invertebrates in grab samples: a lancelet *Branchiostoma virginiae* (top), a haustoriid amphipod *Acanthohaustorius millsi* (middle), and a free-living bryozoan *Reussirella doma* (bottom).
These specimens were frozen prior to the photographs. The scale bar is 2 mm in each image. Photos: C. Frank.

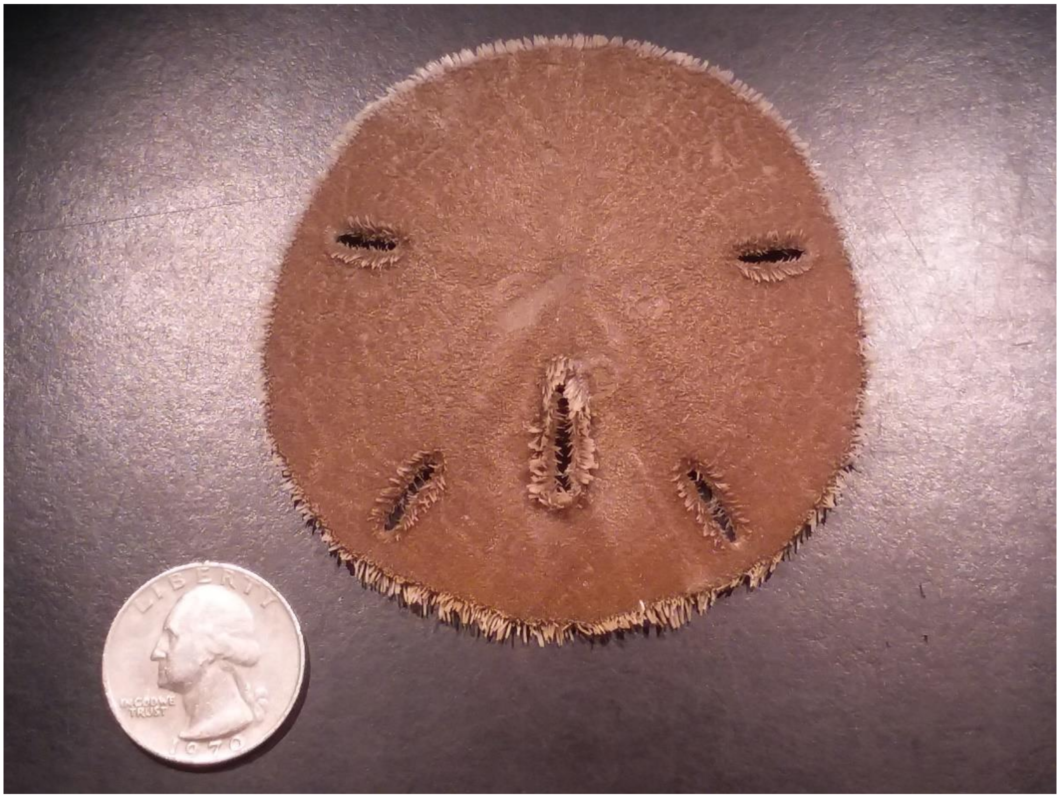

Figure 11-11. Example of a sand dollar (Mellitidae: *Mellita isometra*) from the study (Chester Shoal CSNW-221, fall 2015).
Sand dollars were the largest invertebrate specimens in benthic grab samples. Photo: P. Baker.

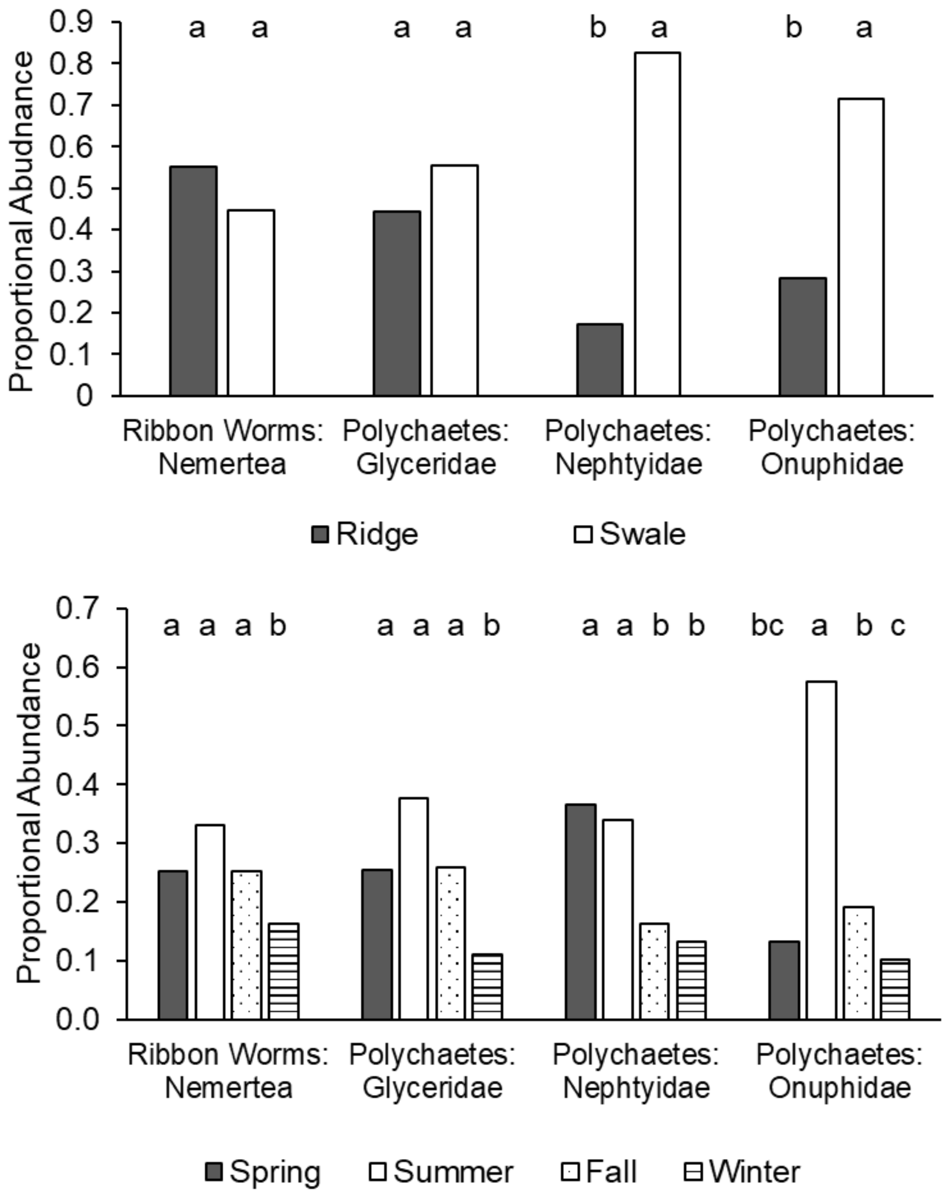

Figure 11-12. Proportional abundance of major groups of predatory and omnivorous worms by ridge versus swale habitat (top) and season (bottom).

Non-significant differences within invertebrate groups are indicated by the same letter.

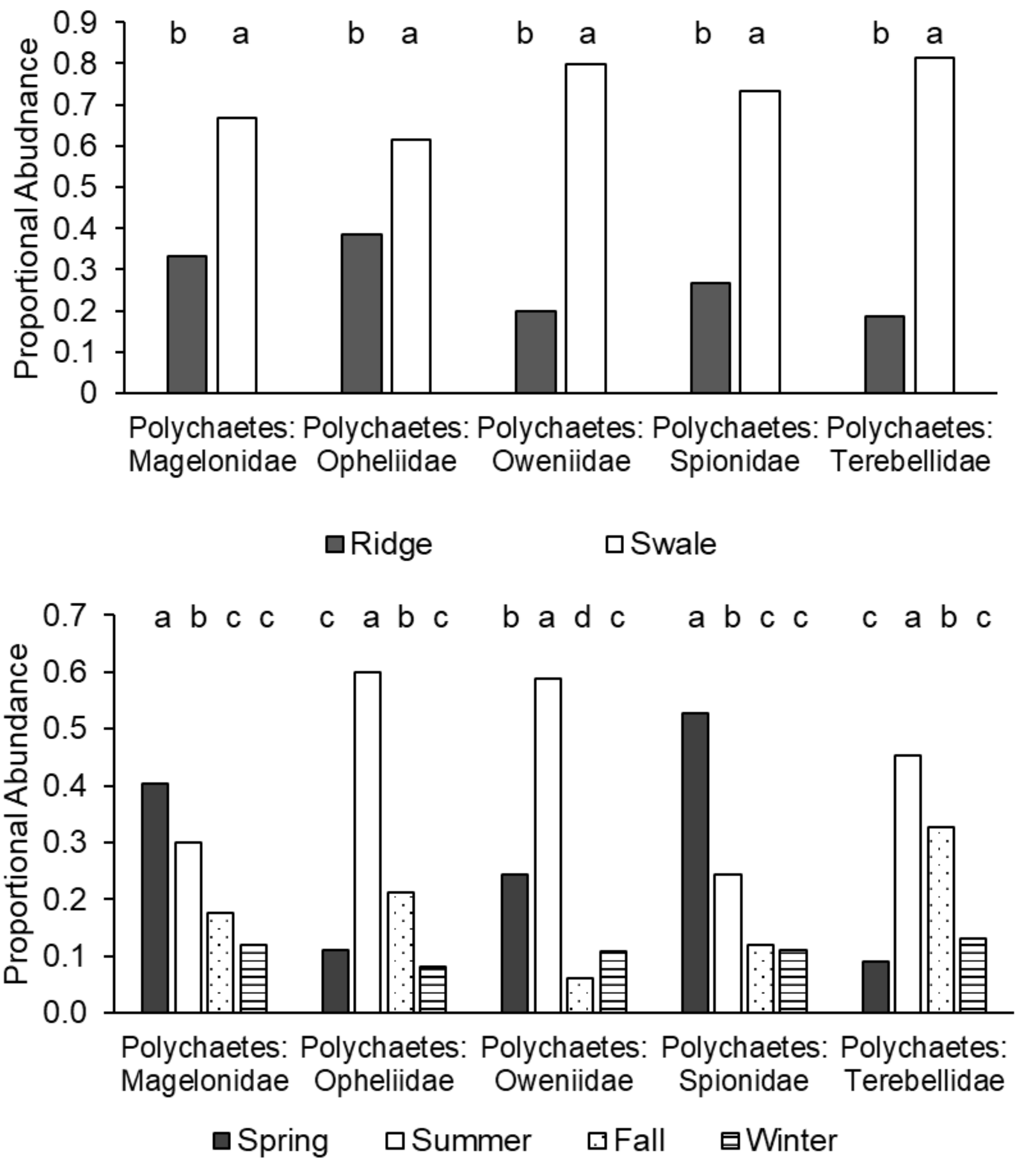

Figure 11-13. Proportional abundance of major groups of suspension- and deposit-feeding worms by ridge versus swale habitat (top) and season (bottom).
Non-significant differences within invertebrate groups are indicated by the same letter.

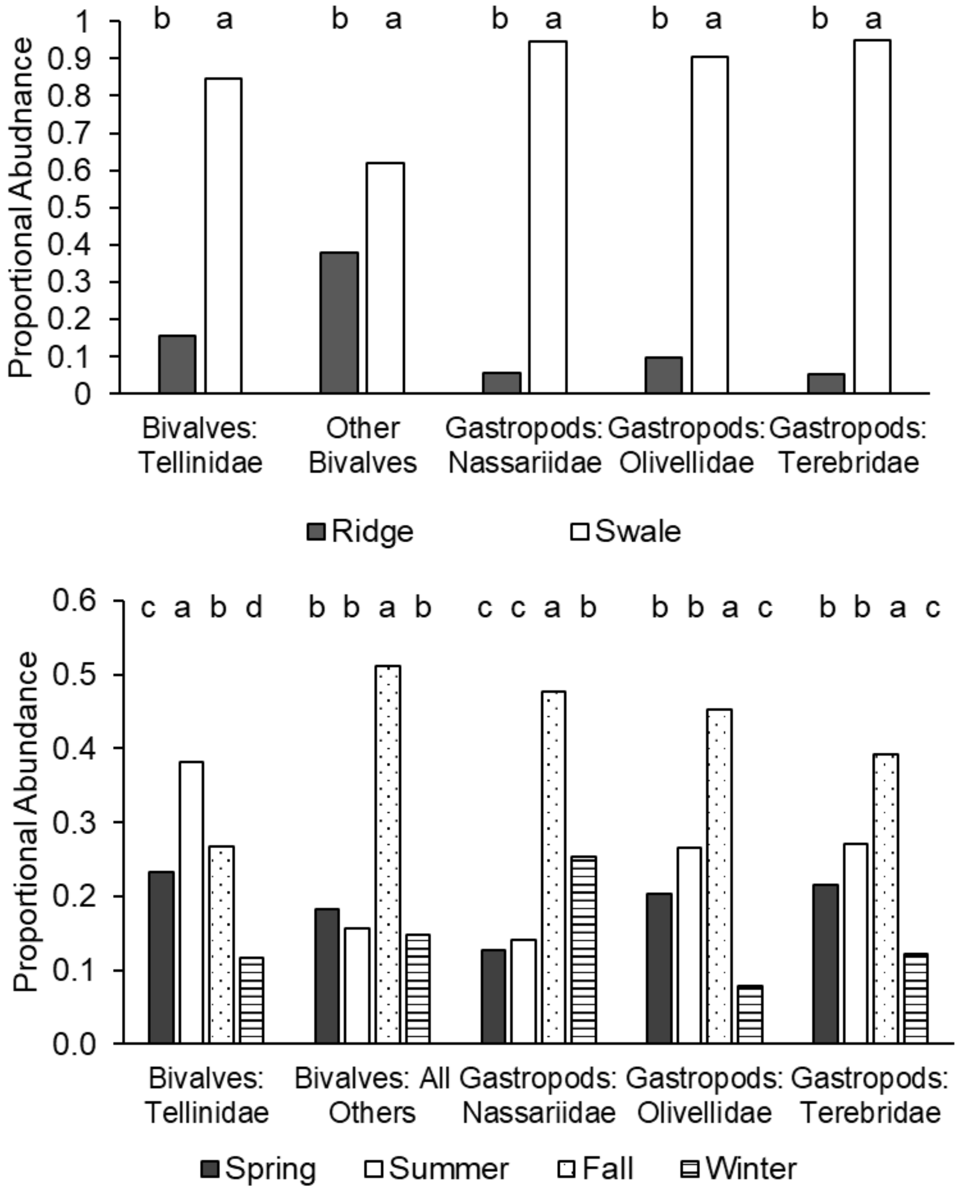

Figure 11-14. Proportional abundance of major groups of shelled mollusks by ridge versus swale habitat (top) and season (bottom).

Non-significant differences within invertebrate groups are indicated by the same letter.

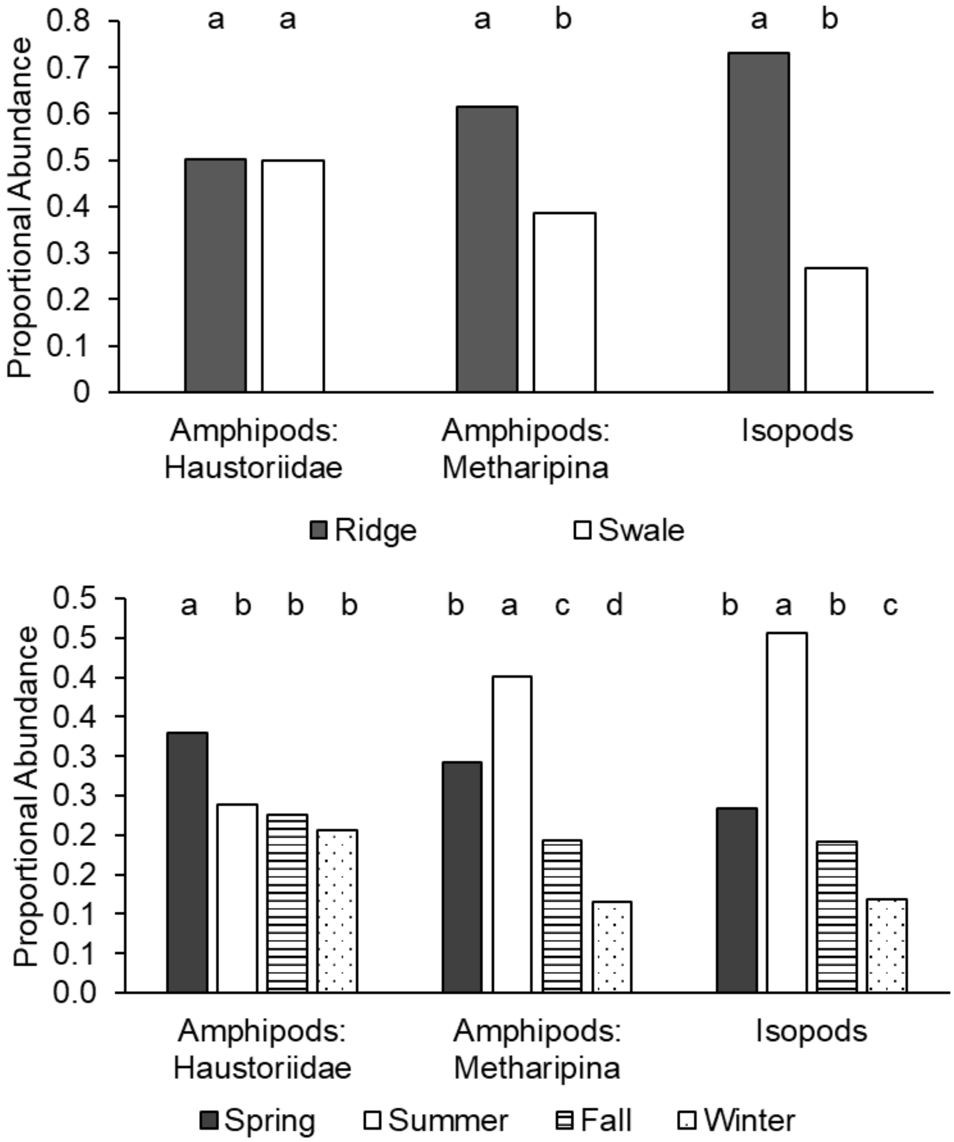

Figure 11-15. Proportional abundance of major groups of small benthic crustaceans by ridge versus swale habitat (top) and season (bottom).
Non-significant differences within invertebrate groups are indicated by the same letter.

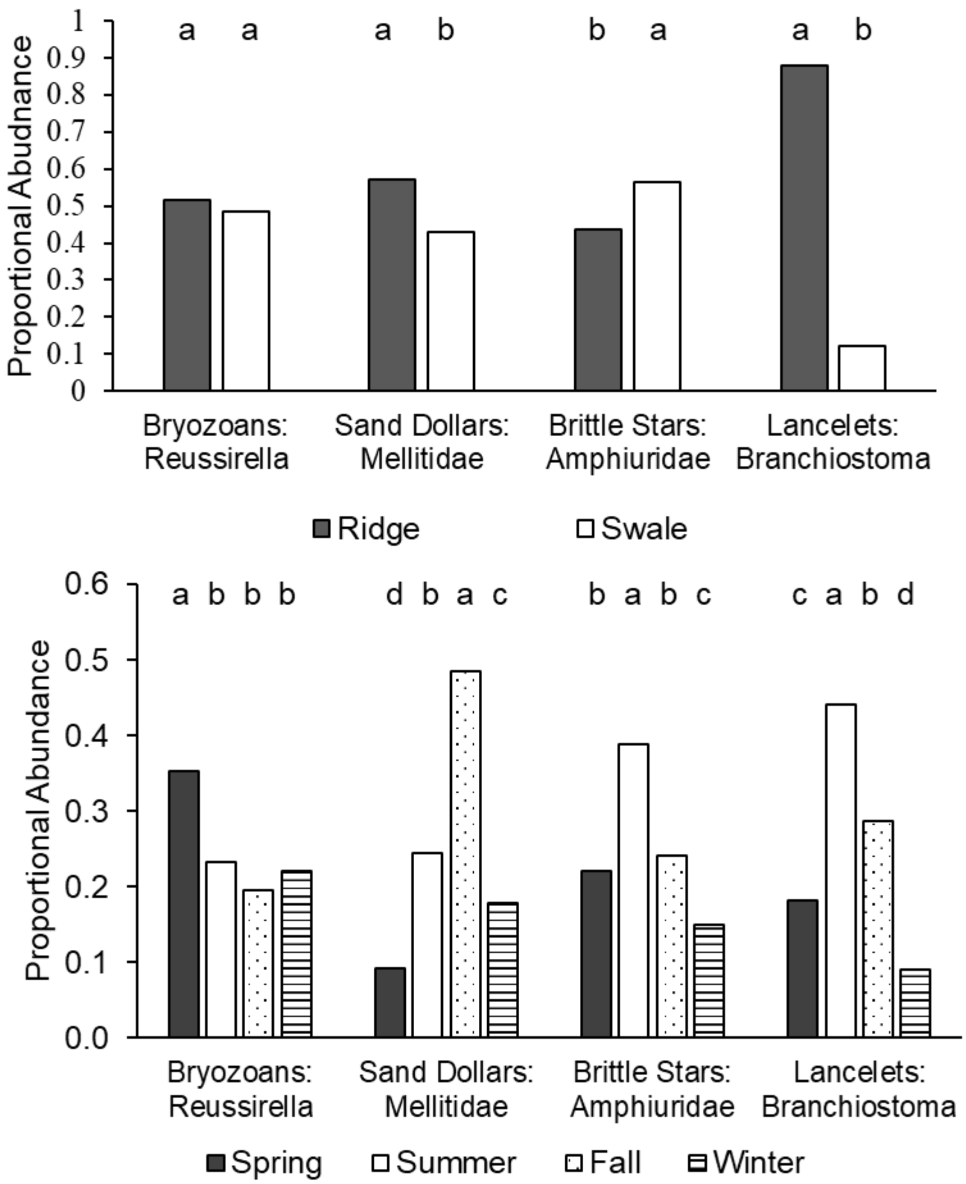

Figure 11-16. Proportional abundance of free-living bryozoans, major groups of echinoderms, and lancelets by ridge versus swale habitat (top) and season (bottom).
Non-significant differences within invertebrate groups are indicated by the same letter.

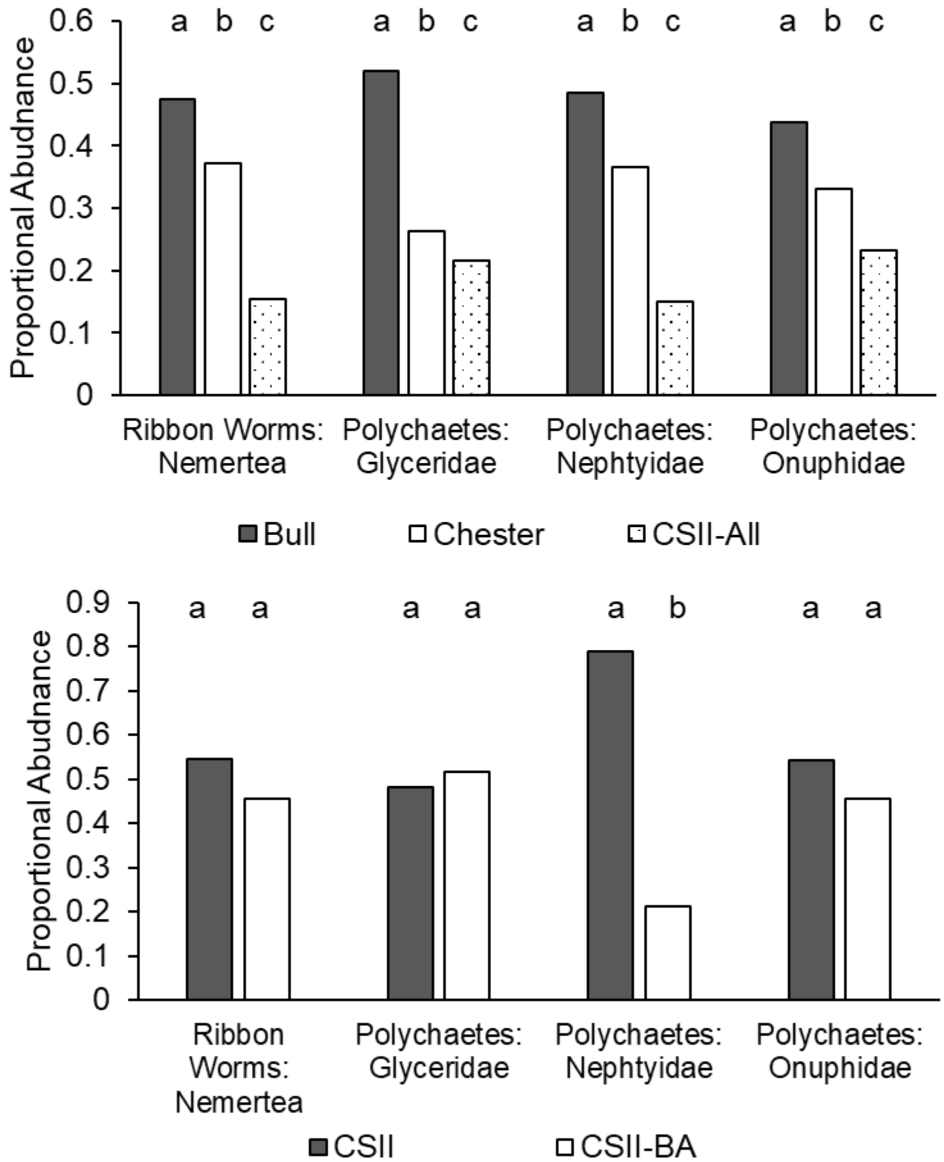

Figure 11-17. Proportional abundance of major groups of predatory and omnivorous worms by shoal (top) and by non-dredged (CSII) versus dredged portions of Canaveral Shoal II (bottom). Non-significant differences within invertebrate groups are indicated by the same letter.

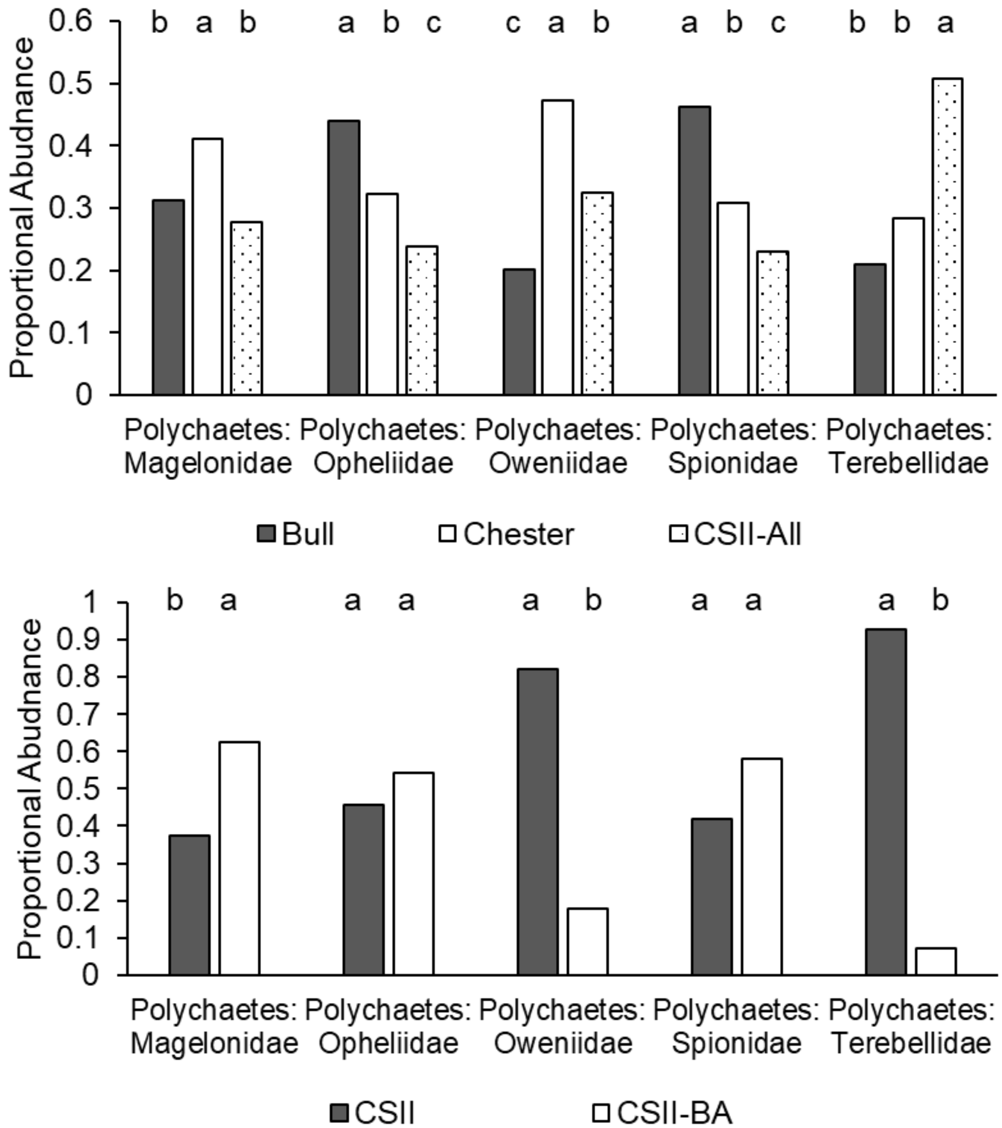

Figure 11-18. Proportional abundance of major groups of suspension- and deposit-feeding worms by shoal (top) and by non-dredged (CSII) versus dredged portions of Canaveral Shoal II (bottom). Non-significant differences within invertebrate groups are indicated by the same letter.

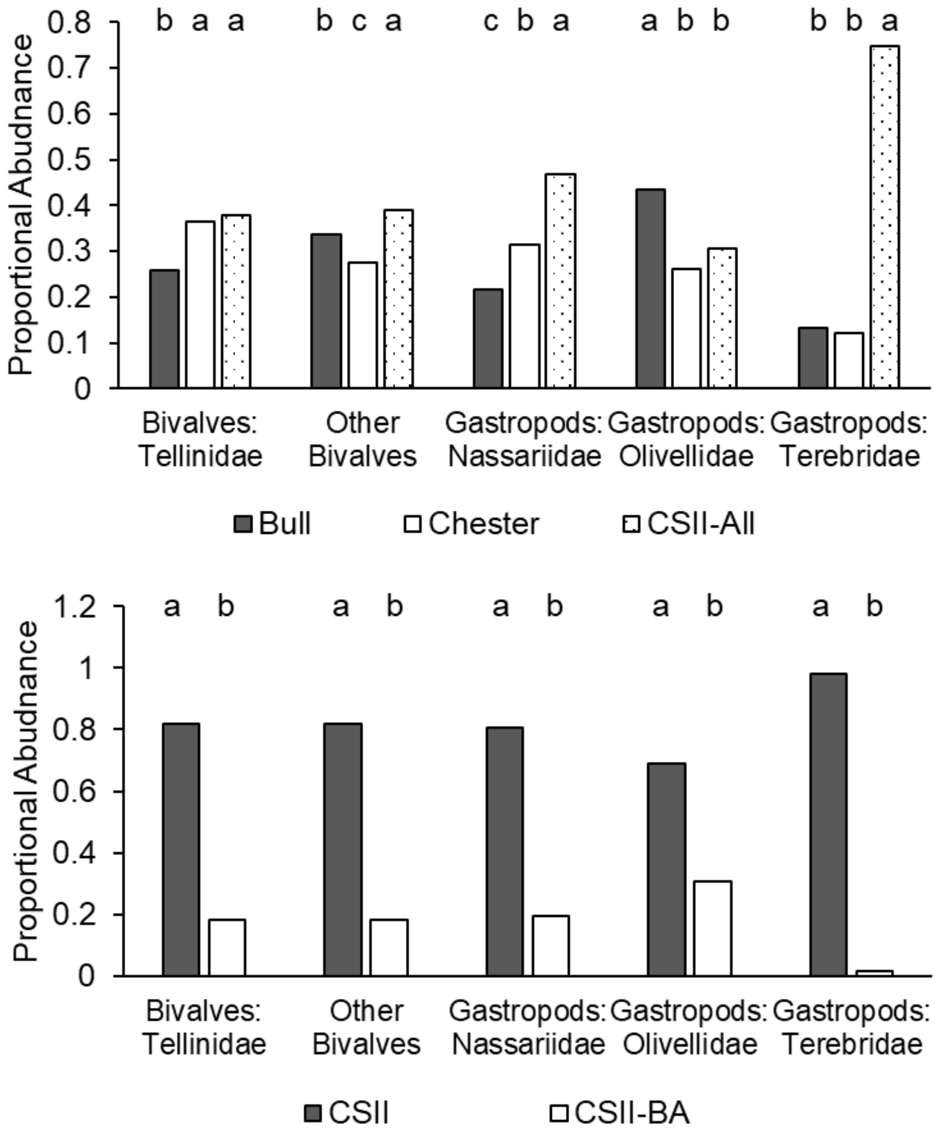

Figure 11-19. Proportional abundance of major groups of shelled mollusks by shoal (top) and by non-dredged (CSII) versus dredged portions of Canaveral Shoal II (bottom).
Non-significant differences within invertebrate groups are indicated by the same letter.

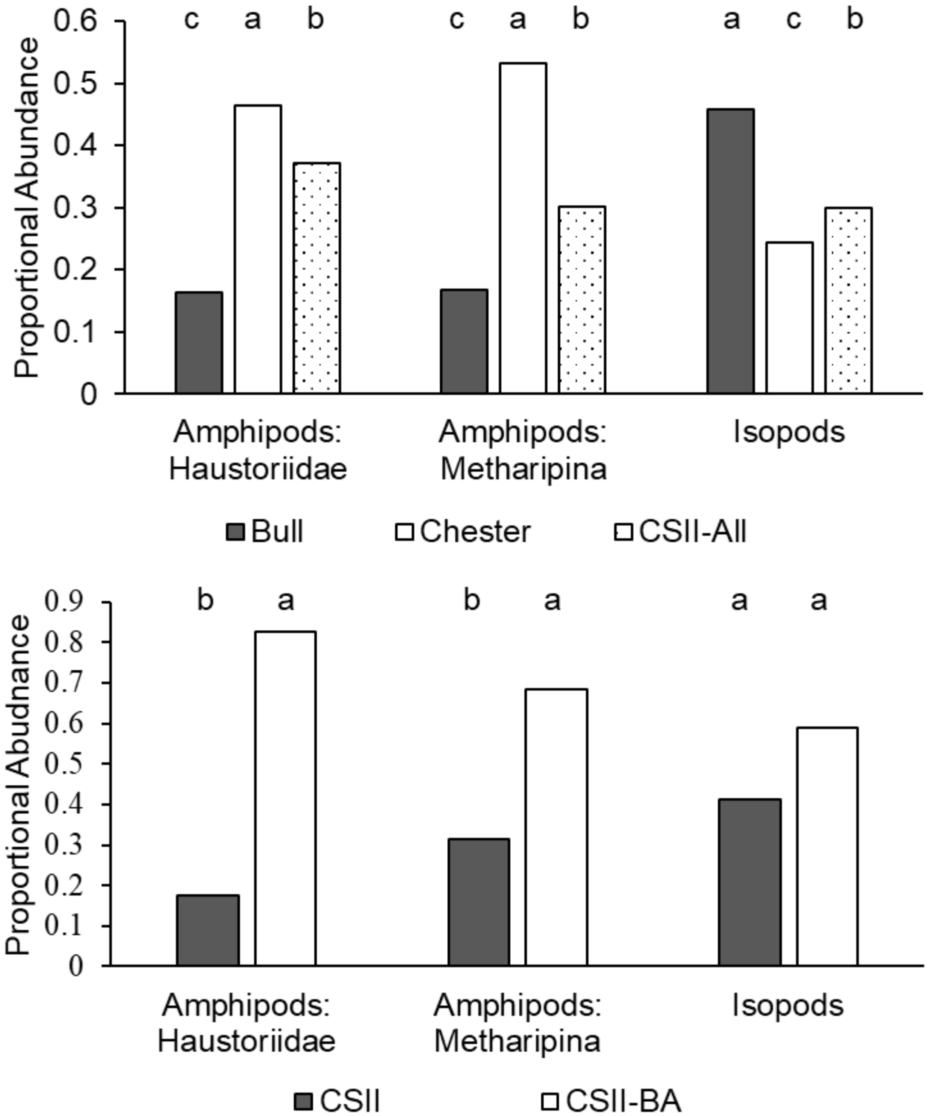

Figure 11-20. Proportional abundance of major groups of small benthic crustaceans by shoal (top) and by non-dredged (CSII) versus dredged portions of Canaveral Shoal II (bottom).
Non-significant differences within invertebrate groups are indicated by the same letter.

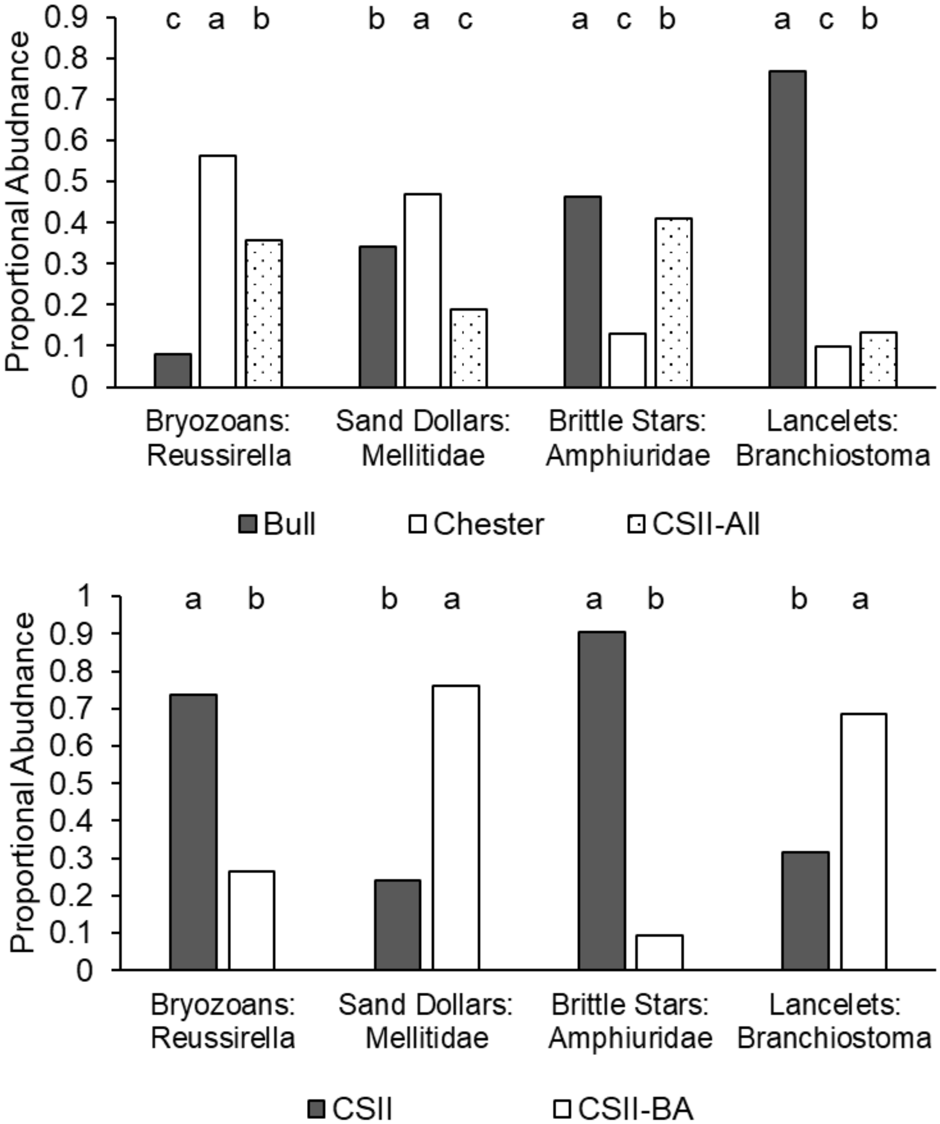

Figure 11-21. Proportional abundance of free-living bryozoans, major groups of echinoderms, and lancelets by shoal (top) and by non-dredged (CSII) versus dredged portions of Canaveral Shoal II (bottom).

