Final Report

Long-term Trends in Lavaca-Colorado and Guadalupe Estuaries

MBMT Contract 011

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Abstract

The purpose of the current project was to determine if the long-term decline in bottom-dwelling invertebrates are still occurring and if pollution from the Formosa discharge into Lavaca Bay may be the cause of the decline if it is still occurring. The primary focus was on water and sediment quality of the Lavaca Bay ecosystem. Four tasks were performed: 1) Analyzed archived benthic samples. 2) Synthesized existing monitoring data from the Texas Parks and Wildlife Department, Coastal Fisheries Program (TPWD). 3) Synthesized existing water and sediment quality monitoring data of the Formosa Plastics Corporation discharge site into Lavaca Bay. 4) Data management, reporting, and outreach.

In the long-term benthic dataset, the bay systems have different long-term characteristic fauna that reflects the long-term average salinity conditions in each bay system. The Lavaca-Colorado Estuary has on average about 37% more inflow than the Guadalupe Estuary, and 11 times more than the Nueces Estuary. San Antonio Bay is small and limited exchange with the Gulf of Mexico, therefore it has lower long-term average salinity than Lavaca Bay. The San Antonio Bay community has a higher contribution of mollusks, which are freshwater indicators, than Lavaca Bay, and much higher than Nueces Bay. Within the estuary systems, the secondary bays have distinct communities compared to the primary bays. This is because secondary bays are closer to freshwater inflow sources and are more oligohaline and/or brackish in nature than primary bays, which are more marine influenced.

In the Formosa dataset, all parameter trends changed over time due to climate, freshwater inflow events, and/or seasonal changes. Biological community structure and sediment changed with distance from the discharge site. Dominance characterized community structure because three to four taxa comprised >70% of individuals for nekton (trawl and gill net), phytoplankton, zooplankton, and ichthyoplankton samples. Sediment became sandier over time (48% to 75%) and away from the discharge. Surface water and porewater at reference (R) stations and stations near the discharge site had similar hydrographical and biological trends over time, indicating no long-term impact due to the discharge. However, 99.9% of 424,671 measurements of organic contaminants were non-detectable because the methods were insensitive to ambient concentrations.

There is an inconsistency between the HRI and Formosa benthic data, in that the HRI data is still declining, but the Formosa data has remained constant over time. Similar trends are true for the TPWD trawl data and the Formosa trawl data.

In conclusion, it is still not known if contaminants play a role in the long-term decline of ecosystem health in Lavaca Bay. Furthermore, only four R stations were sampled, and were all 3,810 meters from the discharge site, so it is possible that trends in R stations do not represent the natural background. Future studies should include more R stations and lower detection limits for contaminants.

Introduction

An earlier study demonstrated that the abundance, biomass, and diversity of bottom-living invertebrates (i.e., benthos) was declining at log-scale rates from 1988-2008 in the Lavaca-Matagorda Bays System (Pollack et al. 2011). Thus, the purpose of the current study was to determine if this still happening, and what may be the cause of the decline?

The initial report suggested that the benthic decline could be due to alterations in freshwater inflow patterns due to climate change. Freshwater inflow drives water quality in Texas bays as indicated by changes in nutrient and chlorophyll concentrations (Montagna et al. 2018). Past studies in Lavaca and Matagorda Bays demonstrated that long-term hydrological cycles, which are driven by long-term climate cycles and other changes, affect freshwater inflow and water quality, and in turn regulates sediment quality as indicated by benthic productivity and diversity (Kim and Montagna 2012 Montagna and Kalke 1665, Palmer et al. 2011). However, there are many emerging environmental stressors emerging over time such as, increased temperatures and more frequent occurrence of low dissolved oxygen, and increased water diversion and pollution (Montagna et al. 2011). These multiple stressors could create a negative feedback where one alone would not cause harm, but do cause harm acting in concert with one another.

Long-term research is important because most ecological questions cannot be answered with short-term studies alone. This is particularly true for questions about sublethal effects and consequences of multiple stressors; or the effects of freshwater inflow because of large year-to-year variability in climate and weather, which leads to periods of floods and droughts. Biodiversity and community structure are powerful assessment metrics because sensitive species are reduced or die, while tolerant species survive or thrive during prolonged unfavorable conditions. So, analysis of biological diversity data has been used to assess ecosystem health everywhere on Earth.

Purpose

There were two overarching goals of this project: 1) to complete a 31-year time series in the Lavaca-Colorado Estuary (i.e., Lavaca and Matagorda Bays), and 2) to analyze monitoring data of the Formosa discharge into Lavaca Bay to determine if it is affecting the health of the estuary.

This data was used to answer the two questions: 1) is benthos still declining in Lavaca Bay, and 2) if so, is the Formosa discharge into Lavaca Bay is responsible for the decline.

Benthos are excellent bioindicators of sediment quality and estuarine health, because they are relatively long-lived, fixed in place, and integrate variations in the overlying water column over time. In additions, benthos are forage for commercial and recreational fish species, so potential disappearance of benthos is of great concern.

Methods

There were four tasks for this project:

Task 1): Laboratory analysis of archived benthic samples. The sediment samples were collected between 2010 and 2019 with a 6.7-cm diameter core tube (35.4 cm^2 area). Organisms were extracted on a 0.5 mm sieve and enumerated to the lowest taxonomic level possible, usually the species level. Biomass was determined for higher taxonomic groupings by drying at 55 °C for 24 hours. Calcium carbonate shells were dissolved by acid fumigation and not included in the biomass measurements.

