Contract No:
23-020-019-E048
Integrative Assessment of Bacterial Pollution

Final report

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By

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Executive Summary

The General Land Office (GLO) contracted with Texas A&M AgriLife to conduct the analysis titled "Integrative Assessment of Bacterial Pollution", Contract No: 23-020-019-E048. Texas A&M AgriLife used these CMP Cycle 27 funds to identify hotspots and potential drivers of coastal fecal bacterial pollution. This increased resolution as well as new data linking bacterial pollution with on-site sewage facilities (OSSF), sanitary sewer overflows (SSO), stormwater runoff, wastewater treatment plant (WWTP) effluent, and beach attendance is expected to inform retrofit planning. This final report provides a detailed summary of various tasks (T) completed, and deliverables (D) submitted to GLO related to water quality dataset cleaning and analysis, and Enterococci Data and Human-Specific Fecal Pollution Analysis for Nueces County, Texas. Main output from each task was summarized in an Infographic which is included in the Appendix-A. Dataset and source files data analyses, along with all deliverables were submitted electronically to the GLO during the project and with this final report.

Texas Beach Watch Enterococci Data dataset had records from January 2009 to March 2023. Anomalies, duplicate samples, and "field duplicates" (Required for quality assurance) were flagged and edited, resulting in the creation of a new database (**TBW Hx data 2009-2023 Nueces Co. Results.XLSX**), which included a total of 33,805 records. Summary statistics were calculated, including maximum, minimum, average, median, geometric mean, and percentage of exceedance (104 MPN/100mL). Time Analysis showed that stations did not have very similar patterns, except for a tendency to have higher values either in the late spring, the early summer, or the fall. Space-Time Analysis showed that sampling stations in close geographic proximity shared trends and characteristics. Beaches and sampling stations were ranked based on the Enterococci exceedance percentage.: High (> 10%), Medium (5 – 10%), and Low (< 5%). All stations and beaches on the bay side were High or Medium (particularly high from Laguna Shores and JFK Causeway until Corpus Christi Marina), while all stations and beaches facing the ocean were Medium or Low (all beaches are Low.

Environmental metadata were collected from various sources, including TexMesonet, GCOOS, and NOAA and analyzed (three stations for rainfall and five stations for sea level). Analysis indicated that correlation between rainfall and Enterococci was slightly higher compared to correlation between water sea level and Enterococci. Coefficients were low, indicating that there might be other drivers.

A micro-watershed map of Nueces County was created using LIDAR data to identify potential sources of pollution (OSSFs, stormwater and WWTP outfalls, sewer infrastructure, and leaks/spills in sewage systems). Analysis showed that most OSSF are mostly located inside micro-watersheds that drain toward the bay. Little evidence suggests that OSSFs or flow violations have impact on Enterococci sampling results; OSSFs are located near areas with high counts but are very limited in number, and flow violations are very few and the percentage exceeding the limit was low. Correlation between Violation of Enterococci from WWTPs and GLO Enterococci was weak but somewhat positive in most cases, with the highest violations percentages often corresponding to the highest Enterococci counts. Sewer incidents from the SSO database appear to be located mostly nearby the GLO sampling station that fall in the

“High” category for yearly average exceedance; correlation appears weak, but there are several sources of uncertainty on this analysis, including location and timing of discharge.

Direct and indirect estimates of recreational beach attendance on Nueces County were determined using foot traffic data from various sources. Direct estimates obtained with field visits helped identify trends both spatially and in time. Indirect estimates, including Hotel Occupancy Tax (HOT), confirmed consistent peaks in March, June, and July, and higher values in the northern and southern portions of Mustang Island and in the northern portion of Corpus Christi Bay. Statistical Clustering and Space-Time Pattern Analyses showed “high” clusters along 358 in Corpus Christi and Industrial Canal, and “low” clusters in Mustang Island. Correlation analyses (Kendall coefficient) between monthly HOT (all structures) and monthly Enterococci geomean for the year 2023, stations by station, indicated good correlation in some of the stations along Mustang Island, but no correlation along the Corpus Christi Bay; more private homes/university playing maybe a role on this. Space-time patterns appear various depending on the areas observed, and spatial regression identifies a good overall fit for the study area.

Microbial Source Tracking (MST) analysis was conducted for selected water samples collected from Corpus Christi. A total of 41 samples exceeded the enterococci recreational water quality limit (104 MPN/100 mL) were collected in the period of October 2024 - April 2025. Additionally, samples from Oso Creek along the outfalls of a subdivision—which connects downstream into Oso Bay which feeds into Corpus Christi Bay—showed levels of Enterococci above the recreational water quality limit as well. In the same subdivision, 25 stormwater samples were collected from one of the stormwater outfalls during 4 storm events; the samples showed *E. coli* and Enterococci above the recreational water quality standard. The samples were analyzed using qPCR markers and DNA sequencing-based source tracking for human, dog, and seagull sources. In beach watch samples, Gull was the most common and most abundant source detected for both the marker and DNA sequencing method, while the human and dog sources were low for both detection methods. For the creek samples, a similar result was observed with gull being a main contributor of fecal contamination with both the marker and DNA-sequencing method, human fecal sources were found at generally low levels for both detection methods, and the dog marker was shown at a lower frequency and was found as a contributor for some samples with DNA-sequencing. The stormwater runoff samples showed human sources (septic and wastewater treatment plant) as the most prominent contributor of fecal pollution for the sequencing method in comparison to dog and gull, whereas the dog marker was the highest among the 3 sources. Statistical relationship of the source-specific molecular marker abundance and the environmental metadata showed some significant correlation. Dog markers showed most correlation with rainfall data, gull markers with water level data, while human markers did not show any significant correlation with environmental data.

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Introduction

The General Land Office (GLO) contracted with Texas A&M AgriLife to conduct the analysis titled "Integrative Assessment of Bacterial Pollution", Contract No: 23-020-019-E048. This final report summarizes the data and findings in written narrative, graphs, charts, and tables from the project. Copy of data and source files for all analyses are submitted electronically to the GLO Project Manager. The report provides a detailed account of various tasks related to water quality dataset cleaning and analysis for Nueces County, Texas. Each task focuses on specific aspects of the analysis. Texas A&M AgriLife conducted a similar analysis for Galveston Island, Texas, using CMP Cycle 25 funds (Contract No:21-060-025-D274).

Studies have shown that fecal pollution is associated with a decrease in the resilience and diversity of marine coastal systems. A meta-analysis of 216 studies clearly demonstrated that anthropogenic contamination, including sewage contamination, reduces diversity and resilience in coastal marine systems (Johnston and Roberts, 2009). Threats to diversity and resilience disrupt ecosystem services and endanger the sustainability of marine and socioeconomic systems (Levin and Lubchenco, 2008). For example, the presence of human pathogens associated with sewage contamination can negatively impact recreational bathing and shellfish hygiene (Malham et al., 2014).

A long-term analysis of Texas Beach Watch (TBW) bacterial data by Texas A&M University-Corpus Christi (TAMU-CC) revealed that 25 Texas beaches are hotspots of bacterial pollution. Results also revealed that bacterial pollution is increasing with time, population growth, and sea level rise. Texas A&M AgriLife used these CMP Cycle 27 funds to identify hotspots and potential drivers of coastal fecal bacterial pollution. Data were re-analyzed to pinpoint individual sampling stations that exhibit a history of bacterial pollution. Potential drivers of coastal bacterial pollution were evaluated by assessing 1) the density and integrity of On-Site Sewage Facilities (OSSF), 2) the occurrence of leaks, spills, and sanitary sewer overflows (SSO), 3) the potential connectivity between wastewater infrastructure and surface water pollution, 4) the inflow of stormwater runoff and Wastewater Treatment Plant (WWTP) effluent, and 5) changes in recreational beach attendance. Additionally, the presence of human, canine, and gull fecal waste was confirmed by collecting water samples and testing for the abundance of host-specific molecular markers of fecal pollution.

This increased resolution as well as new data linking bacterial pollution with OSSF, SSO, stormwater runoff, WWTP effluent, and beach attendance is expected to inform retrofit planning. Data derived from this project will inform retrofit planning, primarily through engagement with the local jurisdiction, with a goal of improving coastal water quality, which is essential to the sustainability of coastal ecosystems and coastal economies.

Task 1: Analyze Texas Beach Watch Enterococci Data

<u>Data Cleaning:</u>

- This Task begins with an explanation of the data cleaning process for the two *Enterococci* datasets provided by GLO's Texas Beach Watch (TWB) (**TBW Hx data 2009-Mar 2023.XLSX** and **TBW 2023 Nueces Co Results.XLSX**), which includes stations in Nueces County.
- This first dataset included 116,854 records, from 01/05/2009 to 03/30/2023, and refers to all counties from the entire Texas coastal zone (dataset already cleaned resulting from a previous project phase), while the second included 2,012 records and refers only to the Nueces County most recent data.
- Both of these databases were merged to form a single datasets which contained a total of 33,805 records, from 01/05/2009 to 12/20/2023
- Anomalies, duplicate samples, and "field duplicates" were flagged and addressed during cleaning. As a result of cleaning the Enterococci dataset, a total of 8 records were deleted, 7,450 records were corrected for the Enterococci result, and 18 records were corrected for the analysis method. Identified flags include:
    - Anomalies: Enterococci result = 0 or under the limit of detection; change of analysis method; or assignment to the wrong analysis method.
    - Duplicate samples: Sample results entered in the database by mistake.
    - Field duplicates: Required for quality assurance sample taken on the same day at the same station with the same event tag.
- The cleaning process resulted in the creation of a new, cleaned database (**TBW Hx data 2009-2023 Nueces Co. Results.XLSX**). An additional column was created to identify records' unique IDs (Figure 1).

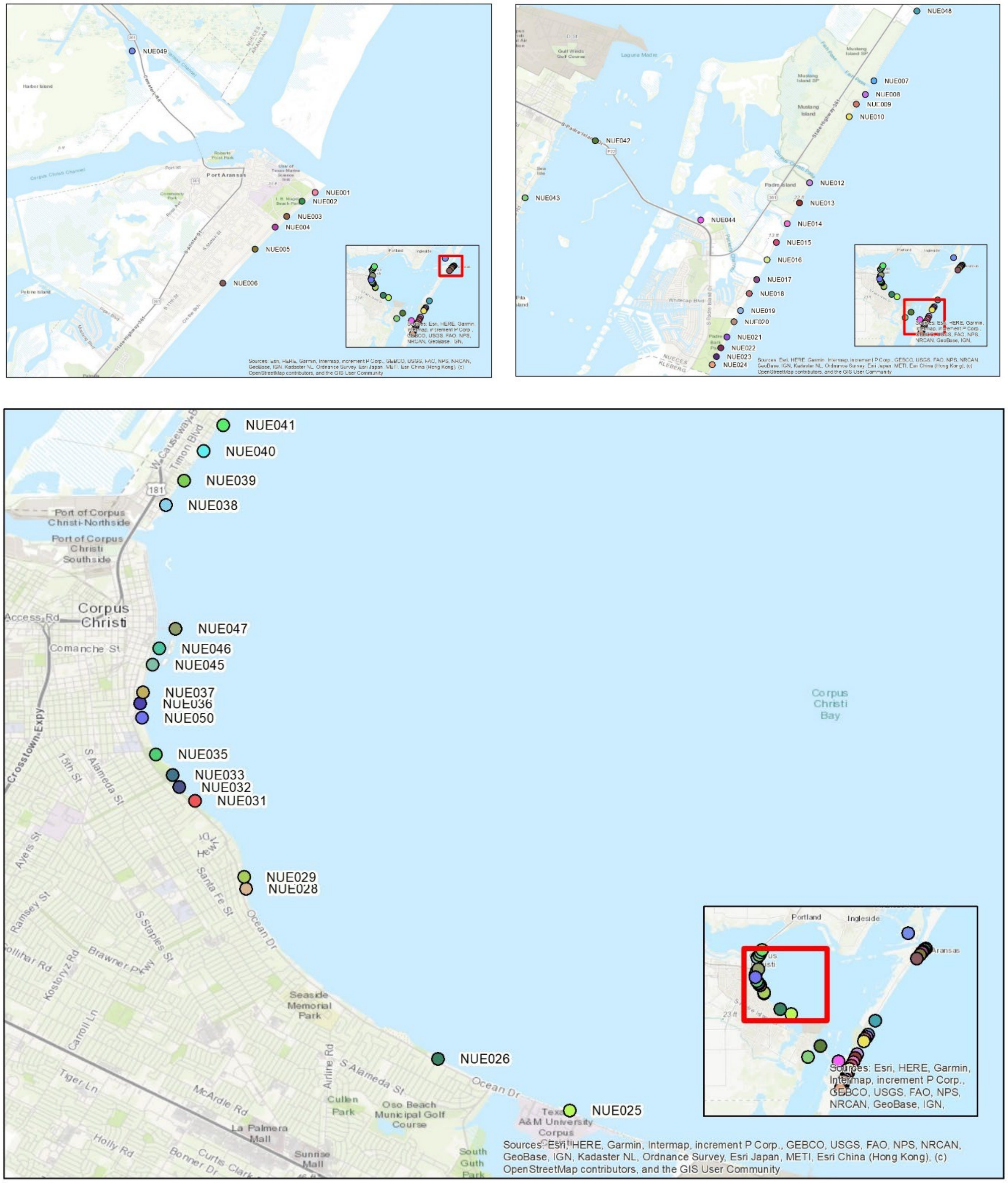


Figure 1. Location map showing Stations in the project area.

Summary Statistics:

- This Task outlines the generation of summary statistics for the cleaned Enterococci dataset (maximum, minimum, average, median, geometric mean, and percentage of exceedance).
- For each summary statistic, we created a universal key to identify stations and beaches to simplify the look of tables and figures (Table 1).
- Trends and changes over time and space were explored, revealing correlations between specific stations and seasonal variations.
- Exceedance is known in this context as the percentage of *Enterococci* above the coastal water quality standard of 104 MPN/100mL, established by the Beaches Environmental Assessment and Coastal Health (BEACH) Act with the goal of protecting human health.
- Peaks in maximum values were found in Ropes Park (#28 and #29), Cole Park (Stations #30 - #35) and Poenisch Park. Average values had a similar behavior, though TAMUCC-University Beach had a higher average as compared to the median value. This trend for median values was shared quite closely also by geomean and exceedance values. Minimum values were for all stations 5 MPN/100ml. Based on these results, and the typical assessment conducted on this type of data (Enterococci), it was decided to perform most of the analysis for this project using geomean and exceedance values (Figure 2).
- The analysis of time and space patterns in the project area showed that sampling stations in close geographic proximity shared trends and characteristics. Yearly Kendall correlation coefficients were calculated for each station or beach. A slight positive correlation was found in most cases. When combining all stations together, both yearly GeoMean and yearly average exceedance confirm a slight positive correlation with time, with peaks in the years 2020 and 2021 (Figure 3). Auto-Regressive Integrated Moving Average (ARIMA) models are models that base their analysis on the previously observed time series data and, depending on the seasonal patterns, can create accurate forecasts. In this project, the model was used to identify seasonal trends based on monthly GeoMean values from the entire dataset (2009-2023). The model showed that stations did not have very similar patterns, except for a tendency to have higher values either in the late spring, the early summer, or the fall (Figure 4).
- The Inverse Distance Weighting tool (IDW) was completed similarly to what was done in previous studies analyzing Beach Watch data for the coastal zone of Texas, i.e., comparing side to side yearly maps. Values increase within the study period, with maximums observed in 2020 and 2021. The general spatial pattern is similar, but some stations have peaks in different years (Figure 5).