Non-significant differences within invertebrate groups are indicated by the same letter (i.e., all differences within invertebrate groups were significant).

Table 11-1. Taxonomic groups and common names of invertebrates used in comparisons among habitats, shoals, and seasons.

Taxonomic Group	Common Name
Nemertea	ribbon worms
Polychaeta: Glyceridae	bloodworms
Polychaeta: Nephtyidae	errant polychaetes
Polychaeta: Onuphidae	errant polychaetes
Polychaeta: Magelonidae	shovelnose worms
Polychaeta: Opheliidae	lancelet worms (and others)
Polychaeta: Oweniidae	Tubeworms
Polychaeta: Spionidae	polychaete worms
Polychaeta: Terebellidae	spaghetti worms
Bivalvia: Tellinidae	tellin clams
Bivalvia: other	various clams
Gastropoda: Nassariidae	mud snails
Gastropoda: Olivellidae	dwarf olive snails
Gastropoda: Terebridae	auger snails
Amphipoda: Haustoriidae (Crustacea)	Amphipods
Amphipoda: *Metharpina* (Crustacea)	Amphipods
Isopoda (Crustacea)	Isopods
Cupuladriidae: *Reussirella* (Bryozoa)	free-living moss animals
Echinoidea: Mellitidae	sand dollars
Ophiuroidea: Amphiuridae	brittle stars
Cephalochordata: *Branchiostoma*	Lancelets

Table 11-2. Comparison of abiotic and general biotic factors between ridge and swale habitats.

Means and standard deviation (SD) given for each factor for ridge sites (n = 288) or swale sites (n = 575), with significant differences ($P \leq 0.05$) in bold.

Variable	Ridge (Mean)	Ridge (SD)	Swale (Mean)	Swale (SD)	*P*
Sample Depth (m)	8.1	2.2	13.1	2.4	**< 0.0001**
Sediment Size (mm)	0.46	0.18	0.35	0.21	**< 0.0001**
Sediment Size (φ)	0.7	0.5	1.4	0.9	**< 0.0001**
Organic Content (prop.)	0.009	0.003	0.010	0.007	**< 0.0001**
Invert. Abundance ($\cdot m^{-2}$)	463	624	467	398	0.9108
Invert. Biomass ($g \cdot m^{-2}$)	15.8	45.1	32.9	181.6	0.1163
Species Richness	6.3	4.6	8.8	4.8	**< 0.0001**
Simpson's Index	0.74	0.29	0.85	0.16	**< 0.0001**

Table 11-3. Comparison of abiotic and biotic factors among seasons for all shoals combined.

Means and standard deviation (SD) given for each variable for each season (n = 216 per season), with significant differences (P ≤ 0.05) in bold. Pairs of means that were not significantly different (P > 0.05) within a variable share the same letter value.

Variable	Spring (Mean)	Spring (SD)	Summer (Mean)	Summer (SD)	Fall (Mean)	Fall (SD)	Winter (Mean)	Winter (SD)	*P*
Sample Depth (m)	11.1	3.2	11.3	3.1	11.9	3.5	11.5	3.4	0.0587
Sediment Size (mm)	0.37	0.18	0.39	0.19	0.38	0.24	0.39	0.20	0.8510
Sediment Size (φ)	1.1	0.7	1.1	0.8	1.2	0.8	1.1	0.9	0.3050
Organic Content (prop.)	0.0096	0.0049	0.0102	0.0077	0.0095	0.0058	0.0095	0.0067	0.6202
Invert. Abundance ($\cdot m^{-2}$)	455.9 B	481.9	651.9 A	652.0	406.9 BC	375.2	346.6 C	304.9	**< 0.0001**
Invert. Biomass ($g \cdot m^{-2}$)	25.1	90.1	16.8	46.0	31.3	112.3	35.5	260.8	0.5978
Species Richness	8.1 B	4.4	10.1 A	6.1	7.20 BC	3.9	6.5 C	4.2	**< 0.0001**
Simpson's Index	0.83	0.21	0.83	0.18	0.81	0.24	0.80	0.25	0.2482

Table 11-4. Comparison of abiotic and biotic factors across study shoals.

CSII-All is Canaveral Shoal II (all sites). Means and standard deviation (SD) given for each variable for each shoal (n = 288 per shoal). Significant differences (P ≤ 0.05) are in bold; means that were not significantly different based on a posteriori Tukey tests share the same letter value.

Variable	Bull (Mean)	Bull (SD)	Chester (Mean)	Chester (SD)	CSII-All (Mean)	CSII-All (SD)	*P*
Sample Depth (m)	13.0 A	3.9	11.3 B	2.1	10.1 C	3.1	**< 0.0001**
Sediment Size (mm)	0.46 A	0.28	0.36 B	0.12	0.34 B	0.15	**< 0.0001**
Sediment Size (φ)	1.0 C	0.9	1.1 B	0.6	1.3 A	0.9	**< 0.0001**
Organic Content (prop.)	0.011 A	0.089	0.008 B	0.065	0.010 A	0.078	**< 0.0001**
Invert. Abundance ($\cdot m^{-2}$)	534 A	618	472 A	440	388 B	348	**0.0011**
Invert. Biomass ($g \cdot m^{-2}$)	25.4	99.3	30.9	225.4	25.3	86.9	0.8792
Species Richness	8.5 A	5.5	8.2 A	4.7	7.2 B	4.2	**0.0025**
Simpson's Index	0.82	0.24	0.83	0.20	0.80	0.22	0.1547

Table 11-5. Comparison of abiotic and biotic factors across Canaveral Shoal dredged (CSII-BA) and non-dredged (CSII) shoals.

Means and standard deviation (SD) given for each variable for each shoal (n = 144 per shoal). Significant differences ($P \leq 0.05$) are in bold.

Variable	CSII (Mean)	CSII (SD)	CSII-BA (Mean)	CSII-BA (SD)	*P*
Sample Depth (m)	9.6	3.3	10.6	2.8	**0.0043**
Sediment Size (mm)	0.28	0.18	0.39	0.10	**< 0.0001**
Sediment Size (φ)	1.7	1.1	0.9	0.4	**< 0.0001**
Organic Content (prop.)	0.012	0.007	0.008	0.004	**< 0.0001**
Invert. Abundance ($\cdot m^{-2}$)	412	382	363	307	0.2324
Invert. Biomass ($g \cdot m^{-2}$)	37.1	113.1	13.5	45.6	**0.0207**
Species Richness	7.8	4.7	6.5	3.3	**0.0068**
Simpson's Index	0.81	0.23	0.79	0.23	0.4339

Table 11-6. Regression analysis of major taxonomic groups in samples, expressed as counts, as a function of sample depth, weighted mean sediment size (ϕ), and proportional organic content.

Significant differences (P ≤ 0.05) are in bold.

Taxon or Group	Depth (r^2)	Depth (*P*)	Sediment Size φ (r^2)	Sediment Size φ (*P*)	Organic Content (r^2)	Organic Content (*P*)
Nemertea	0.0017	0.2270	0.0025	**0.0141**	0.0007	0.4335
Polychaeta: Glyceridae	0.0069	**0.0146**	0.0413	**< 0.0001**	0.0054	**0.0298**
Polychaeta: Magelonidae	0.0090	**0.0052**	0.0004	0.5563	0.0001	0.7339
Polychaeta: Nephtyidae	0.0620	**< 0.0001**	0.0025	0.1360	0.0098	**0.0035**
Polychaeta: Onuphidae	0.0212	**< 0.0001**	0.0008	0.4015	0.0016	0.2363
Polychaeta: Opheliidae	0.0095	**0.0041**	0.0005	0.5165	< 0.0001	0.8921
Polychaeta: Oweniidae	0.0056	**0.0274**	0.0153	**0.0003**	0.0044	0.0525
Polychaeta: Spionidae	0.0215	**< 0.0001**	0.0028	0.1178	0.0023	0.1572
Polychaeta: Terebellidae	0.0055	**0.0294**	0.0340	**< 0.0001**	0.0092	**0.0048**
Bivalvia: Tellinidae	0.0326	**< 0.0001**	0.1187	**< 0.0001**	0.0163	**0.0002**
Bivalvia: other	0.0091	**0.0051**	0.0177	**0.0001**	0.0169	**0.0001**
Gastropoda: Nassariidae	0.0223	**< 0.0001**	0.1124	**< 0.0001**	0.0304	**< 0.0001**
Gastropoda: Olivellidae	0.0221	**< 0.0001**	0.0375	**< 0.0001**	0.0003	0.6321
Gastropoda: Terebridae	0.0044	**0.0524**	0.1230	**< 0.0001**	0.0369	**< 0.0001**
Bryozoa: *Reussirella*	0.0013	0.2905	0.0067	**0.0161**	0.0001	0.7676
Amphipoda: Haustoriidae	0.0039	0.0654	0.0136	**0.0006**	0.0444	**< 0.0001**
Amphipoda: *Metharpina*	0.0253	**< 0.0001**	0.0423	**< 0.0001**	0.0100	**0.0038**
Isopoda	0.0297	**< 0.0001**	0.0457	**< 0.0001**	0.0016	0.2351
Echinoidea: Mellitidae	0.0003	0.6069	0.0226	**< 0.0001**	0.0074	0.1145
Ophiuroidea: Amphiuridae	0.0022	0.1724	0.0007	0.4262	0.0072	**0.0127**
Cephalochordata: *Branchiostoma*	0.0228	**< 0.0001**	0.0746	**< 0.0001**	0.0084	**0.0069**

Table 11-7. Total counts (n) and total biomass of abundant taxa from all stations across all shoals.

Total number of stations at which the taxon was collected is given as # Stations.

Higher Taxon	Family	Lowest Taxon	# Stations	n	Biomass (g)
Cnidaria: Anthozoa	all taxa	all species	11	16	4.36
Cnidaria: Hydrozoa	Campanulariidae	all species	141	281	0.62
Cnidaria: Hydrozoa	all other taxa	all other species	64	91	0.17
Platyhelminthes	all taxa	all species	1	1	0.01
Nemertea	all taxa	all species	135	216	2.54
Annelida: Clitellata	all taxa	all species	52	95	0.03
Annelida: Echiura	Thallassematidae	all species	1	1	0.29
Annelida: Polychaeta	Glyceridae	all species	200	269	2.73
Annelida: Polychaeta	Goniadidae	all species	112	203	0.36
Annelida: Polychaeta	Magelonidae	all species	181	231	1.74
Annelida: Polychaeta	Nephtyidae	all species	202	221	3.09
Annelida: Polychaeta	Onuphidae	all species	151	202	3.00
Annelida: Polychaeta	Opheliidae	all species	134	239	2.23
Annelida: Polychaeta	Oweniidae	all species	164	467	3.98
Annelida: Polychaeta	Spionidae	all species	233	466	1.43
Annelida: Polychaeta	Terebellidae	all species	103	272	14.06
Annelida: Polychaeta	all other taxa	all other species	663	1,150	11.49
Sipuncula	all taxa	all species	90	132	1.25
Mollusca: Bivalvia	Tellinidae	all species	210	347	14.26
Mollusca: Bivalvia	all other taxa	all other species	391	659	141.28
Mollusca: Gastropoda	Nassariidae	all species	96	143	8.07
Mollusca: Gastropoda	Olivellidae	all species	80	138	3.67
Mollusca: Gastropoda	Terebridae	all species	57	75	5.84
Mollusca: Gastropoda	all taxa	all species	79	89	30.87
Mollusca: Scaphopoda	all taxa	all species	38	54	3.31
Entoprocta	Loxosomatidae	all species	1	2	0.00
Brachiopoda	Lingulidae	*Glottidia pyramidata*	9	10	0.03
Phoronida	Phoronidae	*Phoronis* sp.	18	38	0.10
Bryozoa	Cupuladriidae	*Reussirella doma*	164	1,010	16.73
Bryozoa	Cupuladriidae	all other species	11	14	0.47
Bryozoa	all other taxa	all other species	21	33	0.54
Cephalorhyncha	Priapulidae	all species	2	2	0.02
Arthropoda: Cumacea	Diastylidae	all species	112	142	0.24
Arthropoda: Amphipoda	Bathyporeiidae	all species	109	192	0.24
Arthropoda: Amphipoda	Haustoriidae	*Acanthohaustorius millsi*	348	1,248	7.32
Arthropoda: Amphipoda	Haustoriidae	*Protohaustorius wigleyi*	262	729	2.23
Arthropoda: Amphipoda	Haustoriidae	all other species	94	191	1.18

Higher Taxon	Family	Lowest Taxon	# Stations	n	Biomass (g)
Arthropoda: Amphipoda	Phoxocephalidae	*Metharpinia floridana*	307	684	1.81
Arthropoda: Amphipoda	all other taxa	all other species	175	230	0.26
Arthropoda: Decapoda	Pinnotheridae	all species	119	230	1.63
Arthropoda: Decapoda	all other taxa	all other species	310	382	51.84
Arthropoda: Isopoda	all taxa	all species	187	284	1.05
Arthropoda: Maxillopoda	Balanidae	all species	17	279	3.40
Arthropoda: Mysida	Mysidae	all species	121	165	0.64
Arthropoda: Ostracoda	all taxa	all species	5	7	0.03
Arthropoda: Stomatopoda	Squillidae	all species	6	6	0.07
Arthropoda: Tanadida	all taxa	all species	38	53	0.04
Echinodermata: Echinoidea	Mellitidae	*Mellita isometra*	121	396	188.02
Echinodermata: Echinoidea	Mellitidae	all other species	130	331	170.61
Echinodermata: Echinoidea	all other taxa	all other species	44	62	100.06
Echinodermata: Holothuroidea	all taxa	all species	13	15	7.55
Echinodermata: Ophiuroidea	Amphiuridae	all species	146	388	27.08
Echinodermata: Ophiuroidea	all other taxa	all other species	71	124	3.13
Chordata: Actinopterygii	Ophichthidae	all species	3	3	0.31
Chordata: Cephalochordata	Branchiostomatidae	*Branchiostoma virginiae*	214	1,994	37.12
Chordata: Tunicata	all taxa	all species	3	3	0.02

Table 11-8. Abundance of major taxonomic groups in samples, expressed as proportion of specimens, between ridge and swale habitats.

Proportions were corrected for differing samples sizes; ridge sites (n = 288) and swale sites (n = 576). Significant differences at P ≤ 0.05 were indicated by χ^2-values > 3.3841, indicated in bold.

Taxon or Group	Ridge	Swale	χ^2
Ribbon Worms: Nemertea	0.552	0.448	2.235
Polychaetes: Glyceridae	0.445	0.555	2.684
Polychaetes: Nephtyidae	0.174	0.826	**7.296**
Polychaetes: Onuphidae	0.284	0.716	**25.126**
Polychaetes: Magelonidae	0.332	0.668	**18.721**
Polychaetes: Opheliidae	0.385	0.615	**9.674**
Polychaetes: Oweniidae	0.200	0.800	**103.556**
Polychaetes: Spionidae	0.268	0.732	**67.060**
Polychaetes: Terebellidae	0.187	0.813	**64.971**
Bivalves: Tellinidae	0.154	0.846	**97.406**
Bivalves: All Others	0.379	0.621	**29.445**
Gastropods: Nassariidae	0.054	0.946	**60.003**
Gastropods: Olivellidae	0.097	0.903	**49.598**
Gastropods: Terebridae	0.052	0.948	**31.740**
Amphipods: Haustoriidae	0.501	0.499	0.011
Amphipods: *Metharpina*	0.614	0.386	**37.007**
Isopods	0.732	0.268	**76.169**
Bryozoans: *Reussirella*	0.515	0.485	0.821
Sand Dollars: Mellitidae	0.572	0.428	**14.660**
Brittle Stars: Amphiuridae	0.435	0.565	**5.278**
Lancelets: *Branchiostoma*	0.879	0.121	**1,829.338**

Table 11-9. Abundance of major taxonomic groups in samples, expressed as proportion of specimens, across seasons.

Total samples included 216 sites in each season. Significant differences at $P \leq 0.05$ were indicated by χ^2-values > 7.815, indicated in bold. Proportion of invertebrates within each group that were not significantly different share the same letter value.

Taxon or Group	Spring	Summer	Fall	Winter	χ^2
Ribbon Worms: Nemertea	0.252 A	0.332 A	0.252 A	0.163 B	**11.465**
Polychaetes: Glyceridae	0.254 A	0.377 A	0.259 A	0.110 B	**32.807**
Polychaetes: Nephtyidae	0.365 A	0.340 A	0.164 B	0.132 B	**27.088**
Polychaetes: Onuphidae	0.133 BC	0.574 A	0.191 B	0.101 C	**108.723**
Polychaetes: Magelonidae	0.404 A	0.301 B	0.176 C	0.119 C	**37.736**
Polychaetes: Opheliidae	0.109 C	0.600 A	0.211 B	0.080 C	**284.039**
Polychaetes: Oweniidae	0.244 B	0.588 A	0.060 D	0.109 C	**263.306**
Polychaetes: Spionidae	0.528 A	0.243 B	0.119 C	0.111 C	**106.872**
Polychaetes: Terebellidae	0.090 C	0.452 A	0.327 B	0.131 C	**107.872**
Bivalves: Tellinidae	0.233 C	0.383 A	0.268 B	0.117 D	**78.971**
Bivalves: All Others	0.182 B	0.157 B	0.512 A	0.149 B	**44.719**
Gastropods: Nassariidae	0.127 C	0.142 C	0.478 A	0.254 B	**42.179**
Gastropods: Olivellidae	0.203 B	0.266 B	0.453 A	0.078 C	**18.750**
Gastropods: Terebridae	0.216 B	0.270 B	0.392 A	0.122 C	**11.297**
Amphipods: Haustoriidae	0.329 A	0.239 B	0.226 B	0.206 B	**60.429**
Amphipods: *Metharpina*	0.292 B	0.401 A	0.193 C	0.115 D	**104.389**
Isopods	0.234 B	0.455 A	0.191 B	0.119 C	**59.179**
Bryozoans: *Reussirella*	0.352 A	0.232 B	0.196 B	0.220 B	**53.776**
Sand Dollars: Mellitidae	0.092 D	0.244 B	0.486 A	0.178 C	**213.228**
Brittle Stars: Amphiuridae	0.221 B	0.388 A	0.242 B	0.149 C	**40.367**
Lancelets: *Branchiostoma*	0.182 C	0.441 A	0.287 B	0.091 D	**451.287**

Table 11-10. Abundance of major taxonomic groups in samples, expressed as proportion of specimens, across shoals.

CSII-All is Canaveral Shoal II (all sites). Total samples included 288 sites per shoal. Significant differences at P ≤ 0.05 were indicated by χ^2-values > 5.991, indicated in bold. Proportion of invertebrates within each group that were not significantly different share the same letter value.

Taxon or Group	Bull	Chester	CSII-All	χ^2
Ribbon Worms: Nemertea	0.474 A	0.372 B	0.153 C	**34.670**
Polychaetes: Glyceridae	0.520 A	0.264 B	0.216 C	**43.323**
Polychaetes: Nephtyidae	0.484 A	0.367 B	0.149 C	**22.372**
Polychaetes: Onuphidae	0.437 A	0.332 B	0.231 C	**12.673**
Polychaetes: Magelonidae	0.312 B	0.411 A	0.277 B	**6.727**
Polychaetes: Opheliidae	0.439 A	0.322 B	0.238 C	**14.594**
Polychaetes: Oweniidae	0.201 C	0.473 A	0.325 B	**51.936**
Polychaetes: Spionidae	0.461 A	0.309 B	0.230 C	**38.785**
Polychaetes: Terebellidae	0.210 C	0.283 B	0.507 A	**39.272**
Bivalves: Tellinidae	0.259 B	0.363 A	0.378 A	**8.651**
Bivalves: All Others	0.335 B	0.275 C	0.390 A	**13.159**
Gastropods: Nassariidae	0.217 C	0.315 B	0.469 A	**13.818**
Gastropods: Olivellidae	0.435 A	0.261 B	0.304 B	**6.783**
Gastropods: Terebridae	0.133 B	0.120 B	0.747 A	**57.680**
Amphipods: Haustoriidae	0.163 C	0.465 A	0.372 B	**311.597**
Amphipods: *Metharpina*	0.167 C	0.532 A	0.301 B	**140.246**
Isopods	0.458 A	0.243 C	0.299 B	**21.134**
Bryozoans: *Reussirella*	0.081 C	0.563 A	0.355 B	**359.732**
Sand Dollars: Mellitidae	0.343 B	0.468 A	0.190 C	**84.465**
Brittle Stars: Amphiuridae	0.461 A	0.129 C	0.410 B	**74.541**
Lancelets: *Branchiostoma*	0.768 A	0.100 C	0.132 B	**1700.775**

Table 11-11. Abundance of major taxonomic groups in samples, expressed as proportion of specimens, in dredged (CSII-BA) and non-dredged (CSII) Canaveral Shoal II samples.

CSII-BA (n=144) and CSII (n=144). Significant differences at P ≤ 0.05 were indicated by χ^2-values > 3.841, indicated in bold.

Taxon or Group	CSII	CSII-BA	χ^2
Ribbon Worms: Nemertea	0.545	0.455	0.273
Polychaetes: Glyceridae	0.483	0.517	0.069
Polychaetes: Nephtyidae	0.788	0.212	**17.230**
Polychaetes: Onuphidae	0.543	0.457	0.348
Polychaetes: Magelonidae	0.375	0.625	**4.000**
Polychaetes: Opheliidae	0.456	0.544	0.439
Polychaetes: Oweniidae	0.822	0.178	**63.184**
Polychaetes: Spionidae	0.421	0.579	2.701
Polychaetes: Terebellidae	0.928	0.072	**100.899**
Bivalves: Tellinidae	0.817	0.183	**52.588**
Bivalves: All Others	0.817	0.183	**103.381**
Gastropods: Nassariidae	0.806	0.194	**25.090**
Gastropods: Olivellidae	0.690	0.310	**6.095**
Gastropods: Terebridae	0.982	0.018	**52.071**
Amphipods: Haustoriidae	0.175	0.825	**341.543**
Amphipods: *Metharpina*	0.316	0.684	**28.039**
Isopods	0.412	0.588	2.647
Bryozoans: *Reussirella*	0.736	0.264	**81.275**
Sand Dollars: Mellitidae	0.239	0.761	**37.565**
Brittle Stars: Amphiuridae	0.906	0.094	**104.660**
Lancelets: *Branchiostoma*	0.316	0.684	**35.776**

Table 11-12. Abiotic and general biotic parameters for the first dredging event by shoal.

Means and standard deviation (SD) given for each variable within each shoal (n=6 per shoal). Bull and Chester Shoals were not sampled for invertebrate abundance during fall 2013. Significant differences (P ≤ 0.05) are in bold.

Shoal	Variable	Fall 2013 (Mean)	Fall 2013 (SD)	Summer 2014 (Mean)	Summer 2014 (SD)	*P*
CSII-BA	Sample Depth (m)	10.1	2.6	9.43	3.2	0.3114
"	Sediment Size (φ)	1.3	0.2	0.8	0.3	**0.0338**
"	Organic Content (prop.)	0.0060	0.0013	0.0054	0.0004	0.2063
"	Invert. Abundance ($\cdot m^{-2}$)	171.8	116.0	283.5	207.5	0.2063
"	Invert. Biomass ($g\cdot m^{-2}$)	1.88	1.87	7.92	12.09	0.2832
"	Species Richness	3.5	1.5	5.7	3.1	0.1152
"	Simpson's Index	0.69	0.35	0.76	0.07	0.2712
CSII	Sample Depth (m)	9.4	4.1	8.3	3.3	0.6036
"	Sediment Size (φ)	2.2	1.3	1.5	1.3	0.3458
"	Organic Content (prop.)	0.0083	0.0019	0.0102	0.0060	0.4562
"	Invert. Abundance ($\cdot m^{-2}$)	356.5	209.0	498.3	314.7	0.3797
"	Invert. Biomass ($g\cdot m^{-2}$)	68.12	145.64	22.56	26.86	0.4685
"	Species Richness	8.0	4.6	7.0	2.5	0.6487
"	Simpson's Index	0.79	0.39	0.76	0.08	0.8883
Bull	Sample Depth (m)	13.9	4.7	12.9	3.6	0.5750
"	Sediment Size (φ)	1.2	0.7	1.1	1.0	0.9847
"	Organic Content (prop.)	0.0135	0.0094	0.0091	0.0040	0.1490
Chester	Sample Depth (m)	11.7	1.7	10.2	2.0	0.0629
"	Sediment Size (φ)	1.4	0.4	0.8	0.6	**0.0029**
"	Organic Content (prop.)	0.0062	0.0013	0.0071	0.0035	0.4090

Table 11-13. Abiotic and general biotic parameters for the second dredging event by shoal.

Means and standard deviation (SD) given for each variable within each shoal (n=6 per shoal). Bull and Chester Shoals were not sampled for invertebrate abundance during fall 2013. Significant differences ($P \leq 0.05$) are in bold.

Shoal	Variable	Spring–Summer 2017 (Mean)	Spring–Summer 2017 (SD)	Spring–Summer 2018 (Mean)	Spring–Summer 2018 (SD)	*P*
CSII-BA	Sample Depth (m)	10.1	3.6	10.1	3.0	0.9894
"	Sediment Size (φ)	1.0	0.4	0.8	0.4	0.1490
"	Organic Content (prop.)	0.0096	0.0020	0.0061	0.0011	**< 0.0001**
"	Invert. Abundance ($\cdot m^{-2}$)	622.8	650.6	403.4	221.7	0.3646
"	Invert. Biomass ($g \cdot m^{-2}$)	41.62	72.50	15.00	29.49	0.2861
"	Species Richness	8.3	4.9	7.7	2.6	0.7541
"	Simpson's Index	0.77	0.20	0.86	0.09	0.2015
CSII	Sample Depth (m)	9.4	3.3	9.1	3.5	0.8481
"	Sediment Size (φ)	2.1	1.2	1.4	0.7	0.0742
"	Organic Content (prop.)	0.0165	0.0095	0.0084	0.0030	**0.0103**
"	Invert. Abundance ($\cdot m^{-2}$)	412.6	322.6	505.4	404.7	0.5409
"	Invert. Biomass ($g \cdot m^{-2}$)	10.34	11.29	57.46	71.57	**0.0346**
"	Species Richness	9.1	5.5	8.3	3.4	0.6601
"	Simpson's Index	0.87	0.14	0.87	0.09	0.9366
Bull	Sample Depth (m)	12.9	3.6	12.8	4.4	0.9408
"	Sediment Size (φ)	1.2	0.7	1.2	1.0	0.9848
"	Organic Content (prop.)	0.0118	0.0072	0.0129	0.0155	0.7458
Chester	Sample Depth (m)	11.2	1.8	10.7	2.2	0.3950
"	Sediment Size (φ)	1.4	0.4	1.1	0.4	**0.0219**
"	Organic Content (prop.)	0.0102	0.0057	0.0063	0.0018	**0.0022**

Table 11-14. Results of paired t-tests of taxon abundance (count) data from a full year of data before (fall 2016 to summer 2017) and after (spring 2018 to winter 2018/19) dredging at CSII-BA.

Values are means (with standard deviations in parentheses) (n = 24). Significant differences ($P \leq 0.05$) are in bold. For comparisons with zero-values, no test was conducted.

Taxon	Fall 2016–Summer 2017	Spring 2018–Winter 2019	*P*
Ribbon Worms: Nemertea	0.1 (0.2)	0.2 (0.5)	0.7701
Polychaetes: Glyceridae	0.5 (0.7)	0.3 (0.3)	0.2599
Polychaetes: Nephtyidae	0.1 (9.3)	0.1 (0.3)	0.6643
Polychaetes: Onuphidae	0.1 (0.4)	0.2 (0.4)	0.7466
Polychaetes: Magelonidae	0.3 (0.6)	0.3 (0.6)	0.8241
Polychaetes: Opheliidae	0.2 (0.4)	0.1 (0.3)	0.5748
Polychaetes: Oweniidae	0	0.1 (0.6)	-
Polychaetes: Spionidae	0.4 (0.8)	0.4 (0.8)	1.0000
Polychaetes: Terebellidae	0.3 (0.4)	0	-
Bivalves: Tellinidae	0.1 (0.4)	0.04 (0.2)	0.4259
Bivalves: All Others	0.4 (0.7)	0.1 (0.3)	0.0695
Gastropods: Nassariidae	0.04 (0.2)	0.1 (0.3)	0.5748
Gastropods: Olivellidae	0	0.1 (0.3)	-
Gastropods: Terebridae	0	0.04 (0.2)	-
Amphipods: Haustoriidae	3.7 (5.4)	7.7 (6.0)	**0.0431**
Amphipods: *Metharpina*	0.9 (0.9)	0.6 (0.9)	0.1834
Isopods	0.6 (1.2)	0.3 (0.5)	0.2325
Bryozoans: *Reussirella*	2.2 (9.2)	0.2 (0.6)	0.2648
Sand Dollars: Mellitidae	0.6 (1.2)	1.2 (1.9)	0.2039
Brittle Stars: Amphiuridae	0.2 (0.7)	0.04 (0.2)	0.2567
Lancelets: *Branchiostoma*	5.0 (16.4)	0.4 (1.4)	0.1767

Table 11-15. Regressions for sediment weighted mean size (ϕ) and sediment proportional organic content factors for all shoals, and depth and general biotic factors for CSII-BA over the inter-dredging period from spring 2014 to summer 2017.

The regression coefficient for the linear model is given as r^2. Significant differences ($P \leq 0.05$) are in bold.

Shoal	Variable	r^2	*P*
CSII-BA	Sample Depth (m)	0.0008	0.7977
"	Sediment Size (φ)	0.1290	**0.0008**
"	Organic Content (prop.)	0.1810	**< 0.0001**
"	Invert. Abundance ($\cdot m^{-2}$)	0.0212	0.1867
"	Invert. Biomass ($g \cdot m^{-2}$)	0.0017	0.7087
"	Species Richness (sample)	0.0069	0.4518
"	Simpson's Index	0.0040	0.5499
CSII	Sediment Size (φ)	0.0448	0.0533
"	Organic Content (prop.)	0.0860	**0.0067**
Bull	Sediment Size (φ)	0.0260	**0.0359**
"	Organic Content (prop.)	0.0520	**0.0030**
Chester	Sediment Size (φ)	0.0860	**0.0001**
"	Organic Content (prop.)	0.1020	**< 0.0001**

Table 11-16. Abundance of major taxa in CSII-BA regressed against days after dredging, during the interval between dredging events.

Abundance (n = count). The regression coefficient for the linear model is given as r2. Significant differences (P ≤ 0.05) are in bold. Taxa for which there were fewer than three data points were not tested.

Taxon Counts	n	r^2	*P*
Ribbon Worms: Nemertea	11	0.0210	0.1915
Polychaetes: Glyceridae	21	0.0470	**0.0483**
Polychaetes: Nephtyidae	2	-	-
Polychaetes: Onuphidae	11	0.0016	0.7204
Polychaetes: Magelonidae	24	0.0004	0.8512
Polychaetes: Opheliidae	25	0.0003	0.8783
Polychaetes: Oweniidae	21	0.0023	0.6681
Polychaetes: Spionidae	44	0.0001	0.9185
Polychaetes: Terebellidae	7	0.0570	**0.0281**
Bivalves: Tellinidae	18	0.0150	0.2719
Bivalves: All Others	27	0.0071	0.4455
Gastropods: Nassariidae	7	< 0.0001	0.9457
Gastropods: Olivellidae	7	0.0829	**0.0079**
Gastropods: Terebridae	0	-	-
Amphipods: Haustoriidae	353	0.0040	0.5682
Amphipods: *Metharpina*	108	0.0010	0.7713
Isopods	37	0.0260	0.1429
Bryozoans: *Reussirella*	83	0.0081	0.4145
Sand Dollars: Mellitidae	61	0.0005	0.8389
Brittle Stars: Amphiuridae	10	0.0048	0.5321
Lancelets: *Branchiostoma*	164	0.0270	0.1393

12 Demersal Invertebrates

Donald Behringer and Lucas Jennings

Key Points

- There were no clear effects of dredging on the diversity or mean biomass metrics used to assess demersal invertebrate communities on CSII-BA, CSII, Chester, and Bull Shoals.
- Bull Shoal had higher community diversity and mean biomass than Chester and CSII Shoals, but this pattern was not pronounced with respect to the dredged portion of CSII (CSII-BA).
- Diversity and biomass of demersal invertebrates varied from year to year for all shoals.
- Seasonal patterns in the community diversity and mean biomass were evident but not consistent. The most consistent pattern was higher diversity on the ridges and higher biomass in the swales, but this trend was also seasonal. Summer generally had the highest diversity of all seasons.
- The abundance of commercially important invertebrate species collected from trawls was low and did not include any high-value species.
- There were two major hurricanes during the study period, Hurricane Matthew and Hurricane Irma. There appeared to be no effect of these hurricanes on the diversity and biomass of demersal/epibenthic invertebrate communities.
- These results were consistent with similar studies on the effects of dredging on soft-bottom communities in high energy, subtropical environments that favor diverse communities of small, mobile, opportunistic species. These characteristics may ameliorate any effect of dredging through a continuous and diverse supply of recruits available to colonize the recently disturbed habitat.

12.1 Introduction

Benthic primary and secondary consumers, such as benthic invertebrates, represent a diverse assemblage of organisms that serve as a prey source for secondary and tertiary consumers such as fishes and humans. Newell et al. (1998) and Boyd et al. (2005) have reviewed dredging impacts on benthic fauna in the North Atlantic. Newell et al. (1998) divided impacts into removal, burial, and more graded forms of sedimentation, but most work has focused on removal impacts because they were the most severe, clearly quantifiable, yet ultimately gave way to recovery. At the time of dredging, the initial benthic biological impacts of removal were severe due to the large amount of substrate that was removed. When compared to the pre-dredged area, there was a loss of 80% of biodiversity and 90% of biomass post dredging, including a loss of almost all bivalves, as these animals lack high mobility and are incapable of escaping dredging methods (Desprez 2000; van Dalfsen et al. 2000).

Along with polychaete worms and mollusks, crustaceans play a major role in the ecosystem services of marine habitats. Among the soft sediment substrates offshore of Florida, crustaceans are present in the demersal, epibenthic, infaunal, and meiofaunal communities (Brooks et al. 2004). However, their presence and abundance vary with temperature, grain size, organic content, water depth, and characteristics of the primary producers (e.g., abundance, community composition, chemical composition, energetics). Amphipods, isopods, decapods, tanaids, maxillopods, and ostracods are among the crustaceans previously reported from the Florida area (Brooks et al. 2004).

Valuable crustacean fisheries exist in Florida, with some occurring in nearshore or among inland waterways, most are seasonal, and some occur in deep water. Thus, not all were likely to be directly impacted by dredging activities, but indirect effects were possible. In Florida, there are several managed crustacean fisheries in the waters off the east coast of Florida (Brevard County), including Blue Crabs *Callinectes sapidus*, Spiny Lobsters *Panulirus argus*, Stone Crabs *Menippe mercenaria*, and various shrimp species. Hard and soft-shelled Blue Crabs comprised > 65% of the non-shrimp invertebrates landed in 2012 but they are taken primarily from nearshore and inland waterways (Tomlinson et al. 2007; FWC 2020). However, their larvae and post-larvae spend an appreciable amount of time (~40–70 days) offshore during development and could be affected by dredging operations. Adult female Blue Crabs also move to the mouths of estuaries or beyond to spawn and overwinter, and they may be impacted by nearshore dredge operations. Spiny Lobster and Stone Crab landings are typically low offshore of Brevard County and accounted for only 1.4% and 0.5% of the non-shrimp invertebrate landings in 2012, respectively. However, Spiny Lobsters are highly mobile benthic predators and so their ecological impact may outweigh their numerical abundance. They are known to migrate seasonally from shallow nearshore habitats to deeper water (Hernkind 1980; Childress and Jury 2006) for several reasons, including foraging, reproduction, water temperature, and to avoid winter storm events (Childress and Jury 2006; Bertelsen and Hornbeck 2009); it is currently unknown whether they use the ridge-swale habitats.

A variety of shrimps also comprise various fisheries off the coast of Florida and can add significantly to the prey base of these ecosystems as a link between detritus and primary benthic productivity and higher level consumers like fishes. These shrimps include Brown Shrimp *Penaeus aztecus*, Pink Shrimp *Farfantepenaeus duorarum*, White Shrimp *Penaeus setiferus*, Rock Shrimp *Sicyonia brevirostris*, and Royal Red Shrimp *Hymenopenaeus robustus*. White, pink, and brown shrimps are all found at depths < 60 m and within soft sediment habitats (FWRI 2010). However, their microhabitat preferences (e.g., grain size) differ. All of these economically important species had the potential to be impacted by dredging to some degree.

12.1.1 Goal and Objectives

The overall goal of this study was to describe and quantify the diversity and biomass of demersal/epibenthic invertebrates from a dredged sand shoal (CSII-BA) and non-dredged (reference) shoals (CSII, Chester, and Bull) off the east coast of Florida in relation to effects of year, season, time of day (day versus night), and habitat (ridge versus swale). Potential impacts from two nearby major hurricanes (Matthew and Irma) during the study period were also assessed for their effect on taxonomic diversity and biomass.

12.2 Methodology

12.2.1 Trawl Surveys

A pre - and post - impact stratified-random sampling design was used to assess impact and recovery of demersal/epibenthic invertebrates (hereafter collectively referred to as demersal invertebrates) on the dredged shoal (CSII-BA) relative to control (reference) shoals (CSII, Chester, and Bull Shoals). Specifics of the sampling design are given in Chapter 1. In summary, a standardized, bottom (otter) trawl (Figure 12-1) was used to sample sites on each shoal and had dimensions of: body mesh of 3.8 cm (1.5 in), cod-end mesh 2.54 cm (1 in) stretched mesh with an inner liner of 0.3175 mm (1/8 in) knotless netting in the cod-end, 6.1 m (20 ft) headrope, 18 in x 36 in boards, with an installed trawling-efficiency device (TED) to allow sea turtles to escape the trawl. The trawl was towed at 1.5–2.0 kts for 10 minutes (on-bottom to off-bottom time). The exact length of the trawl path was determined by GPS positions and swept area was standardized to allow the estimation of density and species richness (# species/m^2) for comparison.