Task 2): Analyze existing monitoring data from the Texas Parks and Wildlife Department, Coastal Fisheries Program (TPWD). Data was obtained from Mark Fisher. Species surveys were completed using trawls, bag seines, and gill nets (1982-present) (Martinez-Andrade et al. 2005). Benthic epifauna (that live on the sediment) are collected by trawls in a stratified randomized sampling design. The trawls are 6.1 m wide at mouth, 3.8 cm mesh, doors 1.2 m long x 0.5 m tall; and towed in a circular pattern for 10 minutes. Juvenile fish and small invertebrates are collected using bag seines. The Bag seine is 18.3 m long x 1.8 m deep with 1.3 cm mesh, it is pulled parallel to the shore for 15.2 m, thus collects an area of about 0.01 ha. Large fish are collected using gill nets. The gill net is 183 m long, 1.2 m deep, four 45.7 sections of 7.6, 10.2, 12.7, and 15.1 cm mesh, is set perpendicular to the shoreline, and is set overnight. Oysters are collected by dredge. The dredge is a Louisiana style 9-tooth dredge that is 46 cm wide, 25 cm tall, and 36 cm deep bag.

Task 3): Synthesized existing water and sediment quality data obtained from Freese and Nichols, Inc. monitoring of the Formosa Plastics Corporation discharge site into Lavaca Bay (Freese and Nichols 2020). The monitoring program was supervised by four consulting firms over 23 years. However, no staff turnover occurred because the name differences were due to buyouts. Subcontractor groups completed external analyses (i.e., chemical detection and bioassays). Sampling was collected at 19 stations in Lavaca Bay. Distances A-, B-, C-, D-, and R- form rings around the diffuser with a total of 4 replicate stations (1, 2, 3, 4) per ring, except for D-stations which only have 3. One sample was taken at each station during each sampling trip except for plankton samples. Four replicate plankton samples were collected at each of the R stations and one plankton sample was collected at each of the B stations

Task 4): Data Management, Reporting, and Outreach Engagement. Quarterly Progress Reports were submitted, peer-reviewed manuscripts were published, and public presentations were made. All deliverables are listed in Appendix I.

Results

Long-Term Trends

In general, there were declining trends in benthic abundance across all three estuaries over the 31-year study period. In the Lavaca-Colorado Estuary and the Nueces Estuary, benthic abundance was higher in the primary bay than the secondary bay. In the Guadalupe Estuary, benthic abundance was higher in the secondary bay (Figure 1).