Table 1. Keys for each Station and Beach, and their relation

BEACH_NAME	BEACH_ID	Beach Simplified ID	BEACH_STATION_NAME	SITE_IDS	Site Simplified ID
Port Aransas Park	TX722300	1	Port Aransas #1	NUE001	1
			Port Aransas #2	NUE002	2
			Port Aransas #3	NUE003	3
			Port Aransas #4	NUE004	4
Port Aransas - South	TX315916	2	Port Aransas #5	NUE005	5
			Port Aransas #6	NUE006	6
Mustang Island State Park	TX551380	3	Mustang Island SP #1	NUE007	7
			Mustang Island SP #2	NUE008	8
			Mustang Island SP #3	NUE009	9
			Mustang Island SP #4	NUE010	10
			Mustang Island SP #6	NUE012	12
JP Luby Park	TX607336	4	J.P. Luby Park #1	NUE013	13
			J.P. Luby Park #2	NUE014	14
			J.P. Luby Park #3	NUE015	15
			J.P. Luby Park #4	NUE016	16
Padre Balli Park	TX314643	5	Bob Hall Pier/Seawall #1	NUE017	17
			Bob Hall Pier/Seawall #2	NUE018	18
			Bob Hall Pier/Seawall #3	NUE019	19
			Bob Hall Pier/Seawall #4	NUE020	20
			Bob Hall Pier/Seawall #5	NUE021	21
			Bob Hall Pier/Seawall #6	NUE022	22
			Bob Hall Pier/Seawall #7	NUE023	23
			Bob Hall Pier/Seawall #8	NUE024	24
TAMUCC - University Beach	TX149569	6	University Beach	NUE025	25
Poenisch Park	TX682648	7	Poenisch Park	NUE026	26
Ropes Park	TX821303	8	Ropes Park #2	NUE028	28
			Ropes Park #2*	NUE029	29
Cole Park	TX259473	9	Cole Park#2	NUE031	31
			Cole Park#3	NUE032	32
			Cole Park#4	NUE033	33
			Cole Park#6	NUE035	35
McGee Beach	TX536781	10	McGee Beach #1	NUE036	36
			McGee Beach #2	NUE037	37
North Beach	TX546628	11	North Beach - Coastal	NUE038	38
			North Beach - Breakers	NUE039	39
			North Beach - Gulfspray	NUE040	40
			North Beach - Gulden	NUE041	41

JFK Causeway - SW	TX442541	12	JFK-A	NUE042	42
Laguna Shores	TX937228	13	Laguna Shores	NUE043	43
Packery Channel Park	TX227625	14	Park Road 22	NUE044	44
Corpus Christi Marina	TX305317	15	Corpus Christi Marina - South	NUE045	45
			Corpus Christi Marina - Center	NUE046	46
			Corpus Christi Marina - North	NUE047	47
Mustang Island	TX396020	16	Mustang Island	NUE048	48
Lighthouse Lake	TX538780	17	Lighthouse Lake	NUE049	49
Emerald Beach	TX199413	18	Emerald Beach	NUE050	50

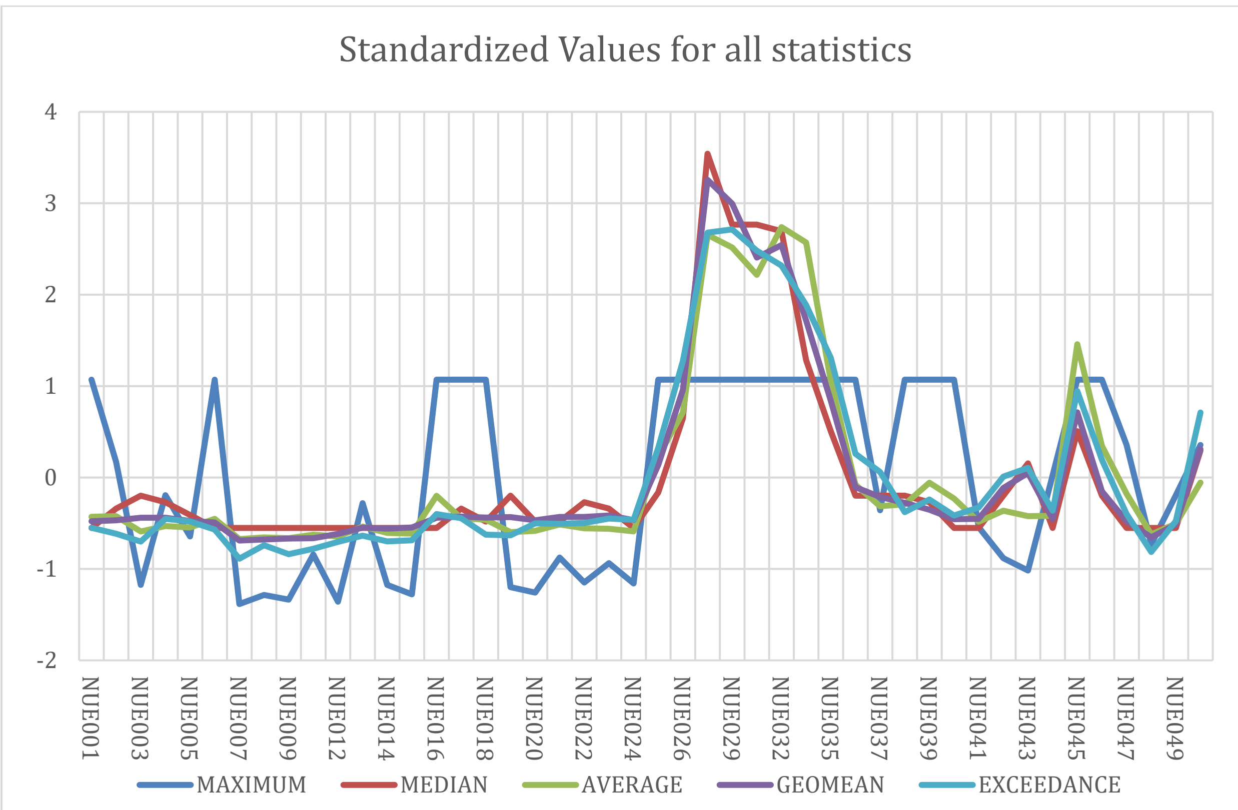


Figure 2. Standardized values for all statistics, so trends can be compared.

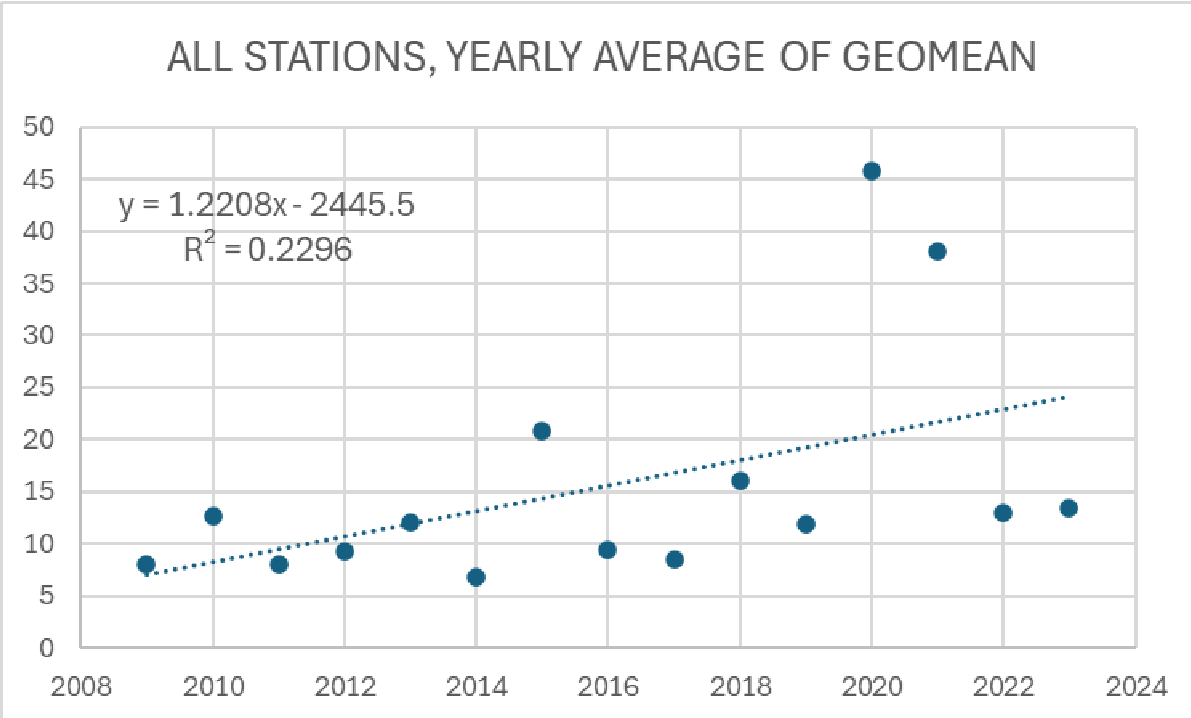


Figure 3. Yearly average exceedance for all stations combined, and linear regression interpolating lines.

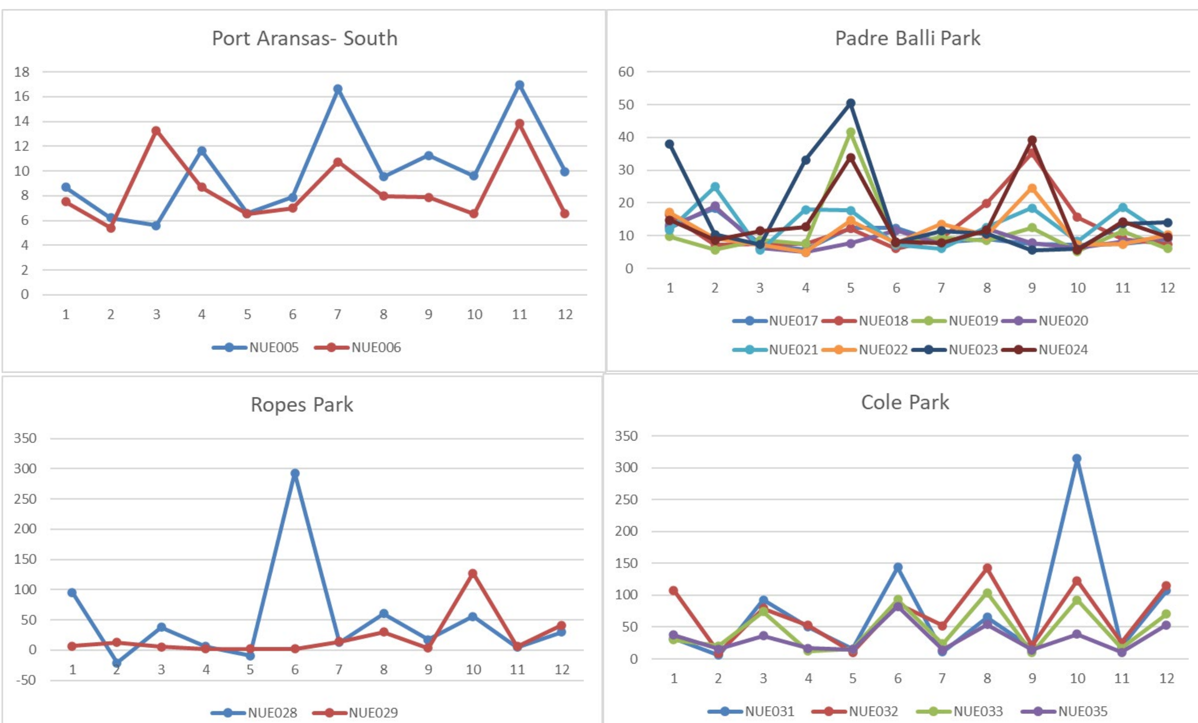


Figure 4. Seasonal trend estimate for Enterococci count in four example beaches, which show different behavior.

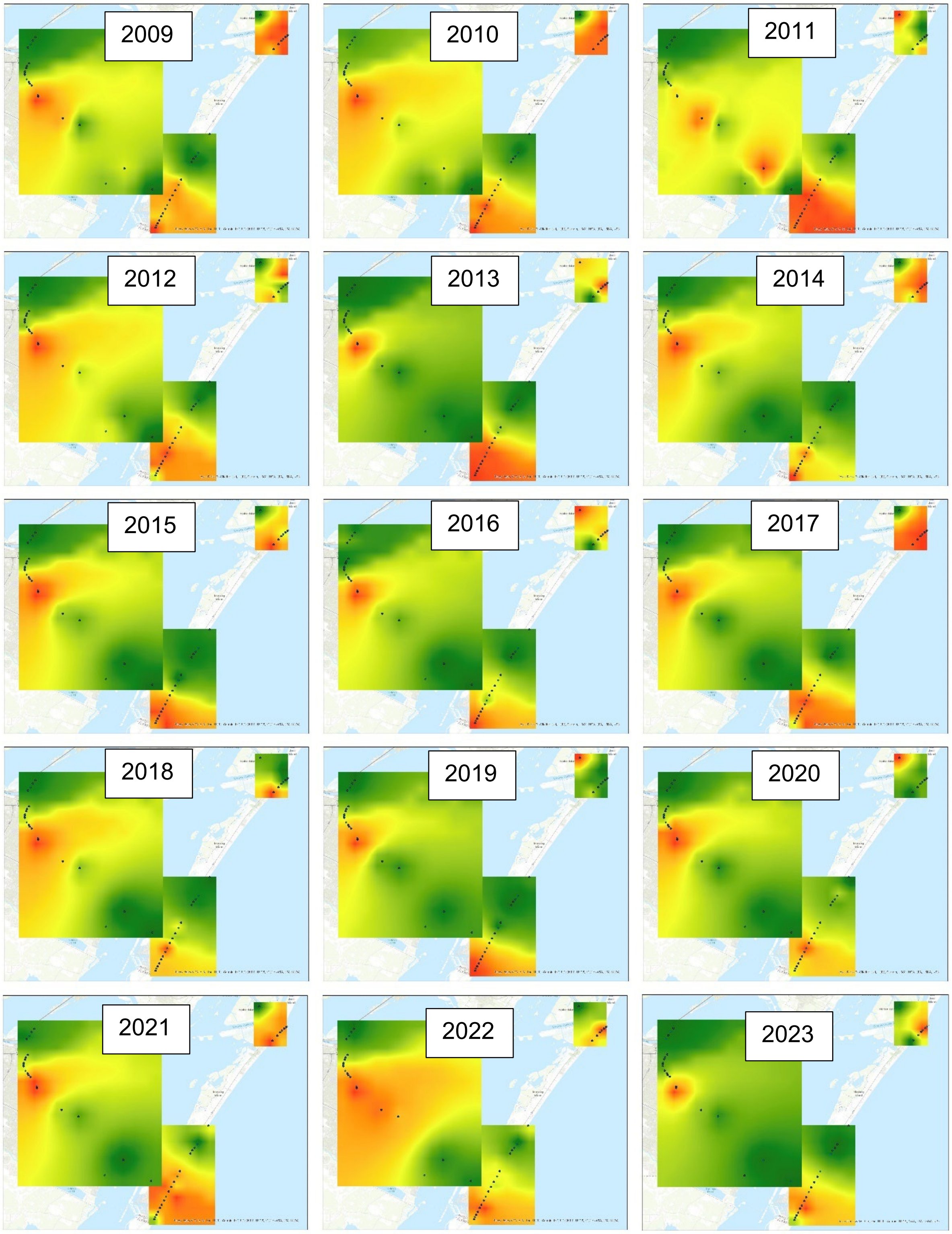


Figure 5. Inverse Distance Weighting tool (IDW) analysis on yearly GeoMean by station (range of values automatically calculated within each of three Zones, to show relative differences among nearby sampling stations).