Shoals were sampled seasonally, with spring from March–May, summer from June–September, fall from October–November, and winter from December to the following February. Sampling started in fall 2013 and continued seasonally until summer 2019. On a seasonal basis, two stratified-random tows were conducted on each habitat-quadrant (ridge versus swale) for a total of 12 tows on each of Chester and Bull Shoals, and 6 tows on each of (CSII and CSII-BA, for in total 36 trawls per season. Beginning spring 2014, an additional set of trawls (closed-TED trawls) were collected using an identical trawl without a TED or cod-end liner to check for bias towards small invertebrates and make sure that larger organisms were not being excluded in the standardized tows. These standardized trawls were repeated during the night as well since to examine whether there was a difference in both diversity and abundance of organisms between night and day trawling. Surface and bottom measurements of water temperature and water depth were collected using a temperature-depth recorder attached to the trawl.

Invertebrates captured were sorted by trawl date, time, and number. Upon return to the University of Florida, samples were organized and frozen. Frozen samples were later thawed, sorted, identified to the lowest taxonomic level (usually species), counted, and weighed. Invertebrate samples were also saved for stable isotope analysis (Chapter 15).

12.2.2 Trawl Biomass Analysis

Macroinvertebrate biomass (CPUE, grams per m^2) was calculated for each species based on trawl swept area. These data were analyzed using Fit Linear Mixed-Effects Models (LMM) with post-hoc Tukey honestly significant difference (HSD) multiple comparisons tests. Canaveral Shoals II was separated into two separate sampling areas: Canaveral Shoals II (CSII) and the Canaveral Shoals II Borrow Area (CSII-BA) for some of the analyses. Diversity and biomass were compared both within Canaveral Shoals (CSII vs. CSII-BA) and to the two reference shoals (Bull Shoal and Chester Shoal).

12.2.3 Closed-TED Trawl Catch Analysis

As noted above, additional closed-TED-trawls were conducted during each sampling period beginning in spring 2014 (see Section 12.2.1 for detailed methods). To determine if the TED was allowing larger invertebrates to escape capture, we compared the mean size and biomass of the two primary families of benthic invertebrates that reach a size large enough to potentially be excluded by the TED: penaeid shrimp and portunid crabs. These data failed the test for normality and could not be transformed adequately so a non-parametric Kruskal–Wallis one-way ANOVA was used for comparison. For penaeid shrimp and portunid crabs, we compared their mean carapace length (tip of rostrum to rear of the cephalothorax) or carapace width (lateral spine to lateral spine), respectively. Biomass was measured as the mean wet weight (g) of all penaeids or portunids captured in a trawl event.

12.2.4 Community Structure Analysis

Macroinvertebrate assemblages were initially compared using non-metric multidimensional scaling (Principal Component Analysis) to investigate relationships among sampling areas, environmental factors and periods. These analyses were intended to provide a framework to compare species assemblages and relate those assemblages to possible environmental drivers (e.g., water temperature, sediment characteristics). The faunal communities represented by the trawl samples were compared using the Simpson's diversity index and trawl sample mean biomass in multivariate and univariate analyses. Simpson's Index was selected over Shannon-Wiener because the former offers a superior measure of community evenness (relative abundance of species) rather than richness, which agrees with the focus of this study. The use of multiple indicators allowed for an in-depth evaluation of changing community structure. These community metrics were analyzed using Fit LMM with post-hoc Tukey HSD multiple comparisons tests to assess the seasonal variation, habitat-driven variation (ridge versus swale), variation among shoals, and the potential effect of dredging.

12.3 Results

When running the LMM models, all factors (e.g., shoal, year, season, habitat (ridge versus swale), quadrant of the shoal, etc.) were loaded into the initial model. If a factor was not significant, it was removed from the model and the model was run again to search for interaction effects. In Section 12.3.5 we present all analyses between CSII and CSII-BA where CSII, CSII-BA, Chester and Bull were all treated as separate shoals. These results indicated that the effects of dredging did not have a significant impact on the dermersal invertebrate communities within the study area. Instead, there was a strong seasonal effect on these communities throughout all the project years. Since the difference between CSII and CSII-BA were not significantly relevant, all seasonal analyses were perfomed with CSII and CSII-BA combined to increase the statistical power. In this section, we discuss the seasonal variations prior to the impacts of dredging as that was the main factor influencing the benthic communities within this area. The impacts of initial and post-dredging periods are discussed following the seasonal analysis.

12.3.1 Closed-TED Trawls

Penaeid shrimp showed no significant difference in mean carapace length or wet weight between the standard trawls and the closed-TED trawls (P=0.611 and P=0.384, respectively) (Figures 12-2 and 12-3). Portunid crabs also showed no difference in mean carapace width or wet weight between the standard trawls and the closed-TED trawls (P=0.934 and P=0.424, respectively) (Figures 12-4 and 12-5). These results demonstrated that significant numbers of large invertebrates were not lost through the TED in the standard trawls, which would have otherwise necessitated assessment of the closed-TED trawl collections. As such, only the standard trawls were analyzed from this point forward.

12.3.2 Functional Groups

Pelagic crustaceans were found in the highest numbers compared to all other functional groups (Figure 12-6). This group typically holds a low position on the food web and is particularly important as it includes many species of small crustaceans that are fed upon by higher trophic level organisms. These include seasonally abundant shrimp from the genus *Acetes*, numerous species of mysid shrimp, and shrimp belonging to the genus *Belzebub* (commonly known as Lucifer Shrimp).

12.3.3 Seasonal Comparisons

In general, season had a strong effect, thus it was considered in all analyses, either by including it explicitly as a factor or analyzing other factors separately by season. The seasonal variation in the Simpson’s diversity index / evenness and mean biomass are presented in Figures 12-7 to 12-14. Simpson’s diversity/evenness and biomass appeared to be highest in the spring or summer seasons and lowest in the fall or winter. The type III linear mixed-effects model of Simpson’s diversity index was significant for all model factors (Table 12-1). The same model of mean biomass was not significant for shoal or the shoal:year interaction (Table 12-2). Tukey HSD multiple comparisons tests by year showed that seasons often grouped together for both the Simpson’s diversity index (Table 12-3) and the mean biomass (Table 12-4), but there were no consistent seasonal patterns. However, the diversity in spring 2016 dropped precipitously with no clear environmental rationale, so we explored this further. Tukey HSD multiple comparisons tests between years of the mean Simpson’s diversity index and mean biomass (both averaged across all shoals) for spring showed that all years were similar except the diversity in spring 2016, which was anomalously low.

12.3.4 Ridge-swale Habitat Comparisons

The focus for these analyses was on differences between ridge and swale habitats, so Canaveral Shoals II was left as a single shoal and not split into CSII and CSII-BA. The effects of dredging did not have a significant impact on the communities within the study area and as such, did not warrant splitting Canaverals Shoals II into CSII and CSII-BA (see Section 12.3.5). By keeping Canaveral Shoals II as one shoal rather than two, the analysis provided below had stronger statistical power, which allowed for better comparisons to be made.

12.3.4.1 Season: Fall

Figures 12-15 to 12-17 show Simpson's diversity index for CSII, Bull, and Chester Shoals over all years for the fall season. The type III LMM of Simpson's diversity index for the fall season was significant for all factors and the interactions between shoal and habitat type, year, and time of day (Tables 12-5 and 12-6). Tukey multiple comparisons tests showed that CSII was the only shoal with a significant difference in diversity between ridges and swales, and this difference held across all years (Table 12-7). During the fall season from 2013–2017 diversity was higher on the ridges than the swales on CSII but for 2018, the opposite was true (higher diversity in the swales) (Figure 12-15). See Section 12.3.5 for details on the timing and impacts of the dredging events.

Figures 12-18 to 12-20 show the mean biomass of the ridges and swales for CSII, Bull, and Chester Shoals overall years for the fall season. The box plot for ridge samples in 2013 is truncated due to incomplete sampling of ridges during that initial season. The type III linear mixed-effects model of mean biomass was significant for all factors except shoal (Table 12-8). Tukey HSD multiple comparisons tests showed consistent differences in mean biomass between ridge and swale habitats across shoals but not across years (Table 12-9). For all shoals, the mean biomass was different between ridges and swales but only in 2015, 2017, and 2018. The swales predominantly had higher mean biomass than the ridges.

12.3.4.2 Season: Winter

Figures 12-21 to 12-23 show the Simpson's diversity index for CSII, Bull and Chester Shoals over all years for the winter season. The type III LMM of Simpson's diversity index for the winter season was significant for all factors and the interactions between shoal and habitat type, year, and time of day (Tables 12-10 and 12-11). Tukey multiple comparisons tests again showed that CSII was the only shoal with a significant difference in diversity between ridges and swales, and this difference held across all years (Table 12-12). During all winter seasons from 2014–2019 diversity was higher on the ridges than the swales on CSII.

Figures 12-24 to 12-26 show the mean biomass of the ridges and swales for CSII, Bull, and Chester Shoals over all years for the winter season. The type III LMM of mean biomass was significant for habitat type and year (Tables 12-13 and 12-14). Tukey HSD multiple comparisons tests showed that swale habitats had significantly higher mean biomass than ridges for the years 2016–2019, but the remaining years showed no difference (Table 12-15). For all shoals, the mean biomass was different between ridges and swales but only in 2015, 2017, and 2018. The swales predominantly had higher mean biomass than the ridges.

12.3.4.3 Season: Spring

Figures 12-27 to 12-29 show the Simpson's diversity index for CSII, Bull, and Chester Shoals over all years for the spring season. The type III LMM of Simpson's diversity index for the spring season was significant for all factors except shoal and the interactions between shoal and year, and shoal and time of day (Tables 12-16 and 12-17). Tukey multiple comparisons tests showed no difference in diversity between ridge and swale habitat types for any years.

Figures 12-30 to 12-32 show the mean biomass of the ridges and swales for CSII, Bull, and Chester Shoals over all years for the spring season. The type III LMM of the mean biomass were significant for habitat type and year (Table 12-18), but there were no significant interactions. Tukey HSD multiple comparisons tests showed that ridge and swale habitats were similar during the spring among all shoals except for the spring of 2017 where biomass was higher in the swales for all shoals.

12.3.4.4 Season: Summer

Figures 12-33 to 12-35 show the Simpson's diversity index for CSII, Bull, and Chester Shoals over all years for the summer season. The type III LMM of Simpson's diversity index for the summer season was significant for year and time of day and the interaction between these factors (Tables 12-19 and 12-20). Tukey multiple comparisons tests found no differences between ridge and swale diversity for the summer season.

Figures 12-36 to 12-38 show the mean biomass of the ridges and swales for CSII, Bull, and Chester Shoals over all years for the summer season. The type III LMM of the mean biomass were significant for all factors except shoal, and for the interaction between habitat type and year (Tables 12-21 and 12-22). Tukey HSD multiple comparisons tests showed that swale habitats had significantly higher mean biomass than ridges on all shoals for 2017 and 2019 only.

12.3.5 Effects of Dredging

12.3.5.1 Initial Impacts

The following analyses were aimed at determining the short-term effects of dredging by only comparing sampling periods immediately before, during, and immediately after the dredging event. The first dredging event during the project occurred from late November 2013 through April 2014. Fall 2013 was the only season sampled prior to the start of dredging, and only limited sampling was possible on CSII, CSII-BA, and Bull Shoals. Dredging occurred during winter 2013–2014 and spring 2014 sampling periods. The summer 2014 sampling period was included in the analysis since it occurred immediately after dredging was completed. The second dredging event occurred between February and April 2018. Fall 2017 was immediately prior to the dredging, and winter 2017–2018 and spring 2018 seasons occurred during the dredging activity, with spring 2018 encompassing post dredging as well. For this section, Canaveral Shoals II (CSII) was split into CSII (non-dredged) and CSII-BA (the borrow area that was dredged) for all analyses. When considering diversity, there appeared to be no impact of dredging activities on the demersal/epifaunal invertebrates diversity (Tables 12-23, 12-24, 12-25). Overall, the fall and winter months showed low diversity and therefore could not be attributed to the dredging event. The same results were seen when comparing biomass were there was no significant difference between CSII and CSII-BA. When comparing CSII and CSII-BA to the reference shoals there were also no significant differences within each season.

The impact to demersal invertebrate communities was initially examined using non-metric multidimensional scaling. To do this, a principal coordinates analysis was performed on the data. As can be seen in Figure 12-39, there was very little dissimilarity among the seasons. The plot showed animals grouped by season (see color code below figure) while the ellipses showed where there were significant clusters. If there were differences using this analysis, the seasons in question would cluster together separately, however, in this plot they overlaid each other. Because of this, the groups cannot be discriminated from each other given this ordination.

12.3.5.2 First Dredging Event

Figure 12-40 shows a comparison of the Simpson's diversity index between CSII and CSII-BA from fall 2013 through summer 2014. A type III ANOVA analysis found no difference in the Simpson's diversity index between CSII and CSII-BA for any of the seasons fall 2013 through summer 2014 (Table 12-23). Shoal was not a significant factor in the initial model but became significant when the time of day interaction was included in the model. However, a type III ANOVA analysis followed by Tukey HSD multiple comparisons tests found no differences between the CSII and CSII-BA during any season from fall 2013 through summer 2014 (Tables 12-2, and 12-25). Figure 12-41 shows the results of the biomass (g/m^2) analysis complimentary to the diversity results reported above. Again, type III ANOVA analysis showed no difference between CSII and CSII-BA (Table 12-26). Additional years and seasons were not included in the analysis comparing CSII and CSII-BA because if there was no impact observed during and immediately after the dredging event, then any differences observed later could not be attributed to dredging.

We then assessed demersal invertebrates for all of the shoals immediately before, during, and after the first dredging period. Figure 12-42 shows the Simpson's diversity index calculated for invertebrates on all shoals during the first dredging period. A type III ANOVA showed a significant difference between shoals, season by year, and time of day (Table 12-27), but Tukey multiple comparisons tests showed no difference between shoals for any season. Figure 12-43 shows the complimentary mean biomass (g/m^2) for all shoals during the first dredging event. Similar to diversity, mean biomass was not significantly different for any season by year during or immediately after the dredging event (Tables 12-28 and 12-29). Habitat type and time of day were signficant but were not relevant to the quesiton of dredging impact, and were previously assessed across all years in the analysis of seasonality above. Based on the diversity and mean biomass, there appeared to be no significant impact of dredging on demersal invertebrates when compared to the reference shoals (Bull and Chester Shoals).

12.3.5.3 Second Dredging Event

Figure 12-44 shows the Simpson's diversity index for demersal invertebrates on CSII and CSII-BA only. A type III ANOVA showed that as with the first dredging event, there was no significant difference between CSII and CSII-BA (Table 12-30 and 12-31). Figure 12-45 shows the mean biomass for CSII and CSII-BA during the second dredging event. As with diversity, the type III ANOVA found no differences in biomass when comparing the dredged area(CSII-BA) to the non-dredged area (CSII) (Tables 12-32 to 12-33).

We then assessed invertebrates for all of the shoals immediately before, during and after the second dredging period. Figure 12-46 shows the Simpson's diversity index calculated for invertebrates on all shoals during the second dredging period. The initial type III ANOVA model showed no difference between shoals (Table 12-34). However, a subsequent model including the relevant interaction between shoal and habitat type resulted in a significant effect of shoal (Table 12-35). We therefore used Tukey HSD multiple comparisons tests which showed no significant differences between any of the shoals for any of the seasons. Figure 12-47 shows the complimentary mean biomass (g/m^2) for all shoals during the second dredging event. Mean biomass was not significantly different for any season by year during or immediately after the dredging event (Tables 12-36 and 12-37). There were significant factors and interactions (Table 12-38) but these were not relevant to the question of dredge impact, and were previously assessed across all years in the analysis of seasonality. Therefore, based on these metrics of diversity and mean biomass, there appeared to be no significant impacts of dredging on demersal invertebrates when compared to the control shoals (Bull and Chester Shoals).

12.3.6 Long-term Post-dredging Response

The following analyses were aimed at determining the long-term effects of dredging on the community metrics of diversity and mean biomass. These analyses were performed by season considering the strong seasonal influence. The time period for the first response analysis considered the season immediately prior to the first dredging event (fall 2013) until the fall prior to the second dredging event (fall 2017).

The time period for the second response analysis considered the season immediately prior to when the second dredging event started (fall 2017) until the last sample period of the project (summer 2019). We analyzed these data with the ridge and swale habitat data combined and separated to ensure that we captured an effect of dredging, if one existed.

12.3.6.1 Post-First Dredging Event—Fall

Figure 12-48 shows the Simpson's diversity index calculated for invertebrates from samples collected during and after the first dredging event for fall only. Type III ANOVA models showed that during the fall season for all years following the first dredging event there were differences in diversity between shoals (Tables 12-39 and 12-40). Tukey HSD multiple comparisons tests showed that these differences occurred during fall 2015 and fall 2017, but they were not consistent, which indicated the lack of a pattern that could be attributed to the effect of dredging on diversity (Table 12-41).

However, because there was a significant interaction between habitat type and shoal (Table 12-40), we plotted ridge and swale habitats separately (Figure 12-49) and used Tukey HSD multiple comparisons tests to assess ridge and swale habitats separately (Table 12-42). For all years, there were no significant differences in the diversity within the swales; only the ridges showed differences. Fall 2013 was the start of the project and dredging was set to begin so there were inconsistencies in the sampling effort. CSII-BA was sampled more heavily than the other shoals because it was the target of the pending dredging effort and we wanted to sample that site prior to the start of dredging. As a result, not all of the other shoals could be sampled before the winter season began. Despite separating the Tukey HSD analysis into ridge and swale habitats, there were no consistent patterns.

Figure 12-50 shows the mean biomass calculated for invertebrates from samples collected during and after the first dredging event for fall only. Type III ANOVA models showed that during the fall season for all years during and following the first dredging event there were significant differences in mean biomass between shoals (Tables 12-43 and 12-44). These differences could not be attributed to dredging impacts as the effect of shoal on the model was insignificant ($P=0.587$). Tukey HSD multiple comparisons tests showed that these differences occurred during fall 2015 (Table 12-45). For all other years, biomass was not significantly different between shoals. For mean biomass, there was no sigificant interaction between shoal and habitat type so no additional analysis was conducted to separate by habitat type.

12.3.6.2 Post-First Dredging Event—Winter

Figure 12-51 shows the Simpson's diversity index calculated for invertebrates from samples collected during and after the first dredging event for winter only. Type III ANOVA models showed that during the winter season for all years following the first dredging event there were differences in diversity between shoals (Tables 12-46 and 12-47). Tukey HSD multiple comparisons tests showed that these differences occurred during winter 2013/2014 and winter 2015/2016, but they were not consistent, which indicated the lack of a pattern that could be attributed to the effect of dredging on diversity (Table 12-48).

However, because there was a significant interaction between habitat type and shoal (Table 12-47), we plotted ridge and swale habitats separately (Figure 12-52) and used Tukey HSD multiple comparisons tests to assess ridge and swale habitats separately (Table 12-49). The results of these tests showed no clear pattern in diversity among the ridges or swales during any season by year except, importantly, that CSII-BA ridges and swales were not significantly different than CSII during any season and were often similar to Bull and Chester Shoals as well.

Figure 12-53 shows the mean biomass calculated for demersal invertebrates from samples collected during and after the first dredging event for winter only. Type III ANOVA models showed that during the winter season for all years during and following the first dredging event there were no significant differences in mean biomass between shoals (Tables 12-50 and 12-51). For mean biomass, there was no sigificant interaction between shoal and habitat type so no additional analysis was conducted to separate by habitat type.

12.3.6.3 Post-First Dredging Event—Spring

Figure 12-54 shows the Simpson's diversity index calculated for demersal invertebrates from samples collected after the first dredging event for spring only. Type III ANOVA models showed that during the spring season there were signficant differences in diversity between shoals following the first dredging event (Tables 12-52 and 12-53). Tukey HSD comparisons showed that these differences occurred during spring 2018 but only Bull and Chester Shoals differed from one another, which was unlikely to be attributable to dredging activities (Table 12-54). For the Simpson's diversity index, there was no sigificant interaction between shoal and habitat type so no additional analysis was conducted to separate by habitat type.

Figure 12-55 shows the mean biomass calculated for demersal invertebrates from samples collected following the first dredging event for spring only. Type III ANOVA models showed that during the spring season for all years following the first dredging event there were no significant differences in biomass between shoals; however, the interactions between shoal and habitat type, and shoal and season by year, were signficant (Tables 12-55 and 12-56). Because there was a significant interaction between shoal and habitat type (Table 12-56), we plotted the ridge and swale habitats separately (Figure 12-56) and used Tukey HSD multiple comparisions tests to assess ridge and swale habitats separately. The Tukey HSD comparisons showed that these differences were also only found during spring 2018, which, was unlikely to be attributable to dregding activities, similar to the diversity analysis above.

12.3.6.4 Post-First Dredging Event—Summer

Figure 12-57 shows the Simpson's diversity index calculated for demersal invertebrates from samples collected during and after the first dredging event for summer only. Type III ANOVA models showed that during the summer season there were signficant differences in diversity between shoals following the first dredging event (Tables 12-57 and 12-58). Tukey HSD comparisons showed that these differences occurred during summer 2014, 2015, and 2018 (Table 12-59). In summer 2014, CSII-BA differed from Bull Shoal, in 2015 CSII differed from Chester Shoal, and in 2018 CSII-BA again differed from Bull Shoal. While there was similarity between the results from summer 2014 and 2018, they did not represent a pattern indicative of an effect from dredging activities. For the Simpson's diversity index, there was no sigificant interaction between shoal and habitat type so no additional analysis was conducted to separate by habitat type.

Figure 12-58 shows the mean biomass calculated for demersal invertebrates from samples collected after the first dredging event for summer only. Type III ANOVA models showed that during the summer season following the first dredging event there were significant differences in biomass between shoals; however, only the interaction between shoal and season by year was signficant (Tables 12-60 and 12-61). Tukey HSD multiple comparisons tests revealed that the only signifcant difference between shoals occurred during summer 2017 when Bull Shoal difffered from CSII and Chester Shoals. There was no sigificant interaction between shoal and habitat type so no additional analysis was conducted to separate by habitat type.

12.3.6.5 Post-Second Dredging Event

Following the second dredge event that occurred between November 2017 and March 2018, we again assessed the diversity and mean biomass of demersal invertebrates. Figure 12-59 shows the Simpson's diversity index calculated for demersal invertebrates from samples collected during and after the second dredging event. A type III ANOVA analysis found no significant differences in diversity among the shoals during this time (Table 12-62 and 12-63). Season by year, time of day, and the season by year:time of day interaction were all significant factors but not relevant to the question of dredging impacts.

Figure 12-60 shows the mean biomass calculated for demersal invertebrates from samples collected during and after the second dredging event. Similar to diversity, there was no signficant differences in mean biomass among shoals during or following the second dredging event and the same individual factors were significant (Table 12-64 and 12-65).

12.3.7 Seasonal Abundance of Commercial Species

During the course of the study, we frequently collected invertebrates in trawls which have (or historically had) value to commercial fisheries. These included the Calico Scallop *Argopecten gibbus*, Rock Shrimp *Sicyonia* spp., penaeid shrimps *Penaeus* spp., and squids *Doryteuthis* spp. None of these species were collected in high abundance and in many instances their landings were low and/or sporadic.

The Calico Scallop was occasionally collected in our trawl samples, but these were very sporadic and without a clear pattern (Figure 12-61). Commercial landings of Calico Scallops were last reported by the Florida Fish and Wildlife Conservation Commission in 2013 (FWC 2020). Rock Shrimp were also landed regularly in our trawl samples and these included three species: *Sicyonia brevirostris*, *S. typical* and *S. dorsalis*. Due to their low abundance (typically a mean of < 5 individuals per trawl sample) we combined the three species (Figure 12-62). Two species of penaeid shrimp, Brown Shrimp *Penaeus aztecus* and White Shrimp *P. setiferus*, were frequently caught but in low abundance and were therefore combined (Figure 12-63). There were two species of commercially important squid found in the area: *Doryteuthis plei* (Arrow Squid) and *D. pealeii* (Longfin Inshore Squid). Figure 12-64 shows their mean abundance during all years. The two species were combined here because of the difficulty in identifying them to species level. *Lolliguncula brevis* was another species of squid frequently collected during trawl sampling but it has been excluded because it was not of commerical value.

12.4 Discussion

12.4.1 Summary of Dredging Effects

Based upon our methods for trawl sampling of demersal invertebrate communities, there did not appear to be any clear and significant effects of dredging activities on the diversity or mean biomass metrics we used to assess these communities. We did not find any consistent, significant effects during, immediately following, or years after dredging activities. In general, Bull Shoal had higher community diversity and mean biomass than Chester Shoal and CSII but this pattern was not particularly pronounced with respect to the dredged shoal (CSII-BA). Diversity and biomass did vary from year to year, but those changes were typically for all shoals, not just CSII-BA, which experienced sand dredging. There were also other patterns in diversity and mean biomass observed, but those patterns were associated with season, time of day (night versus day), and the habitat (ridge versus swale habitat). Even when the interactions between these factors and shoal were considered, no effect of dredging on diversity or mean biomass were apparent.

12.4.2 Seasonality and Habitat Type

Seasonal patterns in the community diversity and mean biomass were evident but not always consistent. Diversity and biomass also often differed between organisms collected from trawls conducted on ridge habitats compared to swale habitats but again, not consistently. The most consistent patterns suggest that diversity was higher on the ridges and biomass was higher in the swales, but this was also seasonal. For example, diversity was higher on the ridges of CSII each fall but higher in swales in the winter. However, in the winter there were no differences in diversity between ridges and swales for Bull or Chester Shoals. In the spring, there were no differences in diversity between the ridges and swales for any year. Summer generally had the highest diversity of all seasons but there were no differences in diversity between ridge and swale habitats during the summer. This type of variability was also present with regards to biomass. Clearly, variability is high, which underscores the dynamic nature of these soft-bottom communities.

12.4.3 Commercial Species

The abundance of commercially important invertebrate species collected from trawls was lower than expected and did not include any high-value species, such as the Caribbean Spiny Lobster. The commercial species groups that were observed, Calico Scallops, rock shrimps, penaeid shrimps, and squids were not captured in consistently high abundance or in a pattern relative to dredging activities that would suggest they are any more vulnerable to impact than any other species group we assessed.

12.4.4 Other Variables—Hurricanes

There were two major hurricanes during the study period. Hurricane Matthew traveled north, offshore of the Florida east coast October 6–7, 2016. There appeared to be no major impacts from this storm on diversity or biomass. Fall sampling occurred in November and December of that year. Hurricane Irma made land fall in the Florida Keys on September 10, 2017, and traveled north through the western side of Florida. Our fall sampling occurred in November and December of that year. Again, there appeared to be no effect of the hurricane on the diversity and biomass of demersal invertebrate communities collected from trawl samples during the season immediately following the hurricane.

12.4.5 Conclusions

Our results appear to be consistent with similar studies on the effects of dredging on soft-bottom communities in high-energy environments. Kotta et al. (2009) found a weak response in biomass sampled during the summer to the effects of dredging but significant variability among years, suggesting environmental factors were more important in dictating the biomass of invertebrate communities from year to year. The dynamic nature of the ridge and swale habitats offshore of Cape Canaveral also favor the establishment of small, often mobile, opportunistic species, which is generally consistent with the communities we observed (Whittaker et al. 2001). These results differ from other studies in presumably lower energy environments that used grab sampling devices to assess the impact of commercial dredging off the coast of the United Kingdom in the North Sea (Boyd et al. 2005), in the English Channel (Desprez 2000; Hitchcock et al. 2002), offshore of Denmark and the Netherlands in the eastern North Sea (van Dalfsen et al. 2000), and offshore Spain (van Dalfsen et al. 2000). In each of these studies, dredging yielded short- and long-term effects, which we did not observe for the sand shoals off Cape Canaveral. This observation is again most likely due to the shallow, dynamic nature of this environment but could also be a consequence of the near subtropical latitude of our study site, with its concomitant high species diversity relative to the temperate locations noted above. The high diversity may ameliorate the observed effects of dredging through a more continuous and diverse supply of recruits available to colonize the available habitat following disturbance.

12.5 References

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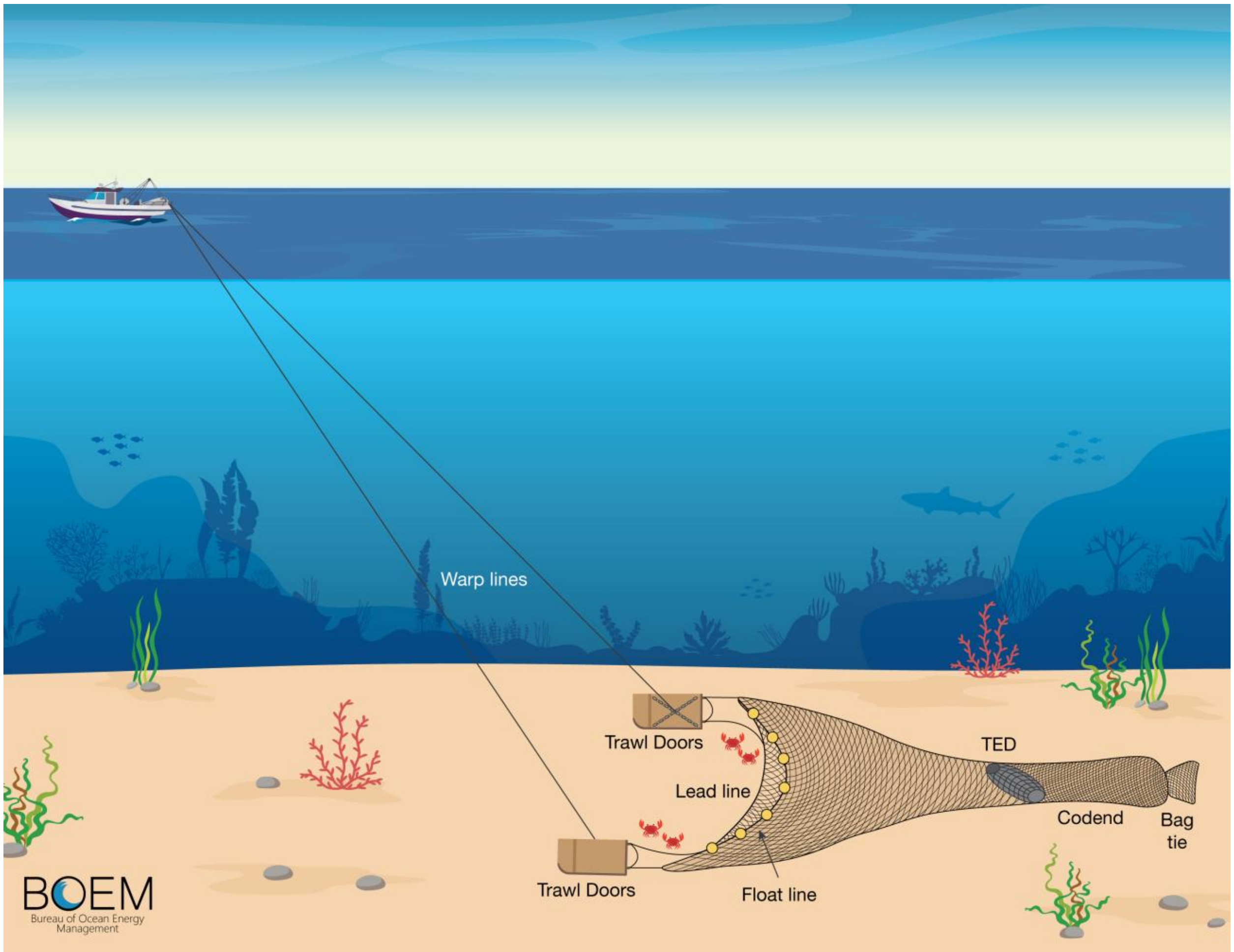

Figure 12-1. Diagram of a bottom trawl used to collect samples of demersal/epibenthic invertebrates and fishes.
TED is the Turtle Excluder Device positioned in the net.

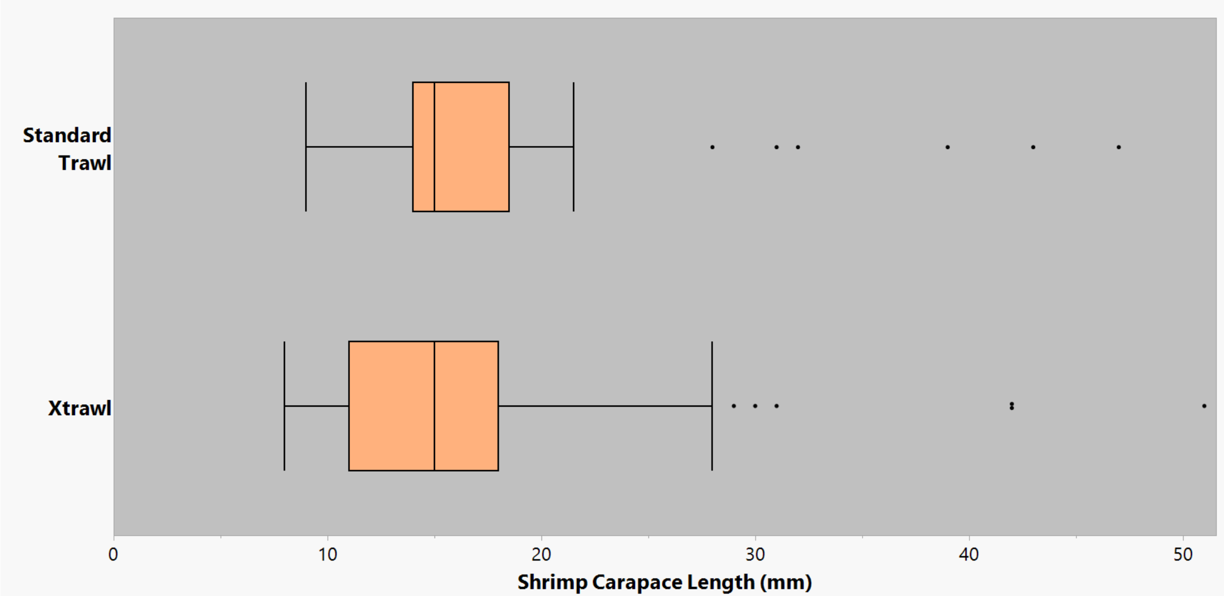

Figure 12-2. Box plots comparing penaeid shrimp carapace length between standard and closed-TED trawls for fall 2018.
The median is indicated by the vertical line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers.

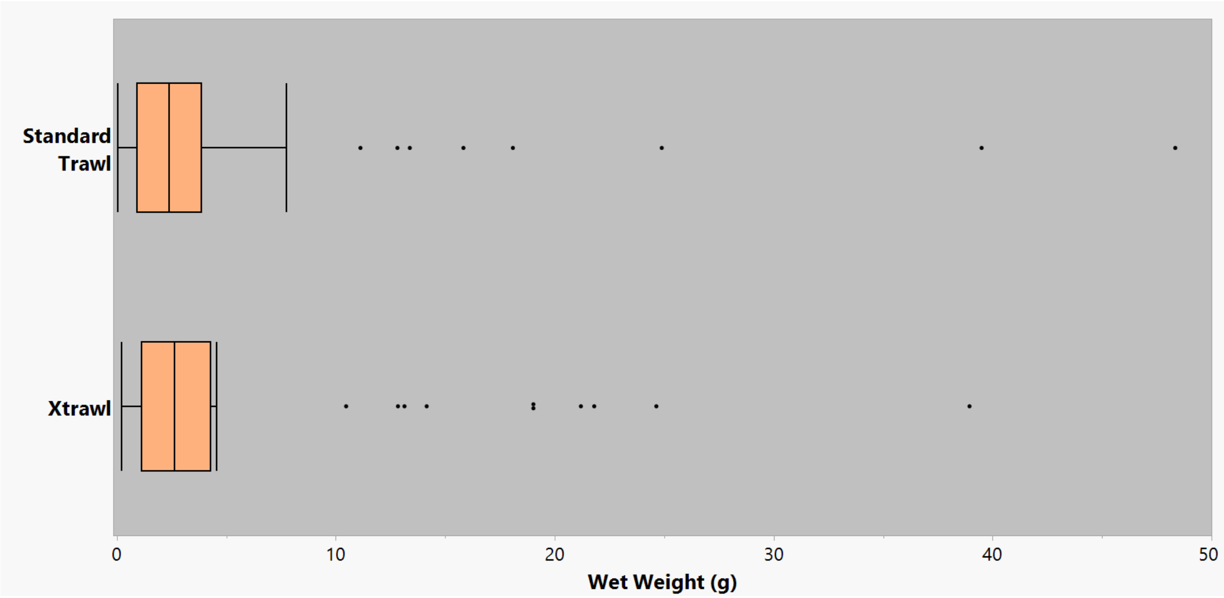

Figure 12-3. Box plots comparing penaeid shrimp wet weight between standard and closed-TED trawls for fall 2018.
The median is indicated by the vertical line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers.

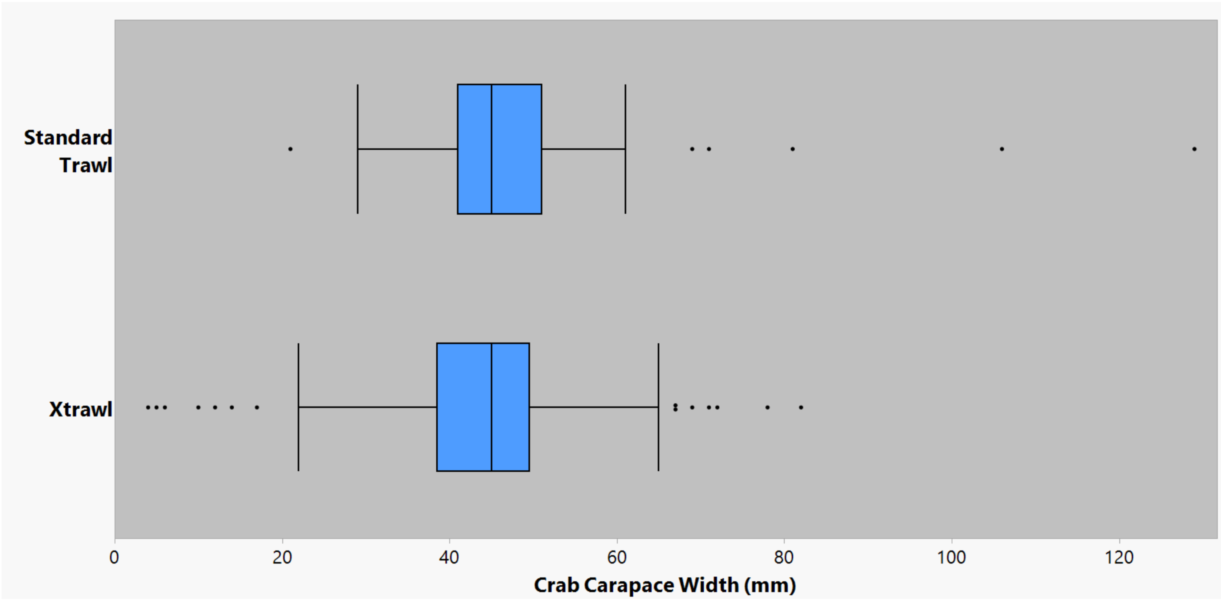

Figure 12-4. Box plots comparing portunid crab carapace width between standard and closed-TED trawls for fall 2018.
The median is indicated by the vertical line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers.