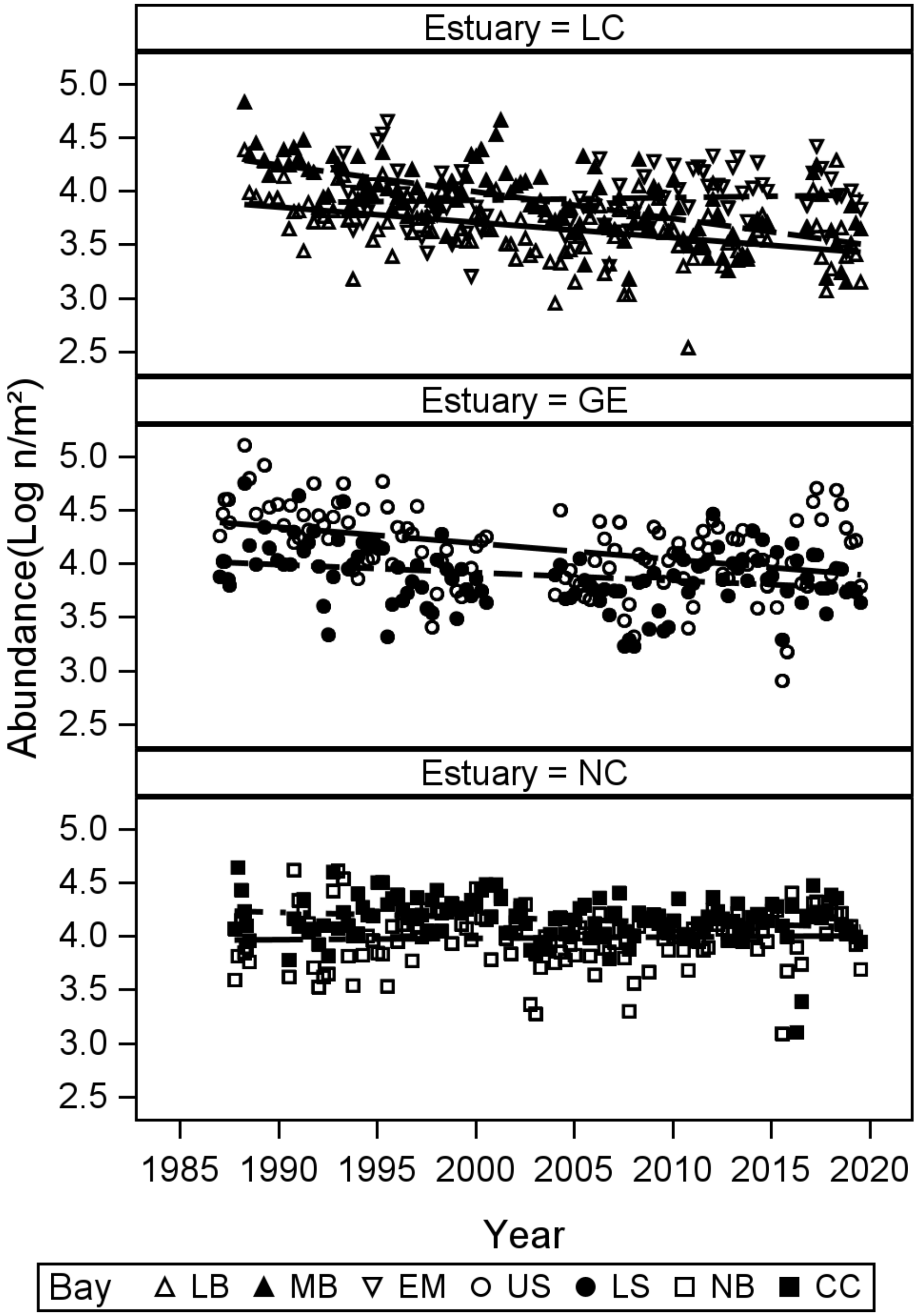

Figure 1. Average quarterly (January, April, July, and October) log10 transformed benthic infauna abundance by bay within estuary. A) Lavaca-Colorado Estuary (LC) includes Lavaca Bay (LB, open triangles), Matagorda Bay (MB, closed triangles), and East Matagorda Bay (EM, open upside-down triangles). B) Guadalupe Estuary (GE) includes Upper San Antonio Bay (US, open circles) and Lower San Antonio Bay (LS filled circles). C) Nueces Estuary (NC) includes Nueces Bay (NB, open squares) and Corpus Christi Bay (CC, filled squares).

Benthic infauna biomass declined in both bays of the Lavaca-Colorado Estuary. Biomass was higher in the primary bay. In the Guadalupe Estuary, biomass increased in the primary bay and decreased in the secondary bay. There was no significant trend over time for biomass in either Nueces or Corpus Christi Bays.

Infauna diversity in the Lavaca-Colorado Estuary and Guadalupe Estuary declined over the 22-year study period and increased in the Nueces Estuary (Fig. 2). Primary bays had higher diversity than secondary bays for all estuaries.

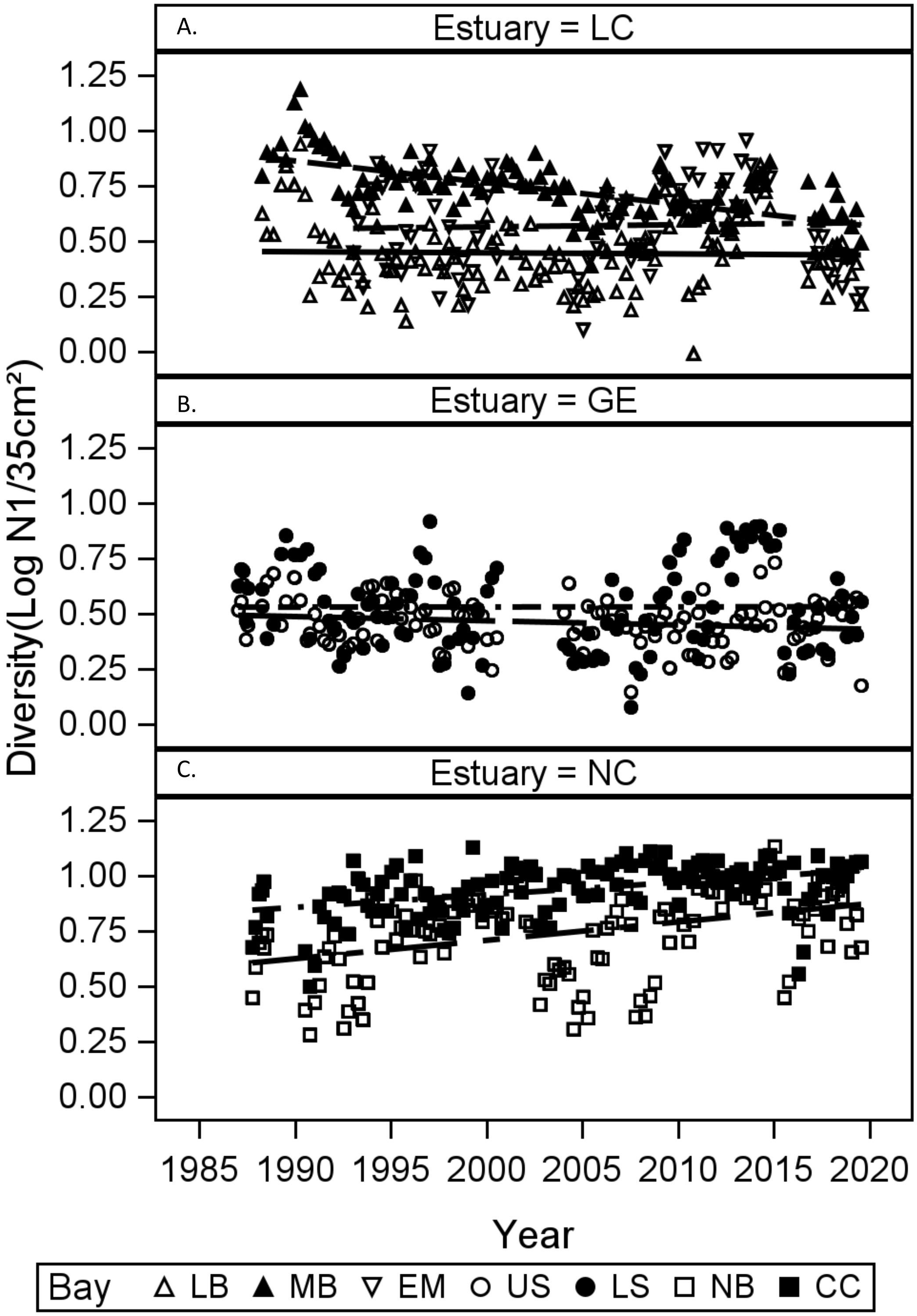

Figure 2. Average quarterly (January, April, July, and October) log10 transformed benthic infauna Hill's N1 diversity by bay from 1987-2018. Abbreviations and symbols defined in Figure 12. A) Lavaca-Colorado Estuary. B) Guadalupe Estuary. C) Nueces Estuary.