Beach Ranking:

- The report details the process of ranking beaches and sampling stations based on bacterial pollution levels (exceedance percentage).
- Three categories were established: low (< 5%), medium (5 – 10%), and high (> 10%) based on previous studies.
- Both stations and beaches had similar percentages in the three categories. All stations and beaches on the bay side were High or Medium (particularly high from Laguna Shores and JFK Causeway until Corpus Christi Marina), while all stations and beaches facing the ocean were Medium or Low (all beaches are Low) (Table 2, Figures 6 and 7).

Table 2. Ranking of stations and beaches based on % Exceedance of water quality limit of 104MPN/100mL: Low (Green < 5%), Medium (Yellow 5-10%), High (Red > 10%)

ID		Exceedance %	
		Result>104	
Site	Beach	Site	Beach
NUE001	Port Aransas Park	4.47	4.16
NUE002		3.79	
NUE003		2.87	
NUE004		5.51	
NUE005	Port Aransas - South	5.23	4.75
NUE006		4.27	
NUE007	Mustang Island State Park	0.87	1.91
NUE008		2.44	
NUE009		1.40	
NUE010		2.02	
NUE012		2.82	
NUE013	JP Luby Park	3.55	3.88
NUE014		2.878	
NUE015		3.02	
NUE016		6.08	
NUE017	Padre Balli Park	5.59	4.84
NUE018		3.67	
NUE019		3.59	
NUE020		4.99	
NUE021		4.94	
NUE022		5.03	
NUE023		5.55	
NUE024		5.40	
NUE025	TAMUCC - University Beach	13.80	13.80
NUE026	Poenisch Park	23.93	23.93

NUE028	Ropes Park	38.90	39.09
NUE029		39.29	
NUE031	Cole Park	36.80	31.65
NUE032		35.06	
NUE033		30.45	
NUE035		24.31	
NUE036	McGee Beach	13.10	12.04
NUE037		10.97	
NUE038	North Beach	6.30	6.70
NUE039		7.77	
NUE040		5.92	
NUE041		6.84	
NUE042	JFK Causeway - SW	10.45	10.45
NUE043	Laguna Shores	11.46	11.46
NUE044	Packery Channel Park	6.47	6.47
NUE045	Corpus Christi Marina	20.43	12.97
NUE046		12.40	
NUE047		6.08	
NUE048	Mustang Island	1.66	1.66
NUE049	Lighthouse Lake	5.27	5.27
NUE050	Emerald Beach	17.93	17.93

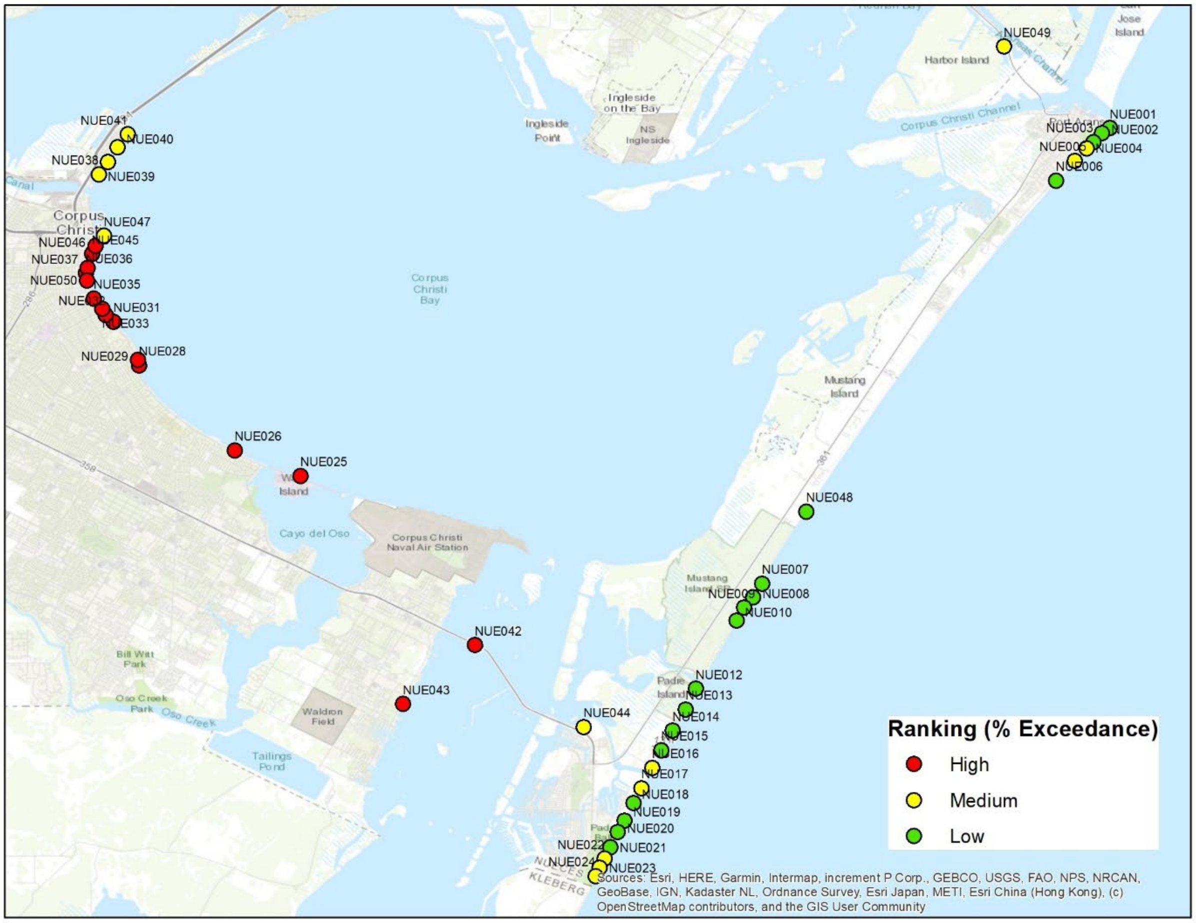


Figure 6. Ranking of stations based on Exceedance of water quality limit of 104 MPN/100mL: Low (Green < 5%), Medium (Yellow 5-10%), High (Red > 10%).

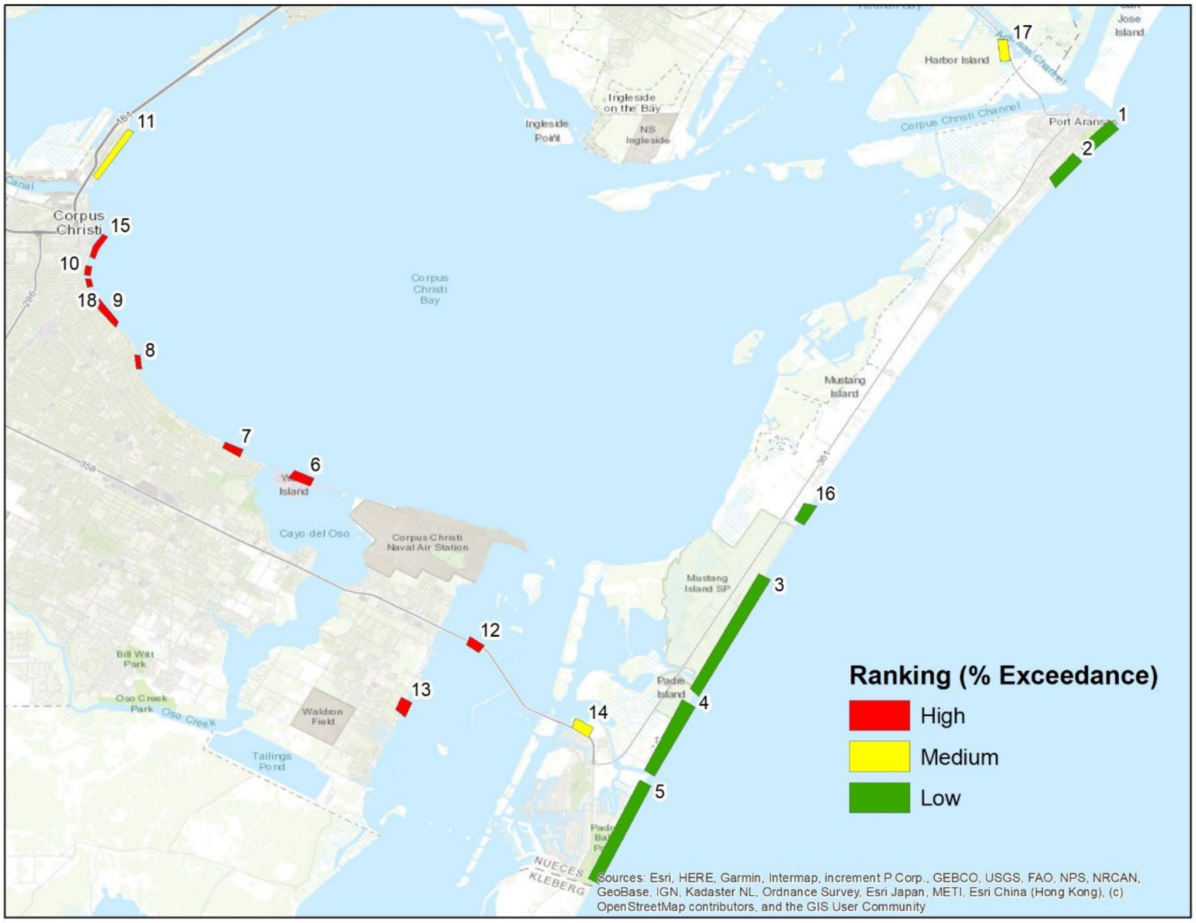


Figure 7. Ranking of beaches based on Exceedance of water quality limit of 104 MPN/100mL: Low (Green < 5%), Medium (Yellow 5-10%), High (Red > 10%).

Task 2: Compare Enterococci Data to Environmental Data

Environmental Data:

- This report discusses the collection and processing of rainfall and sea level data from various sources, including TexMesonet, GCOOS, and NOAA.
- Details about data format, sources, and quality control are provided for each dataset.
- A total of 8 datasets were collected, of which three for rainfall (Corpus Christi International Airport, KCRP, Corpus Christi Naval Air Station/Truax Field, KNGP, and Port Aransas Mustang Beach Airport, KRAS) and 5 for sea level (Port Aransas, 8775237, Aransas Pass, 8775241, USS Lexington Corpus Christi Bay, 8775296, Packery Channel, 8775792, and Bob Hall Pier Corpus Christi, 8775870) (Figure 8).

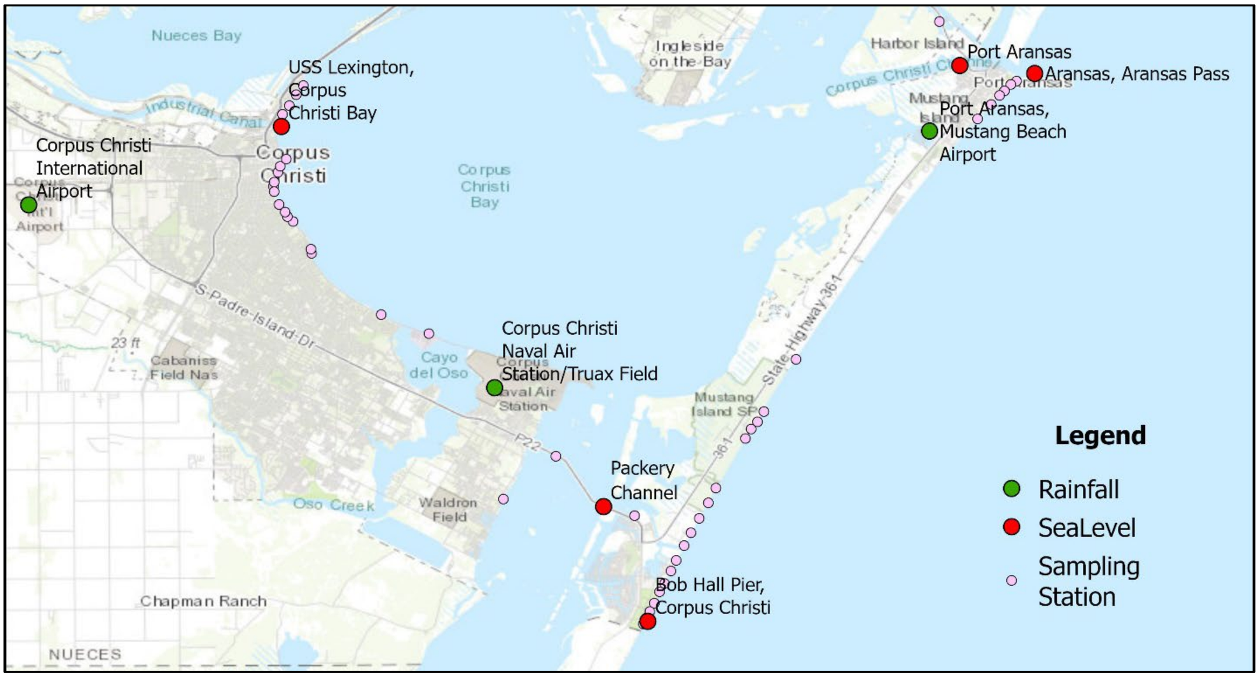


Figure 8. Locations of rainfall and sea level measuring stations.