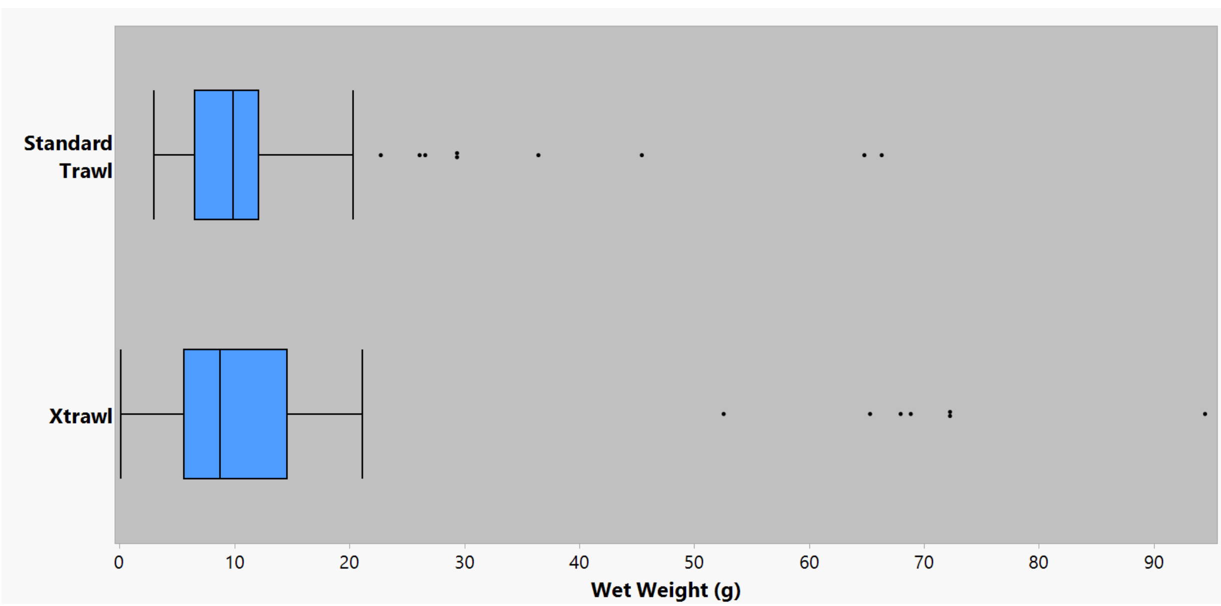

Figure 12-5. Box plots comparing portunid crab wet weight between standard and closed-TED trawls for fall 2018.
The median is indicated by the vertical line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers.

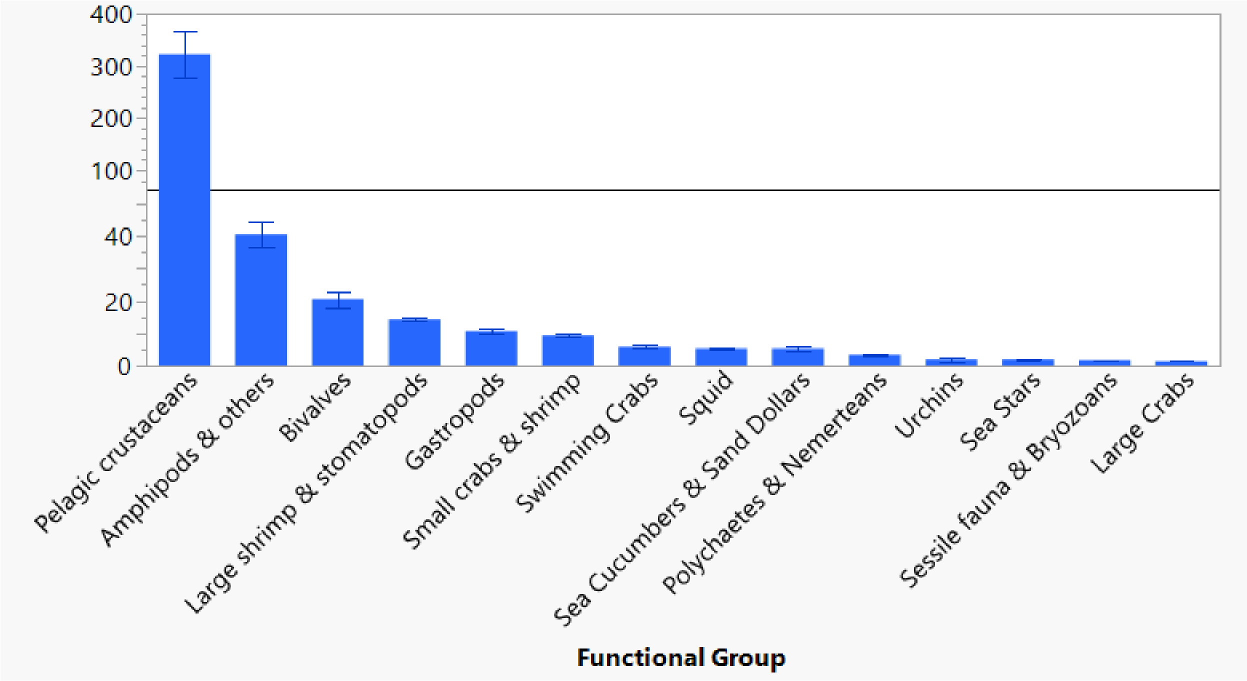

Figure 12-6. Mean number of individuals for the functional groups for all years on all shoals found in the study.
Error bars denote one standard error of the mean.

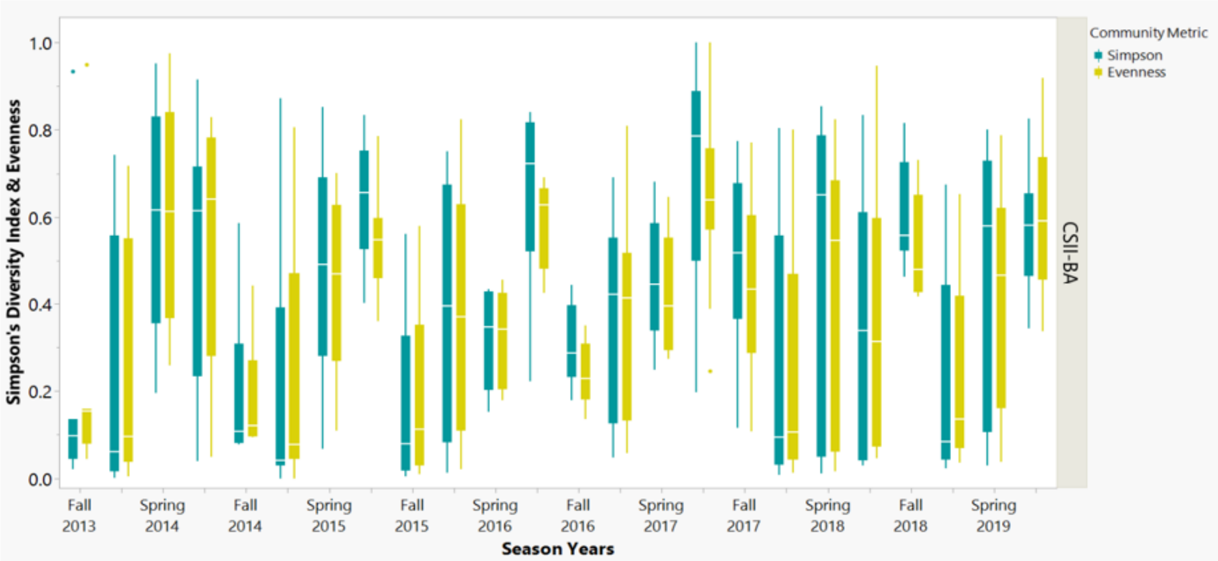

Figure 12-7. Box plots comparing the Simpson's diversity index and evenness for CSII-BA over all seasons.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers.

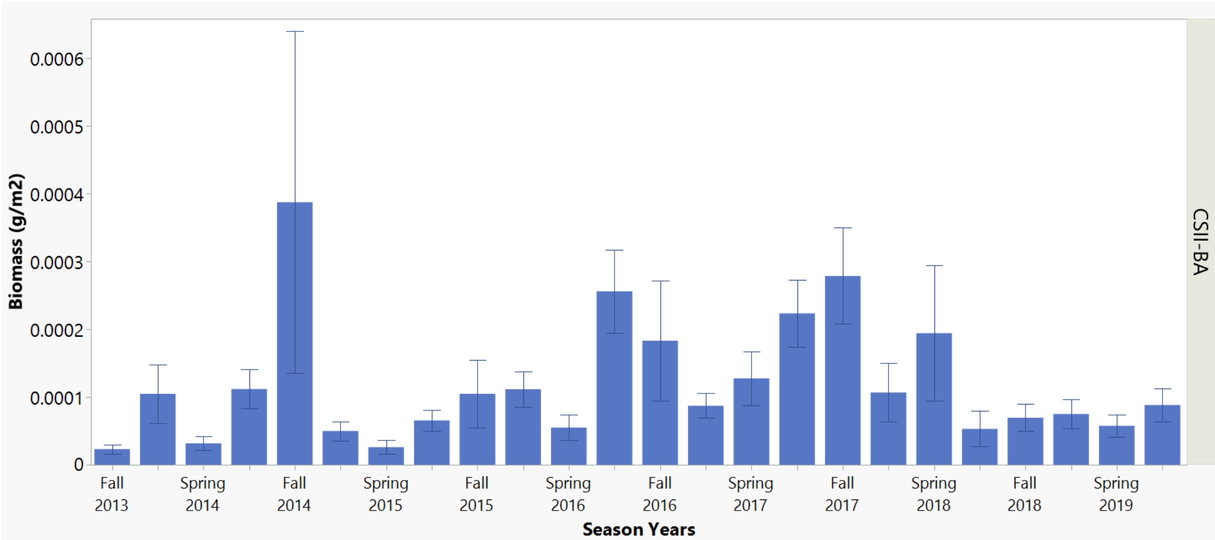

Figure 12-8. Mean biomass of demersal invertebrates (g/m²) over all seasons for CSII-BA.
Error bars denote one standard error of the mean.

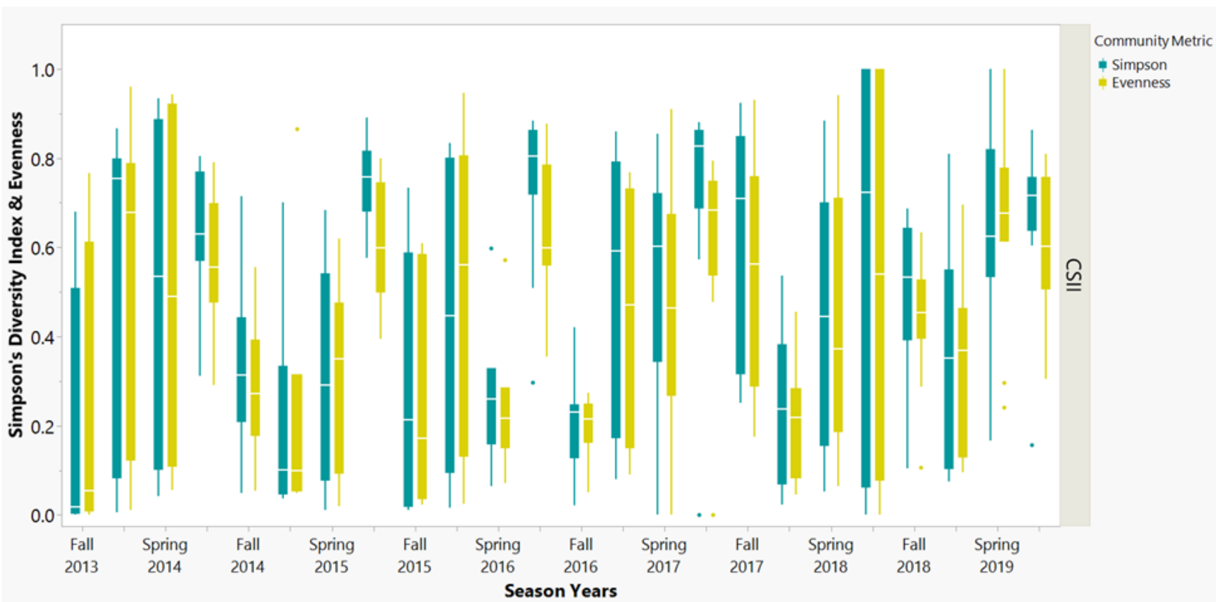

Figure 12-9. Simpson's diversity index and evenness for CSII over all seasons.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers.

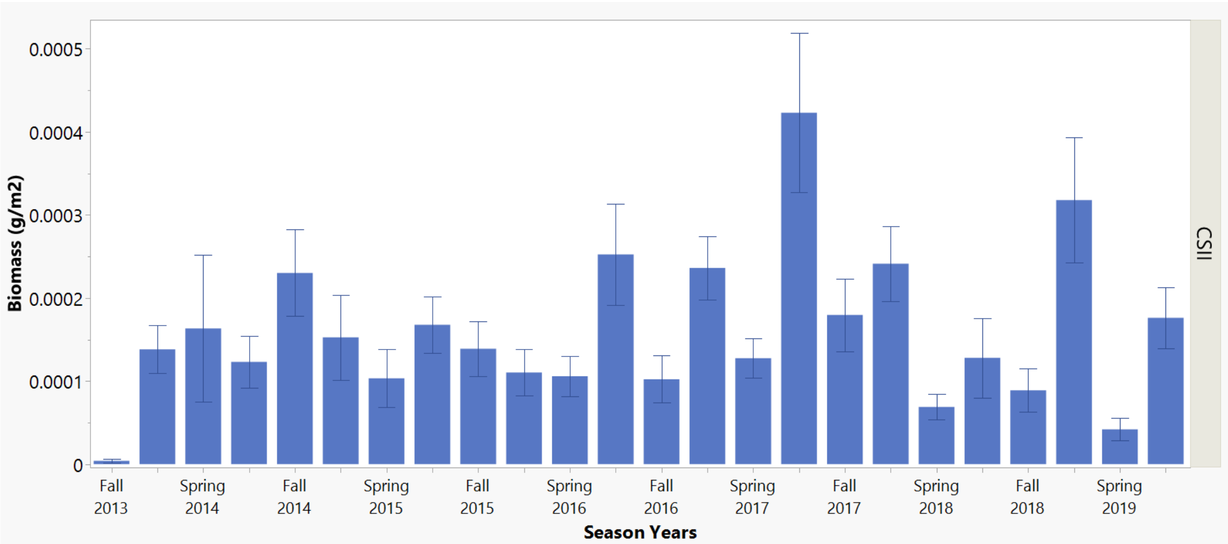

Figure 12-10. Mean biomass of demersal invertebrates (g/m^2) over all seasons for CSII.
Error bars denote one standard error of the mean.

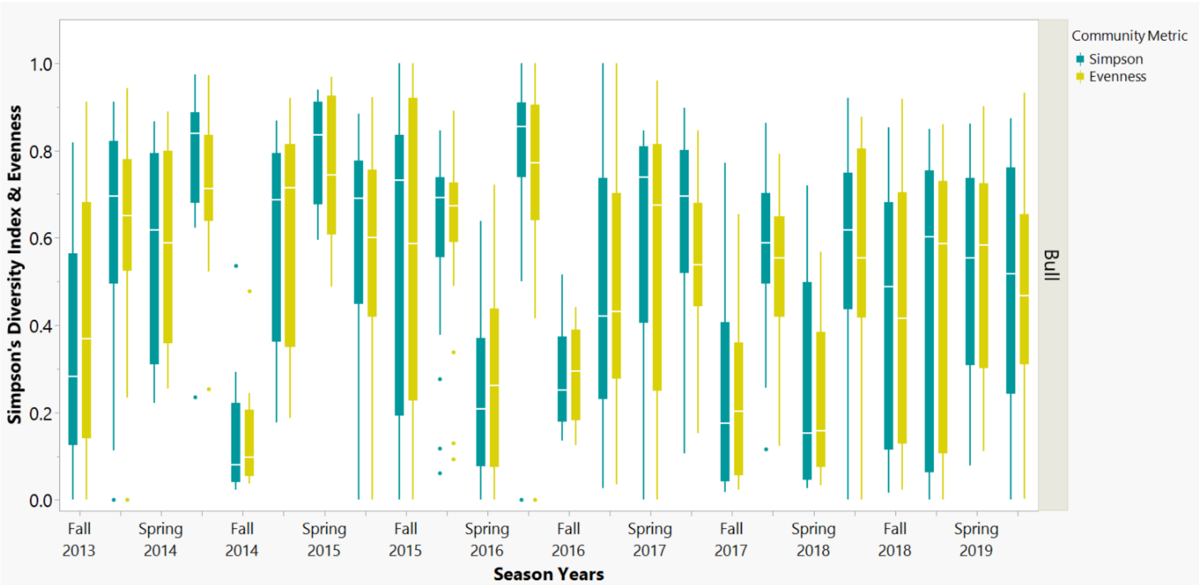

Figure 12-11. Simpson's diversity index and evenness for Bull Shoal over all seasons.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers.

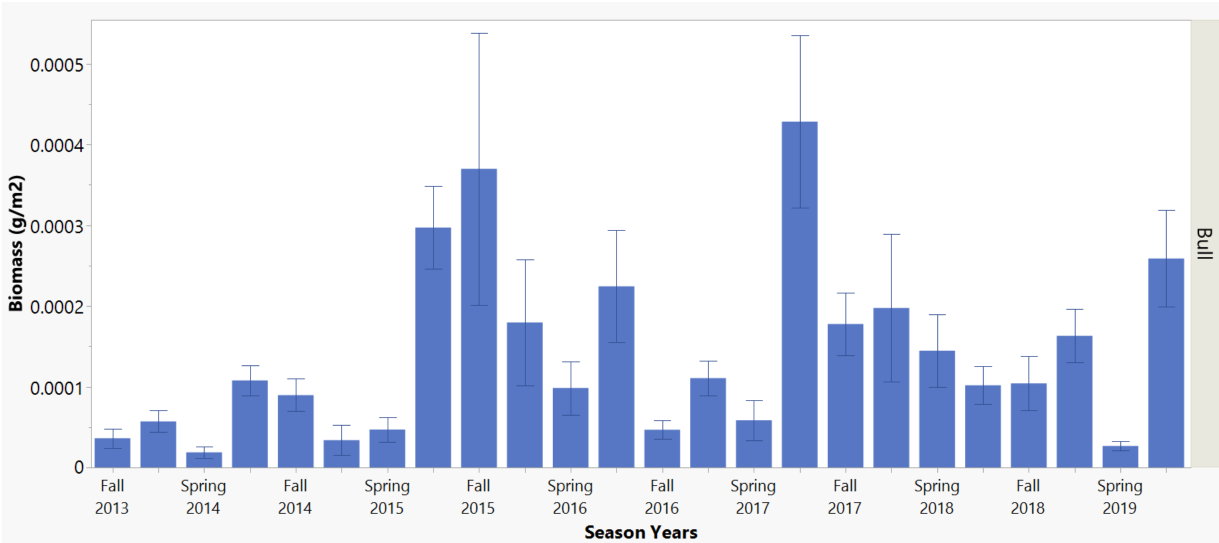

Figure 12-12. Mean biomass of demersal invertebrates (g/m^2) over all seasons for Bull Shoal.
Error bars denote one standard error of the mean.

Figure 12-13. Simpson's diversity index and evenness for Chester Shoal over all seasons.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers.

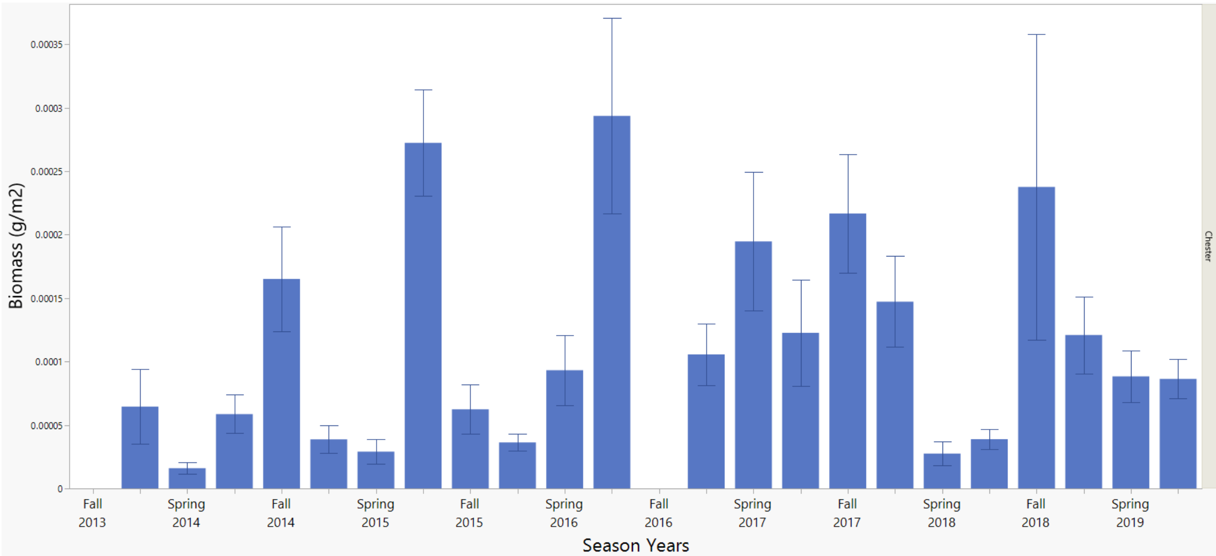

Figure 12-14. Mean biomass of demersal invertebrates (g/m^2) over all seasons for Chester Shoal.
Error bars denote one standard error of the mean.

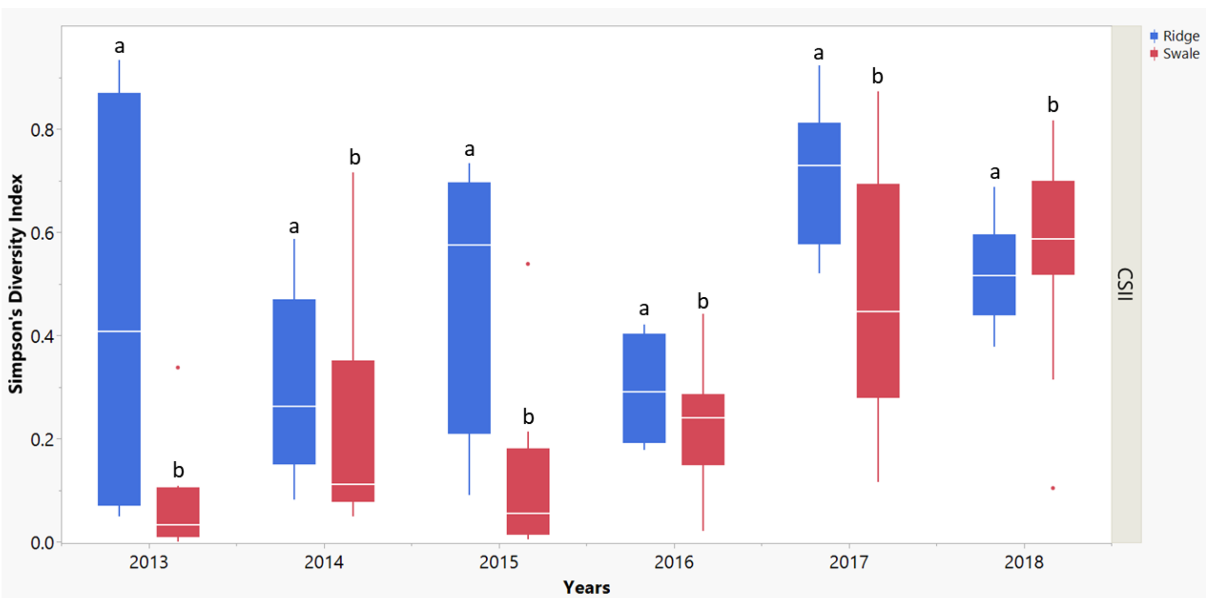

Figure 12-15. Simpson's diversity index comparing ridge versus swale habitats within each year for CSII during the fall.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference ($P \leq 0.05$).

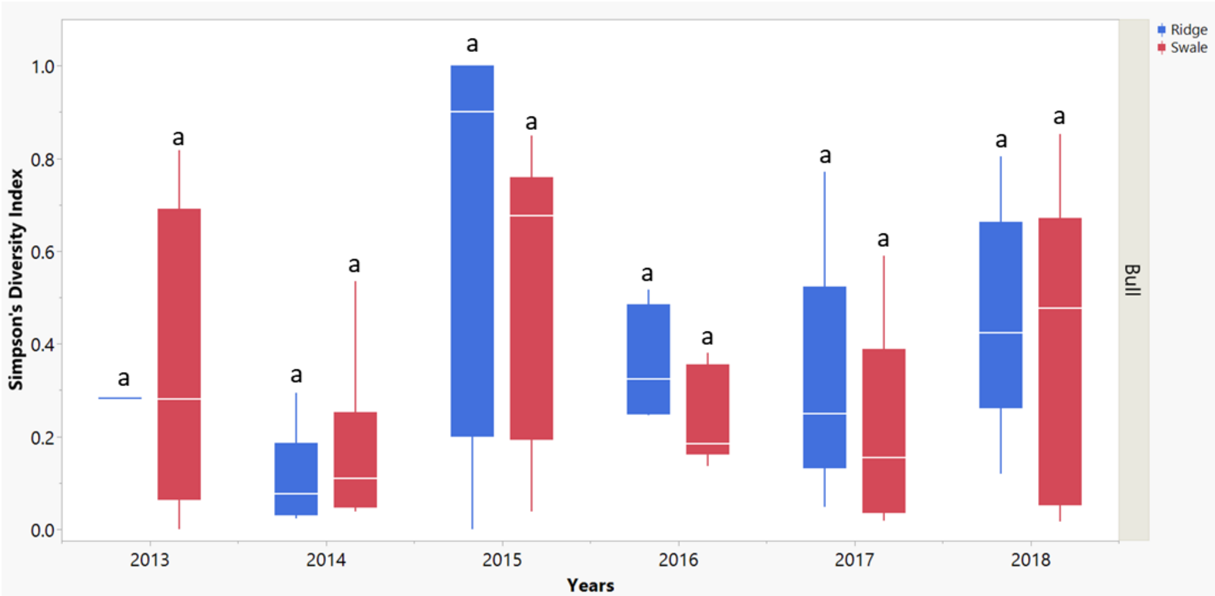

Figure 12-16. Simpson's diversity index comparing ridge versus swale habitats within each year for Bull Shoal during the fall.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

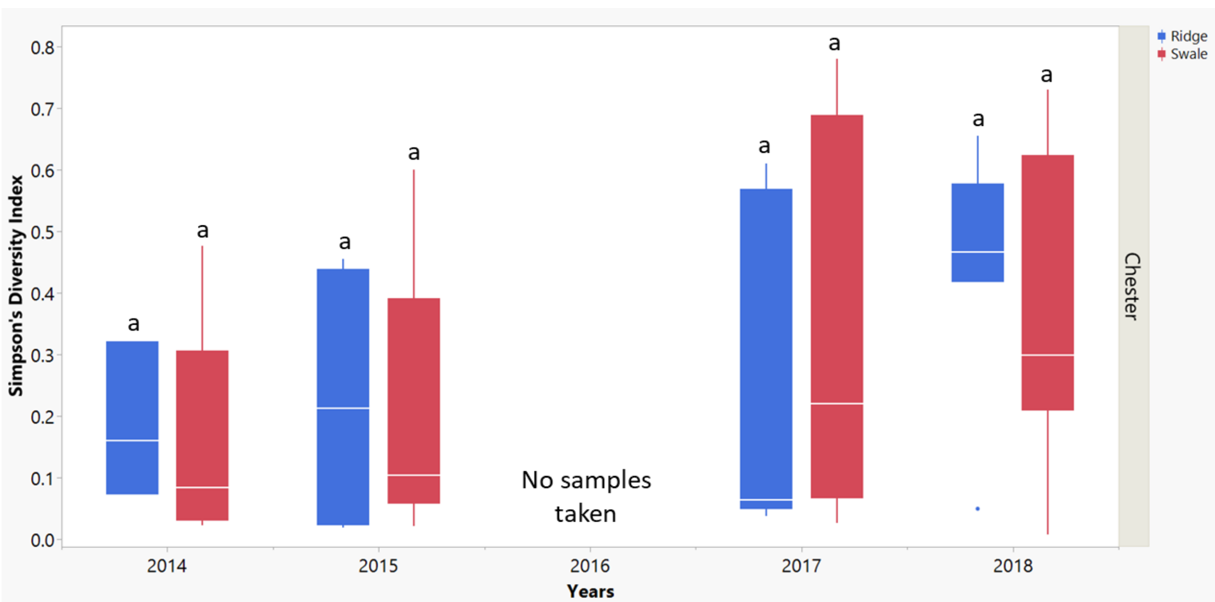

Figure 12-17. Simpson's diversity index comparing ridge versus swale habitats within each year for Chester Shoal during the fall.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

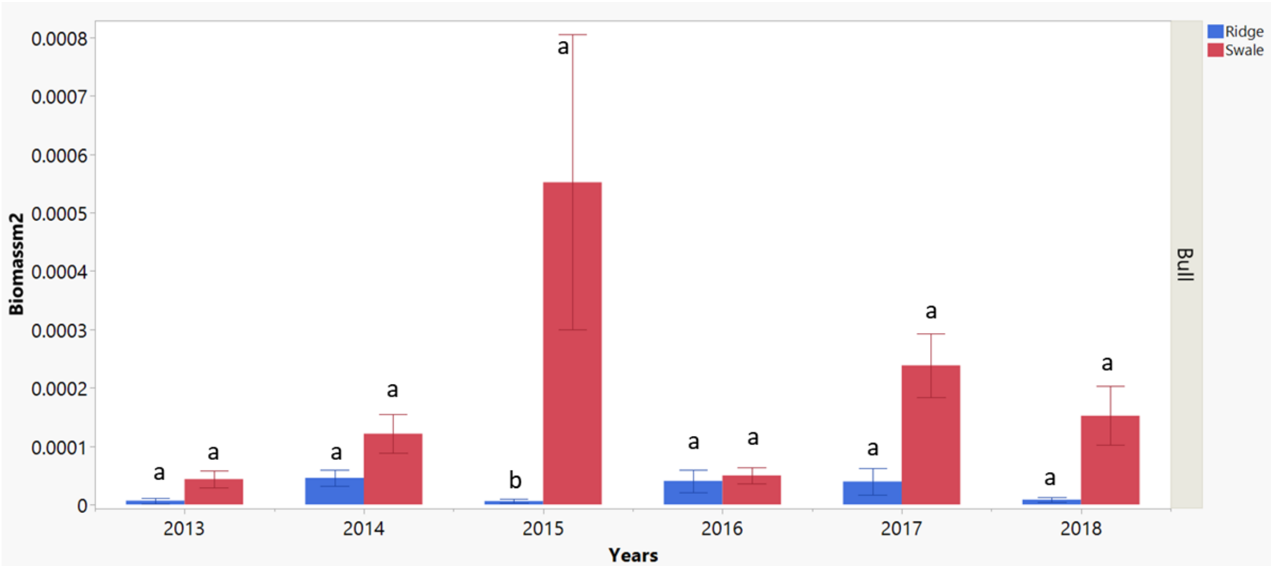

Figure 12-18. Mean biomass (g/m^2) comparing ridge versus swale habitats within each year in trawl samples from CSII during the fall.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test within each year. Like letters indicate no significant differences between groups and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

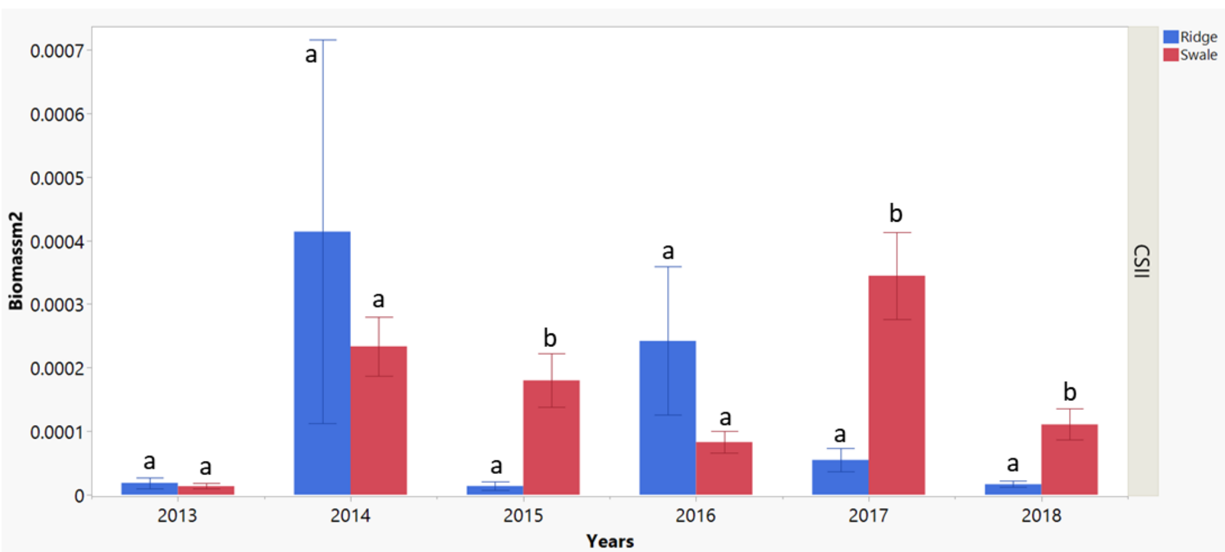

Figure 12-19. Mean biomass (g/m^2) comparing ridge versus swale habitats within each year in trawl samples from Bull Shoal during the fall.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test within each year. Like letters indicate no significant differences between groups and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

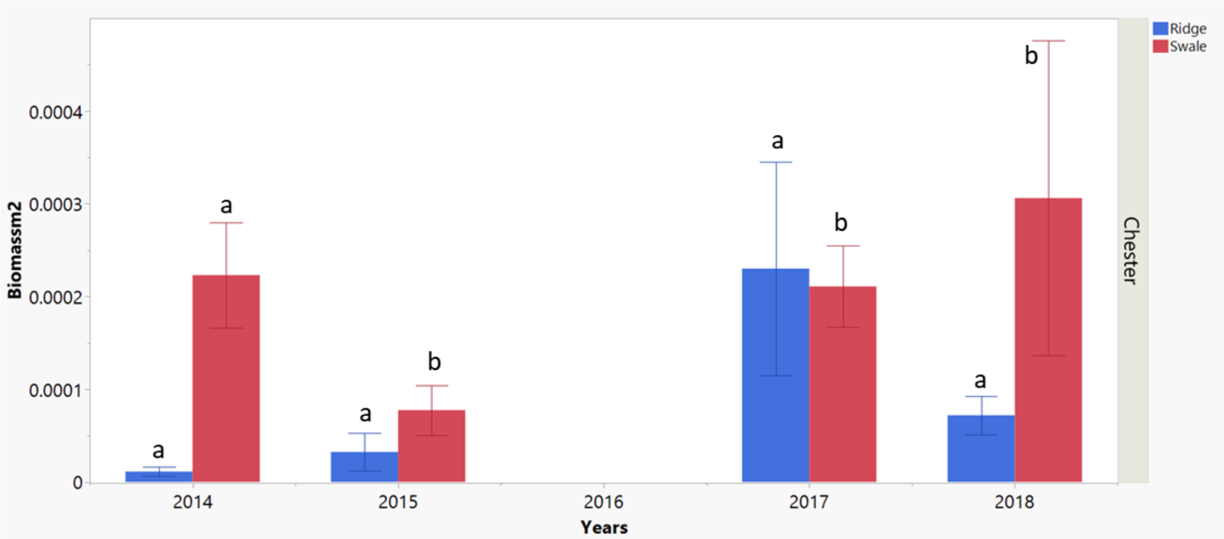

Figure 12-20. Mean biomass (g/m²) comparing ridge versus swale habitats within each year in trawl samples from Chester Shoal during the fall.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test within each year. Like letters indicate no significant differences between groups and unlike letters indicate there is a significant difference between the groups at an $\alpha = 0.05$.

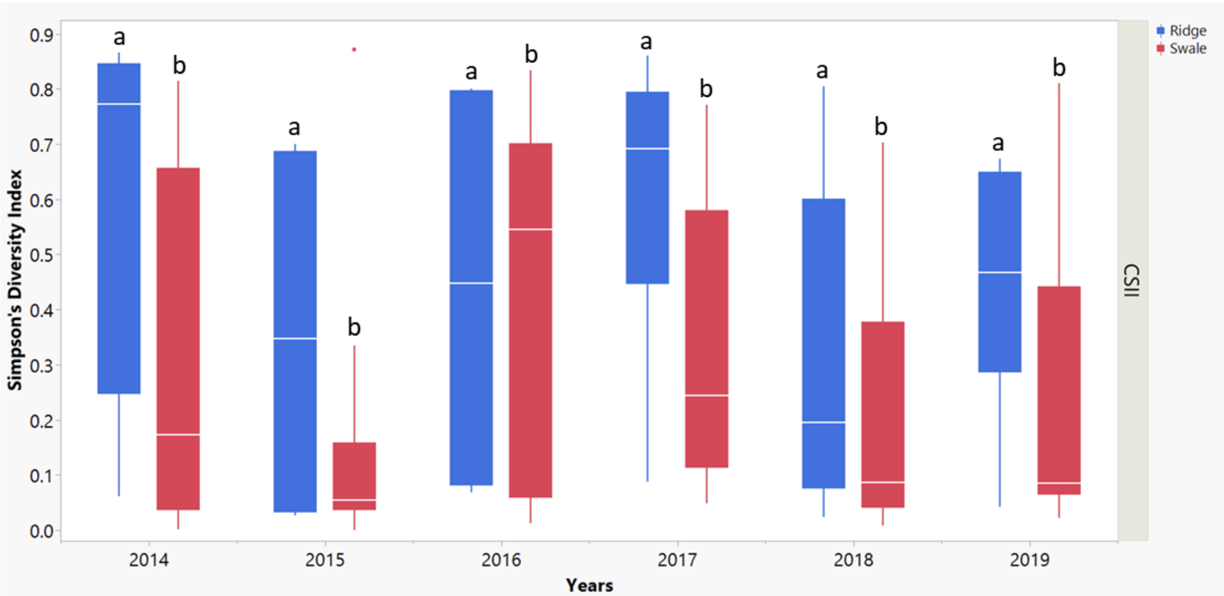

Figure 12-21. Simpson's diversity index comparing ridge versus swale habitats within each year for CSII during the winter.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference ($P \leq 0.05$).