The water column variables that match benthic community structure in the bays were salinity, temperature, dissolved oxygen, NH4, and PO4 between bays (R = 0.905, P-Value = 0.001). The highest correlation to a single variable was to PO4 (R = 0.710, P-value = 0.001). Three bays (Matagorda, Corpus Christi and Nueces Bays) had the highest salinities, and three bays (Lavaca, and upper and lower San Antonio Bays) had the lowest salinities. East Matagorda had the highest nitrogen to phosphorous (N:P) ratios and chlorophyll-a measurements. The spatial patterns of the bays for the macrofauna community structure and water quality were not different (Fig. 3). The largest difference in the spatial patterns was the location of eastern Matagorda Bay, which separates from San Antonio Bay based on very high chlorophyll-a values.

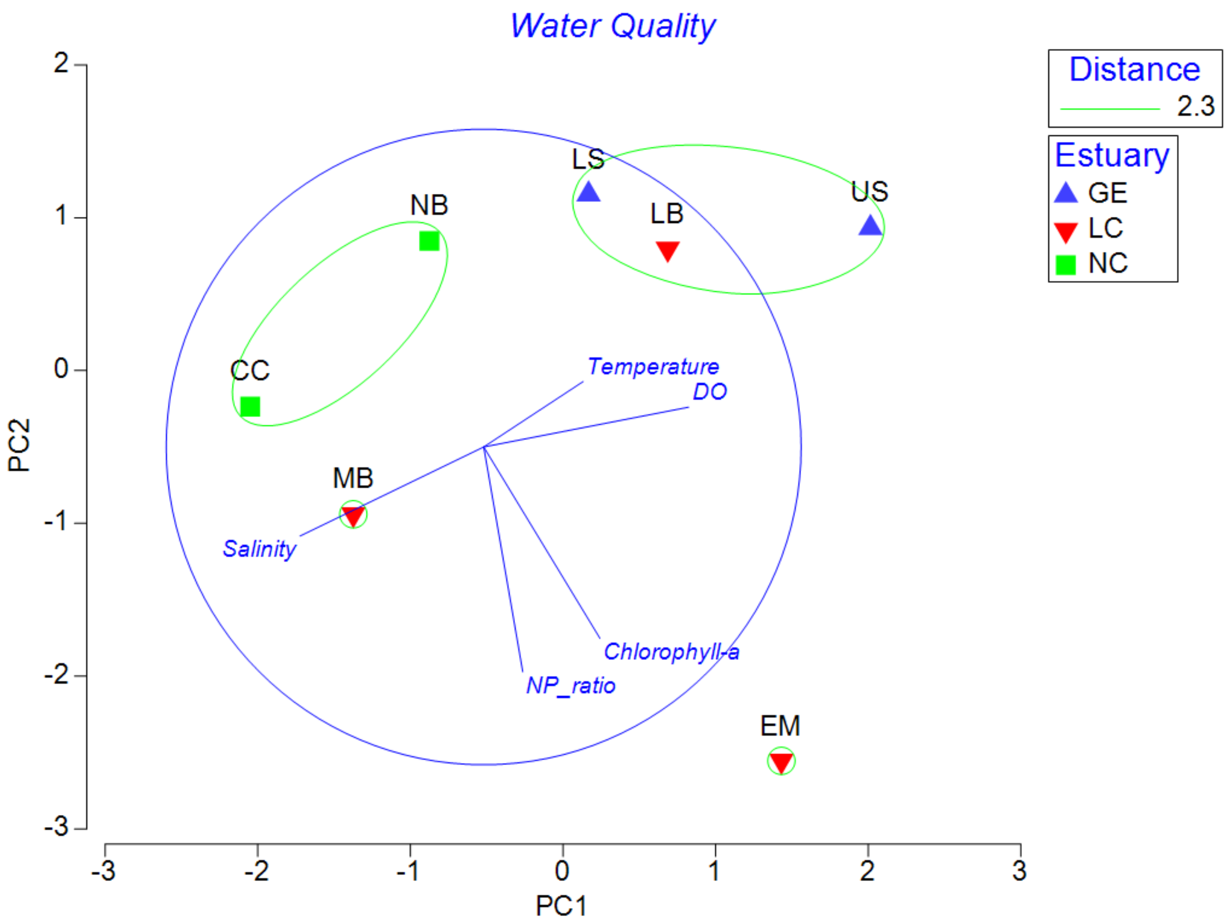

Figure 3. Principal Components Analysis (PC) of water quality variables and non-metric multidimensional scaling (nMDS) of the benthic macrofauna community by estuary and bay with cluster analysis of the benthos overlaid. Each symbol on the nMDS is representative of an estuary.

Formosa Discharge Data

Community structure was analyzed using non-metric multidimensional scaling (nMDS). The nMDS figures demonstrate the community structure of all biological groups were influenced by distance from discharge (Fig. 4).