Enterococci Dataset and Environmental Metadata Comparisons:

- The report covers statistical methods and outputs for comparing Enterococci concentrations with environmental datasets prepared in Task 2.
- Statistical tests, including T-tests and correlation analyses, were used to assess relationships between environmental data and Enterococci concentrations.
- Results suggest that a Moderate or Strong correlation exists with rainfall for 33% (KCRP), 36% (KNGP), and 41% (KRAS) of the sampling stations. Correlation tends to increase when using 2-7 days rainfall sums for sampling stations ranging from #28 to #37, and to decrease for most of the other sampling stations. Correlation appears to increase when using “nearby” (same Zone) rainfall stations (Figure 9).
- Correlations measured between Enterococci and water levels were either Moderate or Strong for the 24-33% of the sampling stations, respectively for the five water level stations (8775237, 8775296, 8775241, 8775870, and 8775792). Patterns are similar among water level stations, with a peak for sampling stations in Zone 3. As observed in the case of rainfall, correlation tends to increase when using “nearby” (same Zone) water level stations (Figure 9).

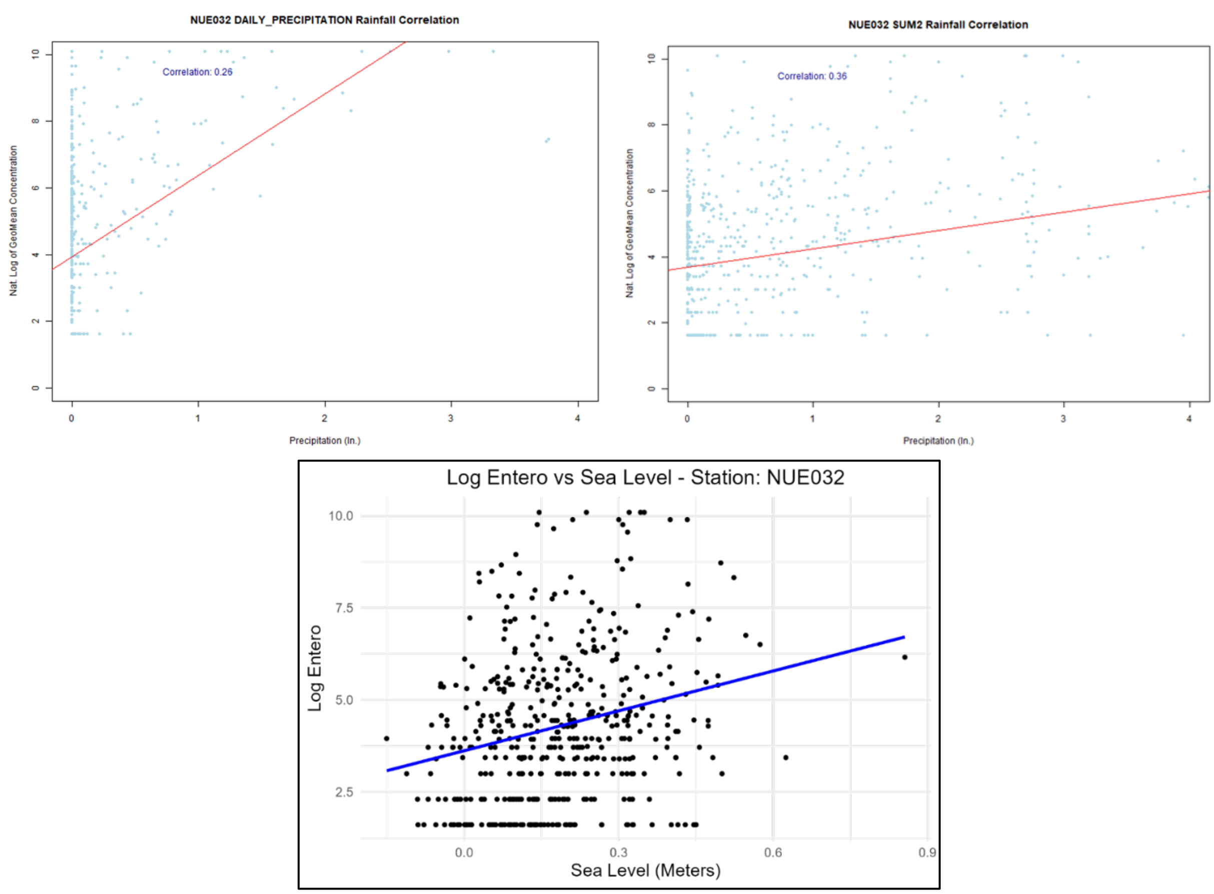


Figure 9. Two examples of Rainfall 2 Day and Single Day Kendall correlation (in inches) and Sea Level compared to natural log of *Enterococci* concentrations for Station #32. 2-days rainfall sum (TOP LEFT), 1-day rainfall sum (TOP RIGHT), and water level (BOTTOM).

Task 3. Compare Enterococci Data to Bacterial Pollution

Micro-Watershed Analysis:

- This report focuses on the creation of a micro-watershed map of Nueces County using LIDAR data to identify potential sources of pollution.
- The estimated flow direction indicated that drainage is mostly toward the bay (Figure 10).
- The analysis includes the identification of coastal OSSFs, stormwater and WWTP outfalls, sewer infrastructure, and leaks/spills in sewage systems.
- are mostly located inside micro-watersheds that drain toward the bay; only 25 of them fall in micro-watersheds draining toward the ocean (the Gulf) and are located near the North and the South portion of Mustang Island.
- WWTP violations for flow were few and the percentage exceeding the limit was low; so, we did not compare these violations to GLO Enterococci data.
- A few violations of *E. Coli* were located on Aransas Pass and were compared to GLO sampling stations NU001-NU006
- Violations of Enterococci were grouped and compared to nearby GLO sampling stations. Each GLO sampling station was compared to all violations in the corresponding group.
- Sewer incidents from the SSO database appear to be located mostly nearby the GLO sampling station that fall in the "High" category for yearly average exceedance. Also, the average incident volume in gallons shows that the cause "infiltration and inflow" has the larger average volume overall.

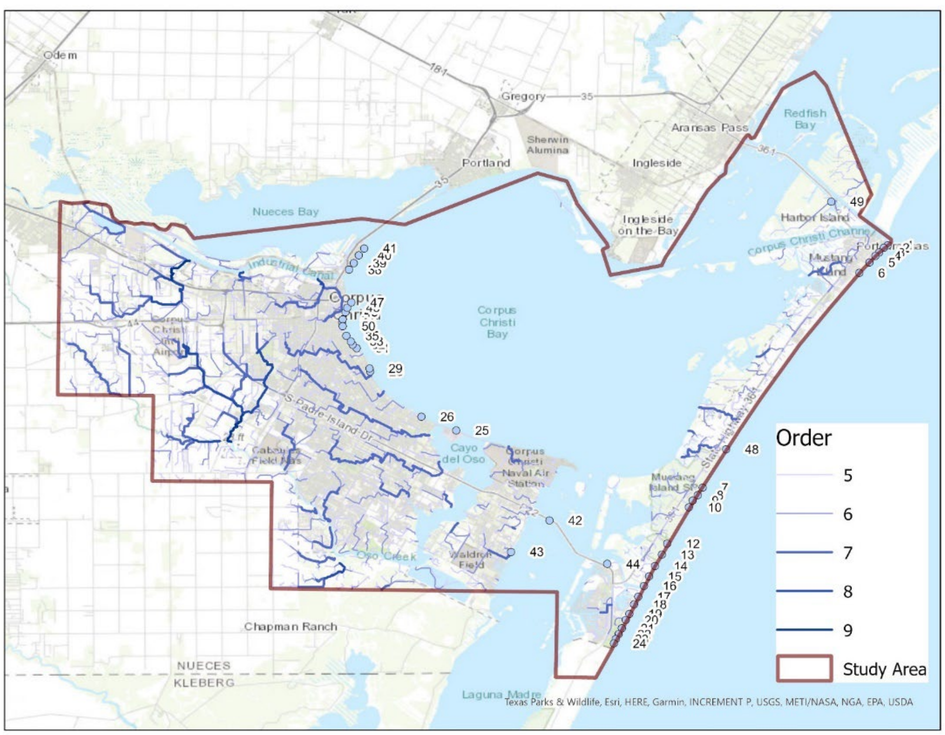


Figure 10. Zones and estimated network relative to Nueces County. Analysis was conducted using ArcGIS Software tools starting from the 2018 Digital Elevation Model (DEM)

Sewage Contamination Analysis:

- This report examines potential sewage contamination sources in micro-watersheds and their relationship with Enterococci concentrations.
- Statistical analyses were performed to assess the impact of OSSFs, flow violations, and E. Coli violations on water quality.
- OSSF location could correlate with the higher GLO Exceedance category found in sampling stations 4, 5 and 22-24 (category “Medium”). The highest concentration of OSSF facilities in Nueces County are along the Oso Creek, which could correlate with the GLO Exceedance category “High” that was found for most GLO sampling stations in the Bay.
- Although there were only two points available, for violations of *E. Coli*, almost all locations showed a positive correlation, for both 7 and 21 days.
- For violations of Enterococci, only one group (violations that occurred along the Industrial Canal in Corpus Christi) showed some correlation; confidence was weak, but correlation was somewhat positive in most cases, with the highest violations percentages often corresponding to the highest Enterococci counts.
- An attempt to correlate these incidents was made by selecting a group of incidents falling inside some of the micro-watershed discharging likely near GLO sampling station that have frequent high counts close to the outside of the Industrial Canal. Correlation appears weak, but there are several sources of uncertainty on this analysis, including location and timing of discharge.

Task 4: Compare Enterococci Data to Beach Attendance

<u>Recreational Beach Attendance Estimates:</u>

- The report provides direct and indirect estimates of recreational beach attendance on Nueces County using foot traffic data from various sources.
- Direct estimates:
    - Texas Beach Watch data were collected only early in the morning; because of this limitation the data was not used.
    - Field observations were conducted on Friday, April 19, 2024, and Saturday, October 12, 2024, and helped identify trends. Saturday counts were slightly higher compared to Friday April 19, but patterns were similar in the two dates
    - Higher counts were observed in the Mustang Island with respect to the Corpus Christi Bay, and in particular in the northern and southern portions of Mustang Island, which are free and easily reachable by car, and in the northern portion of Corpus Christi Bay.
- Indirect estimates:
    - Hotel Occupancy Tax (HOT) showed peaks in March, June, and July (Figure 11), though, analysis of individual cities showed more variability.
    - HOT 911 addresses locations, aggregated into hexagons (16 sq mi), showed higher values in the northern and southern portions of Mustang Island and in the northern portion of Corpus Christi Bay, with maximum values in Port Aransas and at the exit of the Industrial Canal (Figure 12).

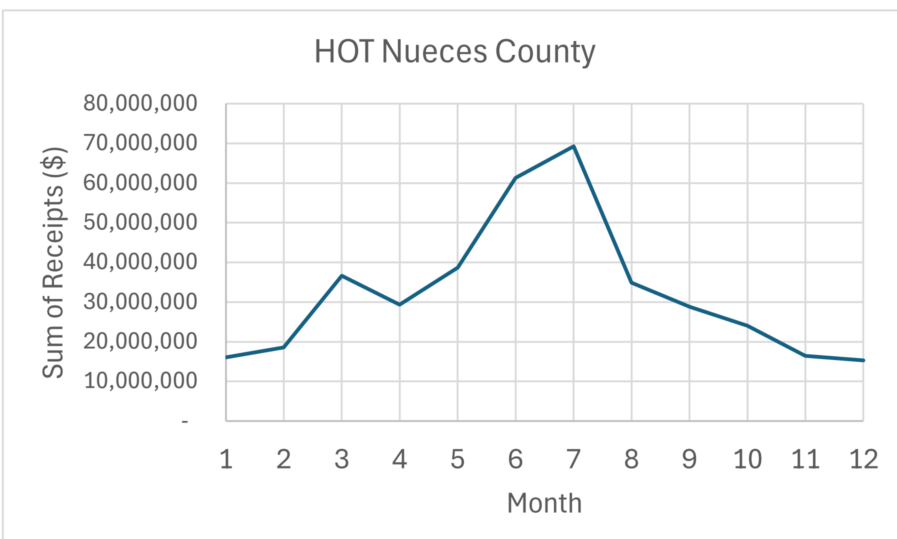


Figure 11. Time series of Hotel Occupancy Tax (HOT) data for the year 2023 in Nueces County.

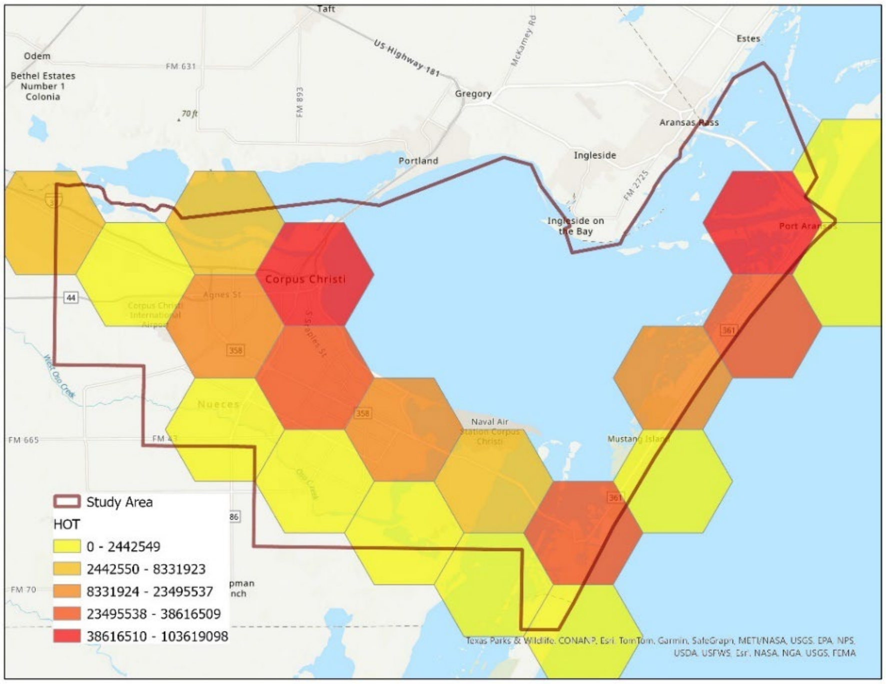


Figure 12. Hotel Occupancy Tax (HOT). Exagon Tessellation covering all hotels, and assignment of the sum of receipts amounts of hotels falling inside the same hexagon (categories were automatically generated using the Natural Breaks ArcMap function)

Statistical Clustering and Space-Time Pattern Analyses:

- This report explores spatial and temporal patterns of recreational beach attendance using statistical clustering and space-time pattern analyses.
- Clustering analysis was conducted on Hotel Occupancy Tax (HOT) data for the year 2023, revealing certain clusters and hotspots (only data for which location and spatial variability were available).
- Results showed "high" clusters along 358 in Corpus Christi and along and at the outlet of the Industrial Canal and "low" clusters in the Mustang Island. Similarly, many "Low-High outliers" are found in Corpus Christi, while "High-Low outliers" are found in the Mustang Island (Figure 13). Several "hot spots" were found along 358 in Corpus Christi and at the outlet of the Industrial Canal.
- Space-Time Pattern Analysis was possible only for the HOT receipts' sums for 2023 in Nueces County, as the field truth was one-time observation only, and was done using the Inverse Distance Weighted (IDW) tool. The space-time dynamic suggested a continuous attendance in the area just South of the Industrial Canal exit; a gradually growing and decreasing attendance from May to August in the middle of Mustang Island, where no GLO sampling stations are available (in between Stations 6 and 48); and an intermittent attendance without clear time pattern along 358 in Corpus Christi, in an area that drains approximatively toward GLO sampling stations NUE025 and NUE026.