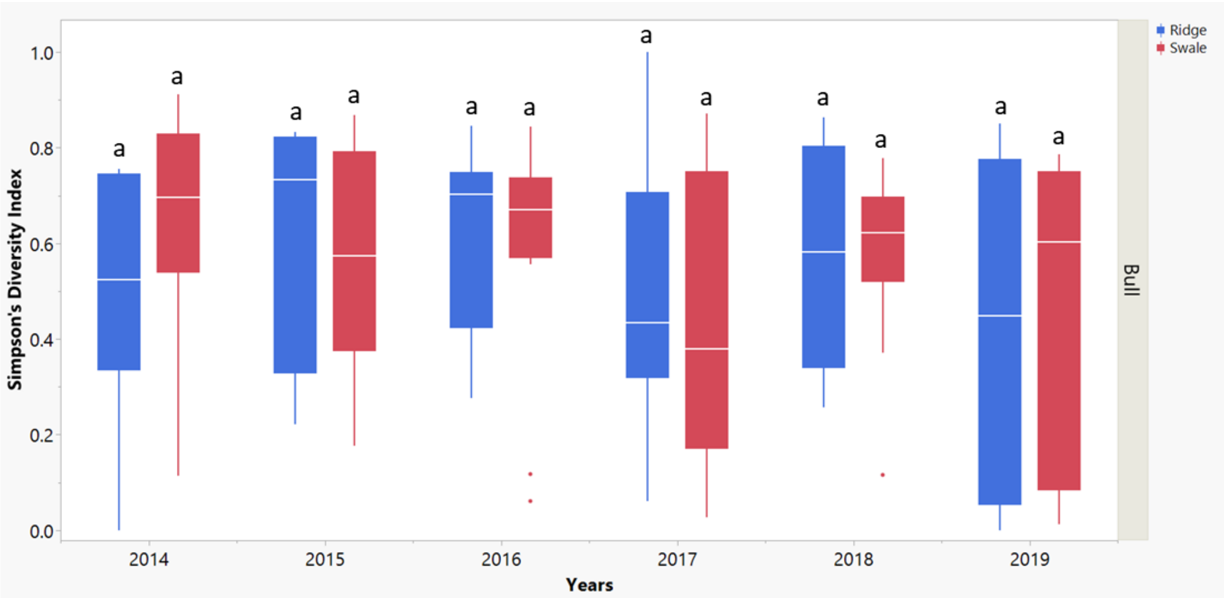

Figure 12-22. Box plots of the Simpson's diversity index for Bull Shoal comparing ridge and swale habitats within each year during the winter.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference ($P \leq 0.05$).

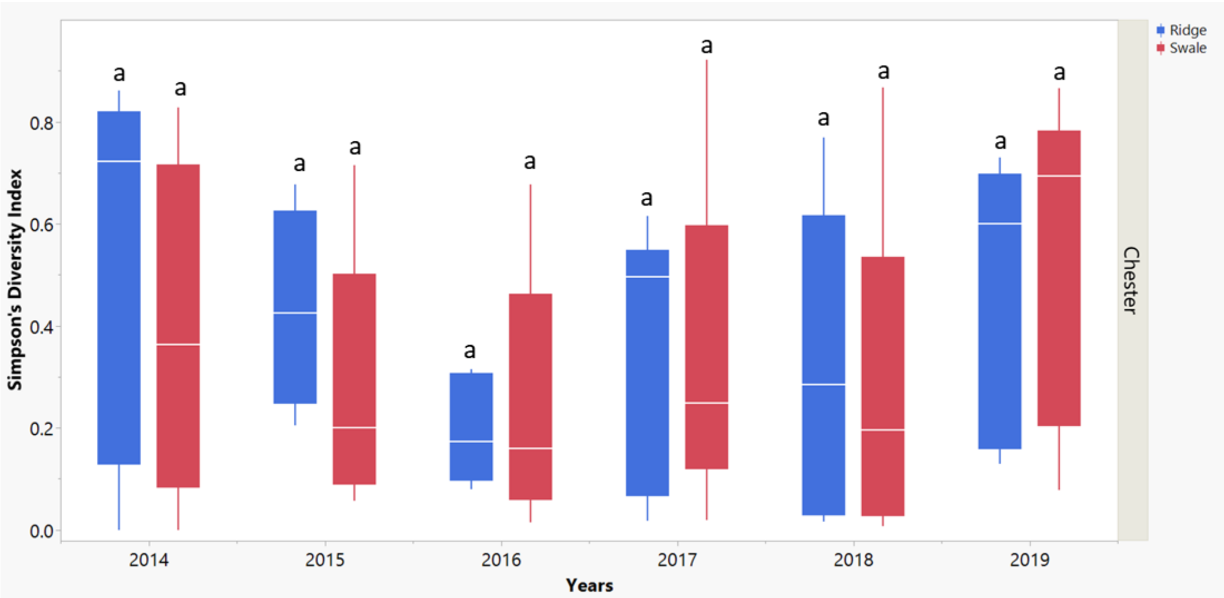

Figure 12-23. Box plots of the Simpson's diversity index for Chester Shoal comparing ridge and swale habitats within each year during the winter.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference ($P \leq 0.05$).

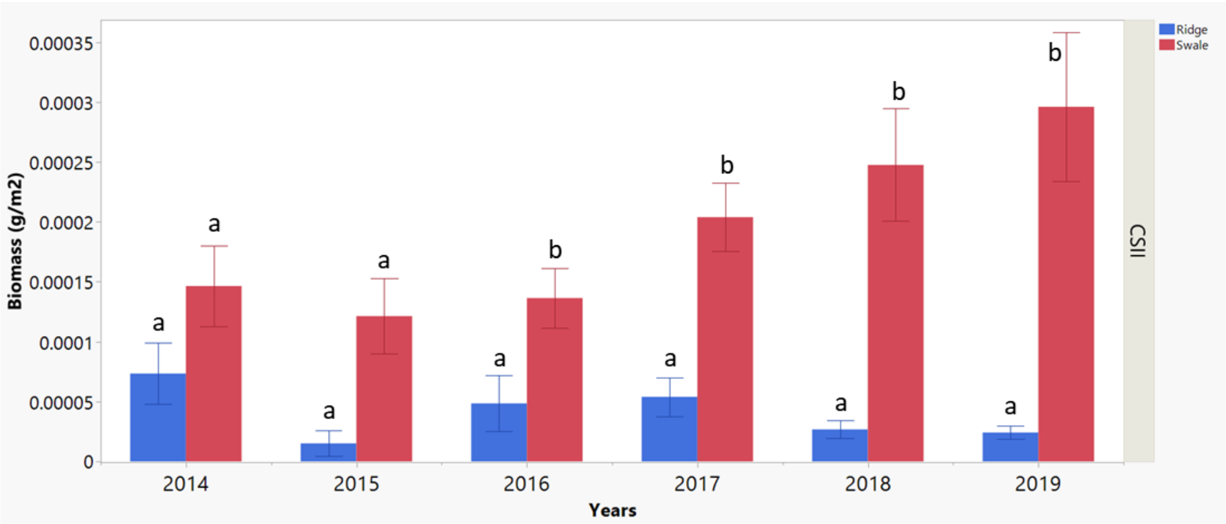

Figure 12-24. Mean biomass (g/m²) in trawl samples comparing ridge versus swale habitats within each year from CSII during the winter.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test within each year. Like letters indicate no significant differences between groups and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

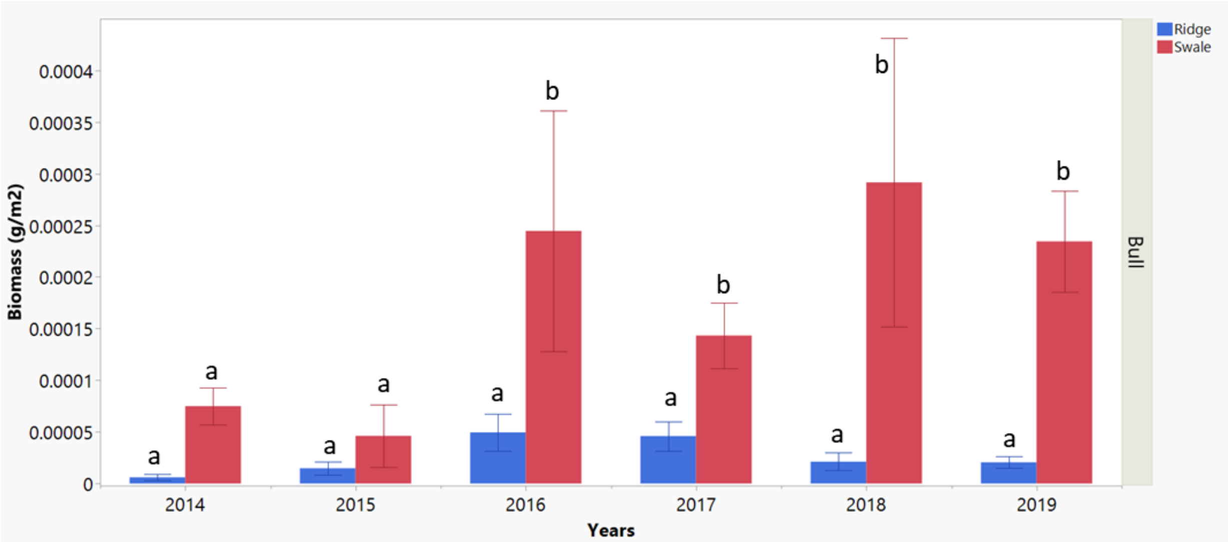

Figure 12-25. Mean biomass (g/m²) in trawl samples comparing ridge versus swale habitats within each year from Bull Shoal during the winter.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test within each year. Like letters indicate no significant differences between groups and unlike letters indicate there is a significant difference between the groups at an α = 0.05.
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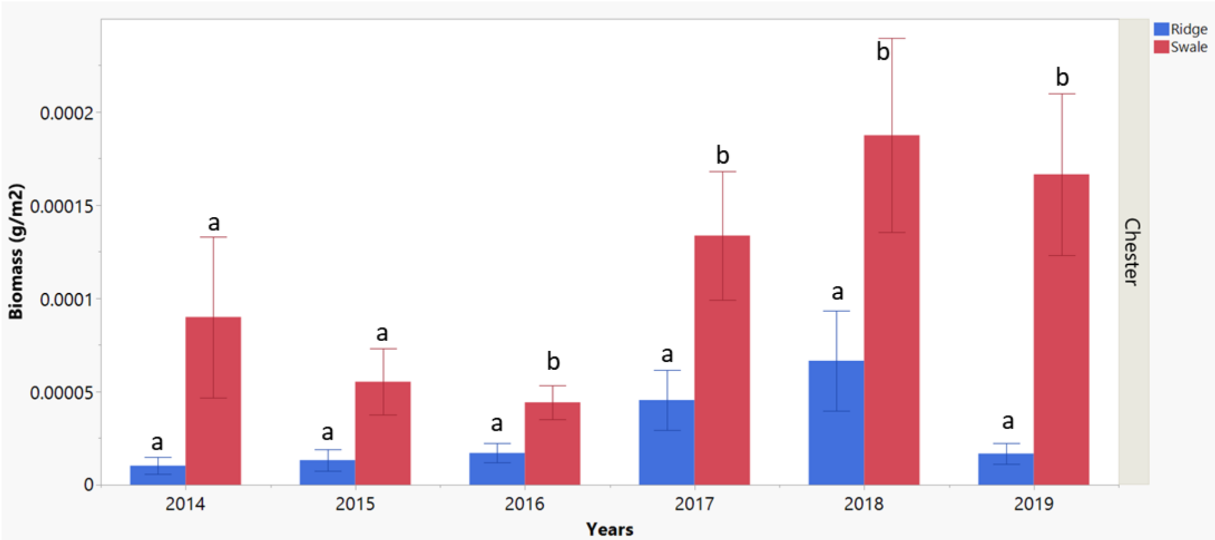

Figure 12-26. Mean biomass (g/m^2) in trawl samples comparing ridge versus swale habitats within each year from Chester Shoal during the winter.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test within each year. Like letters indicate no significant differences between groups and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

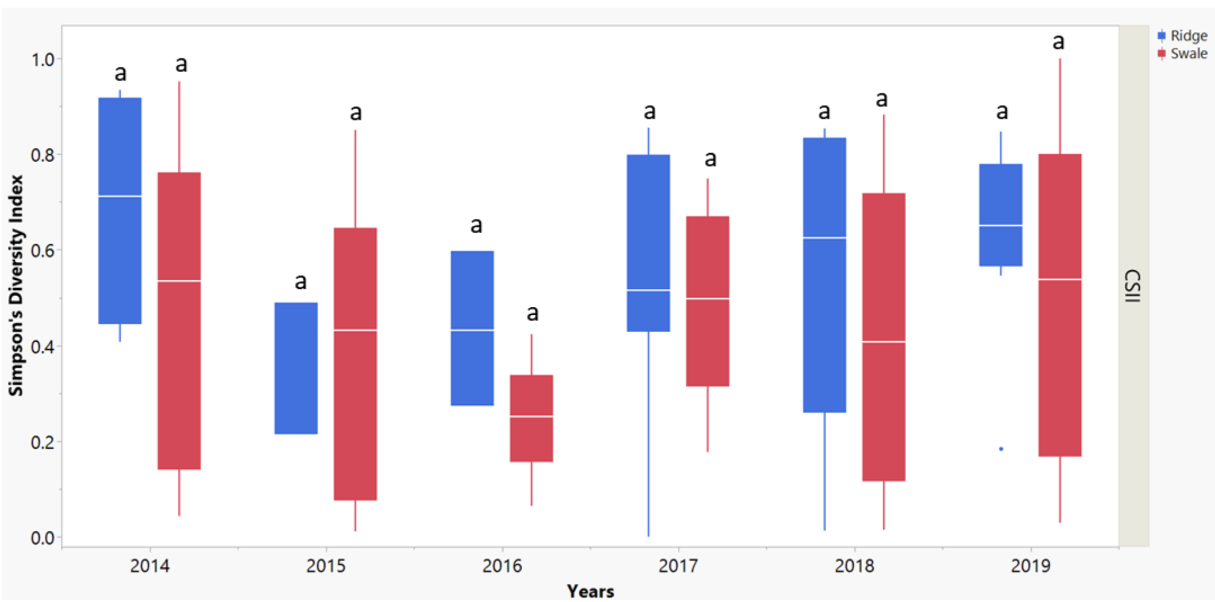

Figure 12-27. Simpson's diversity index comparing ridge versus swale habitats within each year for CSII during the spring.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

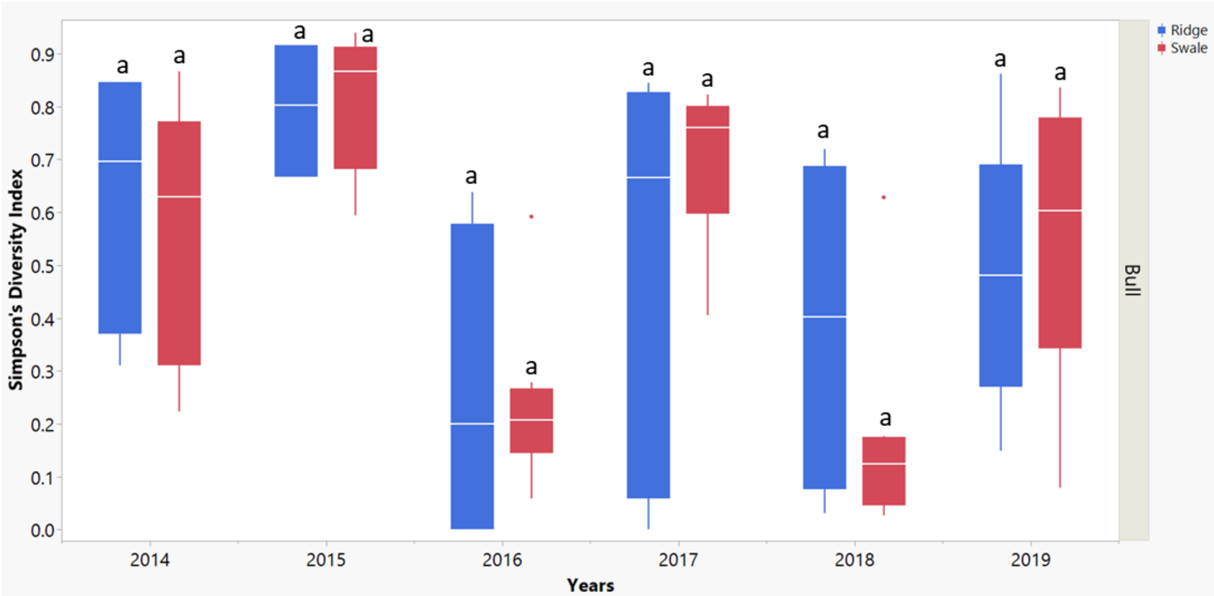

Figure 12-28. Box plots of the Simpson's diversity index for Bull Shoal comparing ridge and swale habitats within each year during the spring.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

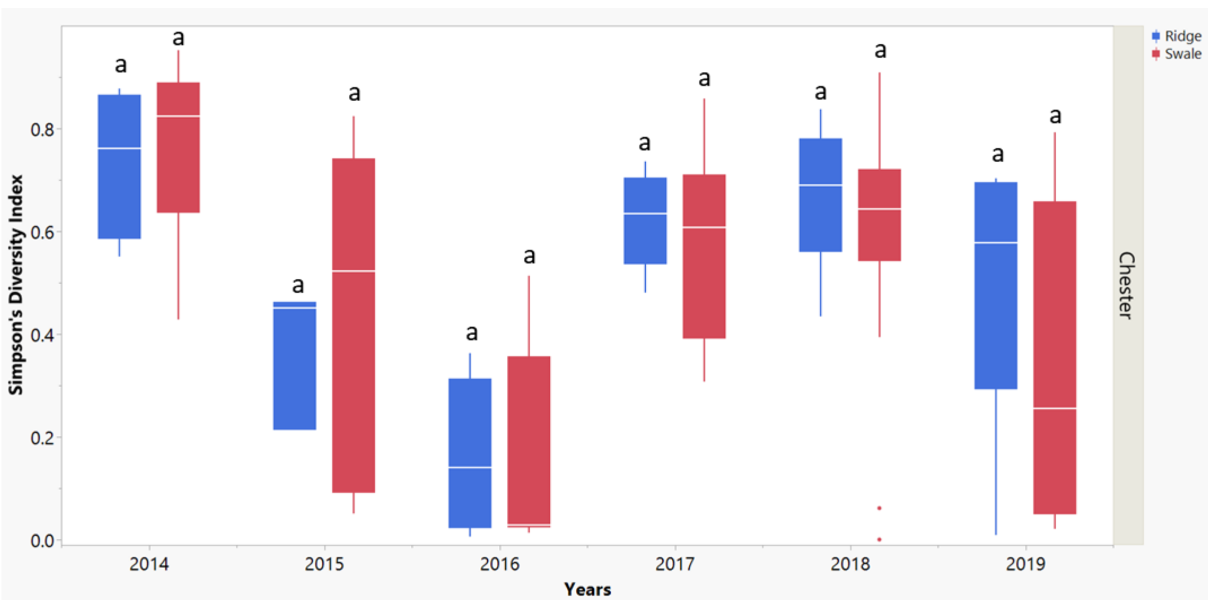

Figure 12-29. Box plots of the Simpson's diversity index for Chester Shoal comparing ridge and swale habitats within each year during the spring.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

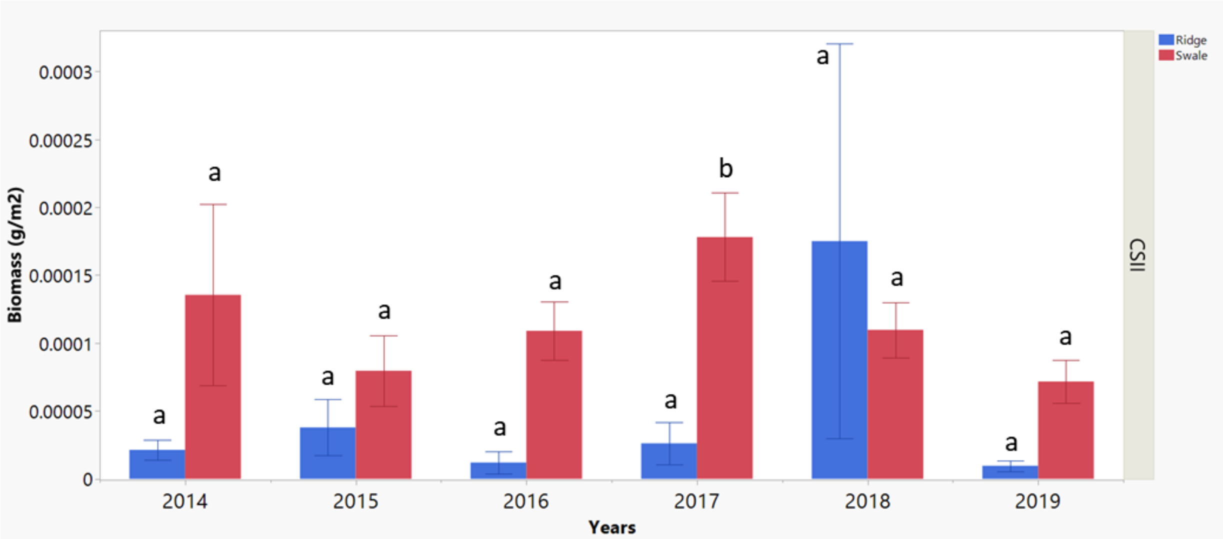

Figure 12-30. Mean biomass (g/m^2) in trawl samples comparing ridge versus swale habitats within each year from CSII during the spring.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test within each year. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

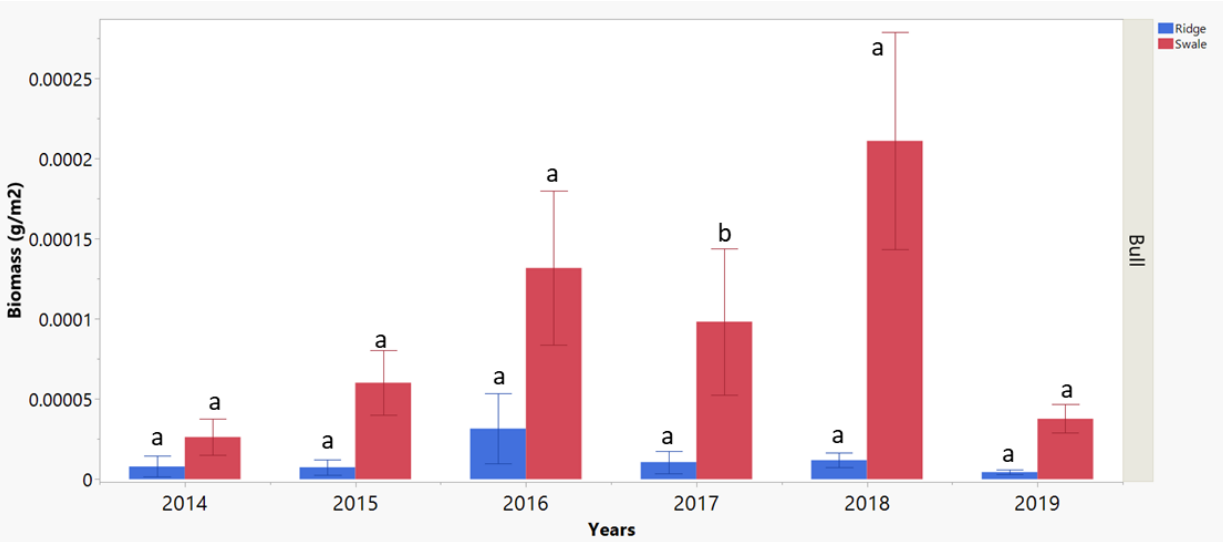

Figure 12-31. Mean biomass (g/m^2) in trawl samples comparing ridge versus swale habitats within each year from Bull Shoal during the spring.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test within each year. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

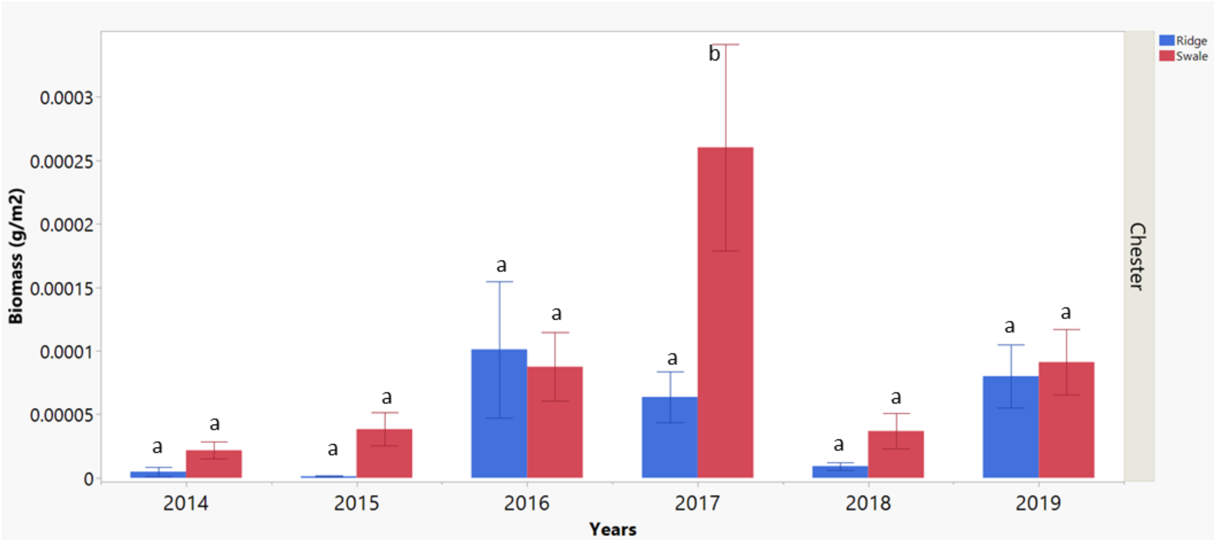

Figure 12-32. Mean biomass (g/m²) in trawl samples comparing ridge versus swale within each year from Chester Shoals during the spring.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test within each year. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

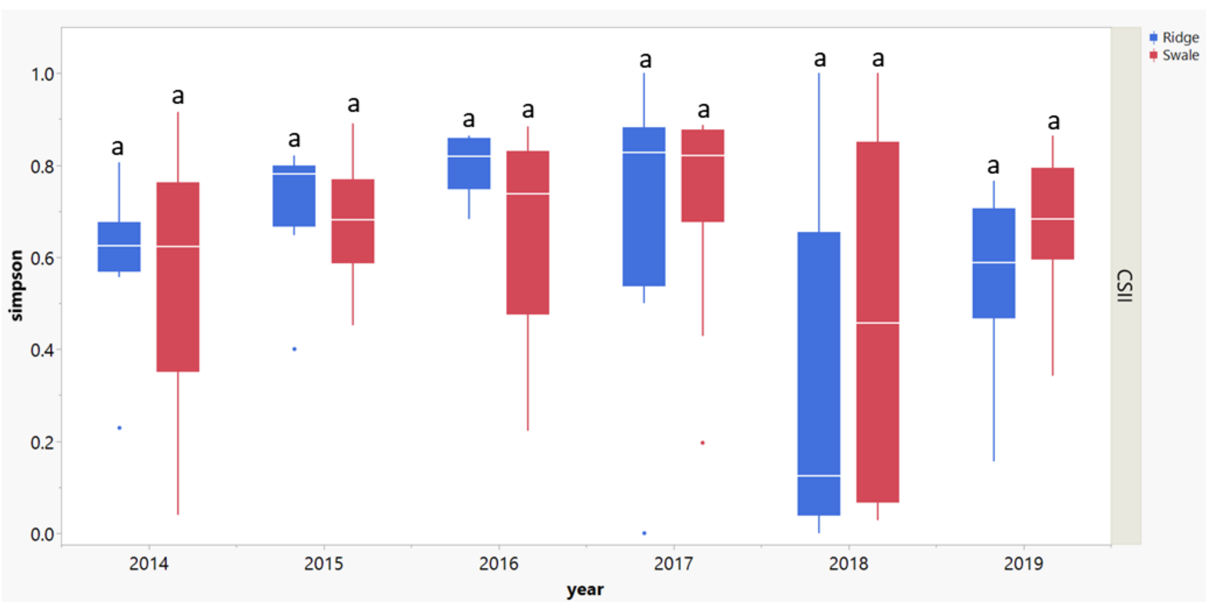

Figure 12-33. Simpson's diversity index comparing ridge versus swale habitats within each year for CSII during the summer.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

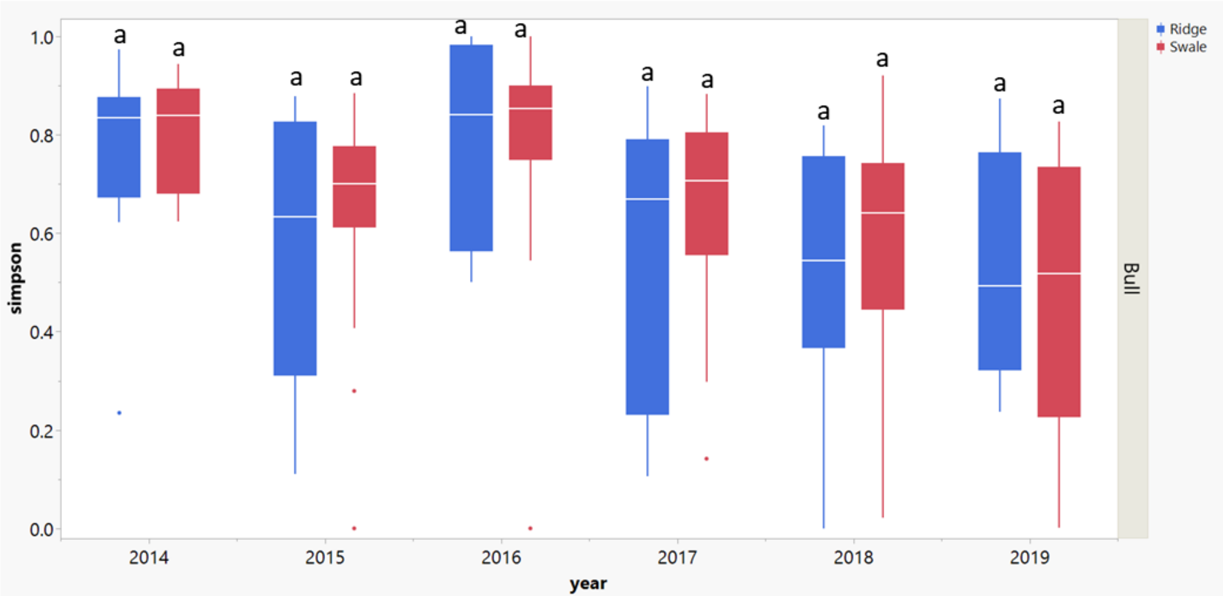

Figure 12-34. Box plots of the Simpson's diversity index for Bull Shoal comparing ridge and swale habitats within each year during the summer.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

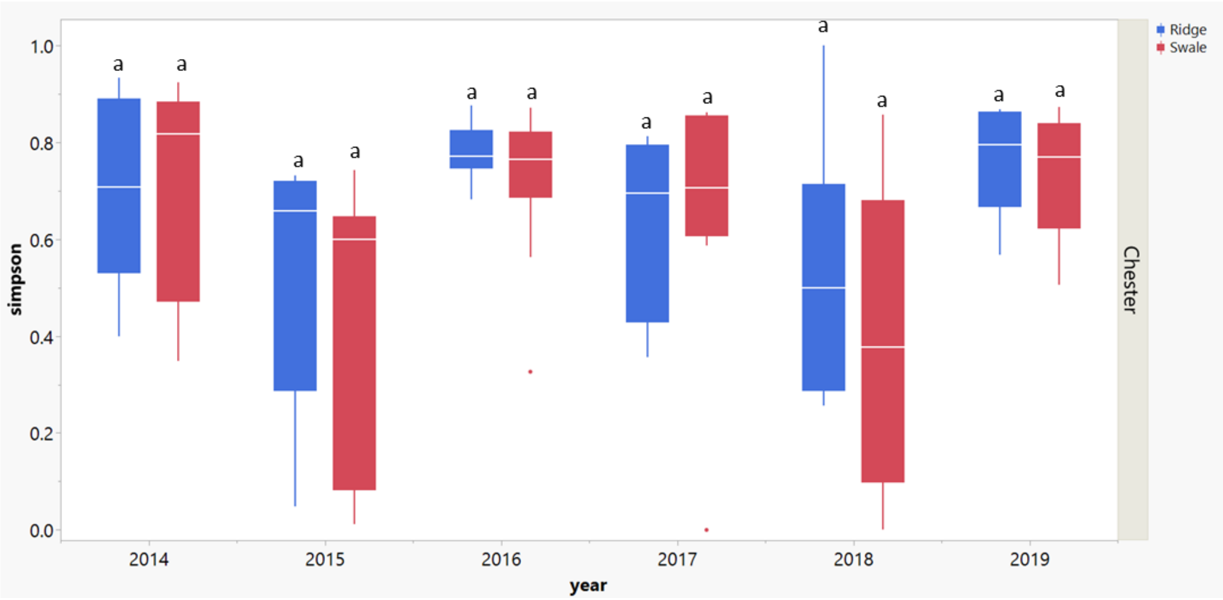

Figure 12-35. Box plots of the Simpson's diversity index for Chester Shoal comparing ridge and swale habitats within each year during the summer.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

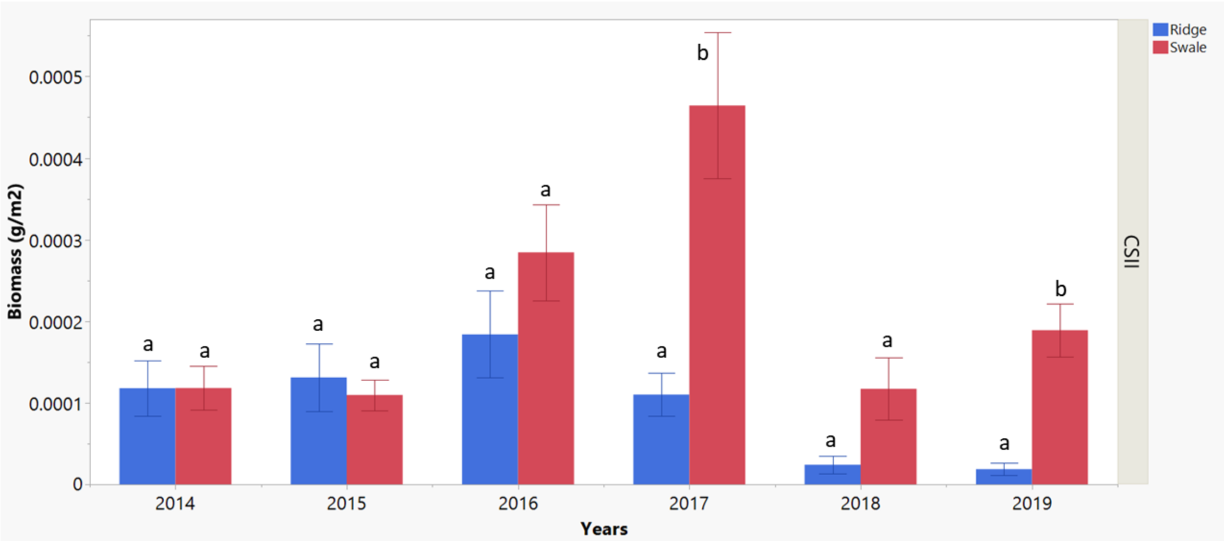

Figure 12-36. Mean biomass (g/m^2) in trawl samples comparing ridge versus swale habitats within each year from CSII during the summer.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test within each year. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

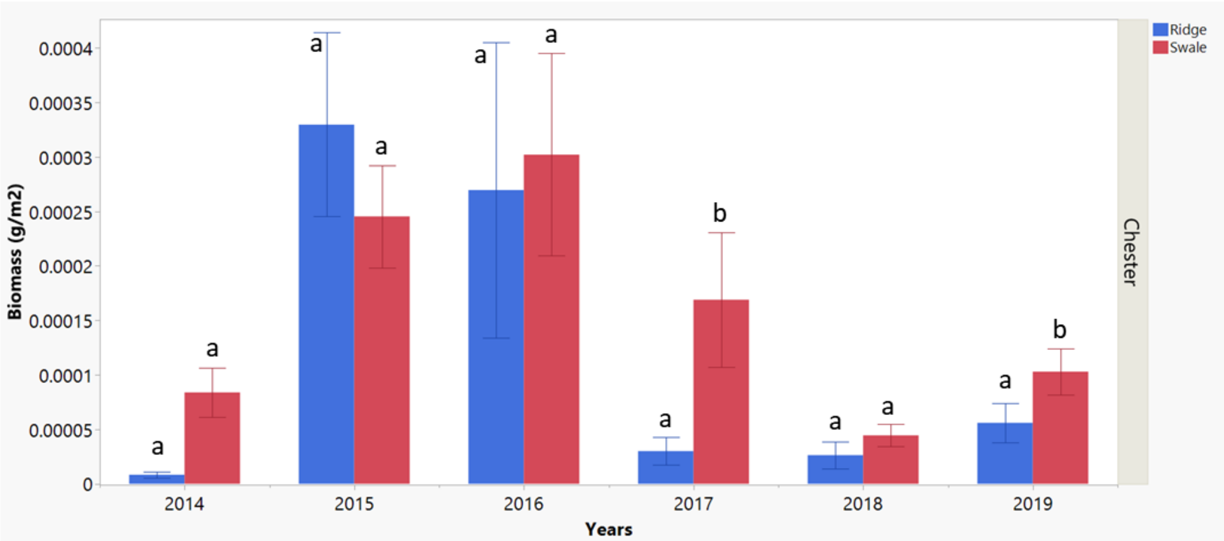

Figure 12-37. Mean biomass (g/m^2) in trawl samples comparing ridge versus swale habitats within each year from Bulls Shoal during the summer.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test within each year. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference (P ≤ 0.05).

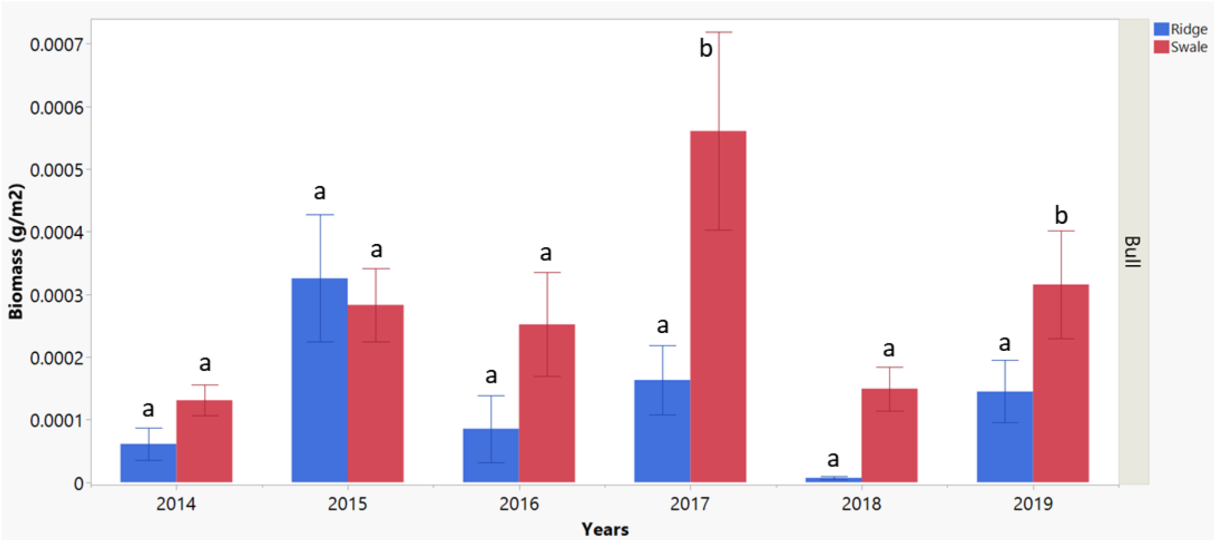

Figure 12-38. Mean biomass (g/m^2) in trawl samples comparing ridge and swale habitats within each year from Chester Shoal during the summer.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test within each year. Like letters indicate no significant difference between ridge versus swale for that year and unlike letters indicate a significant difference ($P \leq 0.05$).