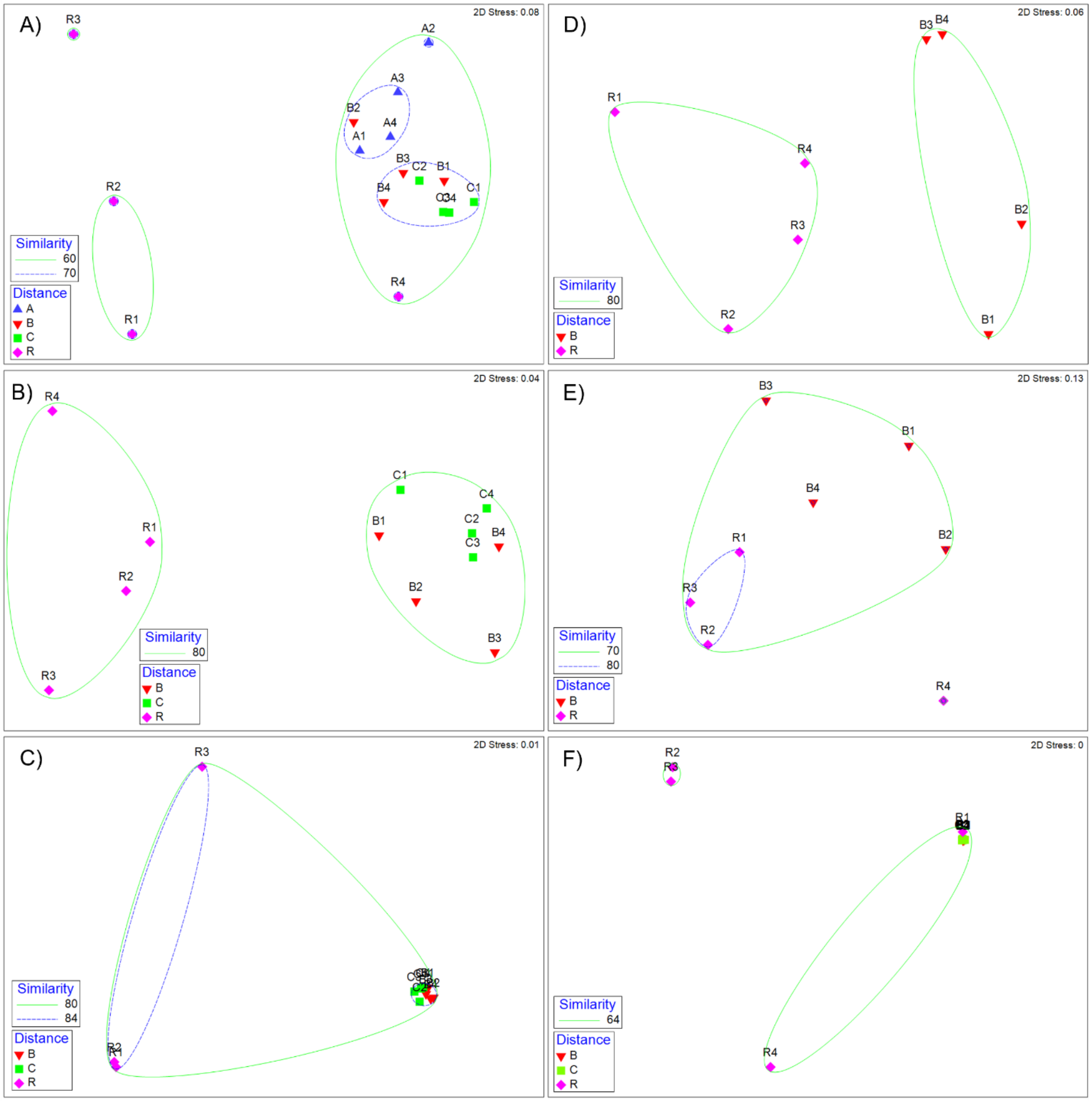

Figure 4. Multivariate analysis of community structure for taxa based on average abundance over time. A) Benthos from cores. B) Nekton from trawls. C) Nekton from gill nets. D) Phytoplankton from pumped water. E) Zooplankton from tows. F) Ichthyoplankton from tows.

Comparison of Formosa, HRI, and TPWD Data

There were differences between the magnitude of measurements between the HRI and Freese & Nichols, Inc. (FNI) studies (Fig. 5). The abundance and richness measurements were compared for the same sample periods, and it would be expected that the data would yield similar results, but they did not. This is explained by differences in the collection and analysis methods. HRI benthic samples were collected with a 35 cm^2 core and sorted using a 0.5 mm mesh. FNI collected benthic samples with a 232 cm^2 Eckman dredge and sorted using a 1 mm mesh. Even though FNI's sample is 6.6 times larger than HRI's sample in square area, HRI calculates their abundances are 6.25 times greater than FNI's abundance measurements. HRI's diversity measurements are approximately 0.25 % lower than FNI's diversity measurements. HRI's benthic abundances tend to plot from 0 to 5,000 nm^2 and FNI's benthos generally plot 2,000 nm^2 or less. HRI benthos data indicates high abundances but lower species richness. FNI benthic data indicates lower species abundance but higher species richness. Benthos abundance and diversity trends were seen differently between both studies. Difference in sampling methods can account for abundance and diversity differences seen between both studies.