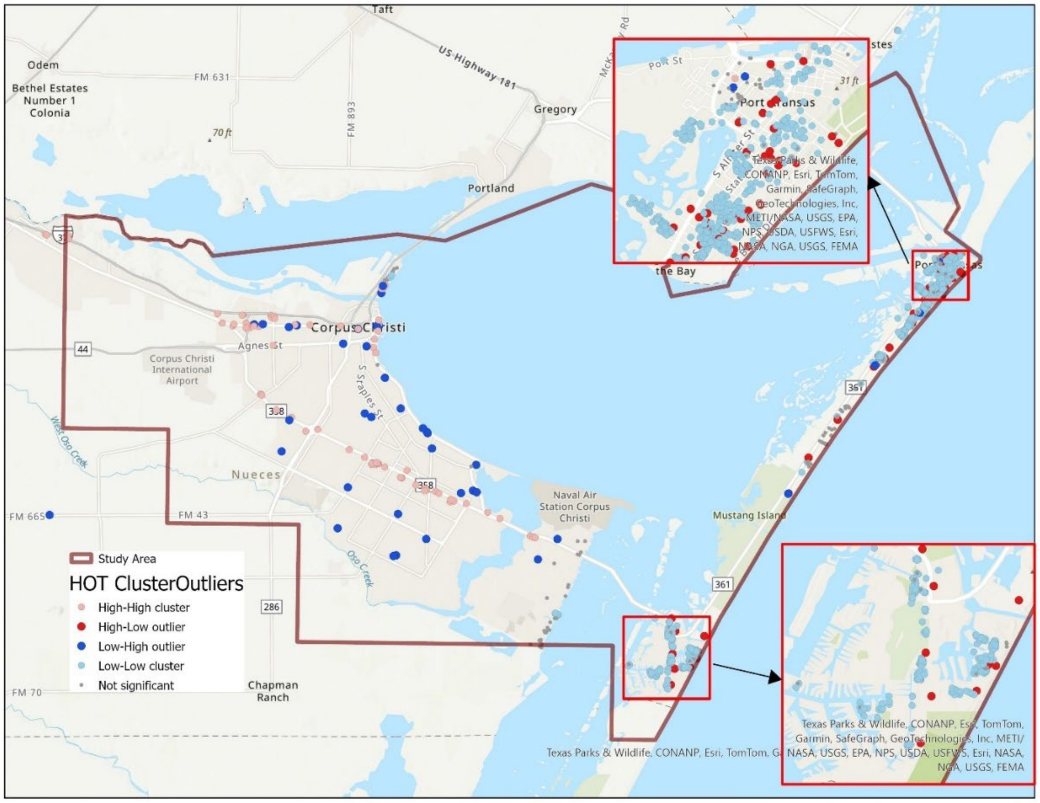


Figure 13. HOT receipts sums for 2023 in Nueces County: Cluster and Outlier Analysis (Anselin Local Morans I), based on hotel annual receipts sums.

Statistical Outputs from Enterococci Dataset and Estimated Recreational Beach Attendance:

- This report investigates the relationship between estimated recreational beach attendance and Enterococci concentrations using correlation tests and spatial regression.
- Correlation was positive and in some cases quite high for most sampling stations in Zones 1 and 2, but negative for most sampling stations in Zone 3. This could be explained by the fact that Enterococci data in Zone 3 has peaks that do not match HOT peaks, as shown in report T1D3.
- Spatial Regression (Geographical Weighted Regression, GWR) was conducted to compare hexagon tiles of Hotel Occupancy Tax (HOT) in 2023 (Figure 12) and monthly Enterococci geomean (year-round, 2009-2023) (Figure 14).
- GWR results included a cold-to-hot rendered map of standardized residuals, and a scatter plot of observed vs predicted geomean values, which showed overall a good fit (Figures 15 and 16).

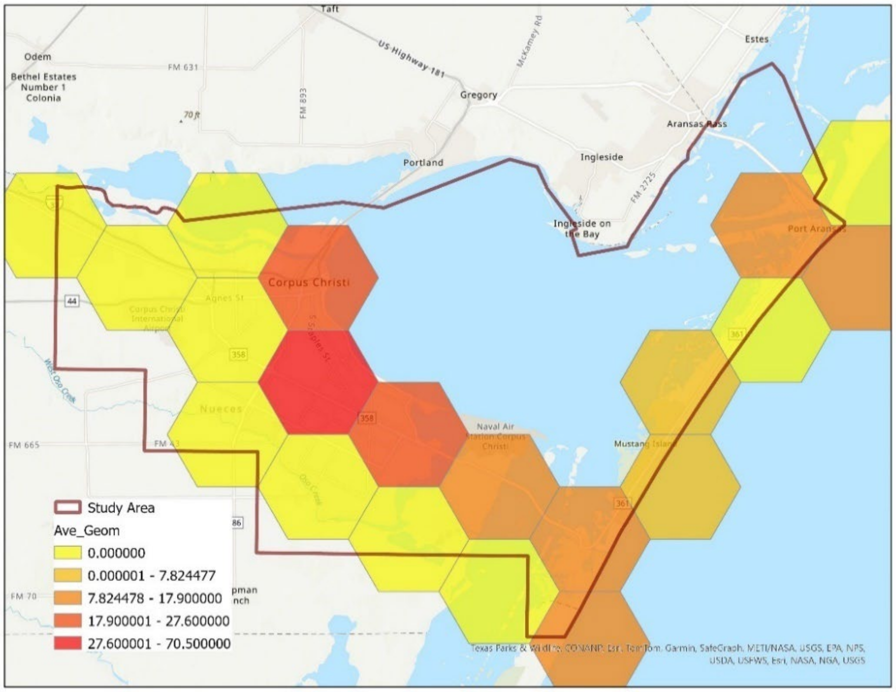


Figure 14. Enterococci geomean overall data (year-round, 2009-2023) after using the Tessellation tool.

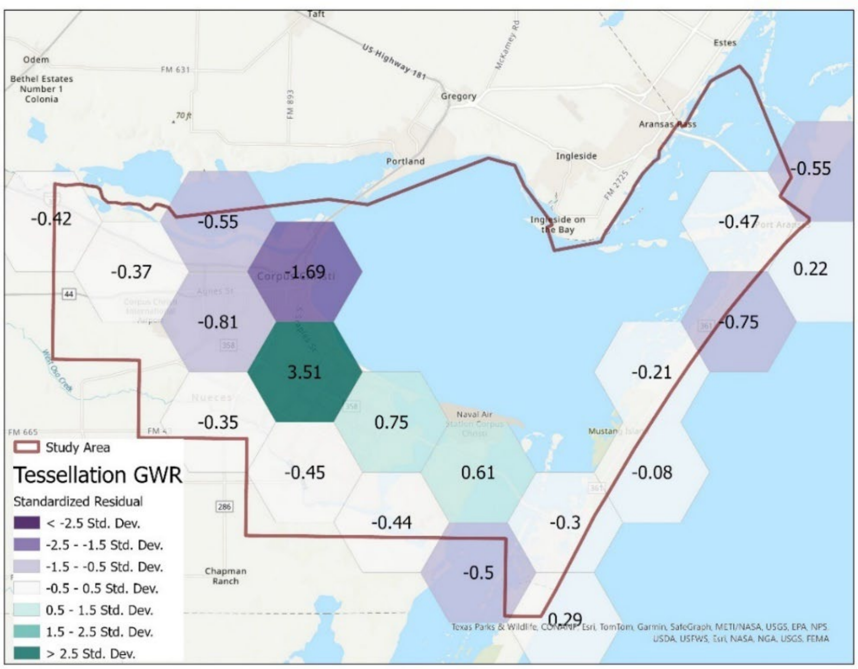


Figure 15. Monthly sums of HOT receipts in 2023 in Nueces County compared to monthly Enterococci geomean from Task 1 (2009-2023). Geographically Weighted Regression (GWR) results as cold-to-hot rendered map of standardized residuals. Labels report each tile's value.

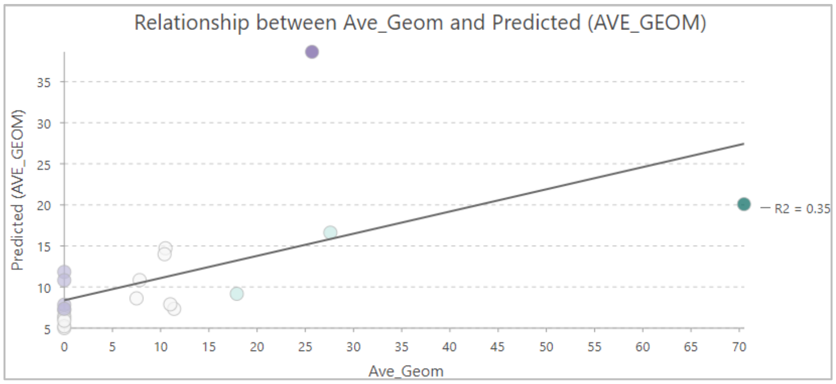


Figure 16. Monthly sums of HOT receipts in 2023 in Nueces County compared to monthly Enterococci geomean from Task 1 (2009-2023). Geographically Weighted Regression (GWR) results as scatter plot comparing observed vs predicted geomean values.

Task 5: Enterococci Data and Human-Specific Fecal Pollution Analysis

- This report describes microbial source tracking analysis for selected water samples collected from Corpus Christi, TX during 2024-2025.
- A total of 41 of the 100 beach watch samples (50 sites) exceeded the Enterococci recreational water quality limit (104 MPN/100 mL) were collected from the period October 2024 - April 2025.
- Of the 10 samples from Oso creek 1 sample exceeded the *E. coli* water threshold (235 MPN/100mL), and 9 samples exceeded the Enterococci recreational water quality limit.
- A total of 25 samples of residential stormwater runoff were collected, for which all exceeded the recreational water quality standard for both *E. coli* and Enterococci.
- Samples were analyzed using qPCR markers for human, dog, and seagull sources. Additionally, samples were analyzed using DNA sequencing-based source tracking.
- Of all the samples tested, gulls were the most common and most abundant source detected using both qPCR and DNA sequencing, mainly with DNA sequencing being the most abundant in beach and creek samples. Human markers were detected at low levels below the limit of quantification except for creek and stormwater samples. The dog marker was the highest among the stormwater samples when compared to the beach and creek samples. Figures 17-19 show TBW stations where markers were detected.
- Statistical relationship of the source-specific molecular marker abundance and the environmental metadata showed some significant correlation. Dog markers showed most correlation with rainfall data, gull markers with water level data, while human markers did not show any significant correlation with environmental data.

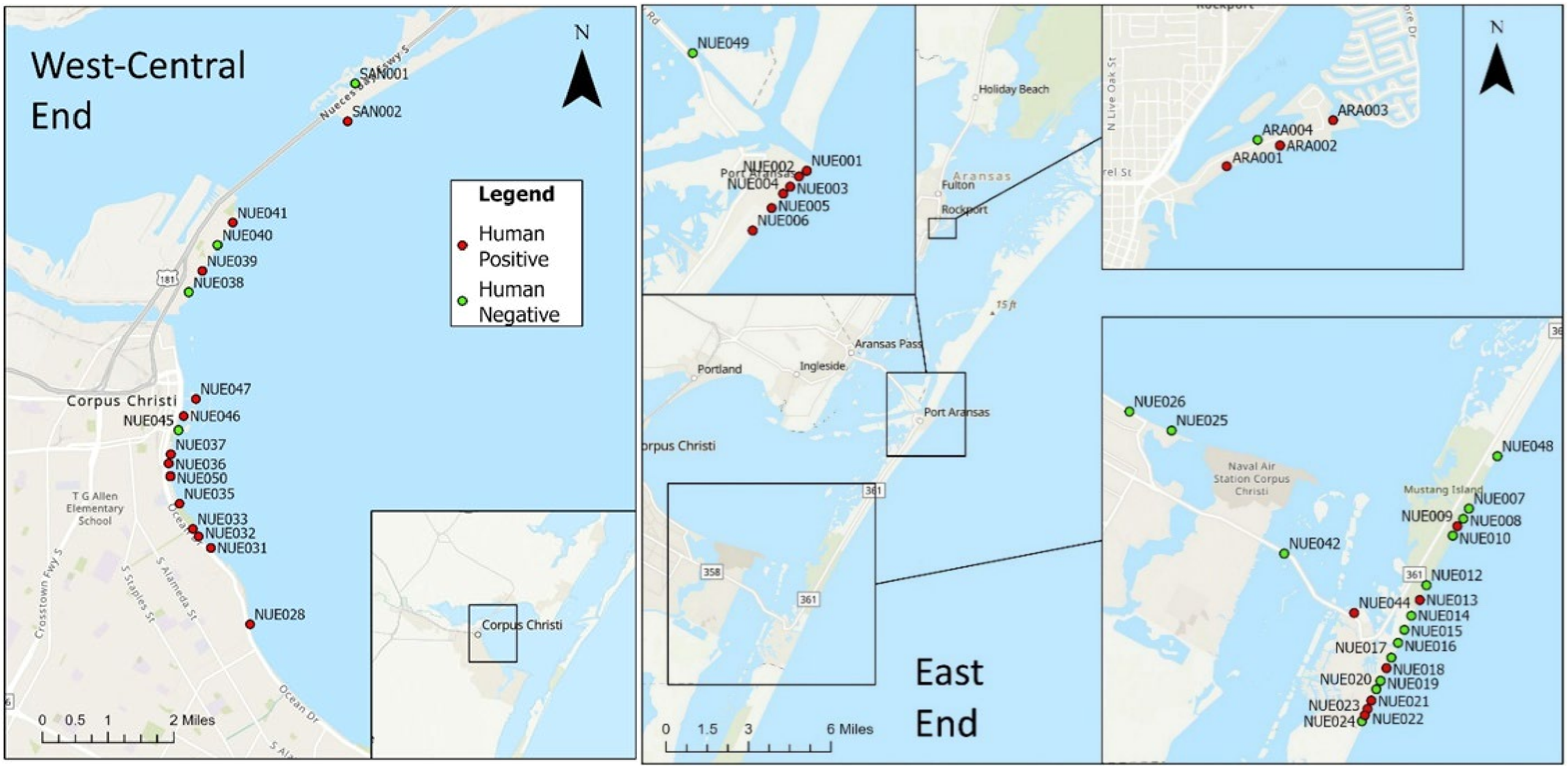


Figure 17. TBW stations where the human marker was detected.