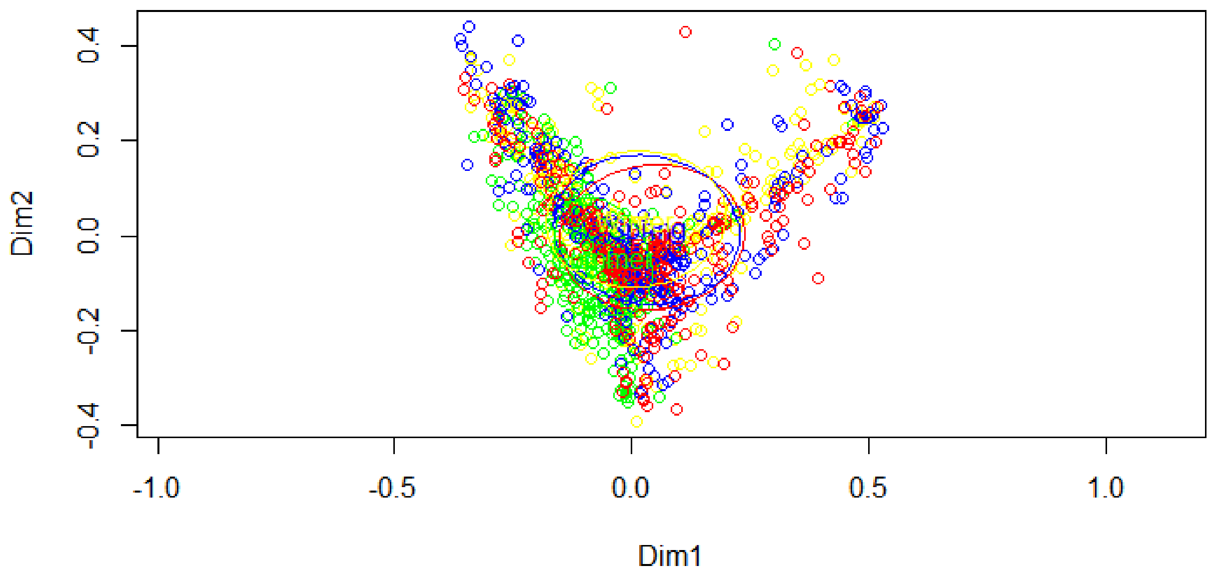

Figure 12-39. Principle coordinates analysis plot for the species abundance data for all years.
Green dots represent summer samples, blue dots represent spring samples, yellow dots represent winter samples and red dots represent fall samples.

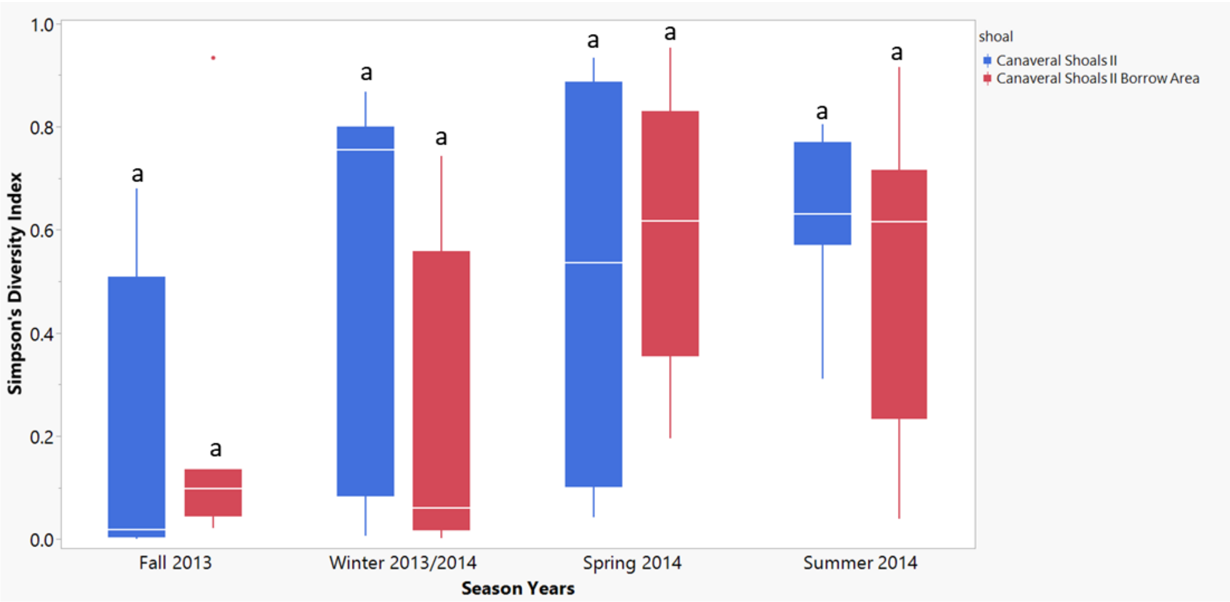

Figure 12-40. Simpson's diversity index calculated for demersal invertebrates on CSII and CSII-BA before and after the first dredging event that occurred from winter 2013/14 until spring 2014.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between shoals for that year and unlike letters indicate a significant difference (P ≤ 0.05).

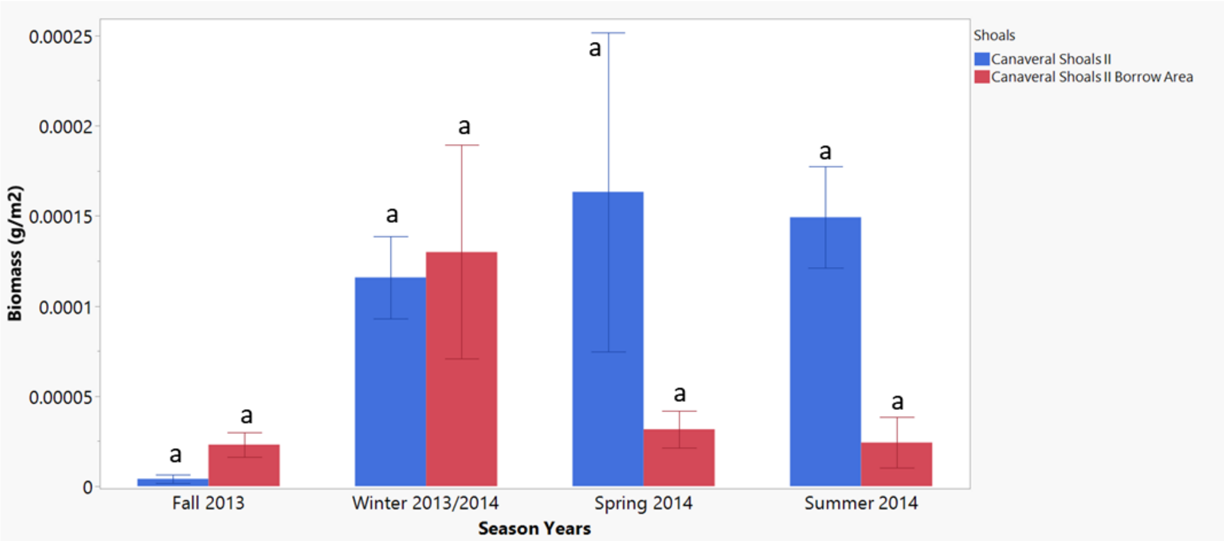

Figure 12-41. Mean biomass (g/m^2) of demersal invertebrates collected from CSII and CSII-BA only before and after the first dredging event that occurred from winter 2013/14 until spring 2014.
Error bars denote one standard error from the meanLetters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between shoals for that year and unlike letters indicate a significant difference (P ≤ 0.05).

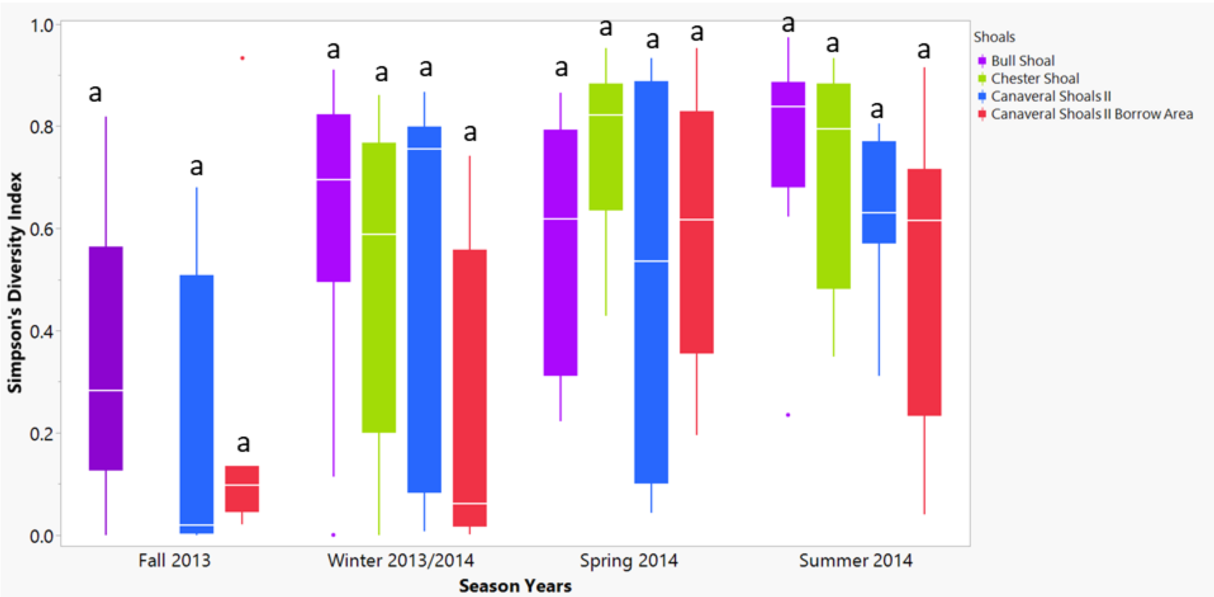

Figure 12-42. Box plots of the Simpson's diversity index calculated for demersal invertebrates on all shoals before and after the first dredging event that occurred from winter 2013/14 until spring 2014.

The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between shoals for that year and unlike letters indicate a significant difference ($P \leq 0.05$).

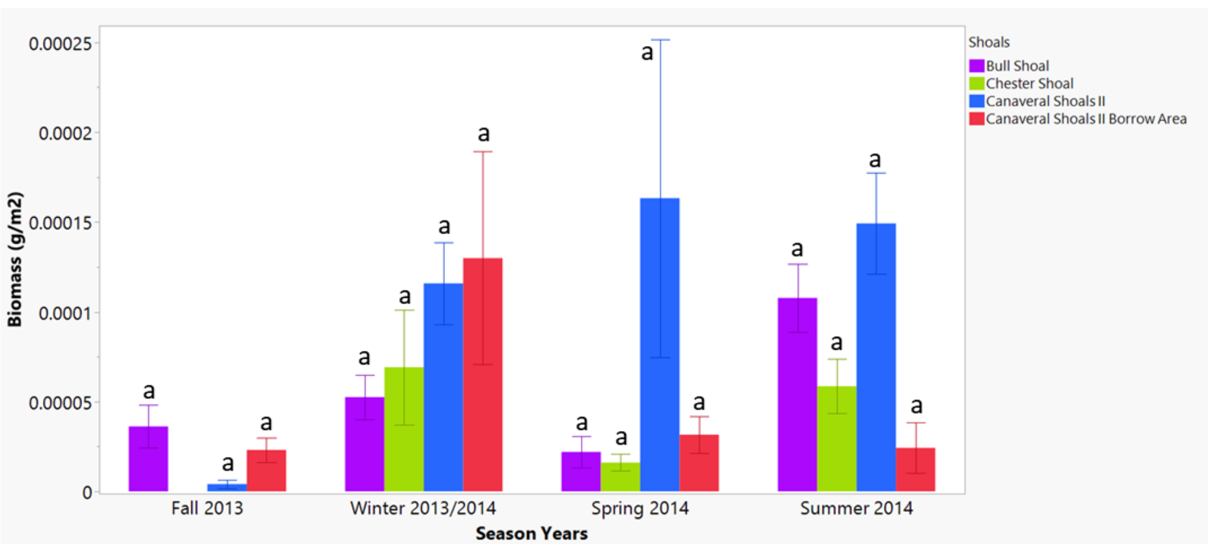

Figure 12-43. Mean biomass (g/m^2) for all shoals before and after the first dredging event that occurred from winter 2013/14 until spring 2014.

Error bars denote one standard error from the mean. Like letters indicate no significant differences between groups. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between shoals for that year and unlike letters indicate a significant difference ($P \leq 0.05$).

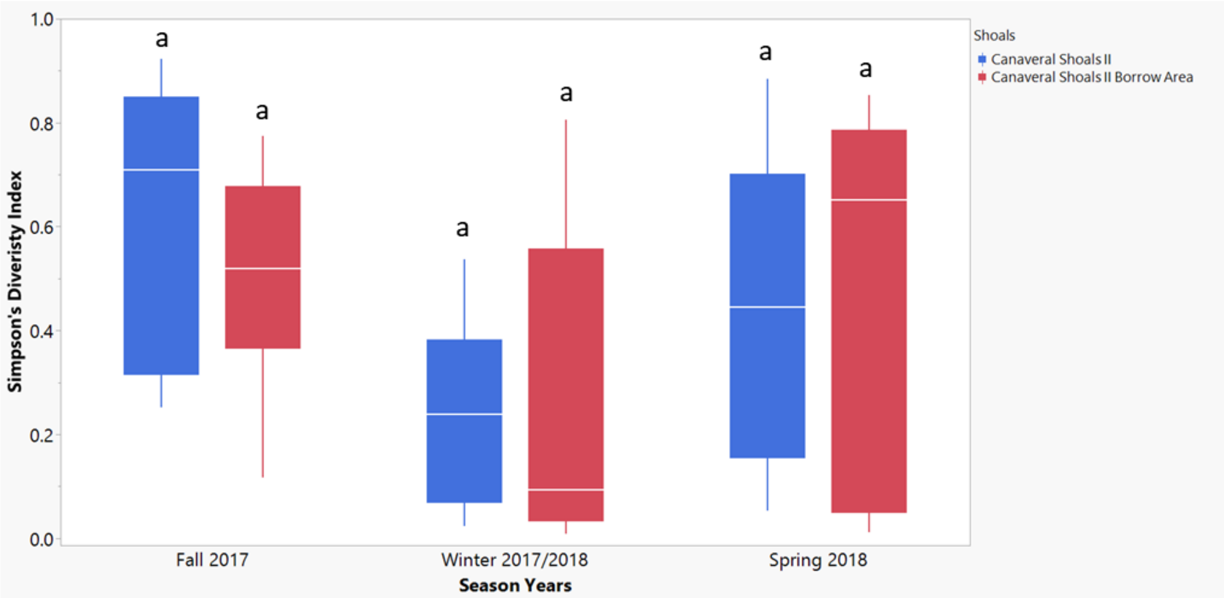

Figure 12-44. Simpson's diversity index calculated for demersal invertebrates on CSII and CSII-BA before and during the second dredging event.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between shoals for that year and unlike letters indicate a significant difference (P ≤ 0.05).

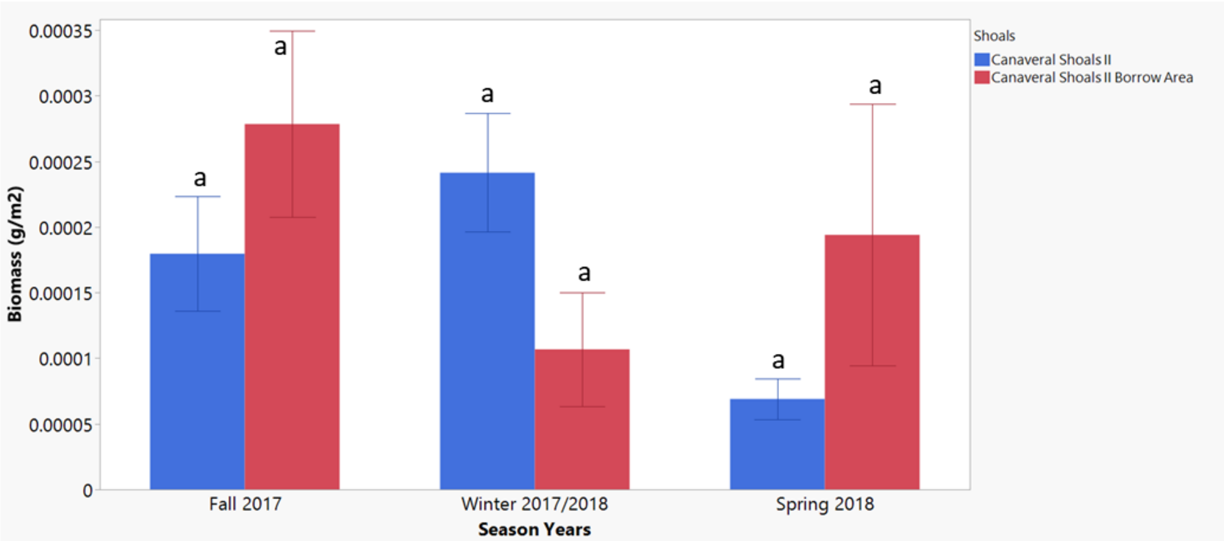

Figure 12-45. Mean biomass (g/m^2) calculated for CSII and CSII-BA only before and during the second dredging event.
Error bars denote one standard error from the mean. Like letters indicate no significant differences between groups. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant difference between shoals for that year and unlike letters indicate a significant difference (P ≤ 0.05).

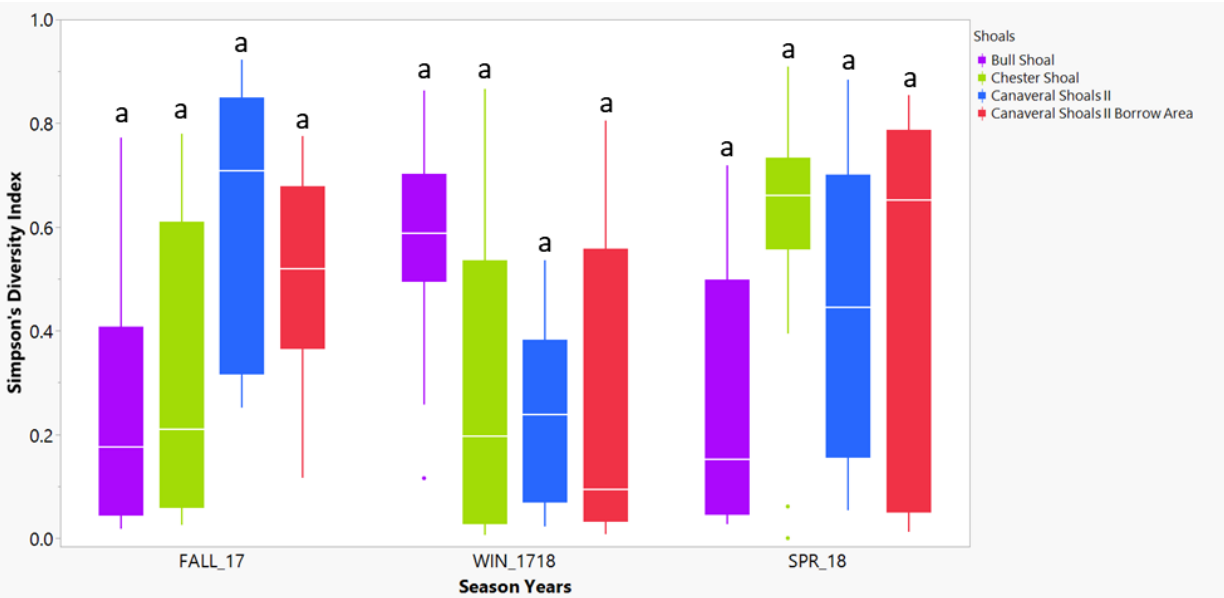

Figure 12-46. Simpson's diversity index calculated for demersal invertebrates on all shoals during the second dredging.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between shoals within each year and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

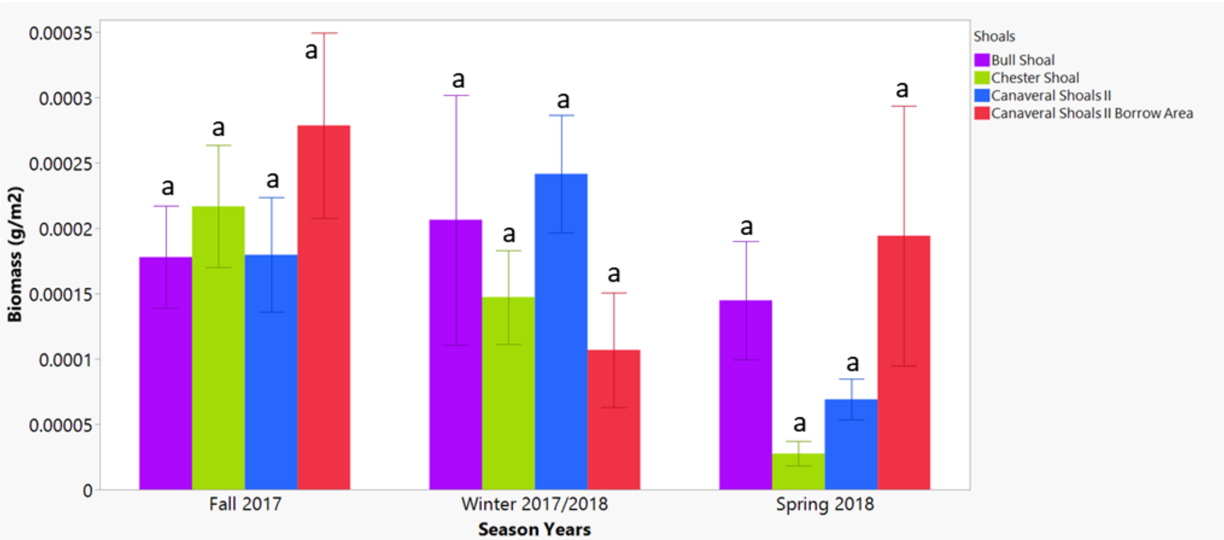

Figure 12-47. Mean biomass (g/m^2) for all shoals during the second dredging event.
Error bars denote one standard error from the mean. Like letters indicate no significant differences between groups. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between shoals within each season and unlike letters indicate there is a significant difference between the shoals at an α = 0.05.

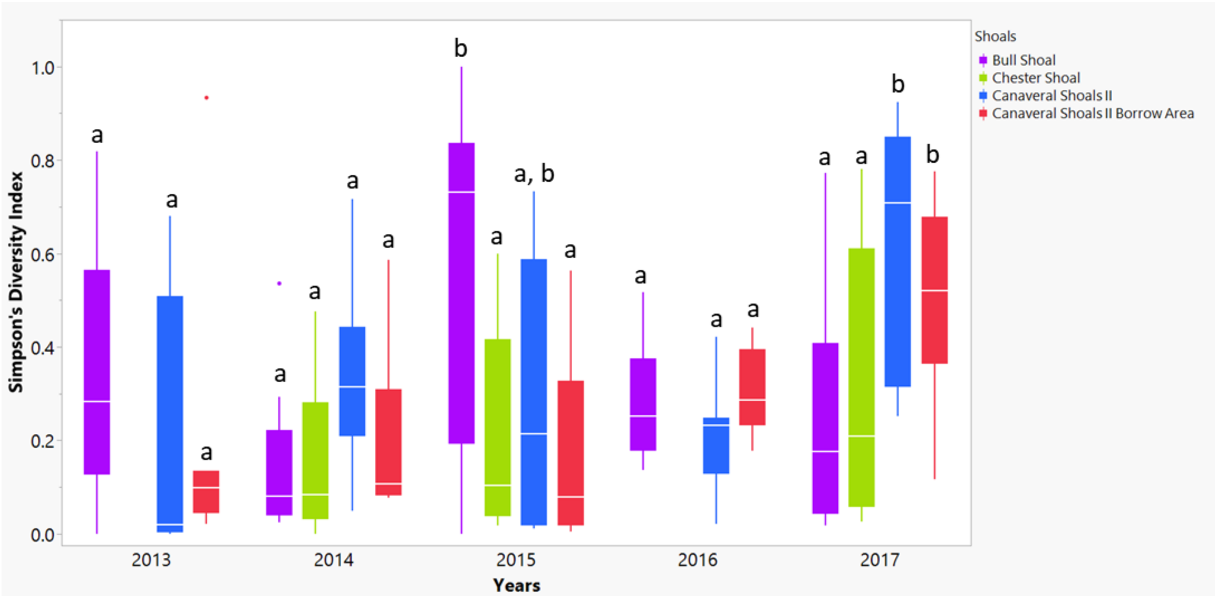

Figure 12-48. Simpson's diversity index calculated for demersal invertebrates for samples collected during and following the first dredging event during the fall only—ridges and swales combined.

The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each year and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

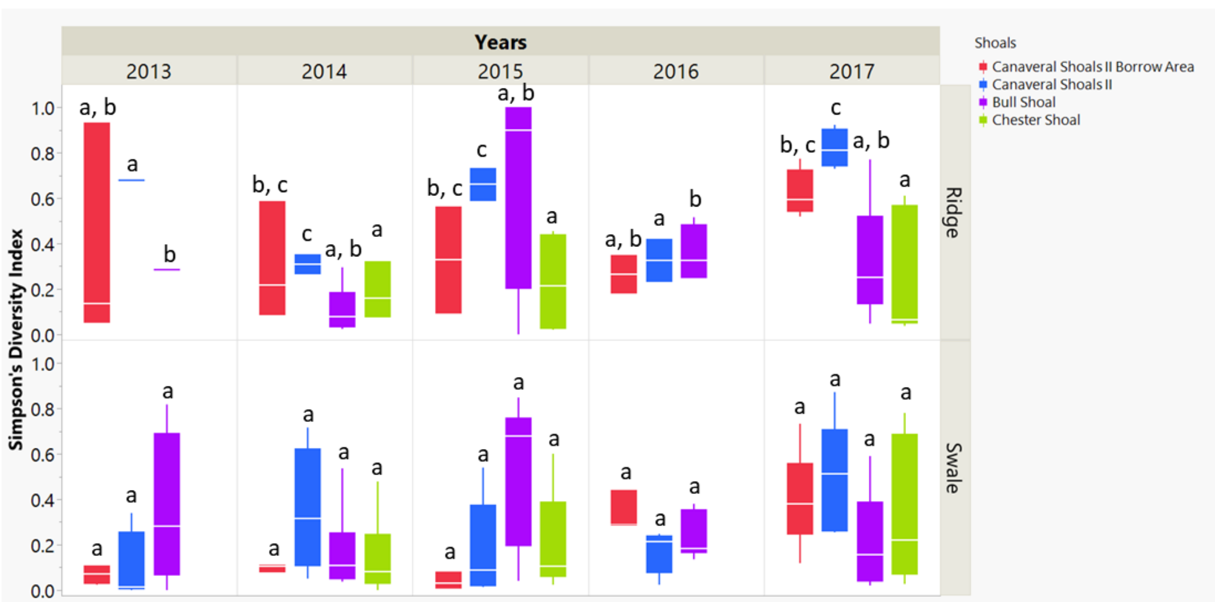

Figure 12-49. Simpson's diversity index calculated for demersal invertebrates for samples collected following the first dredging event during the fall only—ridges and swales plotted separately.

The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each year and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

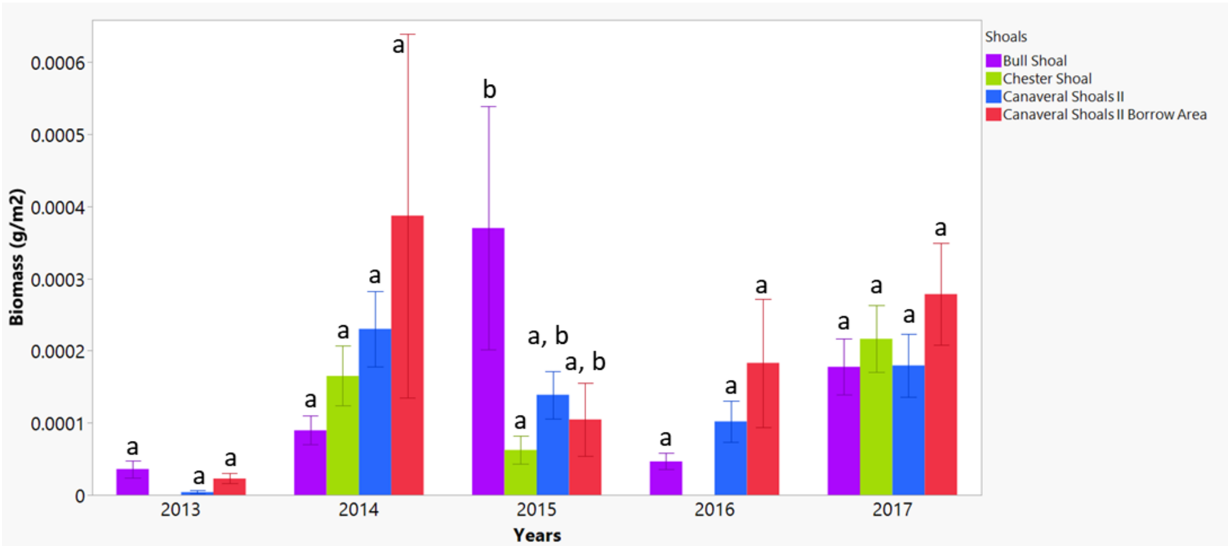

Figure 12-50. Mean biomass (g/m^2) from trawl samples collected during and after the first dredging event for fall only.
Error bars denote one standard error from the mean. Like letters indicated no significant differences between groups. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each year and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

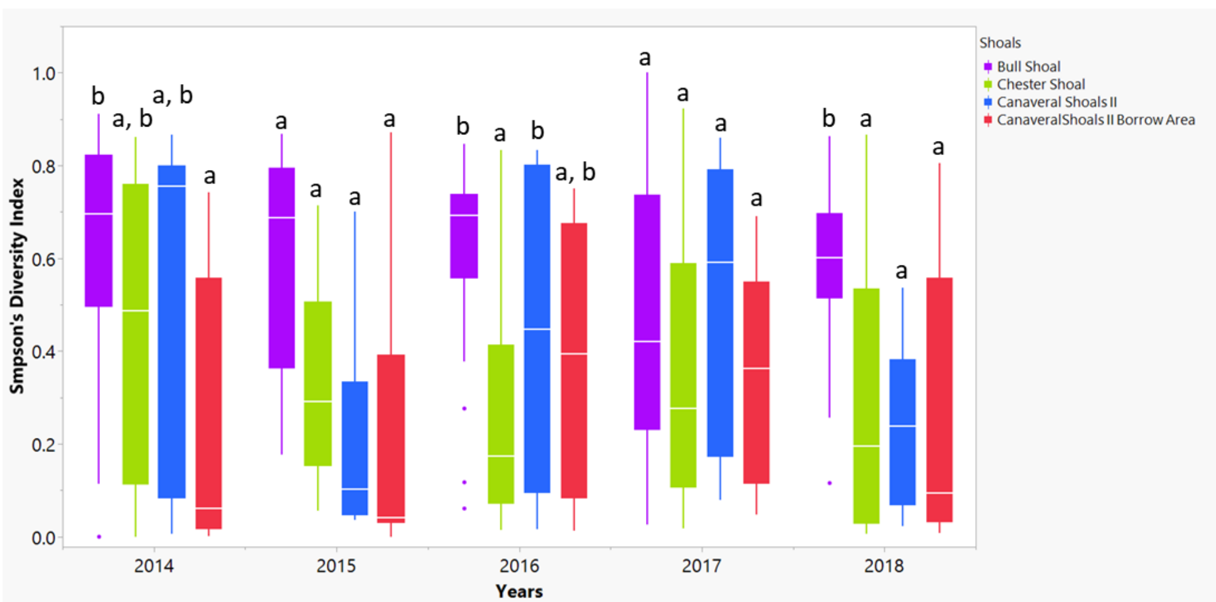

Figure 12-51. Simpson's diversity index calculated for demersal invertebrates from trawl samples collected after the first dredging event—winter only.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each year and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

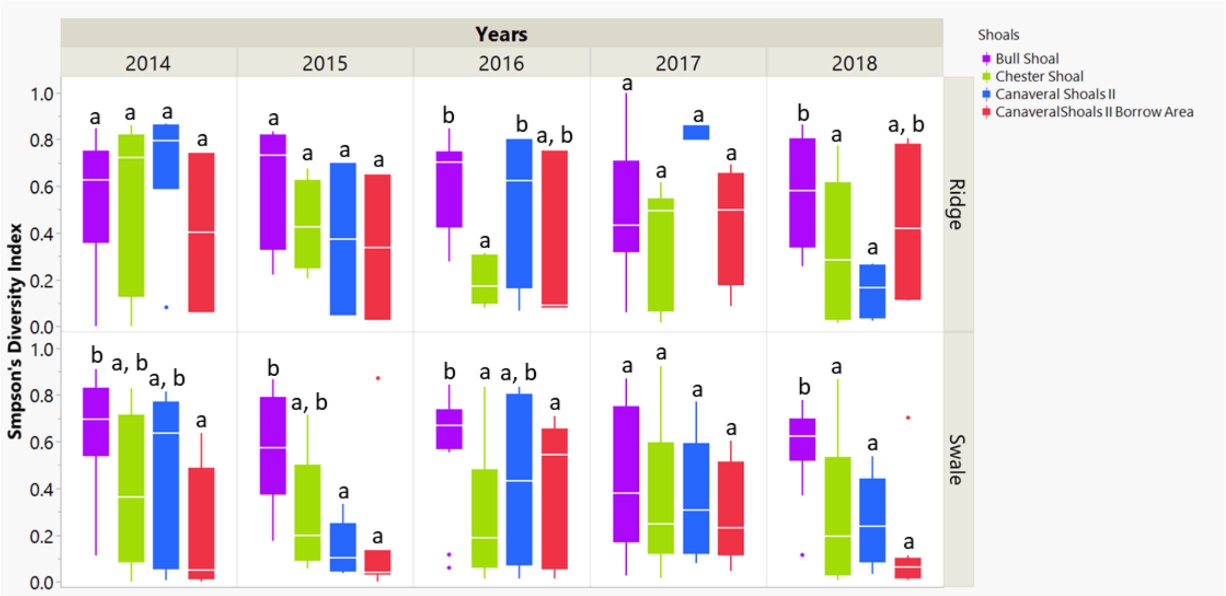

Figure 12-52. Simpson's diversity index calculated for demersal invertebrates for samples collected following the first dredging event during the winter only—ridges and swales plotted separately.

The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each year and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

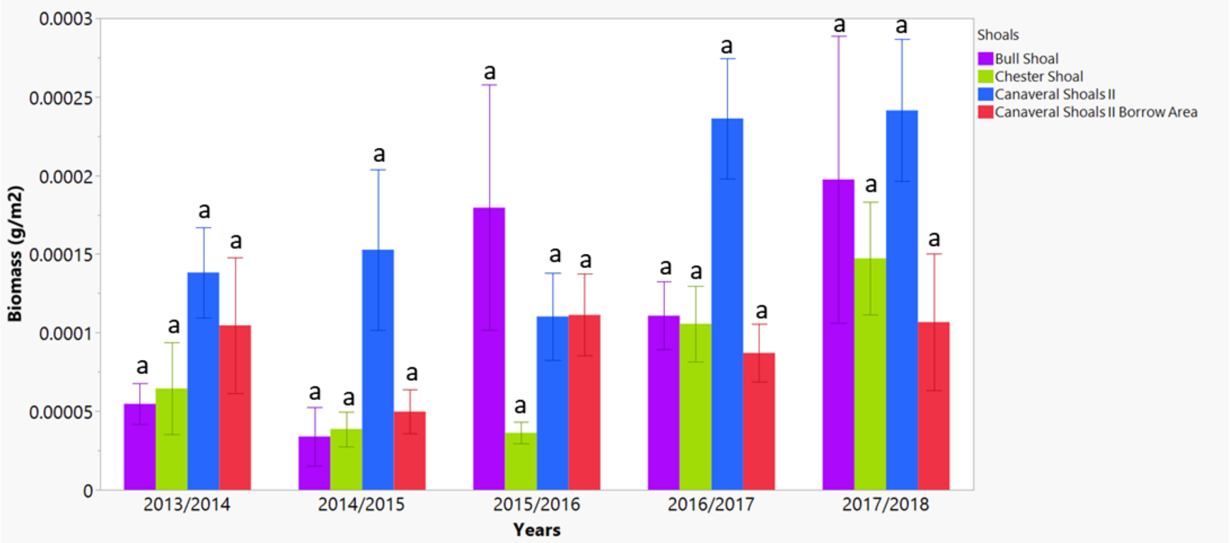

Figure 12-53. Mean biomass (g/m^2) for trawl samples collected during after the first dredging event for winter only.