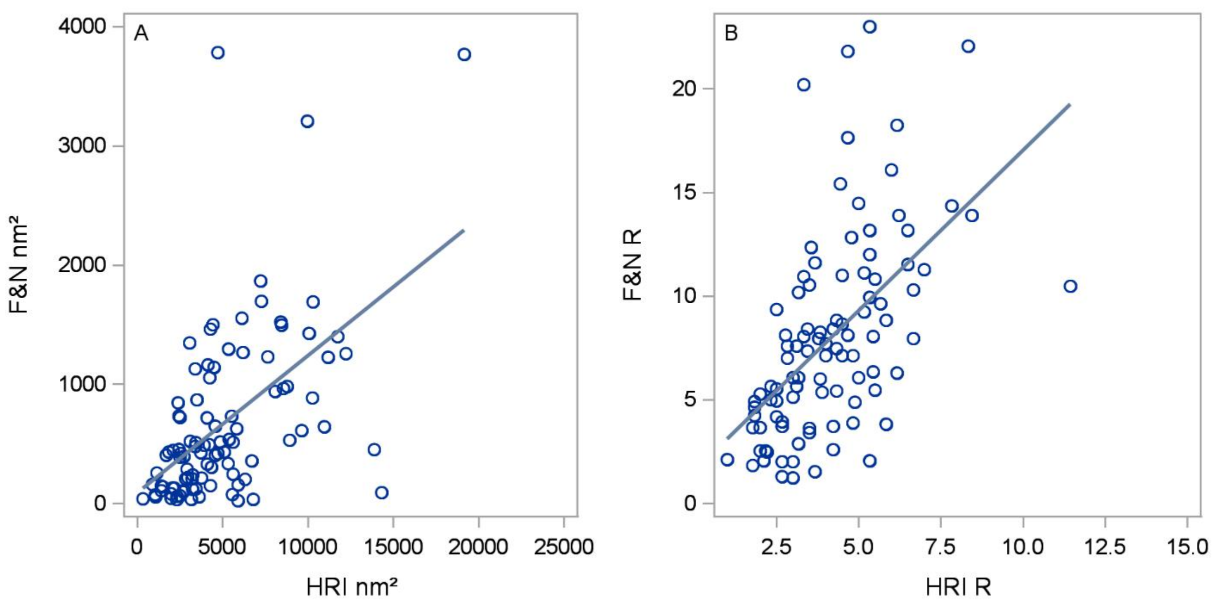

Figure 5. Benthos abundances (nm^2) and richness for both HRI and FNI by quarter.

The Texas Parks and Wildlife Department (TPWD) collects gillnet and trawl samples monthly but using a random sampling design for stations in both upper and lower Lavaca Bay. The data that was collected during the same time frame as the FNI data was compared for sample differences between the TPWD and FNI studies.

Gillnet abundance values remain relatively similar in both studies, but TPWD indicates high abundance events that exceed FNI abundances. TPWD richness exceeds FNI richness (Fig. 6).

Differences found between TPWD and FNI gillnet data indicates the possibility of collection method differences. FNI collected gillnet samples quarterly with a 150-foot by 8-foot gill net while TPWD gillnet collections occurred only in spring and fall with samples collected for 10 weeks per spring and fall. TPWD used three to five nets with different mesh sizes (Martinez-Andrade et al., 2005). TPWD collected on a much larger time scale than FNI and best explains gillnet abundance and richness differences between both studies.

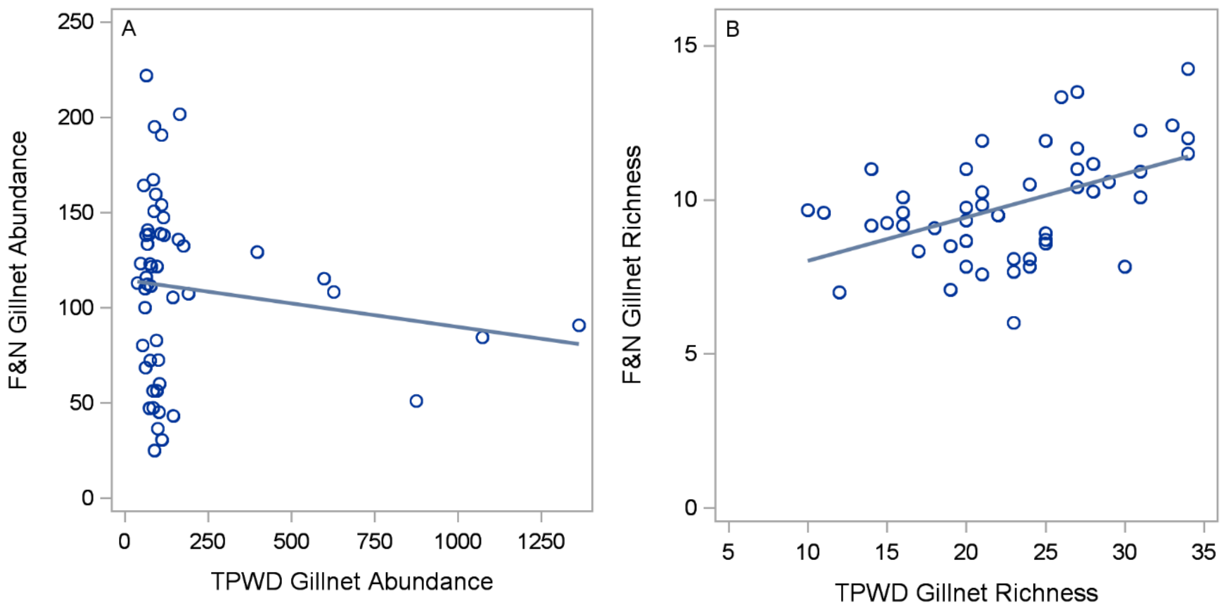

Figure 6. Gillnet abundances and richness for both TPWD and FNI.