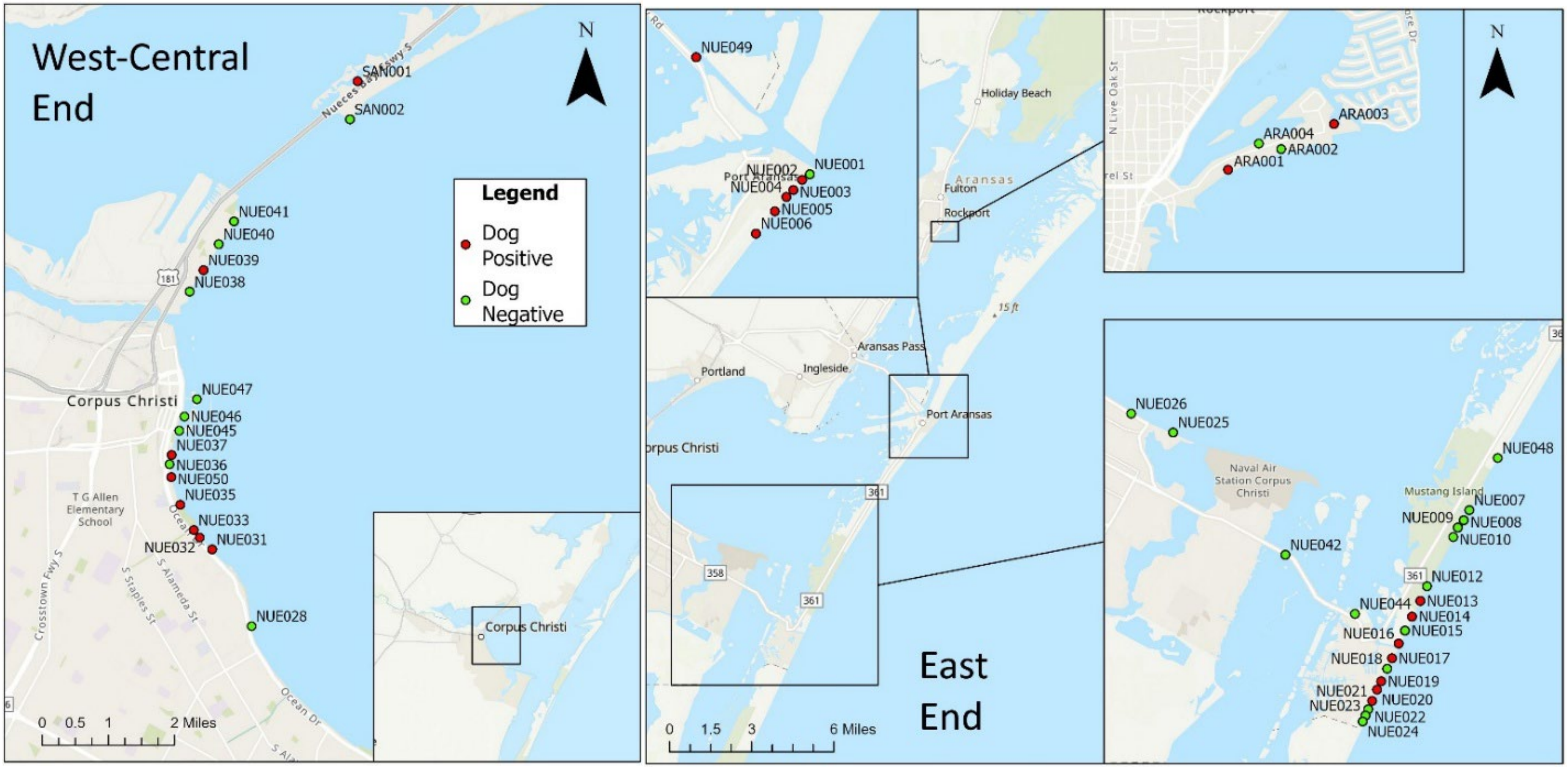


Figure 18. TBW stations where the dog marker was detected.

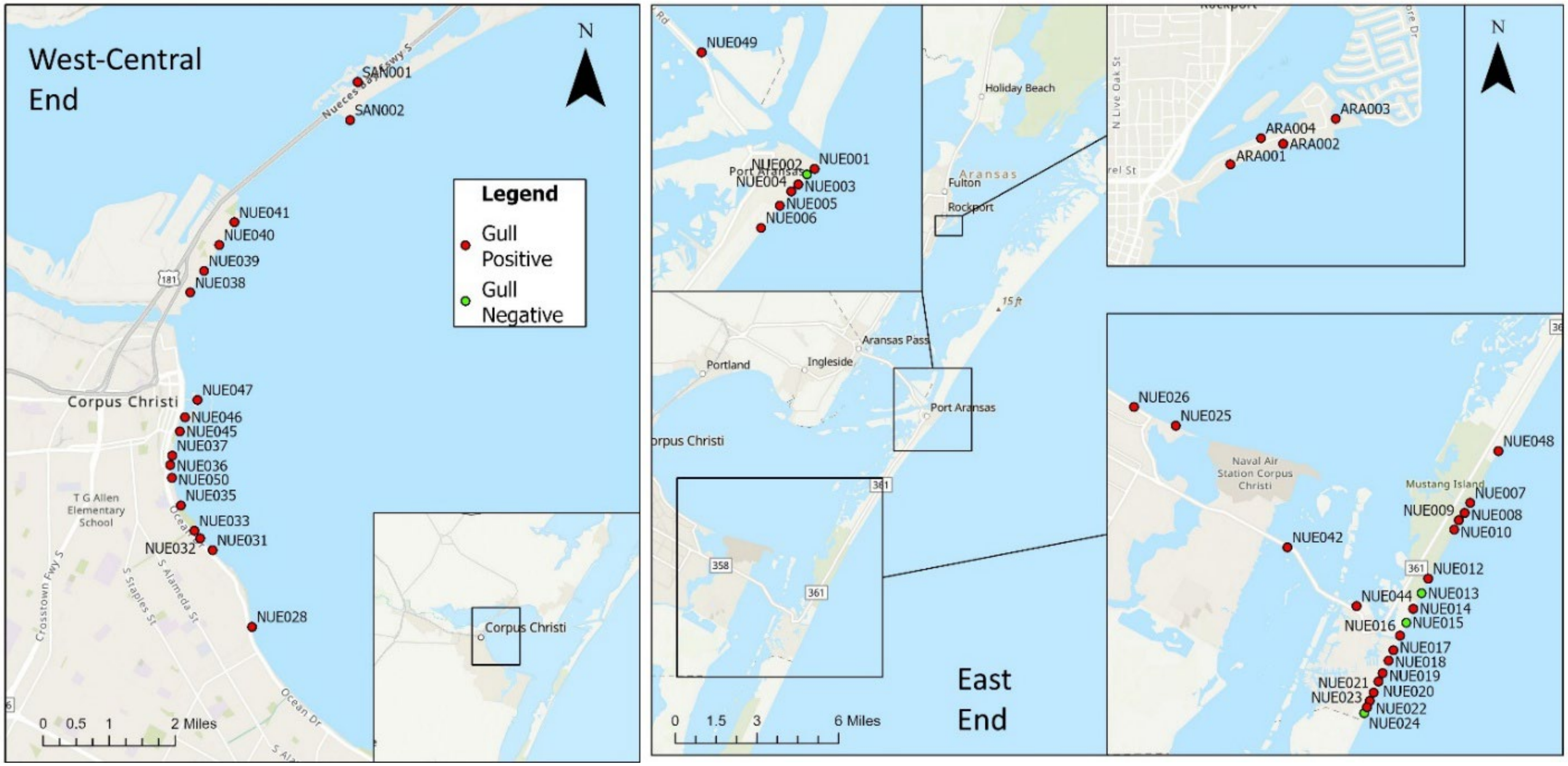


Figure 19. TBW stations where the gull marker was detected.

APPENDIX A - Infographics from each Task (PDF version)

Nueces County

T1D3

Cleaned up Texas Beach Watch Enterococci Dataset

Report contains:

- Received dataset (**TBW 2023 Nueces Co. Results**)
- Flags: anomalies, duplicate samples, and "field duplicates."
  - Anomalies: Entero result = 0 or under the limit of detection; change of analysis method; or assignment to the wrong analysis method
  - Duplicate samples: Sample results entered in the database by mistake
  - Field duplicates: Required for quality assurance, and is a sample taken on the same day at the same station with the same vent tag (two or three samples)

Datasets

33,805 records, from 01/03/2009 to 12/20/2023, each record corresponds to an individual sample

TXGLO

Result of cleaning

→ **BW Data _2009-Feb2022_Final.XLSX**: 33,805 records were corrected for the entero result, and 18 records were corrected for the analysis method.

→ **TBW_Hx_Data_2009-2023_Nueces Co. Results_Flagged:** This file includes all flags for anomalies, duplicates, and field duplicates (column "Flag"), and all notes for changes (column "Note")

New Column "Sample ID", was filled with a progressive unique identification number, and was introduced to facilitate conversation regarding any changes made to the dataset.

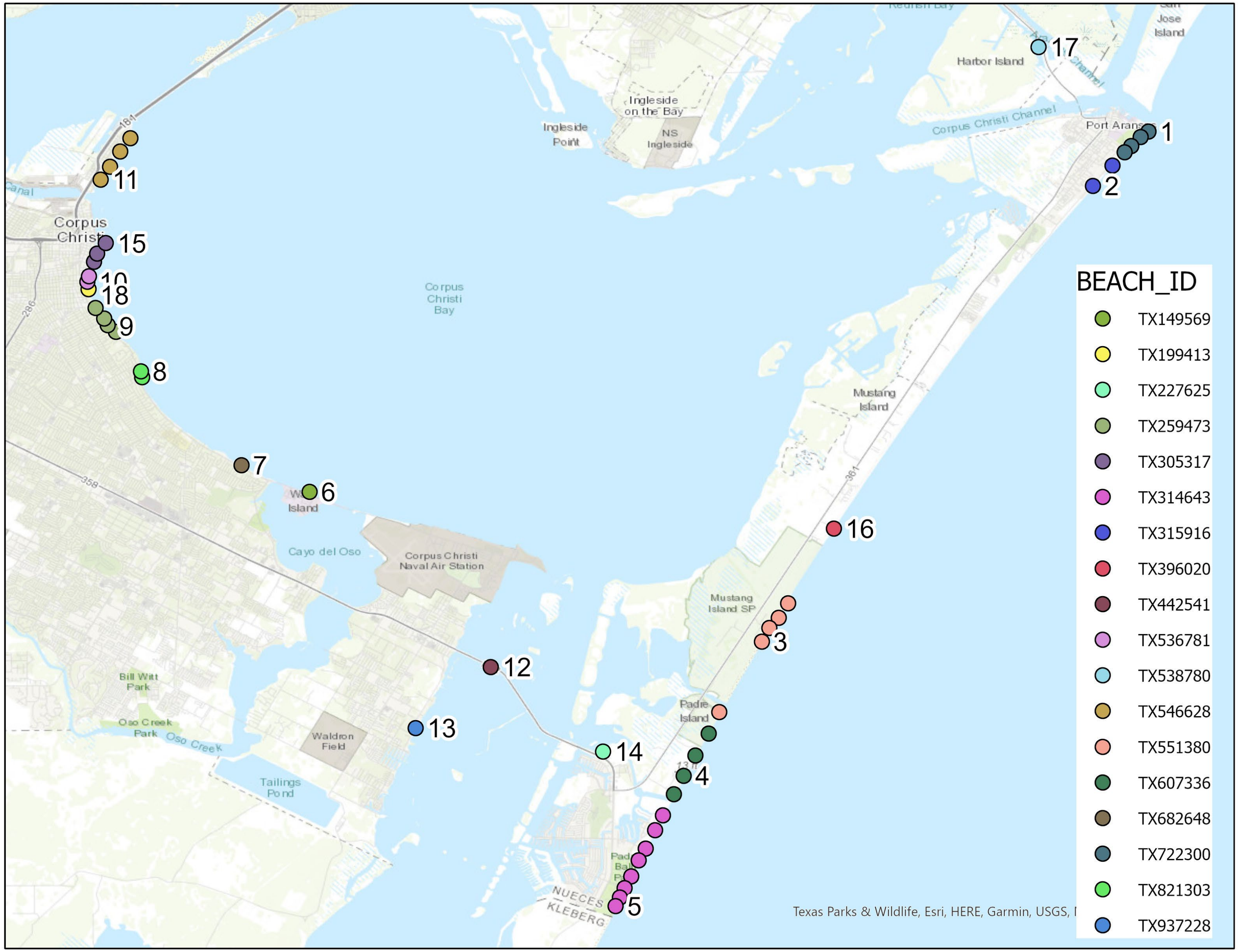
One sample (record ID 107) was identified as a Flag 1 anomaly (Entero result = 0). This sample was removed from the dataset as instructed from GLO:

Sample ID	Beach ID /Simplified ID	Project Name	Site ID /Simplified ID	Station Name	Entero Result	Units	Sample Date	Sample Time	Event ID	Flag	Note
28244	TX305317 /15	Nueces County	NUE045 /45	Corpus Christi Marina	0	MPN/100 mL	11/08/2018	13:15:00	64372	1	Remove