Error bars denote one standard error from the mean. Like letters indicated no significant differences between groups. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each year and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

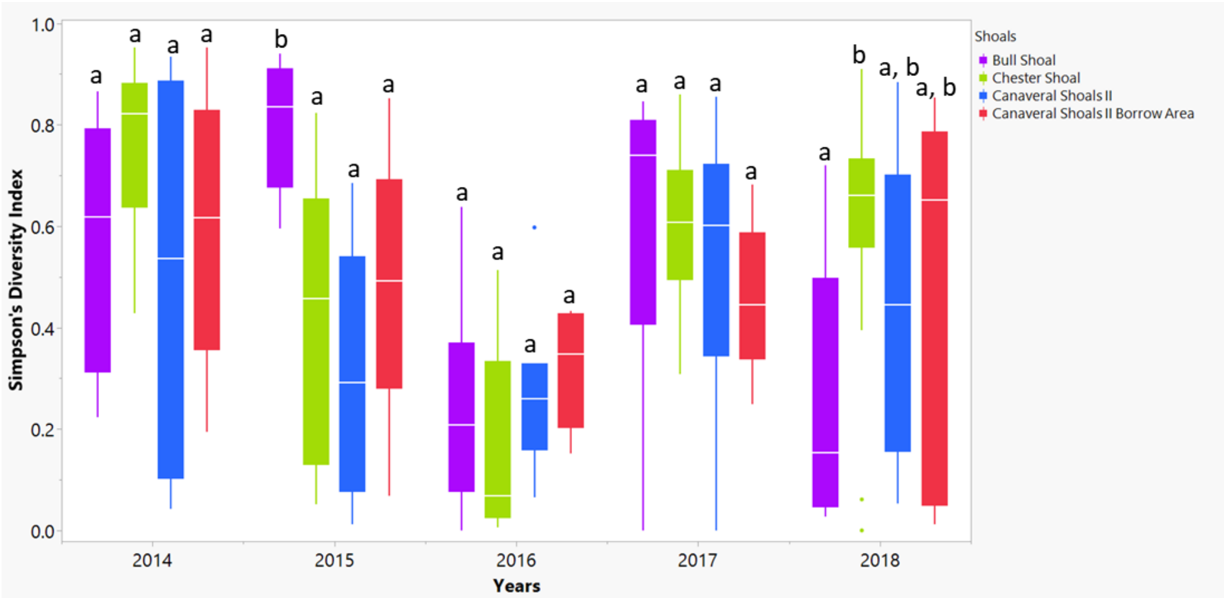

Figure 12-54. Simpson's diversity index calculated for demersal invertebrates from trawl samples collected after the first dredging event—spring only.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each year and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

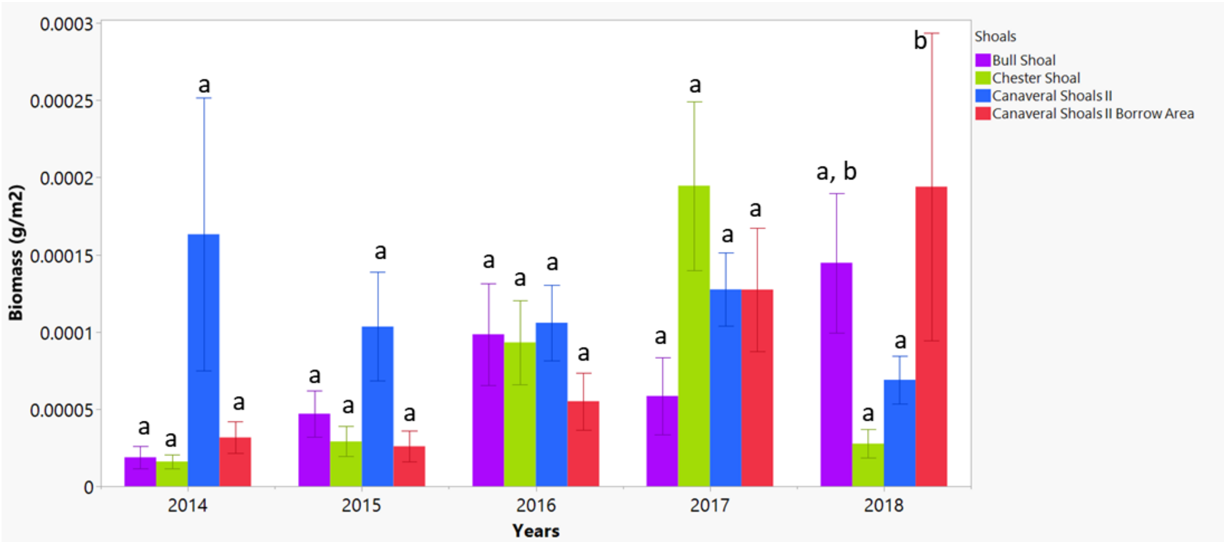

Figure 12-55. Mean biomass (g/m^2) for trawl samples collected after the first dredging event for spring only.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each year and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

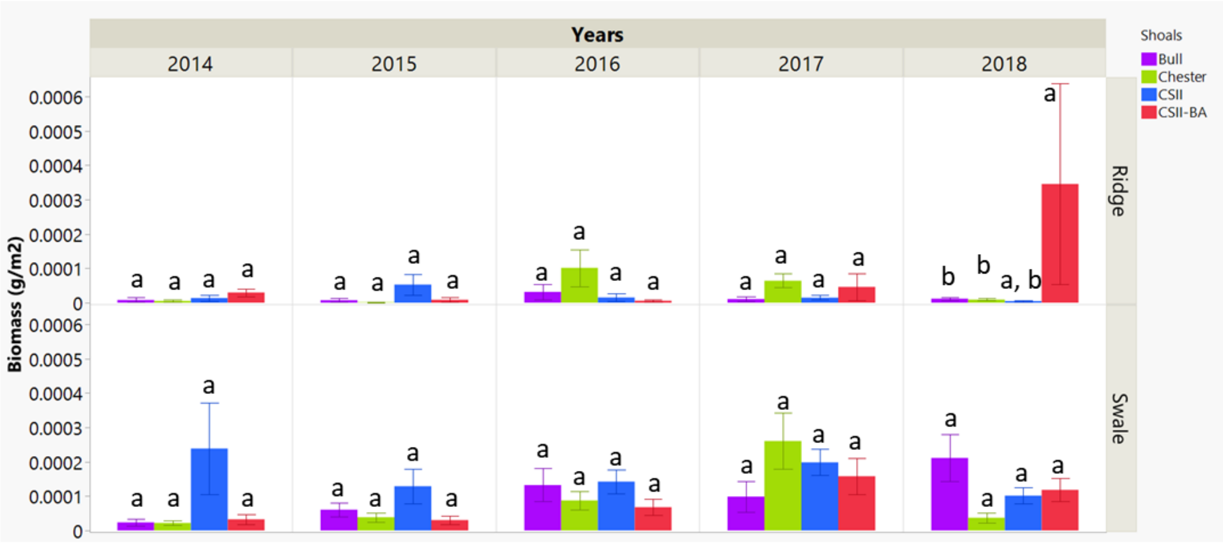

Figure 12-56. Mean biomass (g/m^2) of trawl samples collected from the ridge-swale habitats after the first dredging event—spring only.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each year and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

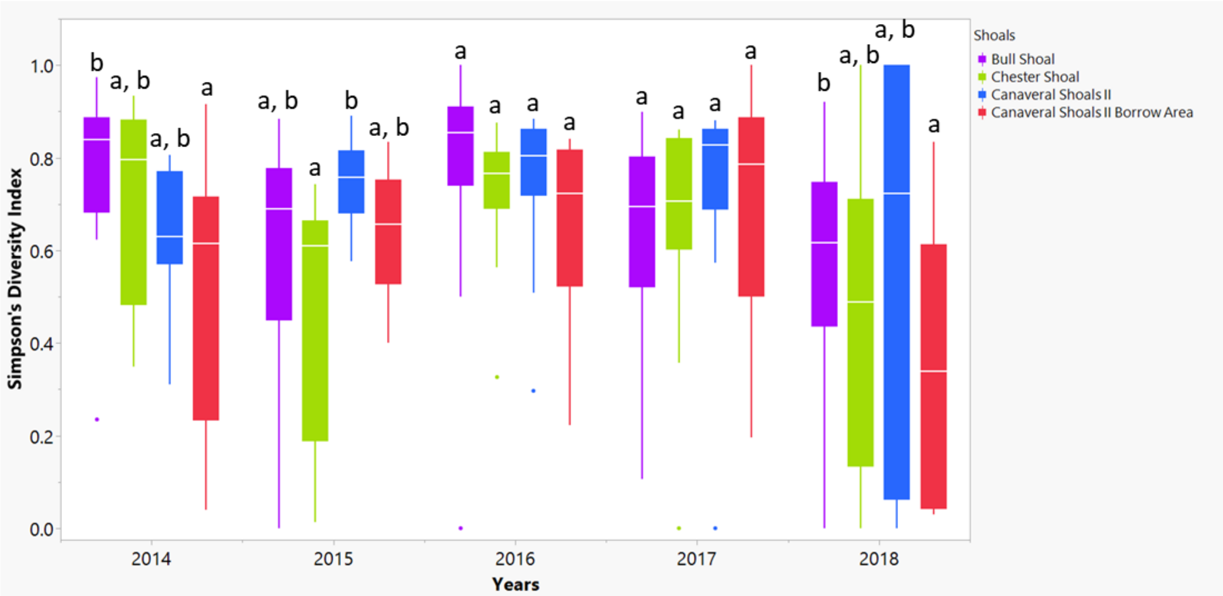

Figure 12-57. Simpson's diversity index calculated for demersal invertebrates from trawl samples collected after the first dredging event—summer only.
The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each year and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

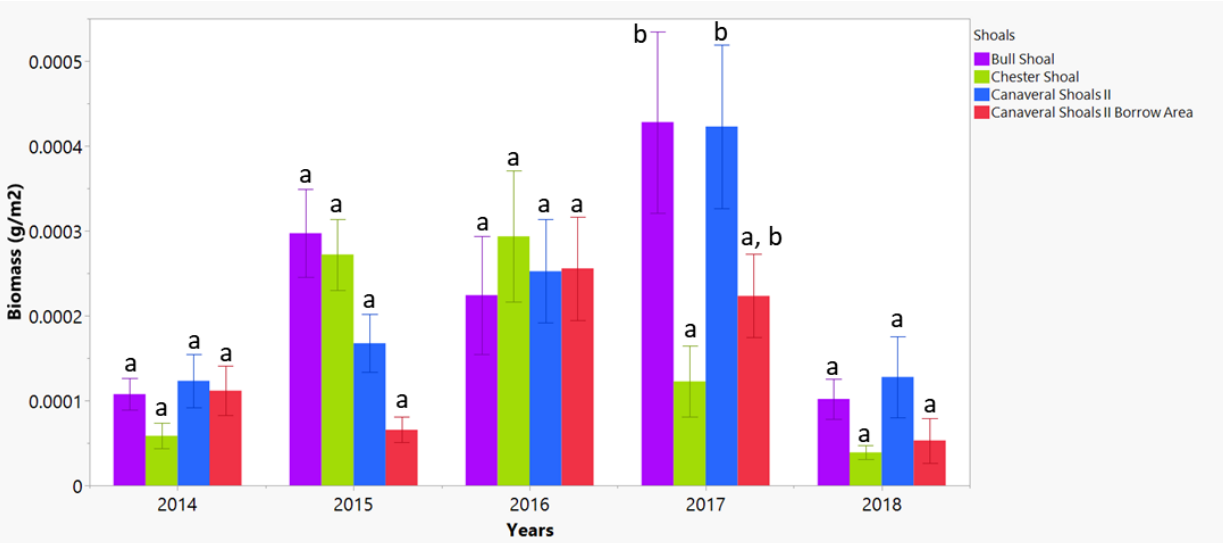

Figure 12-58. Mean biomass (g/m^2) for trawl samples collected after the first dredging event—summer only.

Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each year and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

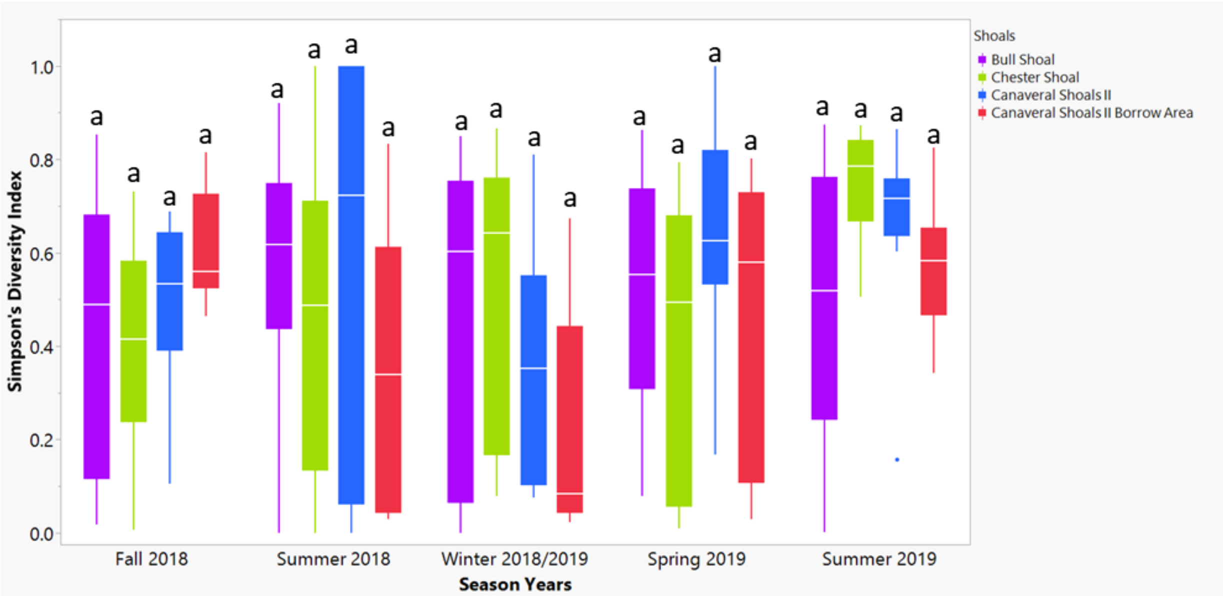

Figure 12-59. Simpson's diversity index calculated for demersal invertebrates for trawl samples collected following the second dredging event.

The median is indicated by the horizontal line within the box; the boundaries of the box indicate the 25th and 75th percentile; whiskers indicate the highest and lowest values of the test; black dots indicate outliers. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each season and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

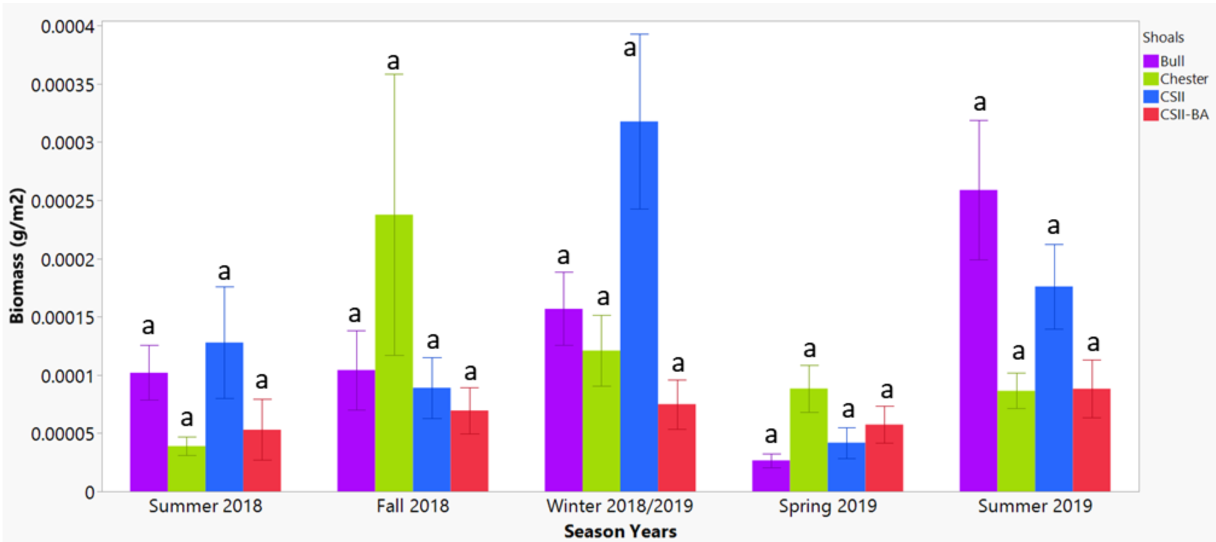

Figure 12-60. Mean biomass (g/m^2) for samples collected following the second dredging event.
Error bars denote one standard error from the mean. Letters indicate the groupings calculated by a Tukey HSD test. Like letters indicate no significant differences between groups within each season and unlike letters indicate there is a significant difference between the groups at an α = 0.05.

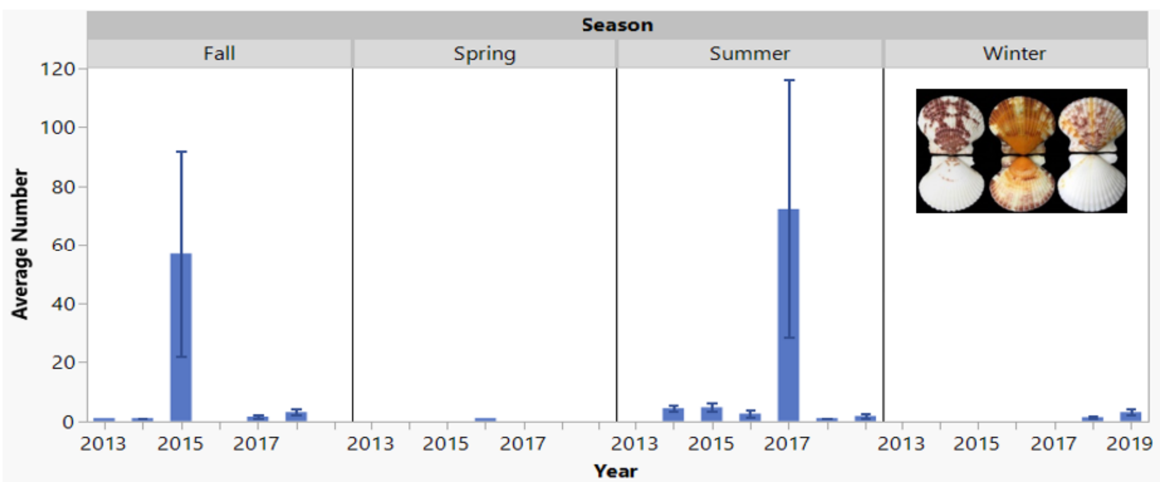

Figure 12-61. Mean number of Calico Scallops caught in each trawl during each season for all project years.
Error bars denote 1 standard error from the mean. Photo credit: Marlo Krisberg.

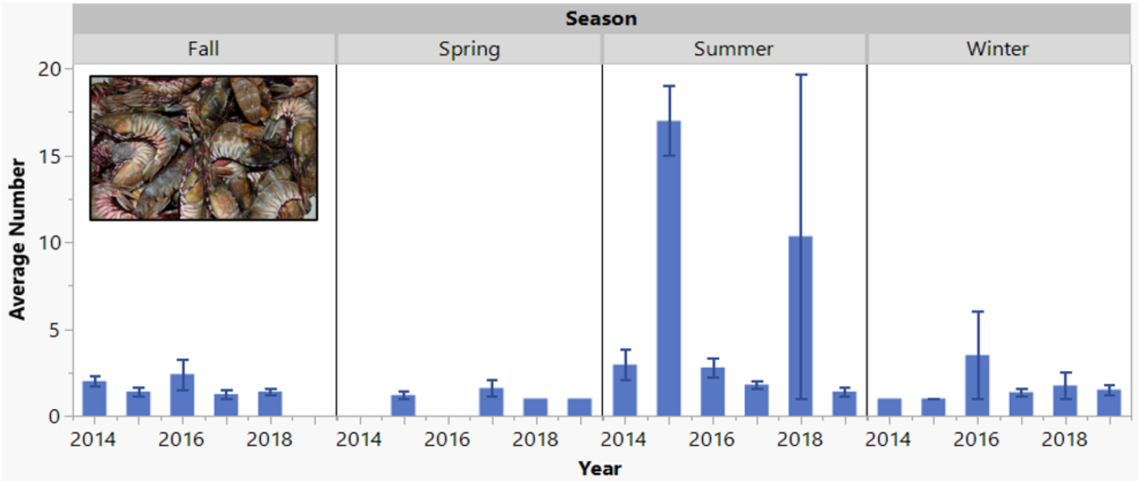

Figure 12-62. Mean number of rock shrimps caught in each trawl during each season for all project years.
All species of rock shrimp are combined for this figure. Photo credit: Randy Moody.

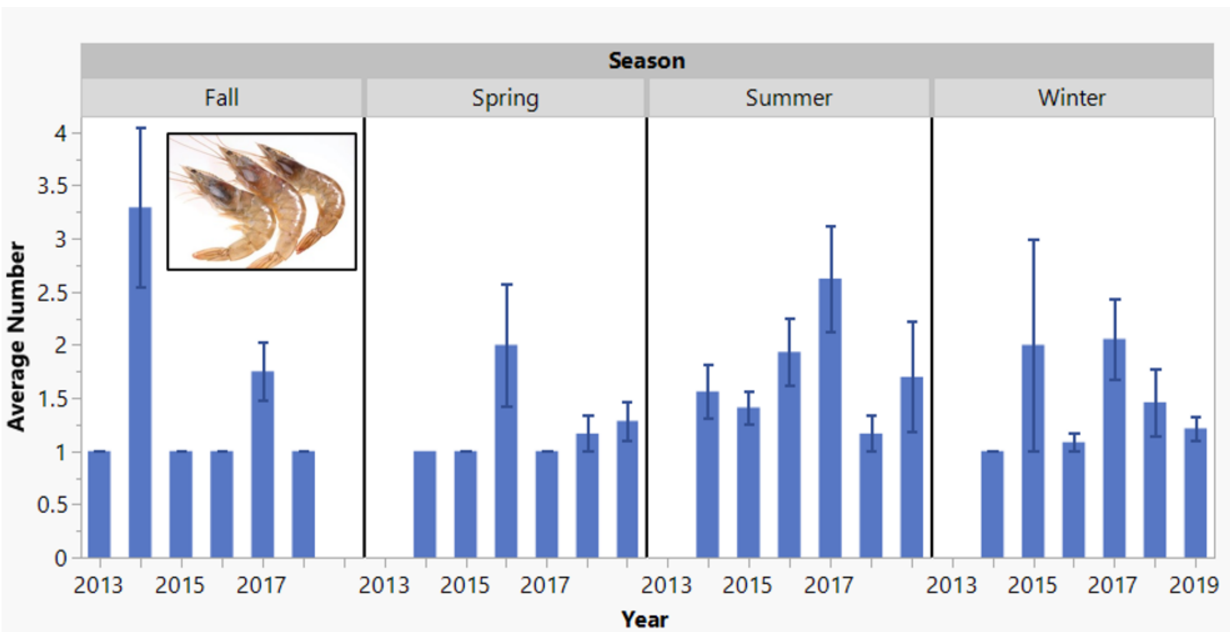

Figure 12-63. Mean number of penaeid shrimps caught in each trawl during each season over all project years.
All penaeid species combined for this figure. Photo credit: Seafood News.

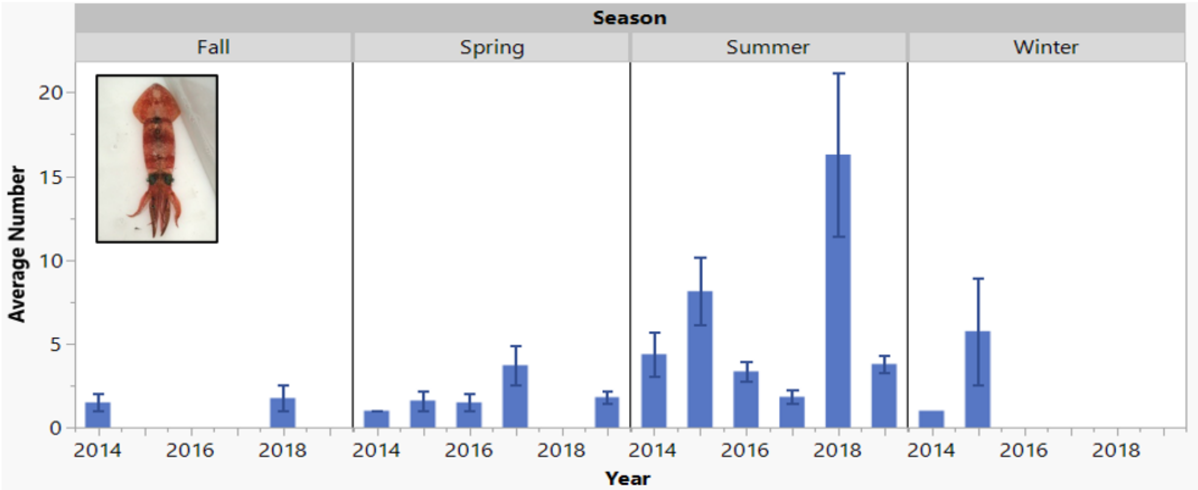

Figure 12-64. Mean number of commercially important squids caught in each trawl during each season for all project years.
Dorytuethis pealeii and *D. plei* were combined in this figure. Photo credit: NOAA.

Table 12-1. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for the different seasons.

Initial and final model shown with significant factors. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	1.5031	0.5010	3	1322	7.5892	**< 0.0001**
Ridge/Swale	0.7826	0.7826	1	1322	11.8542	**0.0006**
Season	15.5892	5.1964	3	1322	78.7113	**< 0.0001**
Year	1.3640	0.2273	6	1322	3.4436	**0.0022**
Shoal:Year	3.5756	0.2103	17	1322	3.1859	**< 0.0001**
Season:Year	8.5251	0.6089	14	1322	9.2237	**< 0.0001**

Table 12-2. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for the different seasons.

Initial and final model shown with significant factors. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	4.99E-05	2E-05	3	8	0.9255	0.4708
Ridge/Swale	0.001368	0.0007	2	534764	38.066	**< 0.0001**
Season	0.000946	0.0003	3	555804	17.538	**< 0.0001**
Year	0.000689	0.0001	6	538420	6.3879	**< 0.0001**
Shoal:Year	0.0003	2E-05	17	533997	0.9831	0.474
Season:Year	0.001217	9E-05	14	543334	4.8389	**< 0.0001**

Table 12-3. Results of Tukey HSD multiple comparisons tests of the Simpson's diversity index between seasons across all shoals for each project year.

The groupings denote significant differences at α = 0.05. Like letters indicate no significant differences between groups.

Year	Season	L-S M	SE	DF	Lower CL	Upper CL	Groupings
2014	Fall	0.18	0.0439	1,086	0.0943	0.266	a
"	Winter	0.482	0.0303	610	0.4225	0.541	b
"	Spring	0.624	0.0434	1,059	0.5385	0.709	c
"	Summer	0.677	0.0311	632	0.6155	0.738	c
2015	Fall	0.343	0.0435	1,064	0.2574	0.428	a
"	Winter	0.372	0.0386	906	0.2964	0.448	a
"	Spring	0.544	0.0442	1,092	0.4568	0.630	b
"	Summer	0.585	0.031	655	0.5242	0.646	b
2016	Fall	0.227	0.0538	1,218	0.1213	0.333	a
"	Spring	0.237	0.0434	1,078	0.1519	0.322	a
"	Winter	0.431	0.0311	670	0.3704	0.492	b
"	Summer	0.755	0.0318	680	0.6929	0.818	c
2017	Fall	0.396	0.0315	683	0.3338	0.458	a
"	Winter	0.427	0.0316	681	0.3655	0.489	a
"	Spring	0.569	0.0340	792	0.5023	0.636	b
"	Summer	0.679	0.0337	778	0.6129	0.745	b
2018	Winter	0.37	0.0311	650	0.3091	0.431	a
"	Fall	0.456	0.0309	664	0.3950	0.516	a
"	Summer	0.475	0.0314	679	0.4138	0.537	a
"	Spring	0.484	0.0336	781	0.4180	0.550	a
2019	Winter	0.431	0.0315	688	0.3690	0.493	a
"	Spring	0.488	0.0314	667	0.4266	0.550	a
"	Summer	0.616	0.0318	702	0.5537	0.678	b

Table 12-4. Tukey HSD multiple comparisons tests of the mean biomass between seasons across all shoals for each project year.

The groupings denote signifcant differences at α = 0.05. Like letters indicate no significant differences between groups. Degrees of freedom calculations have been disabled because the number of observations exceeds 3,000.

Year	Season	L-S M	SE	DF	Lower CL	Upper CL	Groupings
2014	Spring	-4.98E-05	0.0014	Inf	-0.0028	0.0027	a
"	Winter	-1.78E-05	0.0014	Inf	-0.0028	0.0028	a
"	Summer	-1.43E-07	0.0014	Inf	-0.0028	0.0028	a, b
"	Fall	9.57E-05	0.0014	Inf	-0.0027	0.0029	b
2015	Spring	-5.77E-05	0.0014	Inf	-0.0028	0.0027	a
"	Winter	-3.92E-05	0.0014	Inf	-0.0028	0.0027	a
"	Fall	8.95E-05	0.0014	Inf	-0.0027	0.0029	b
"	Summer	1.33E-04	0.0014	Inf	-0.0026	0.0029	b
2016	Fall	-1.67E-05	0.0014	Inf	-0.0028	0.0028	a
"	Spring	-4.96E-06	0.0014	Inf	-0.0028	0.0028	a
"	Winter	9.59E-06	0.0014	Inf	-0.0028	0.0028	a
"	Summer	1.50E-04	0.0014	Inf	-0.0026	0.0029	b
2017	Winter	2.85E-05	0.0014	Inf	-0.0027	0.0028	a
"	Spring	5.01E-05	0.0014	Inf	-0.0027	0.0028	a
"	Fall	1.11E-04	0.0014	Inf	-0.0027	0.0029	a
"	Summer	2.29E-04	0.0014	Inf	-0.0025	0.0030	b
2108	Summer	-2.21E-05	0.0014	Inf	-0.0028	0.0028	a
"	Spring	-1.54E-06	0.0014	Inf	-0.0028	0.0028	a, b
"	Fall	4.23E-05	0.0014	Inf	-0.0027	0.0028	a, b
"	Winter	7.62E-05	0.0014	Inf	-0.0027	0.0029	b
2019	Spring	-4.29E-05	0.0014	Inf	-0.0028	0.0027	a
"	Winter	6.35E-05	0.0014	Inf	-0.0027	0.0028	b
"	Summer	6.66E-05	0.0014	Inf	-0.0027	0.0028	b

Table 12-5. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for all ridge and swale habitats during the fall.

Initial model shown with no interactions. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.70052	0.35026	2	243	6.6300	**0.002**
Ridge/Swale	0.46595	0.46595	1	243	8.8198	**0.003**
Year	0.87885	0.17577	5	243	3.3271	**0.006**
Day/Night	1.88223	1.88223	1	243	35.6280	**< 0.001**

Table 12-6. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for all ridge and swale habitats during the fall.

Model shown with factors and significant interactions. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.32680	0.16340	2	231	3.6978	**0.026**
Ridge/Swale	0.34453	0.34453	1	231	7.7968	**0.006**
Year	0.84446	0.16889	5	231	3.8221	**0.002**
Day/Night	1.84098	1.84098	1	231	41.662	**< 0.001**
Shoal:Ridge/Swale	0.21020	0.10510	2	231	2.3784	0.095
Shoal:Year	2.26420	0.28302	8	231	6.4050	**< 0.001**
Shoal:Day/Night	0.38682	0.19341	2	231	4.3770	**0.014**

Table 12-7. Results of Tukey HSD multiple comparisons tests for the Simpson's diversity index between ridges and swales for each shoal during the fall.

The groupings denote signifcant differences at α = 0.05. Like letters indicate no significant differences between groups.

Shoal	Year	Habitat	L-S M	SE	DF	Lower CL	Upper CL	Groupings
CSII	2013	Swale	0.190	0.0701	153.8	0.0519	0.329	a
"	"	Ridge	0.347	0.0764	151.6	0.1966	0.498	b
CSII	2014	Swale	0.240	0.0704	172.1	0.1009	0.379	a
"	"	Ridge	0.397	0.0742	167.2	0.2506	0.543	b
CSII	2015	Swale	0.234	0.0697	163.5	0.0965	0.372	a
"	"	Ridge	0.391	0.0755	171.9	0.2422	0.54	b
CSII	2016	Swale	0.241	0.0694	173.7	0.1038	0.378	a
"	"	Ridge	0.398	0.0753	181.6	0.2494	0.546	b
CSII	2017	Swale	0.500	0.0479	66.1	0.4045	0.596	a
"	"	Ridge	0.657	0.0531	69.7	0.5513	0.763	b
CSII	2018	Swale	0.504	0.0459	60.4	0.4122	0.596	a
"	"	Ridge	0.661	0.0536	75.9	0.5544	0.768	b

Table 12-8. Results of a type III ANOVA for the linear mixed-effects model for the trawl sample mean biomass for all ridge and swale habitats during the fall.

Initial model with significant factors shown. There were no significant interactions with any model. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	9.40E-06	4.68E-06	2	7	0.1501	0.863
Ridge/Swale	0.00035	0.000349	1	62187	11.188	**0.001**
Year	0.00048	9.63E-05	5	52840	3.0865	**0.009**
Day/Night	0.00042	0.000425	1	101492	13.625	**< 0.001**

Table 12-9. Results of Tukey HSD multiple comparisons tests for the trawl sample mean biomass for all ridge and swale habitats during the fall.

The groupings denote signifcant differences at α = 0.05. Like letters indicate no significant differences between groups.

Shoal	Year	Habitat	L-S M	SE	DF	Lower CL	Upper CL	Groupings
CSII	2013	Ridge	-6.64E-05	1.26E-04	Inf	-3.13E-04	1.80E-04	a
"	"	Swale	-5.65E-05	8.40E-05	Inf	-2.21E-04	1.08E-04	a
"	2014	Ridge	9.96E-05	8.30E-05	Inf	-6.32E-05	2.62E-04	a
"	"	Swale	1.12E-04	6.80E-05	Inf	-2.09E-05	2.46E-04	a
"	2015	Ridge	-6.38E-05	8.65E-05	Inf	-2.33E-04	1.06E-04	a
"	"	Swale	1.89E-04	6.56E-05	Inf	6.01E-05	3.17E-04	b
"	2016	Swale	-1.04E-05	7.55E-05	Inf	-1.58E-04	1.38E-04	a
"	"	Ridge	6.45E-05	1.02E-04	Inf	-1.36E-04	2.65E-04	a
"	2017	Ridge	1.05E-04	6.17E-05	Inf	-1.64E-05	2.26E-04	a
"	"	Swale	2.70E-04	4.81E-05	Inf	1.76E-04	3.65E-04	b
"	2018	Ridge	3.25E-05	6.23E-05	Inf	-8.96E-05	1.55E-04	a
"	"	Swale	1.99E-04	4.66E-05	Inf	1.08E-04	2.90E-04	b
Bull	2013	Ridge	-8.58E-05	1.30E-04	Inf	-3.40E-04	1.69E-04	a
"	"	Swale	-7.60E-05	8.75E-05	Inf	-2.47E-04	9.55E-05	a
"	2014	Ridge	8.01E-05	8.32E-05	Inf	-8.29E-05	2.43E-04	a
"	"	Swale	9.30E-05	6.82E-05	Inf	-4.07E-05	2.27E-04	a
"	2015	Ridge	-8.32E-05	8.66E-05	Inf	-2.53E-04	8.65E-05	a
"	"	Swale	1.69E-04	6.58E-05	Inf	4.03E-05	2.98E-04	b
"	2016	Swale	-2.99E-05	7.57E-05	Inf	-1.78E-04	1.19E-04	a
"	"	Ridge	4.50E-05	1.02E-04	Inf	-1.56E-04	2.46E-04	a
"	2017	Ridge	8.51E-05	6.29E-05	Inf	-3.82E-05	2.08E-04	a
"	"	Swale	2.51E-04	4.73E-05	Inf	1.58E-04	3.44E-04	b
"	2018	Ridge	1.31E-05	6.23E-05	Inf	-1.09E-04	1.35E-04	a
"	"	Swale	1.80E-04	4.66E-05	Inf	8.82E-05	2.71E-04	b
Chester	2013	Ridge	-6.31E-05	1.32E-04	Inf	-3.23E-04	1.96E-04	a
"	"	Swale	-5.33E-05	9.25E-05	Inf	-2.35E-04	1.28E-04	a
"	2014	Ridge	1.03E-04	8.57E-05	Inf	-6.52E-05	2.71E-04	a
"	"	Swale	1.16E-04	6.82E-05	Inf	-1.80E-05	2.49E-04	a
"	2015	Ridge	-6.06E-05	8.72E-05	Inf	-2.31E-04	1.10E-04	a
"	"	Swale	1.92E-04	6.65E-05	Inf	6.16E-05	3.22E-04	b
"	2016	Swale	-7.19E-06	8.31E-05	Inf	-1.70E-04	1.56E-04	a
"	"	Ridge	6.77E-05	1.08E-04	Inf	-1.44E-04	2.79E-04	a
"	2017	Ridge	1.08E-04	6.40E-05	Inf	-1.77E-05	2.33E-04	a
"	"	Swale	2.74E-04	4.85E-05	Inf	1.79E-04	3.69E-04	b
"	2018	Ridge	3.58E-05	6.40E-05	Inf	-8.97E-05	1.61E-04	a
"	"	Swale	2.02E-04	4.74E-05	Inf	1.09E-04	2.95E-04	b

Table 12-10. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for all ridge and swale habitats during the winter.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	2.705	1.3525	2	9.97	24.551	**< 0.001**
Ridge/Swale	0.3176	0.3176	1	392.26	5.7658	**0.017**
Year	0.8199	0.164	5	390.95	2.9765	**0.011**
Day/Night	9.0112	9.0112	1	390.38	163.57	**< 0.001**

Table 12-11 Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for all ridge and swale habitats during the winter.

Model with factors and significant interactions shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	1.7821	0.8911	2	13.480	18.481	**< 0.001**
Ridge/Swale	0.3096	0.3096	1	378.10	6.4204	**0.012**
Year	0.8918	0.1784	5	376.94	3.6991	**0.002**
Day/Night	9.0859	9.0859	1	376.41	188.44	**< 0.001**
Shoal:Ridge/Swale	0.7279	0.3639	2	377.53	7.5479	**< 0.001**
Shoal:Year	2.1064	0.2106	10	376.87	4.3686	**< 0.001**
Shoal:Day/Night	0.6467	0.3233	2	376.41	6.7059	**0.001**

Table 12-12. Results of Tukey HSD multiple comparisons tests for the Simpson's diversity index between ridges and swales at Canaveral Shoals II for each year during the winter.

The groupings denote signifcant differences at α = 0.05. Like letters indicate no significant differences between groups.

Year	Bottom Type	L-S M	SE	DF	Lower CL	Upper CL	Groupings
2014	Swale	0.373	0.0458	97.6	0.2821	0.464	a
"	Ridge	0.561	0.0523	149.6	0.4572	0.664	b
2015	Swale	0.278	0.0590	159.4	0.1618	0.395	a
"	Ridge	0.466	0.0656	215.9	0.3366	0.595	b
2016	Swale	0.362	0.0475	103.4	0.2683	0.457	a
"	Ridge	0.550	0.0541	164.7	0.4432	0.657	b
2017	Swale	0.351	0.0487	106.0	0.2541	0.447	a
"	Ridge	0.538	0.0547	164.5	0.4301	0.646	b
2018	Swale	0.170	0.0481	101.3	0.0746	0.265	a
"	Ridge	0.357	0.0533	152.2	0.2522	0.463	b
2019	Swale	0.244	0.0489	116.4	0.1474	0.341	a
"	Ridge	0.432	0.0537	163.7	0.3258	0.538	b

Table 12-13 Results of a type III ANOVA for the linear mixed-effects model for the trawl sample mean biomass for all ridge and swale habitats during the winter.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	3.84E-05	1.90E-05	2	8	1.3985	0.3
Ridge/Swale	0.000586	0.00059	1	142675	42.667	**< 0.001**
Year	0.000261	5.20E-05	5	147759	3.7954	**0.002**
Day/Night	2.50E-06	2.50E-06	1	162879	0.1817	0.67

Table 12-14. Results of a type III ANOVA for the linear mixed-effects model for the trawl sample mean biomass for all ridge and swale habitats during the winter.

Model shown with interactions and significant factors. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	3.94E-05	1.97E-05	2	8	1.4348	0.29252
Ridge/Swale	0.000535	5.35E-04	1	141856	38.923	**< 0.0001**
Year	0.000132	2.63E-05	5	135346	1.9175	0.08781
Day/Night	2.53E-06	2.53E-06	1	162805	0.1841	0.66784
Ridge/Swale:Year	0.000127	2.54E-05	5	139548	1.8512	0.09928

Table 12-15. Results of Tukey HSD multiple comparisons tests for the trawl sample mean biomass for all ridge and swale habitats during the winter.

The groupings denote significant differences at α = 0.05. Like letters indicate no significant differences between groups.