The TPWD trawl data indicates lower abundances than to FNI abundance trends but higher richness trends for TPWD than FNI (Fig. 7). The ANOVA comparing TPWD trawl and gillnet trends to FNI trawl and gillnet indicates no difference between trawl and gillnet abundances and significant differences between both studies for trawl and gillnet richness. Richness differences can be accounted for because of collection time and space differences

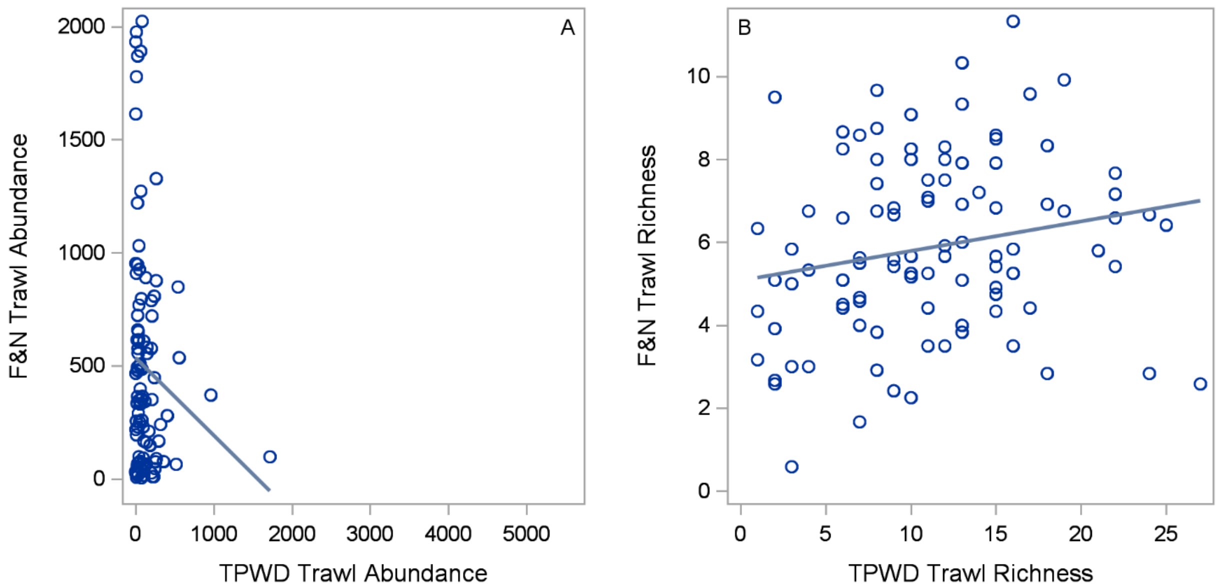

Figure 7. Trawl abundances and richness for both TPWD and FNI.

Discussion

HRI Long-term Benthic Data

Benthic community structure in the Texas bays of the Coastal Bend is linked to salinity. There is extreme dominance in Texas estuaries, and two polychaete species, *Mediomastus ambiseta* and *Streblospio benedicti* represent 48% of all individuals found. Both species are freshwater inflow indicators because they are more abundant in the secondary bays than primary bays, and their distribution follows salinity distributions. For example, where the long-term average salinities for bays are similar, the abundance of these two species are similar. The third dominant species at 6.4% of total is the bivalve *Mulinia lateralis* but it is particularly dominant in upper San Antonio Bay, but less dominant in the other low salinity bays. However, the response to Hurricane Harvey indicates *Mulinia* recruitment is very dependent on the large salinity changes brought by large floods. The fifth dominant species at 3.8% of total is the gastropod *Texadina sphinctostoma*. While *Texadina* occurs primarily in upper San Antonio Bay, it is not a generic inflow indicator because it does not occur in East Matagorda Bay nor Nueces Bay and it appears to be a species mostly found in San Antonio Bay. The only infaunal crustacean that is an inflow indicator is the amphipod *Ampelisca abdita*, which made up 1.2% of total organisms, and occurs primarily in the secondary bays. There are also marine indicators. The polychaete *Dipolydora caulleryi* is the fourth dominant species at 4.6% of all species and is found primarily in the primary bays. The predatory worm Nemertea at 1.6% is also found in primary bays. The tenth dominant species at 1.5% is the polychaete *Cossura delta* and is found primarily in primary bays.

We have learned that salinity is an important driver of estuarine benthic community structure. This is especially true within estuaries along the salinity gradient, and among estuaries along the coastal climatic gradient. However, we have also learned that climate variability is an important driver of salinity in Texas estuaries (Kim et al. 2014, Pollack et al. 2011, Tolan 2007).

Formosa Data

The contaminant chemistry collected around the Formosa discharge was nearly all below methods detection limits. All organic contaminant groups (i.e., PAH, PCB, pesticide, volatile, and semi-volatile) were > 99% of samples non-detected. There was more data for metals with ~62% of all metal samples non-detected. However, only sediment metals were detected in > 75% of samples and are used in further analysis. Physical-chemical groups had higher percentages of detected concentrations compared to the contaminant groups. Conventional, physical, and sediment groups had > 94% detected samples and inorganic, organic and oxygen demand had < 66% of samples detected. However, nitrogen nutrients were below the detection limits. Table S5 displays all sample variables with associated detected and non-detected counts.

All sediment metals, including aluminum (Al), copper (Cu), lead (Pb), Hg, and zinc (Zn), decreased over time along with silt and clay (=mud) content while sand content increased. Mercury concentrations began at ~0.06 mg/kg in 1993, increased to the largest concentration documented for mercury at ~0.65 mg/kg in 1994, and then gradually declined in concentration overtime until a spike of 0.58 mg/kg in 2015. The Hg concentrations dropped back down in 2016 and remained low into 2020.