Nueces County

T1D3

Cleaned up Texas Beach Watch Enterococci Dataset



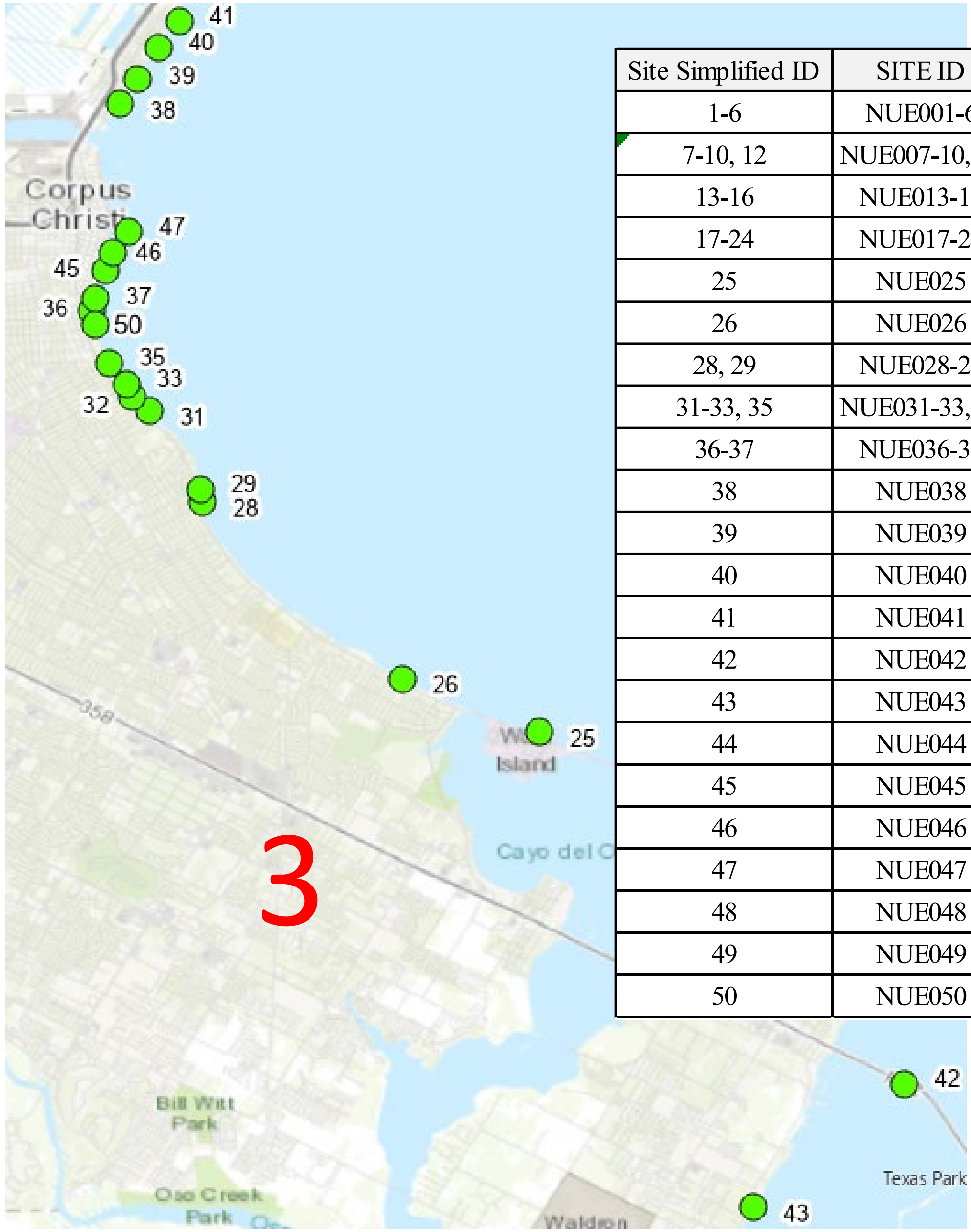
Beaches

Beach Simplified ID	BEACH ID	BEACH NAME
1	TX722300	Port Aransas Park
2	TX315916	Port Aransas - South
3	TX551380	Mustang Island State Park
4	TX607336	JP Luby Park
5	TX314643	Padre Balli Park
6	TX149569	TAMUCC - University Beach
7	TX682648	Poenisch Park
8	TX821303	Ropes Park
9	TX259473	Cole Park
10	TX536781	McGee Beach
11	TX546628	North Beach
12	TX442541	JFK Causeway - SW
13	TX937228	Laguna Shores
14	TX227625	Packery Channel Park
15	TX305317	Corpus Christi Marina
16	TX396020	Mustang Island
17	TX538780	Lighthouse Lake
18	TX199413	Emerald Beach

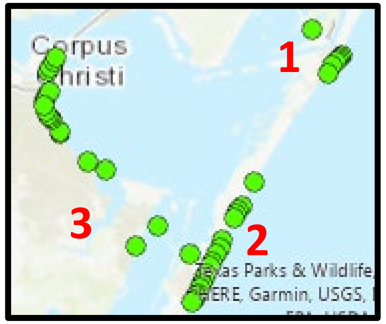
Nueces County

T1D3

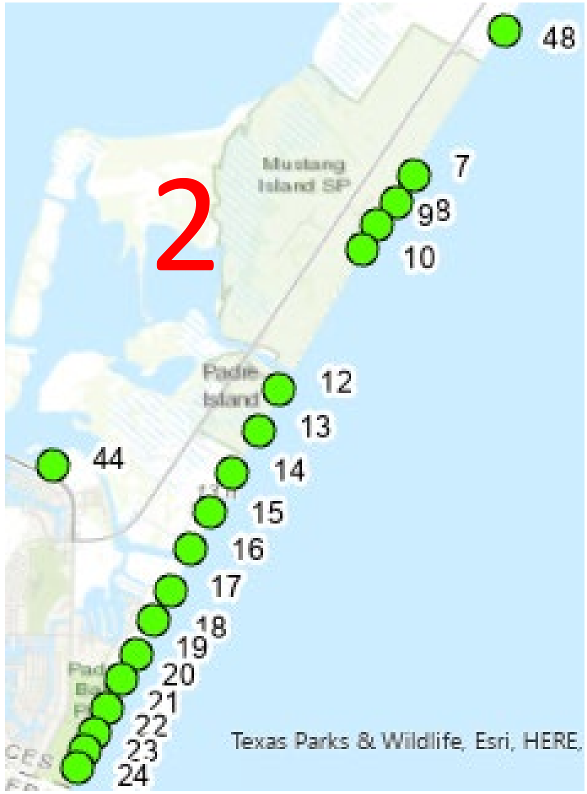
Cleaned up Texas Beach Watch Enterococci Dataset

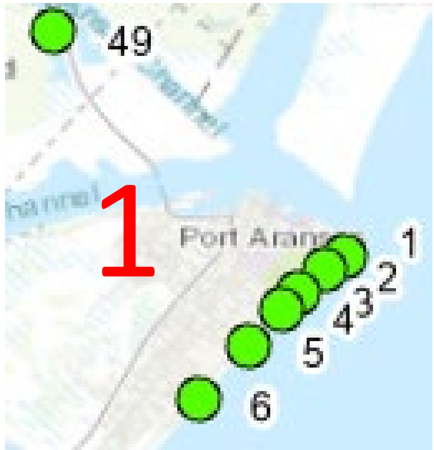


Site Simplified ID	SITE ID	BEACH STATION NAME
1-6	NUE001-6	Port Aransas #1-6
7-10, 12	NUE007-10, 12	Mustang Island SP #1-4, 6
13-16	NUE013-16	J.P. Luby Park #1-4
17-24	NUE017-24	Bob Hall Pier/Seawall #1-8
25	NUE025	University Beach
26	NUE026	Poenisch Park
28, 29	NUE028-29	Ropes Park #2
31-33, 35	NUE031-33, 35	Cole Park#2-4, 6
36-37	NUE036-37	McGee Beach #1-2
38	NUE038	North Beach - Coastal
39	NUE039	North Beach - Breakers
40	NUE040	North Beach - Gulfspray
41	NUE041	North Beach - Gulden
42	NUE042	JFK-A
43	NUE043	Laguna Shores
44	NUE044	Park Road 22
45	NUE045	Corpus Christi Marina - South
46	NUE046	Corpus Christi Marina - Center
47	NUE047	Corpus Christi Marina - North
48	NUE048	Mustang Island
49	NUE049	Lighthouse Lake
50	NUE050	Emerald Beach



Sampling Stations





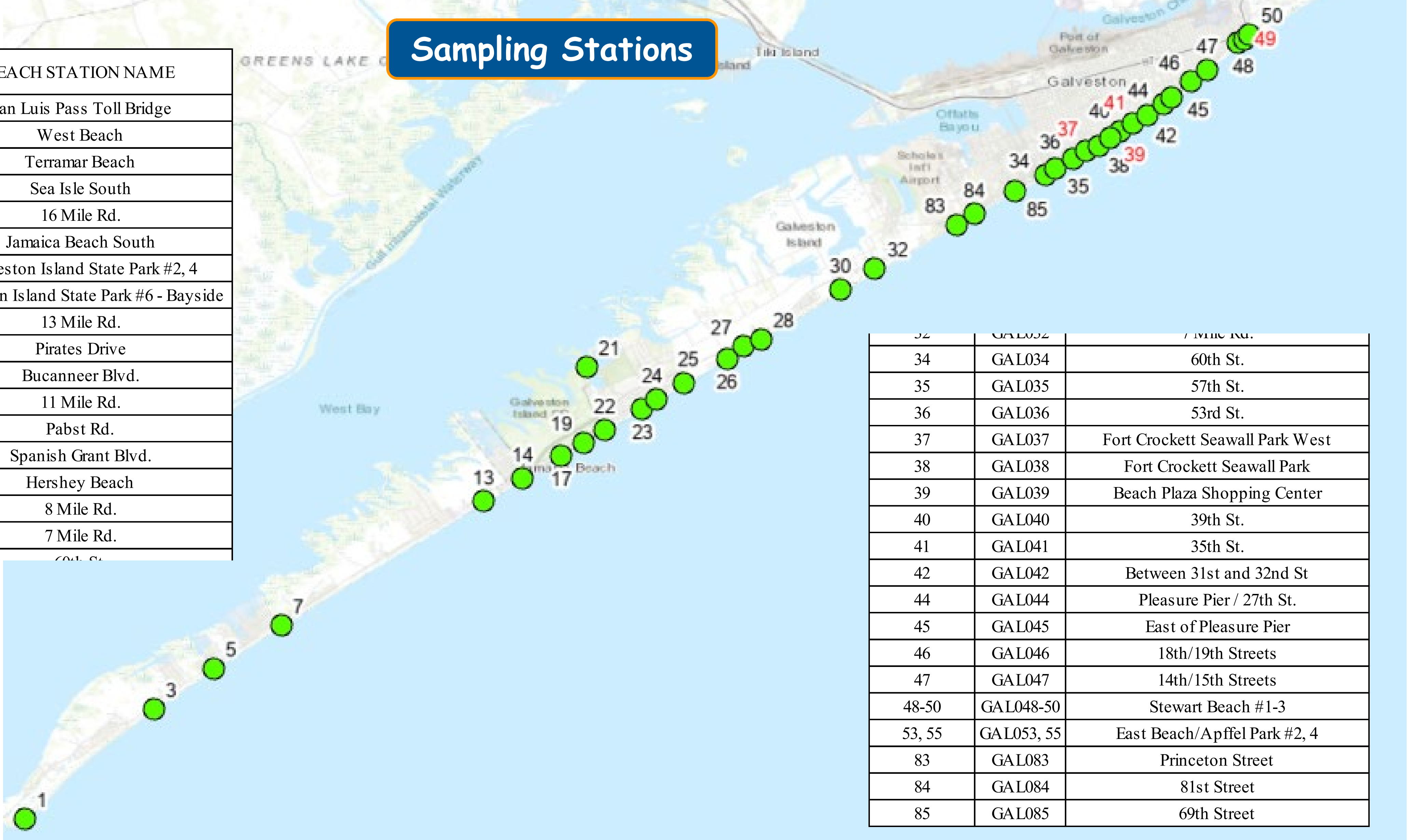
Galveston County

T1D3

Cleaned up Texas Beach Watch Enterococci Dataset

Sampling Stations

Site Simplified ID	SITE ID	BEACH STATION NAME
1	GAL001	San Luis Pass Toll Bridge
3	GAL003	West Beach
5	GAL005	Terramar Beach
7	GAL007	Sea Isle South
13	GAL013	16 Mile Rd.
14	GAL014	Jamaica Beach South
17, 19	GAL017, 19	Galveston Island State Park #2, 4
21	GAL021	Galveston Island State Park #6 - Bayside
22	GAL022	13 Mile Rd.
23	GAL023	Pirates Drive
24	GAL024	Bucanneer Blvd.
25	GAL025	11 Mile Rd.
26	GAL026	Pabst Rd.
27	GAL027	Spanish Grant Blvd.
28	GAL028	Hershey Beach
30	GAL030	8 Mile Rd.
32	GAL032	7 Mile Rd.
34	GAL034	60th St.
35	GAL035	57th St.
36	GAL036	53rd St.
37	GAL037	Fort Crockett Seawall Park West
38	GAL038	Fort Crockett Seawall Park
39	GAL039	Beach Plaza Shopping Center
40	GAL040	39th St.
41	GAL041	35th St.
42	GAL042	Between 31st and 32nd St
44	GAL044	Pleasure Pier / 27th St.
45	GAL045	East of Pleasure Pier
46	GAL046	18th/19th Streets
47	GAL047	14th/15th Streets
48-50	GAL048-50	Stewart Beach #1-3
53, 55	GAL053, 55	East Beach/Apffel Park #2, 4
83	GAL083	Princeton Street
84	GAL084	81st Street
85	GAL085	69th Street