Shoal	Year	Habitat	L-S M	SE	DF	Lower CL	Upper CL	Groupings
CSII	2014	Ridge	7.38E-05	4.94E-05	Inf	-2.30E-05	1.71E-04	a
"	"	Swale	1.43E-04	4.10E-05	Inf	6.28E-05	2.24E-04	a
"	2015	Ridge	5.69E-05	5.81E-05	Inf	-5.70E-05	1.71E-04	a
"	"	Swale	1.14E-04	4.65E-05	Inf	2.25E-05	2.05E-04	a
"	2016	Ridge	7.50E-05	5.07E-05	Inf	-2.43E-05	1.74E-04	a
"	"	Swale	1.82E-04	4.14E-05	Inf	1.01E-04	2.63E-04	b
"	2017	Ridge	9.79E-05	5.10E-05	Inf	-1.98E-06	1.98E-04	a
"	"	Swale	1.98E-04	4.19E-05	Inf	1.16E-04	2.80E-04	b
"	2018	Ridge	8.26E-05	4.96E-05	Inf	-1.46E-05	1.80E-04	a
"	"	Swale	2.80E-04	4.19E-05	Inf	1.98E-04	3.62E-04	b
"	2019	Ridge	5.50E-05	4.99E-05	Inf	-4.29E-05	1.53E-04	a
"	"	Swale	2.68E-04	4.20E-05	Inf	1.86E-04	3.50E-04	a
Bull	2014	Ridge	4.55E-05	4.74E-05	Inf	-4.74E-05	1.38E-04	a
"	"	Swale	1.15E-04	3.82E-05	Inf	4.01E-05	1.90E-04	a
"	2015	Ridge	2.86E-05	5.51E-05	Inf	-7.95E-05	1.37E-04	a
"	"	Swale	8.52E-05	4.38E-05	Inf	-6.97E-07	1.71E-04	a
"	2016	Ridge	4.67E-05	4.81E-05	Inf	-4.76E-05	1.41E-04	a
"	"	Swale	1.54E-04	3.86E-05	Inf	7.84E-05	2.30E-04	b
"	2017	Ridge	6.96E-05	4.83E-05	Inf	-2.52E-05	1.64E-04	a
"	"	Swale	1.69E-04	3.90E-05	Inf	9.30E-05	2.46E-04	b
"	2018	Ridge	5.43E-05	4.73E-05	Inf	-3.83E-05	1.47E-04	a
"	"	Swale	2.52E-04	3.91E-05	Inf	1.75E-04	3.28E-04	b
"	2019	Ridge	2.67E-05	4.76E-05	Inf	-6.65E-05	1.20E-04	a
"	"	Swale	2.40E-04	3.90E-05	Inf	1.63E-04	3.16E-04	b
Chester	2014	Ridge	-6.77E-07	4.69E-05	Inf	-9.27E-05	9.13E-05	a
"	"	Swale	6.86E-05	3.82E-05	Inf	-6.25E-06	1.44E-04	a
"	2015	Ridge	-1.76E-05	5.61E-05	Inf	-1.28E-04	9.23E-05	a
"	"	Swale	3.90E-05	4.46E-05	Inf	-4.83E-05	1.26E-04	a
"	2016	Ridge	5.24E-07	4.84E-05	Inf	-9.44E-05	9.54E-05	a
"	"	Swale	1.08E-04	3.85E-05	Inf	3.24E-05	1.83E-04	b
"	2017	Ridge	2.34E-05	4.86E-05	Inf	-7.18E-05	1.19E-04	a
"	"	Swale	1.23E-04	3.91E-05	Inf	4.64E-05	2.00E-04	b
"	2018	Ridge	8.13E-06	4.72E-05	Inf	-8.44E-05	1.01E-04	a
"	"	Swale	2.06E-04	3.90E-05	Inf	1.29E-04	2.82E-04	b
"	2019	Ridge	-1.95E-05	4.78E-05	Inf	-1.13E-04	7.43E-05	a
"	"	Swale	1.93E-04	3.90E-05	Inf	1.17E-04	2.70E-04	b

Table 12-16. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for all ridge and swale habitats during the spring.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.3039	0.15197	2	287	2.6003	0.076
Ridge/Swale	0.2215	0.22148	1	287	3.7895	**0.053**
Year	3.8212	0.76423	5	287	13.076	**< 0.001**
Day/Night	2.5704	2.57043	1	287	43.980	**< 0.001**

Table 12-17. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for all ridge and swale habitats during the spring.

Model with significant factors and significant interactions shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.2348	0.11738	2	275	2.4592	0.087
Ridge/Swale	0.2056	0.20559	1	275	4.3073	**0.039**
Year	3.8419	0.76839	5	275	16.099	**< 0.001**
Day/Night	0.6259	0.62588	1	275	13.113	**< 0.001**
Shoal:Year	2.9481	0.29481	10	275	6.1766	**< 0.001**
Shoal:Day/Night	1.0286	0.51428	2	275	10.775	**< 0.001**

Table 12-18. Results of a type III ANOVA for the linear mixed-effects model for the trawl sample mean biomass for all ridge and swale habitats during the spring.

Initial model with significant factors shown. There are no significant interactions. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	8.34E-06	4.17E-06	2	121697	0.6163	0.540
Ridge/Swale	1.16E-04	1.16E-04	1	121760	17.078	**< 0.001**
Year	1.40E-04	2.80E-05	5	121760	4.1425	**0.001**
Day/Night	1.15E-05	1.15E-05	1	121760	1.7065	0.191

Table 12-19. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for all ridge and swale habitats during the summer.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.0122	0.0061	2	9.07	0.1095	0.897
Ridge/Swale	0.0017	0.0017	1	398.3	0.0311	0.860
Year	3.0824	0.6165	5	398.59	11.07	**< 0.001**
Day/Night	0.4251	0.4251	1	397.26	7.6329	**0.006**

Table 12-20. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for all ridge and swale habitats during the summer.

Model with significant factors and significant interactions shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.0028	0.0014	2	9.19	0.027	0.973
Ridge/Swale	0.0039	0.0039	1	393.31	0.0741	0.786
Year	3.0944	0.6189	5	393.54	11.772	**< 0.001**
Day/Night	0.4798	0.4798	1	392.23	9.127	**0.003**
Year:Day/Night	1.5168	0.3034	5	393.06	5.7703	**< 0.001**

Table 12-21. Results of a type III ANOVA for the linear mixed-effects model for the trawl sample mean biomass for all ridge and swale habitats during the summer.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	4.00E-05	2.00E-05	2	8	0.8064	0.479
Ridge/Swale	0.0004	0.0004	1	162264	16.962	**< 0.001**
Year	0.0013	0.0003	5	150014	11.947	**< 0.001**
Day/Night	0.001	0.001	1	168046	45.906	**< 0.001**

Table 12-22. Results of a type III ANOVA for the linear mixed-effects model for the trawl sample mean biomass for all ridge and swale habitats during the summer.

Model with significant factors and significant interactions shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	3.00E-05	2.00E-05	2	8	0.7706	0.494
Ridge/Swale	0.0004	0.0004	1	162429	18.49	**< 0.001**
Year	0.001	0.0002	5	138216	9.0885	**< 0.001**
Day/Night	0.001	0.001	1	168227	45.068	**< 0.001**
Ridge/Swale:Year	0.0005	9.00E-05	5	152897	4.1029	**0.001**

Table 12-23. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for the data collected during the first dredging event for Canaveral Shoals II and Canaveral Shoals II Borrow Area only.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.12666	0.12666	1	67	1.8271	0.181
Ridge/Swale	0.50762	0.50762	1	67	7.3226	**0.009**
Season by Year	0.98704	0.32901	3	67	4.7461	**0.005**
Day/Night	0.67463	0.67463	1	67	9.7317	**0.003**

Table 12-24. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for the data collected during the first dredging event for Canaveral Shoals II and Canaveral Shoals II Borrow Area only.

Model tested for difference in the ridge-swale habitats between Canaveral Shoals II and Canaveral Shoals II Borrow Area. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.17842	0.17842	1	62	2.7472	0.102
Ridge/Swale	0.14724	0.14724	1	62	2.2670	0.137
Season by Year	1.04239	0.34746	3	62	5.3500	**0.002**
Day/Night	0.25645	0.25645	1	62	3.9487	0.051
Ridge/Swale:Day/Night	0.36481	0.36481	1	62	5.6172	**0.021**
Shoal:Ridge/Swale	0.20000	0.20000	1	62	3.0795	0.084
Shoal:Season/Year	0.21619	0.07206	3	62	1.1096	0.352

Table 12-25. Results of Type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for the data collected during the first dredging event for Canaveral Shoals II and Canaveral Shoals II Borrow Area only.

Only significant factors and interactions were used in the final model. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.1788	0.1788	1	261	3.3992	**0.066**
Ridge/Swale	1.0809	1.0809	1	261	20.549	**< 0.001**
Season by Year	10.230	0.4448	23	261	8.4558	**< 0.001**

Table 12-26. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass of trawl samples collected from Canaveral Shoals II and Canaveral Shoals II Borrow Area only during the first dredging event.

Full model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	4.18E-06	4.18E-06	1	2.1	0.7933	0.462
Ridge/Swale	1.31E-05	1.31E-05	1	29781.6	2.4873	0.115
Season by Year	3.51E-05	1.17E-05	3	29354.6	2.2174	0.084
Day/Night	4.43E-07	4.43E-07	1	668.5	0.0841	0.772

Table 12-27. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for the data during the first dredging event for all shoals.

Initial with significant factors. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	1.12329	0.3744	3	190	6.4819	**< 0.001**
Ridge/Swale	0.14189	0.1419	1	190	2.4563	**< 0.001**
Season by Year	2.41209	0.804	3	190	13.919	**< 0.001**
Day/Night	1.71684	1.7168	1	190	29.721	**< 0.001**

Table 12-28. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for the data during the first dredging even for all shoals.

Initial model is shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	1.94E-05	6.47E-06	3	7	1.6057	0.275
Ridge/Swale	5.66E-05	5.66E-05	1	70918	14.0505	**< 0.001**
Season by Year	2.90E-05	9.65E-06	3	46882	2.3973	0.066
Day/Night	1.70E-05	1.70E-05	1	11326	4.2197	**0.040**

Table 12-29. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for the data during the first dredging even for all shoals.

Model with significant factors shown. There were no significant interactions. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Ridge/Swale	5.54E-05	5.54E-05	1	74680	13.763	**< 0.001**
Season by Year	2.67E-05	8.89E-06	3	30922	2.2072	0.085
Day/Night	2.05E-05	2.05E-05	1	5269	5.0843	**0.024**

Table 12-30. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for samples collected during the second dredging event for Canaveral Shoals II and Canaveral Shoals II Borrow Area only.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Season by Year	1.25194	0.62597	2	64	10.632	**< 0.001**
Shoal	0.01292	0.01292	1	64	0.2195	0.641
Ridge/Swale	0.46993	0.46993	1	64	7.982	**0.006**
Day/Night	0.56444	0.56444	1	64	9.5871	**0.003**

Table 12-31. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for samples collected during the second dredging event for Canaveral Shoals II and Canaveral Shoals II Borrow Area only.

Model with only significant factors shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Season by Year	1.3397	0.66985	2	64	14.717	**< 0.001**
Day/Night	0.5293	0.5293	1	64	11.629	**< 0.001**
Season/Year:Day/Night	1.3337	0.66687	2	64	14.652	**< 0.001**

Table 12-32. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for samples collected during the second dredging event for Canaveral Shoals II and Canaveral Shoals II Borrow Area only.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	6.17E-06	6.17E-06	1	29104	0.3579	0.550
Ridge/Swale	1.63E-04	1.63E-04	1	29104	9.462	**0.002**
Season by Year	6.06E-05	3.03E-05	2	29104	1.7584	0.172
Day/Night	1.78E-04	1.78E-04	1	29104	10.315	**0.001**

Table 12-33. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for samples collected during the second dredging event for Canaveral Shoals II and Canaveral Shoals II Borrow Area only.

Model with only significant factors shown. There are no interaction effects with this model. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Ridge/Swale	0.00015	0.00015	1	29107	8.8233	**0.003**
Day/Night	0.00017	0.00017	1	29107	10.123	**0.002**

Table 12-34. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for samples collected during the second dredging event for all shoals.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Season by Year	0.7559	0.3779	2	187.74	5.8524	**0.003**
Shoal	0.0156	0.0052	3	13.61	0.0803	0.970
Ridge/Swale	0.4864	0.4864	1	189.94	7.5318	**0.007**
Day/Night	3.2331	3.2331	1	186.72	50.065	**< 0.001**

Table 12-35. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for samples collected during the second dredging event for all shoals.

Model showing no significant interaction between the shoals and ridge-swale complex. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Season by Year	0.0405	0.0135	3	187	0.2118	0.888
Shoal	0.6518	0.6518	1	187	10.225	**0.002**
Ridge/Swale	0.7803	0.3901	2	187	6.1205	**0.003**
Day/Night	3.2842	3.2842	1	187	51.523	**< 0.001**
Shoal:Ridge/Swale	0.3634	0.1211	3	187	1.9004	0.131

Table 12-36. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for samples collected during the second dredging event for all shoals.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	2.00E-05	6.70E-06	3	5	0.3093	0.819
Ridge/Swale	0.00034	0.00034	1	44488	15.833	**< 0.001**
Season by Year	0.00024	0.00012	2	71123	5.6806	**0.003**
Day/Night	0.00049	0.00049	1	81374	22.778	**< 0.001**

Table 12-37. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for samples collected during the second dredging event for all shoals.

Model showing no significant interaction between the shoals and ridge-swale complex. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	2.01E-05	6.70E-06	3	5	0.3123	0.816
Ridge/Swale	0.000361	0.00036	1	42493	16.811	**< 0.001**
Season by Year	0.000244	0.00012	2	67041	5.6847	**0.003**
Day/Night	0.000496	0.0005	1	81216	23.087	**< 0.001**
Shoal:Ridge/Swale	0.000128	4.30E-05	3	39199	1.9923	0.113

Table 12-38 Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for samples collected during the second dredging event for all shoals.

Model shown with significant factors. The interactions shown are not significant. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Ridge/Swale	0.00029	0.00029	1	47317	13.581	**< 0.001**
Season by Year	0.00014	6.90E-05	2	30584	3.2057	**0.041**
Day/Night	0.00034	0.00034	1	44915	15.627	**< 0.001**
Ridge/Swale:Season/Year	0.00012	5.90E-05	2	33409	2.7434	0.064
Ridge/Swale:Day/Night	7.20E-05	7.20E-05	1	73287	3.3456	0.067

Table 12-39. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index calculated for fall only post dredging.

Initial model is shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.5115	0.1705	3	171	3.0823	**0.0289**
Ridge/Swale	0.5748	0.5748	1	171	10.392	**0.0015**
Season by Year	0.5417	0.1354	4	171	2.4482	**0.0482**
Day/Night	1.2819	1.2819	1	171	23.174	**< 0.001**

Table 12-40. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index calculated for fall only post dredging.

Model with significant interactions factors and significant interactions shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.287	0.0957	3	155	2.3077	0.079
Ridge/Swale	0.6296	0.6296	1	155	15.188	**< 0.001**
Season by Year	0.3135	0.0784	4	155	1.8905	0.115
Day/Night	0.831	0.831	1	155	20.047	**< 0.001**
Shoal:Ridge/Swale	0.5848	0.1949	3	155	4.7025	**0.004**
Shoal:Season/Year	1.7813	0.1781	10	155	4.2972	**0.000**
Shoal:Day/Night	0.4002	0.1334	3	155	3.2179	**0.024**

Table 12-41. Results of Tukey HSD multiple comparisons tests between shoals of the Simpson's diversity index for the fall only.

The groupings denote signifcant differences at α = 0.05. Like letters indicate no significant differences between groups. No samples collected= "-".

Season	Shoal	L-S M	SE	DF	Lower CL	Upper CL	Groupings
Fall 2013	CSII-BA	0.221	0.099	62.8	0.0229	0.419	a
"	CSII	0.415	0.1127	139	0.1924	0.638	a
"	Bull	0.473	0.1029	145.9	0.2694	0.676	a
"	Chester	-	-	-	-	-	-
Fall 2014	CSII-BA	0.204	0.1035	71	-0.003	0.41	a
"	CSII	0.503	0.1046	130.6	0.2961	0.71	a
"	Bull	0.263	0.0729	127.5	0.1187	0.407	a
"	Chester	0.365	0.0742	124.6	0.2182	0.512	a
Fall 2015	CSII-BA	0.182	0.1105	83.1	-0.038	0.401	a
"	CSII	0.495	0.1018	105.5	0.2931	0.697	a, b
"	Bull	0.712	0.0733	130	0.5671	0.857	b
"	Chester	0.435	0.0732	125.8	0.2904	0.58	a
Fall 2016	CSII-BA	0.336	0.1105	83.1	0.1167	0.556	a
"	CSII	0.396	0.1006	121.4	0.1966	0.595	a
"	Bull	0.406	0.0735	126.8	0.2607	0.552	a
"	Chester	-	-	-	-	-	-
Fall 2017	CSII-BA	0.512	0.0617	12	0.3772	0.646	b
"	CSII	0.653	0.0625	43.9	0.5274	0.779	b
"	Bull	0.269	0.0439	43.1	0.1809	0.358	a
"	Chester	0.291	0.0447	40.5	0.2004	0.381	a

Table 12-42. Results of Tukey HSD multiple comparisons tests of the Simpson's diversity index calculated for the ridge and swale habitats collected during the fall only.

The groupings denote signifcant differences at α = 0.05. Like letters indicate no significant differences between groups. No samples collected= "-".

Season	Habitat	Shoal	L-S M	SE	DF	Lower CL	Upper CL	Groupings
Fall 2013	Ridge	CSII-BA	0.504	0.0819	23.1	0.3346	0.673	a, b
"	"	CSII	0.656	0.0924	95.74	0.4723	0.839	a
"	"	Bull	0.423	0.0816	132.62	0.2611	0.584	b
Fall 2014	Ridge	CSII-BA	0.47	0.0749	16.63	0.3118	0.628	b, c
"	"	CSII	0.622	0.0824	72.78	0.4576	0.786	c
"	"	Chester	0.206	0.0751	119.78	0.0573	0.354	a
"	"	Bull	0.389	0.0666	99.07	0.2565	0.521	a, b
Fall 2015	Ridge	CSII-BA	0.641	0.0763	17.58	0.4805	0.802	b, c
"	"	CSII	0.793	0.0826	70.63	0.6282	0.958	c
"	"	Chester	0.377	0.0737	118.31	0.2311	0.523	a
"	"	Bull	0.56	0.0677	101.78	0.4255	0.694	a, b
Fall 2016	Ridge	CSII-BA	0.521	0.08	21.19	0.3552	0.688	a, b
"	"	CSII	0.673	0.0857	79.51	0.5028	0.844	a
"	"	Bull	0.44	0.0715	113.78	0.2985	0.582	b
Fall 2017	Ridge	CSII-BA	0.521	0.0641	9.07	0.3766	0.666	b, c
"	"	CSII	0.673	0.0727	51.09	0.5273	0.819	c
"	"	Chester	0.257	0.0643	90.51	0.1296	0.385	a
"	"	Bull	0.44	0.0555	64.01	0.3293	0.551	a, b
Fall 2013	Swale	CSII-BA	0.286	0.0762	17.52	0.1261	0.447	a
"	"	Bull	0.339	0.0708	105.89	0.1983	0.479	a
"	"	CSII	0.348	0.0734	51.83	0.2007	0.495	a
Fall 2014	Swale	CSII-BA	0.252	0.07	12.81	0.101	0.404	a
"	"	Chester	0.261	0.0583	73.4	0.145	0.377	a
"	"	Bull	0.305	0.0574	68.82	0.1901	0.419	a
"	"	CSII	0.314	0.0644	34.15	0.183	0.445	a
Fall 2015	Swale	CSII-BA	0.424	0.0702	12.69	0.2717	0.576	a
"	"	Chester	0.432	0.0592	75.37	0.3144	0.55	a
"	"	Bull	0.476	0.0569	66.46	0.3622	0.59	a
"	"	CSII	0.485	0.0637	31.65	0.3552	0.615	a
Fall 2016	Swale	CSII-BA	0.304	0.0738	15.6	0.1471	0.461	a
"	"	Bull	0.356	0.0614	81.71	0.2341	0.478	a
"	"	CSII	0.365	0.0673	39.03	0.2293	0.502	a
Fall 2017	Swale	CSII-BA	0.304	0.0584	6.26	0.1624	0.446	a
"	"	Chester	0.313	0.0446	31.09	0.2216	0.404	a
"	"	Bull	0.356	0.0417	24.36	0.2703	0.442	a
"	"	CSII	0.365	0.0528	16.38	0.2537	0.477	a

Table 12-43. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass calculated for fall only.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	4.86E-05	1.62E-05	3	5	0.7108	0.587
Ridge/Swale	0.000231	2.31E-04	1	73324	10.14	**0.001**
Season by Year	0.000597	1.19E-04	5	57580	5.239	**< 0.001**
Day/Night	0.000313	3.13E-04	1	73216	13.717	**< 0.001**

Table 12-44. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for fall only.

Model showing significant factors and interactions. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	6.03E-05	2.01E-05	3	5	0.8813	0.507
Ridge/Swale	0.000215	2.15E-04	1	72982	9.4475	**0.002**
Season by Year	0.000343	6.86E-05	5	56744	3.0107	**0.010**
Shoal:Season by Year	0.000395	3.95E-05	10	46897	1.733	0.067

Table 12-45. Results of Tukey HSD multiple comparisons tests of the mean biomass between shoals for the fall only.

The groupings denote signifcant differences at α = 0.05. Like letters indicate no significant differences between groups. No samples collected="-". Degrees of freedom calculations have been disabled because the number of observations exceeds 3000.

Season	Shoal	L-S M	SE	DF	Lower CL	Upper CL	Groupings
Fall 2013	CSII-BA	1.51E-05	1.03E-04	Inf	-1.87E-04	0.0002	a
"	CSII	-3.12E-05	1.12E-04	Inf	-2.51E-04	0.0002	a
"	Bull	1.08E-05	1.10E-04	Inf	-2.05E-04	0.0002	a
"	Chester	-	-	-	-	-	-
Fall 2014	CSII-BA	3.87E-04	1.09E-04	Inf	1.73E-04	0.0006	a
"	CSII	2.12E-04	1.03E-04	Inf	9.25E-06	0.0004	a
"	Bull	8.54E-05	7.31E-05	Inf	-5.78E-05	0.0002	a
"	Chester	1.38E-04	7.62E-05	Inf	-1.11E-05	0.0003	a
Fall 2015	CSII-BA	9.35E-05	1.18E-04	Inf	-1.37E-04	0.0003	a, b
"	CSII	1.18E-04	9.74E-05	Inf	-7.27E-05	0.0003	a, b
"	Bull	3.51E-04	7.31E-05	Inf	2.08E-04	0.0005	b
"	Chester	4.30E-05	7.33E-05	Inf	-1.01E-04	0.0002	a
Fall 2106	CSII-BA	1.72E-04	1.18E-04	Inf	-5.87E-05	0.0004	a
"	CSII	7.93E-05	9.68E-05	Inf	-1.10E-04	0.0003	a
"	Bull	2.18E-05	7.33E-05	Inf	-1.22E-04	0.0002	a
"	Chester	-	-	-	-	-	-
Fall 2017	CSII-BA	2.69E-04	8.57E-05	Inf	1.01E-04	0.0004	a
"	CSII	1.64E-04	8.02E-05	Inf	6.31E-06	0.0003	a
"	Bull	1.55E-04	5.61E-05	Inf	4.47E-05	0.0003	a
"	Chester	1.97E-04	5.63E-05	Inf	8.69E-05	0.0003	a

Table 12-46. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity Index for winter only.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	3.6507	1.2169	3	325	22.693	**< 0.001**
Ridge/Swale	0.3269	0.3269	1	325	6.0969	**< 0.001**
Season by Year	0.8608	0.2152	4	325	4.0132	**< 0.001**
Day/Night	6.4913	6.4913	1	325	121.05	**< 0.001**

Table 12-47. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity Index calculated for winter only samples.

Model with significant factors and significant interactions shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	2.3226	0.7742	3	307	16.389	**< 0.001**
Ridge/Swale	0.5125	0.5125	1	307	10.85	**< 0.001**
Season by Year	0.7833	0.1958	4	307	4.1457	**< 0.001**
Day or Night	6.3057	6.3057	1	307	133.49	**< 0.001**
Shoal:Ridge/Swale	0.4012	0.1337	3	307	2.8312	**< 0.001**
Shoal:Season by Year	1.3434	0.1119	12	307	2.3698	**< 0.001**
Shoal:Day/Night	1.1968	0.3989	3	307	8.4452	**< 0.001**

Table 12-48. Results of Tukey HSD multiple comparisons tests of Simpson's diversity index between shoals for winter only.

The groupings denote signifcant differences at α = 0.05. Like letters indicate no significant differences between groups.

Season	Shoal	L-S M	SE	DF	Lower CL	Upper CL	Groupings
Winter 2013-14	CSII-BA	0.37	0.0708	53.1	0.228	0.512	a
"	CSII	0.521	0.0573	68.1	0.407	0.635	a, b
"	Bull	0.628	0.0442	104.9	0.54	0.715	b
"	Chester	0.473	0.0449	106.3	0.384	0.562	a, b
Winter 2014-15	CSII-BA	0.372	0.0793	78.1	0.214	0.53	a
"	CSII	0.378	0.0872	141.6	0.206	0.551	a
"	Bull	0.61	0.0521	150.2	0.508	0.713	a
"	Chester	0.522	0.065	226.2	0.394	0.65	a
Winter 2015-16	CSII-BA	0.418	0.0649	38.8	0.287	0.549	a, b
"	CSII	0.501	0.0615	102.3	0.379	0.623	b
"	Bull	0.614	0.045	109.9	0.524	0.703	b
"	Chester	0.259	0.0446	111	0.17	0.347	a
Winter 2016-17	CSII-BA	0.373	0.0637	36.2	0.244	0.502	a
"	CSII	0.506	0.0671	131	0.373	0.638	a
"	Bull	0.451	0.0451	105.3	0.361	0.54	a
"	Chester	0.352	0.0472	122.3	0.259	0.446	a
Winter 2017-18	CSII-BA	0.265	0.0637	36.2	0.136	0.395	a
"	CSII	0.252	0.064	99	0.125	0.379	a
"	Bull	0.577	0.047	112.2	0.484	0.67	b
"	Chester	0.303	0.045	112.1	0.214	0.393	a

Table 12-49. Results of Tukey HSD multiple comparisons tests of the Simpson's diversity index calculated for the ridge and swale habitats collected during the winter only.

The groupings denote signifcant differences at α = 0.05. Like letters indicate no significant differences between groups.

Season	Habitat	Shoal	L-S M	SE	DF	Lower CL	Upper CL	Groupings
Winter 2013-14	Ridge	CSII-BA	0.461	0.0874	105.5	0.2881	0.635	a
"	"	CSII	0.599	0.068	112.7	0.4639	0.733	a
"	"	Bull	0.627	0.0526	151.9	0.5232	0.731	a
"	"	Chester	0.485	0.0526	159.9	0.3811	0.589	a
Winter 2014-15	Ridge	CSII-BA	0.463	0.0939	128.5	0.2775	0.649	a
"	"	CSII	0.456	0.0965	172.2	0.2654	0.646	a
"	"	Chester	0.534	0.0715	253.9	0.3934	0.675	a
"	"	Bull	0.61	0.0584	175.3	0.4948	0.725	a
Winter 2015-16	Ridge	CSII-BA	0.51	0.0802	81	0.35	0.669	a, b
"	"	CSII	0.579	0.0737	162.1	0.4331	0.724	b
"	"	Bull	0.613	0.0531	151.1	0.5083	0.718	b
"	"	Chester	0.27	0.0541	177.8	0.1636	0.377	a
Winter 2016-17	Ridge	CSII-BA	0.465	0.0769	70.4	0.3113	0.618	a
"	"	CSII	0.583	0.0793	190.7	0.4266	0.74	a
"	"	Bull	0.45	0.0532	144.9	0.3449	0.555	a
"	"	Chester	0.364	0.0556	179	0.2547	0.474	a
Winter 2017-18	Ridge	CSII-BA	0.357	0.0769	70.4	0.2038	0.51	a, b
"	"	CSII	0.329	0.0751	156.3	0.1811	0.478	a
"	"	Bull	0.577	0.0543	143.6	0.4694	0.684	b
"	"	Chester	0.315	0.0535	170.7	0.2097	0.421	a
Winter 2013-14	Swale	CSII-BA	0.278	0.0679	45.6	0.1415	0.415	a
"	"	CSII	0.443	0.0618	90.5	0.3207	0.566	a, b
"	"	Bull	0.628	0.0457	114.8	0.5377	0.719	b
"	"	Chester	0.461	0.0476	125.2	0.3668	0.555	a, b
Winter 2014-15	Swale	CSII-BA	0.28	0.0774	72	0.1257	0.434	a
"	"	CSII	0.301	0.0882	151.9	0.1263	0.475	a
"	"	Bull	0.611	0.0544	170.5	0.5035	0.718	b
"	"	Chester	0.51	0.0659	227.7	0.3804	0.64	a, b
Winter 2015-16	Swale	CSII-BA	0.326	0.0649	38.8	0.195	0.458	a
"	"	CSII	0.423	0.0632	112	0.298	0.549	a, b
"	"	Bull	0.614	0.0467	124.9	0.5218	0.706	b
"	"	Chester	0.247	0.0453	115.4	0.1569	0.336	a
Winter 2016-17	Swale	CSII-BA	0.281	0.0666	42.5	0.147	0.416	a
"	"	CSII	0.428	0.0677	132.8	0.294	0.562	a
"	"	Bull	0.451	0.0467	121.3	0.3586	0.543	a
"	"	Chester	0.341	0.0486	132.9	0.2444	0.437	a
Winter 2017-18	Swale	CSII-BA	0.174	0.0666	42.5	0.0396	0.308	a
"	"	CSII	0.174	0.0664	107.2	0.0425	0.306	a
"	"	Bull	0.578	0.0491	134.6	0.4808	0.675	b
"	"	Chester	0.291	0.0468	125.5	0.1987	0.384	a

Table 12-50. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass calculated for winter only.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	6.65E-05	2.22E-05	3	3	1.5597	**< 0.001**
Ridge/Swale	0.000371	0.000371	1	80900	26.1379	**< 0.001**
Season by Year	0.000232	5.79E-05	4	85695	4.0779	**< 0.001**
Day/Night	2.03E-05	2.03E-05	1	134049	1.4316	**< 0.001**

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Table 12-51. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for samples collected following the second dredging event for winter only.

Model showing no significant interaction between the shoals and ridge-swale complex. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	6.08E-05	2.03E-05	3	6	1.428	**< 0.001**
Ridge/Swale	0.000339	0.000339	1	95934	23.8875	**< 0.001**
Season by Year	0.000172	4.3E-05	4	30662	3.0241	**< 0.001**
Day/Night	2.88E-05	2.88E-05	1	135208	2.0245	**< 0.001**
Shoal:Ridge/Swale	7.06E-05	2.35E-05	3	50160	1.657	**< 0.001**
Shoal:Season/Year	0.000131	1.09E-05	12	32028	0.7692	**< 0.001**
Shoal:Day/Night	6E-05	2E-05	3	133515	1.4091	**< 0.001**

Table 12-52. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index calculated for spring only.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.4664	0.1555	3	215	2.7615	**0.043**
Season by Year	3.3892	0.8473	4	215	15.051	**< 0.001**
Day/Night	1.483	1.483	1	215	26.343	**< 0.001**
Ridge/Swale	0.1384	0.1384	1	215	2.459	**0.118**

Table 12-53. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index calculated for spring only.

Model with significant factors and significant interactions shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.3922	0.1307	3	203	2.6963	**0.047**
Ridge/Swale	0.1452	0.1452	1	203	2.9958	**0.085**
Season by Year	2.5227	0.6307	4	203	13.009	**< 0.001**
Day/Night	1.0468	1.0468	1	203	21.592	**< 0.001**
Shoal:Season by Year	2.262	0.1885	12	203	3.8881	**< 0.001**

Table 12-54. Results of Tukey HSD multiple comparisons tests of the Simpson's diversity index between shoals for spring only.

The groupings denote signifcant differences at α = 0.05. Like letters indicate no significant differences between groups.

Season	Shoal	L-S M	SE	DF	Lower CL	Upper CL	Groupings
Spring 2014	CSII-BA	0.71	0.0928	62.9	0.524	0.895	a
"	CSII	0.62	0.0933	131.6	0.436	0.805	a
"	Bull	0.682	0.0705	154.4	0.543	0.821	a
"	Chester	0.868	0.0682	130.2	0.733	1.003	a
Spring 2015	CSII-BA	0.608	0.1015	81.6	0.406	0.81	a
"	CSII	0.425	0.0928	142.1	0.242	0.609	a
"	Bull	0.921	0.068	143.2	0.787	1.056	b
"	Chester	0.547	0.0681	143.1	0.413	0.682	a
Spring 2016	CSII-BA	0.442	0.1015	81.6	0.24	0.644	a
"	CSII	0.384	0.0866	124.1	0.213	0.555	a
"	Bull	0.358	0.0676	148.4	0.225	0.492	a
"	Chester	0.265	0.0677	141.6	0.131	0.399	a
Spring 2017	CSII-BA	0.489	0.0668	19.7	0.35	0.629	a
"	CSII	0.526	0.0613	49.6	0.403	0.649	a
"	Bull	0.711	0.0703	146.9	0.572	0.85	a
"	Chester	0.601	0.0453	58	0.51	0.691	a
Spring 2018	CSII-BA	0.476	0.0638	16.4	0.341	0.61	a, b
"	CSII	0.451	0.0638	57.5	0.323	0.579	a, b
"	Bull	0.358	0.0676	148.4	0.224	0.491	a
"	Chester	0.62	0.0453	56.7	0.529	0.711	b

Table 12-55. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for spring only.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	4.66E-06	1.55E-06	3	93057	0.1874	0.905
Season by Year	1.03E-04	2.58E-05	4	93057	3.1133	**0.014**
Day/Night	3.66E-06	3.66E-06	1	93057	0.4415	0.506
Ridge/Swale	1.09E-04	1.09E-04	1	93057	13.1936	**< 0.001**

Table 12-56. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for spring only.

Model with significant factors and interactions shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Ridge/Swale	8.10E-05	8.10E-05	1	93046	9.7789	**0.002**
Season by Year	7.97E-05	1.99E-05	4	93046	2.4055	**0.047**
Shoal:Ridge/Swale	6.05E-05	2.02E-05	3	93046	2.4337	0.063
Shoal:Season/Year	2.00E-04	1.67E-05	12	93046	2.0144	**0.019**

Table 12-57. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for samples collected in summer only.

Initial model is shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.6279	0.2093	3	333	3.6937	**0.012**
Season by Year	3.0462	0.7615	4	333	13.439	**< 0.001**
Day/Night	0.2826	0.2826	1	333	4.987	**0.026**
Ridge/Swale	0.0009	0.0009	1	333	0.0164	0.898

Table 12-58. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for samples collected in summer only.

Model with significant factors and significant interactions shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.5623	0.1874	3	319	3.5415	**0.015**
Season by Year	2.616	0.654	4	319	12.357	**< 0.001**
Day/Night	0.1212	0.1212	1	319	2.2899	0.131
Shoal:Season by Year	1.43	0.1192	12	319	2.2517	**0.010**
Shoal:Day/Night	0.6091	0.203	3	319	3.8361	**0.010**

Table 12-59. Results of Tukey HSD multiple comparisons tests of the Simpson's diversity index between shoals for summer only.

The groupings denote signifcant differences at α = 0.05. Like letters indicate no significant differences between groups.

Season	Shoal	L-S M	SE	DF	Lower CL	Upper CL	Groupings
Summer 2014	CSII-BA	0.513	0.0694	43.8	0.373	0.653	a
"	CSII	0.64	0.0639	104.8	0.513	0.767	a, b
"	Bull	0.785	0.0473	103.5	0.691	0.879	b
"	Chester	0.695	0.0474	92.6	0.601	0.789	a, b
Summer 2015	CSII-BA	0.637	0.0664	37.2	0.502	0.771	a, b
"	CSII	0.743	0.0664	118.4	0.612	0.875	b
"	Bull	0.609	0.047	116.1	0.516	0.702	a, b
"	Chester	0.47	0.0462	101.7	0.379	0.562	a
Summer 2016	CSII-BA	0.648	0.0768	62.7	0.494	0.801	a
"	CSII	0.75	0.0641	97.8	0.623	0.877	a
"	Bull	0.79	0.047	113.9	0.696	0.883	a
"	Chester	0.748	0.0492	126	0.651	0.846	a
Summer 2017	CSII-BA	0.71	0.0694	43.8	0.571	0.85	a
"	CSII	0.734	0.0639	104.8	0.607	0.86	a
"	Bull	0.616	0.047	113.9	0.523	0.709	a
"	Chester	0.722	0.0706	248.2	0.582	0.861	a
Summer 2018	CSII-BA	0.334	0.0664	37.2	0.2	0.469	a
"	CSII	0.541	0.0694	132.1	0.404	0.678	a, b
"	Bull	0.551	0.047	116.1	0.458	0.644	b
"	Chester	0.429	0.0481	119.6	0.334	0.524	a, b

Table 12-60. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for summer only.

Initial model is shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	0.00028	0.000285	1	120901	12.108	**0.001**
Ridge/Swale	0.00127	0.000318	4	135207	13.527	**< 0.001**
Season by Year	0.00079	0.000792	1	132014	33.691	**< 0.001**
Day/Night	0.00016	5.39E-05	3	4	2.2893	0.224

Table 12-61. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for summer only.

Model with significant factors and significant interactions shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Ridge/Swale	0.0003	2.96E-04	1	133401	12.565	**< 0.001**
Season by Year	0.00086	2.14E-04	4	134544	9.0898	**< 0.001**
Shoal:Season/Year	0.00053	4.44E-05	12	124189	1.8875	**0.031**

Table 12-62. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for trawl samples collected following the second dredging event.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Season by Year	1.44092	0.36023	4	342	5.1126	**0.001**
Shoal	0.25194	0.08398	3	342	1.1919	0.313
Ridge/Swale	0.04616	0.04616	1	342	0.6552	0.419
Day/Night	1.70105	1.70105	1	342	24.142	**< 0.001**

Table 12-63. Results of a type III ANOVA for the linear mixed-effects model of the Simpson's diversity index for trawl samples collected following the second dredging event.

Model shown with significant factors only. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Season by Year	1.4129	0.35323	4	339.9	5.6323	**< 0.001**
Day/Night	1.6869	1.6869	1	339.89	26.897	**< 0.001**
Season by Year:Day/Night	2.8449	0.71123	4	339.77	11.34	**< 0.001**

Table 12-64. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for trawl samples collected following the second dredging event.

Initial model shown. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Shoal	2.69E-05	9.00E-06	3	6	0.5262	0.680
Ridge/Swale	0.000509	0.00051	1	134821	29.8943	**< 0.001**
Season by Year	0.000294	7.40E-05	4	136446	4.3202	**0.002**
Day/Night	3.15E-05	3.20E-05	1	143335	1.8491	0.174

Table 12-65. Results of a type III ANOVA for the linear mixed-effects model of the mean biomass for samples collected following the second dredging event.

Model shown with significant factors only. Significant P-values shown in bold.

Factor	SS	MS	DF	DenDF	F value	P-value
Season by Year	1.4129	0.35323	4	339.9	5.6323	**< 0.001**
Day/Night	1.6869	1.6869	1	339.89	26.897	**< 0.001**
Season/Year:Day/Night	2.8449	0.71123	4	339.77	11.34	**< 0.001**

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