There was a consistent linear trend for water quality measures over time indicating freshwater inflow has decreased. Salinity and chemical oxygen demand (COD) increased over time. Dissolved organic nitrogen (DON), total organic carbon (TOC), and turbidity decreased over time. That salinity increased and turbidity and solutes decreased is expected because inflows that dilute seawater and deliver nutrients and sediments from the watershed had decreased. Temperature, pH, and DO did not change over the 27-year period.

There were differences among sampling trips for all biological trophic levels (Table 3). The temporal trends indicate phytoplankton and zooplankton abundance and diversity, and gill net diversity increases, trawl abundance and diversity decreases, and benthic abundance and diversity, ichthyoplankton abundance and diversity, and gill net abundance remain constant. The community structure of all biological groups were influenced by distance from discharge.

There were differences among sampling trips for all biological trophic levels. The temporal trends indicate phytoplankton and zooplankton abundance and diversity, and gill net diversity increases, trawl abundance and diversity decreases, and benthic abundance and diversity, ichthyoplankton abundance and diversity, and gill net abundance remain constant

Conclusion

Analyses of data revealed four key findings: 1) Temporal variability driven by climate, inflow, and season is considerably more important than spatial variability with respect to distance from the discharge in explaining variability of the hydrographical and biological data, but not the sediment data. 2) All stations exhibited similar trends over time for all measured parameters except for sediments. 3) All biological groups exhibited different community structure in reference sites than in the discharge sites. 4) Some methods were inadequate to measure potential contaminant and water quality concentrations in the discharge and ambient waters and sediments. 5) There was no specific chemical marker for discharge effects.

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Appendix I: Published Study Reports and Accomplishments

Task 1): Completed: A total of 465 benthic samples over the project period. Completed database creation. The data will be available on the GRIIDC website: https://gulfresearchinitiative.org/

Task 2): Complete. Analyses reported in:

Harris, E.K. 2022. Influence of Discharge on Long-Term Dynamics of Abiotic and Biotic Resources in Lavaca Bay, Texas. Masters Thesis, Environmental Science Program, Department of Physical and Environmental Science, Texas A&M University-Corpus Christi, Corpus Christi, Texas, available at https://www.proquest.com/docview/2681444847

Task 3): Complete. Analyses reported in three documents:

Harris, E.K. 2022. Influence of Discharge on Long-Term Dynamics of Abiotic and Biotic Resources in Lavaca Bay, Texas. Masters Thesis, Environmental Science Program, Department of Physical and Environmental Science, Texas A&M University-Corpus Christi, Corpus Christi, Texas, available at https://www.proquest.com/docview/2681444847

Montagna, P.A. 2022. Long-Term Benthic Data: Adaptive Management of Three Basins. Final Report to the Texas Water Development Board, Contract # 2000012436. Texas A&M University-Corpus Christi, Corpus Christi, Texas, 73 pp. https://tamucc-ir.tdl.org/handle/1969.6/93830

Harris, E.K., P.A. Montagna, A.R. Douglas, L. Vitale, and D. Buzan. 2023. Influence of an industrial discharge on long-term dynamics of abiotic and biotic resources in Lavaca Bay, Texas, USA. *Environmental Monitoring and Assessment* 195:40 https://doi.org/10.1007/s10661-022-10665-w

The data has been submitted to an archive and can be referenced as follows:

Montagna, P.A., E. Harris, A. Douglas, L. Vitale, D. Buzan. 2022. Formosa Plastics Discharge Monitoring in Lavaca Bay, Texas, USA. Distributed by: Gulf of Mexico Research Initiative Information and Data Cooperative (GRIIDC), Harte Research Institute, Texas A&M University–Corpus Christi. https://doi.org/10.7266/DCNHQD59

Task 4): Complete: All quarterly reports were submitted on June, September, and December 2021, and March, June, and September 2022. Final report was submitted December 2022.

Performed seven presentations related to the project:

Montagna, P.A. "Importance of Environmental Flows in Water Resource Planning," French American Innovation Day 2021, Houston, Texas, Virtual Conference,15 September 2021.

Montagna, P.A. “Focused Flows to Protect Natural Nurseries,” Texas Water Development Board, Virtual Brown Bag Seminar, 24 September 2021

Montagna, P.A. “A Brief History of Freshwater Inflow Policies and Studies,” Texas Water Development Board, Estuary Science Exchange Webinar, 14 October 2021. https://www.twdb.texas.gov/surfacewater/bays/estuary_science/index.asp

Montagna, P.A., Gibeaut, J., Douglas, A. “Evaluation of the Proposal for Widening and Deepening the Matagorda Ship Channel,” Lavaca Bay Foundation, Port Lavaca, TX, 21 October 2021.

Montagna, P.A. Long-Term Benthic Data in Three Basins Can be Used for Adaptive Management of Inflow Standards. Jointly hosted by the Harte Research Institute and Texas Water Development Board, Corpus Christi, TX (virtual), 27 May 2022, 74 participants.

Montagna, P.A., E.K. Harris, A. Douglas, L. Vitale, D. Buzan. Influence Of the Formosa Discharge on Long-Term Dynamics Of Abiotic And Biotic Resources In Lavaca Bay, Texas. Lavaca Bay Foundation, Port Lavaca, Texas, 16 June 2022, 25 participants.

Montagna, P.A. Freshwater Inflow and Bay Health. Environmental Issues Forum, Calhoun County Democratic Club, VFW Hall, Port Lavaca, Texas, August 20, 2022, 40 participants. https://www.youtube.com/watch?v=AQjjLWKwwy0