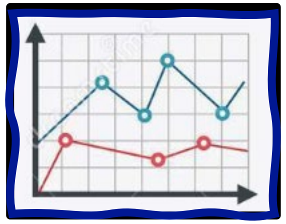
Nueces County

T1D3 Summary Statistics for Each Beach and Sampling Station

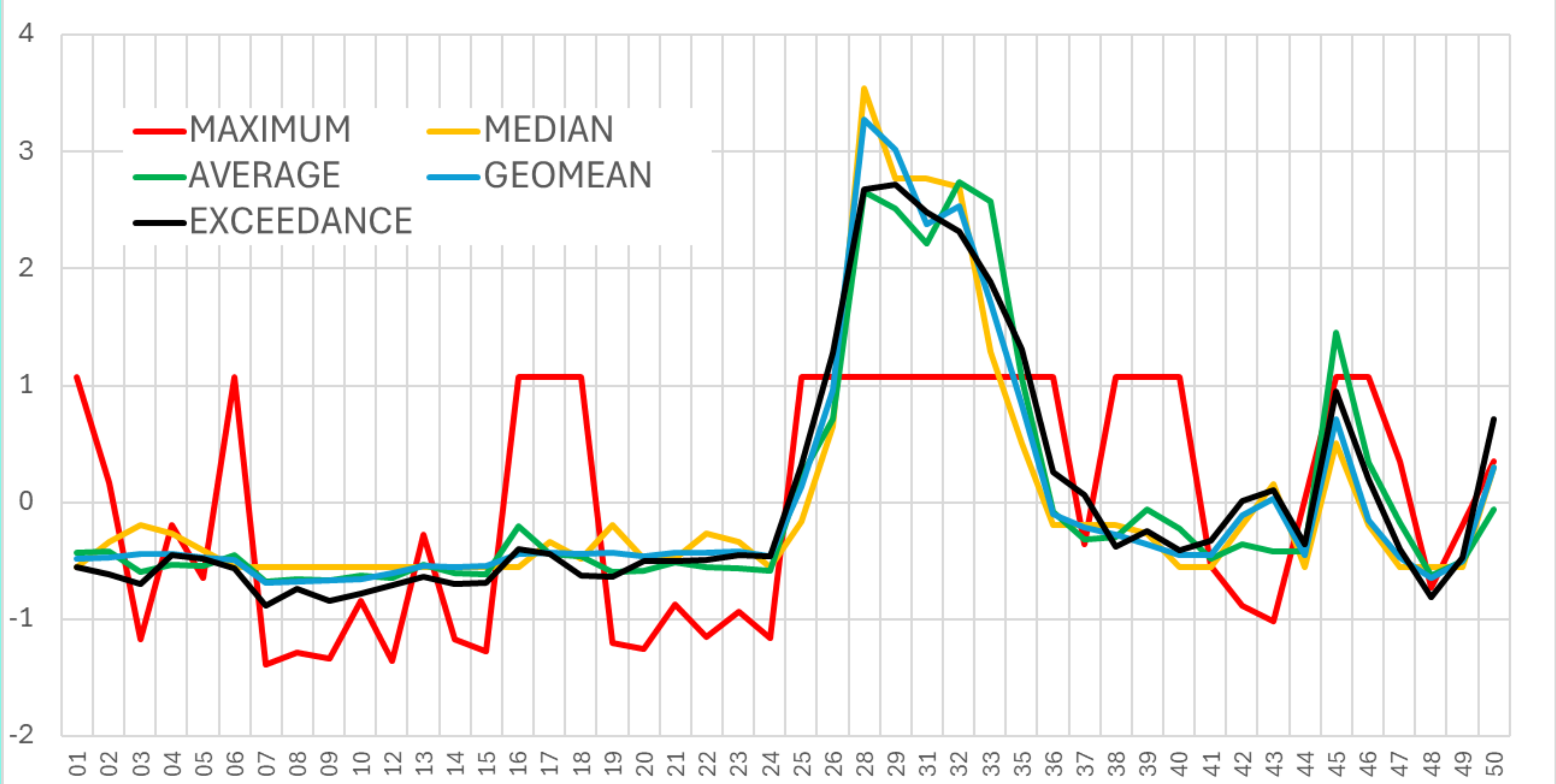
Report on:

- Summary Statistics
- Time & Space
- Dedicated sections on geometric mean & percentage of exceedance calculations:

104 MPN/100mL = Beaches Environmental Assessment and Coastal Health (BEACH) Act with the goal of protecting human health



Summary Statistics:



Maximum values are somehow inconsistent with other summary statistics, while the others are similar and particularly high in stations 25-36, 43, 45, and 50

Nueces County

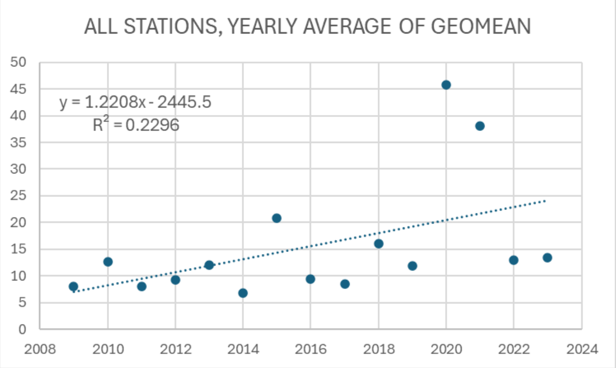
T1D3 Summary Statistics for Each Beach and Sampling Station

Time analysis:

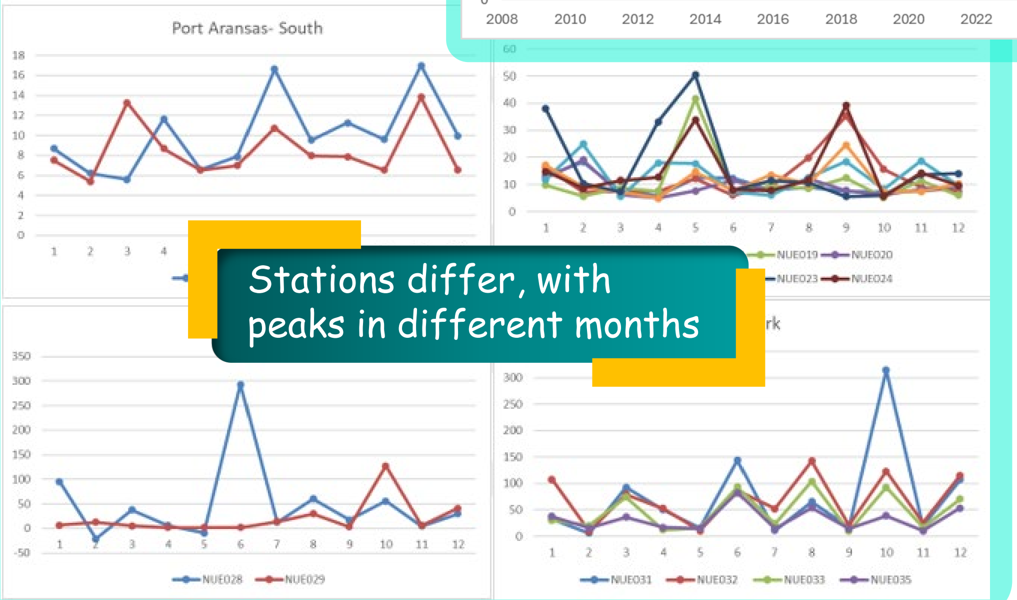
Space patterns in the project area showed that sampling stations in closed geographic proximity shared trend and characteristics

Yearly Trends

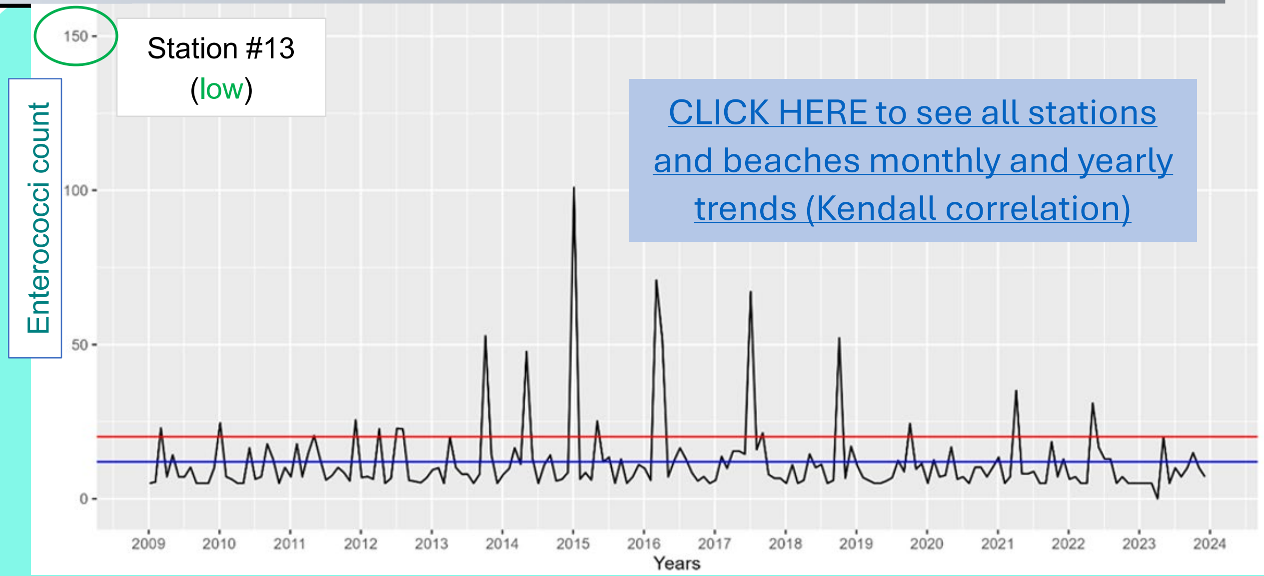
Slight positive correlation with time with peaks in the years 2020 and 2021



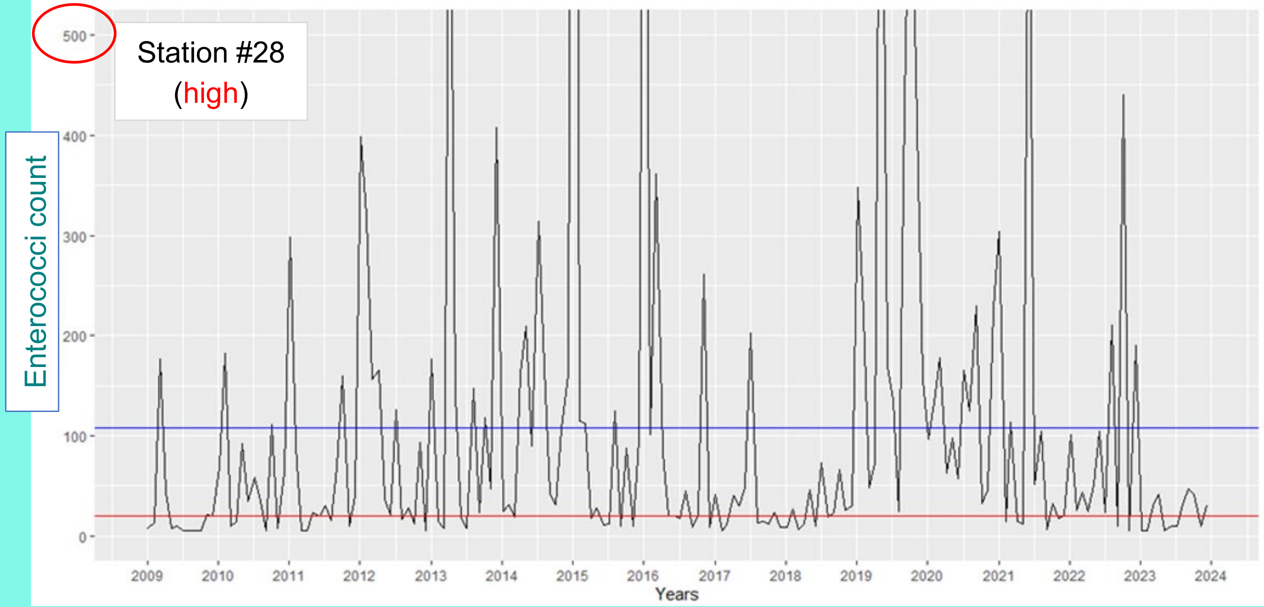
Seasonal Trends



Stations differ, with peaks in different months



[CLICK HERE to see all stations and beaches monthly and yearly trends (Kendall correlation)]



Nueces County

T1D3

Summary Statistics for Each Beach and Sampling Station

Space-Time Analysis:

TIME: 2009 → 2023

SPACE: NE → South → NW

Zone	SS	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
1	49	8	7	9	9	10	7	8	14	6	13	13	14	29	11	8
	01	9	12	8	10	9	11	9	11	9	10	8	9	41	11	12
	02	10	7	9	11	9	12	10	12	9	14	8	11	56	11	9
	03	9	9	9	8	11	11	9	13	9	13	10	11	43	12	12
	04	12	11	8	9	9	11	10	13	10	9	9	12	34	11	13
	05	9	8	10	9	10	11	10	11	10	16	9	12	37	11	8
	06	9	9	9	9	8	8	10	9	9	14	11	10	48	11	8
2	48	7	6	6	6	8	8	8	8	8	7	8	8	29	10	8
	07	7	5	5	6	7	7	7	7	7	7	7	12	18	7	7
	08	6	6	6	7	8	9	7	8	7	6	7	9	22	9	7
	09	6	6	6	7	8	8	7	7	8	8	8	9	20	9	7
	10	6	6	7	7	7	8	7	7	7	7	7	11	28	8	7
	12	6	6	5	9	9	11	8	8	9	8	8	10	30	11	8
	13	8	8	9	8	9	10	7	9	9	11	7	12	34	10	9
	14	8	9	10	8	10	8	8	10	9	8	9	11	23	9	10
	15	7	7	9	9	11	10	10	9	9	10	10	11	26	9	9
	16	8	7	11	9	14	10	11	10	10	8	11	18	53	11	9
	17	7	10	9	10	12	15	13	8	11	14	13	17	32	11	11
	18	8	9	8	9	13	11	12	11	11	11	12	14	46	11	11
	19	7	9	10	8	10	12	15	11	11	12	13	14	29	14	14
	20	7	8	9	10	14	12	12	11	8	10	14	11	28	16	13
	21	7	8	8	10	11	13	15	11	10	12	18	16	38	11	9
	22	8	9	12	10	12	10	14	10	12	12	12	13	36	10	9
	23	7	10	9	7	12	13	18	13	13	13	18	12	30	12	8
	24	8	9	9	8	12	15	12	12	9	11	15	13	24	11	9
3	44	7	8	7	9	9	9	11	12	9	11	19	18	45	11	9
	42	29	28	40	17	14	8	14	12	7	12	12	18	24	11	9
	43	21	15	14	32	25	11						1497			
	25	13	24	15	26	15	14	39	21	10	37	15	20	47	29	14
	26	45	36	40	38	29	19	41	27	16	71	18	32	66	36	25
	28	59	60	27	60	117	41	126	58	65	126	84	78	165	42	76
	29	60	49	26	51	131	35	197	79	56	90					
	31	32	46	38	71	70	40	109	50	33	98	52	71	212	37	43
	32	37	39	27	45	55	39	204	65	32	121	61	87	181	44	38
	33	41	43	17	29	20	12	72	18	100	82	98	101	96	32	38
	35	29	31	13	20	33	15	100	21	28	48	44	30	80	33	17
	50	16	24	13	13	17	23	48	27	26	31	33	29	70	17	13
	36	15	15	10	13	21	10	45	13	15	19	21	19	38	13	11
	37	14	13	10	13	12	11	26	12	11	25	14	19	41	14	11
	45	14	24	26	30	41	25	52	14	16	71	44	40	101	23	20
	46	9	18	9	13	19	14	20	9	11	24	14	28	53	21	12
	47	8	13	8	10	10	6	17	6	10	11	9	15	37	9	9
	38	12	20	10	15	11	8	18	25	10	14	11	16	22	14	9
	39	10	17	10	13	9	8	14	30	8	15	9	16	22	8	12
	40	10	11	7	10	7	8	13	16	8	13	10	13	49	9	8
	41	9	14	9	11	11	8	9	12	6	14	8	18	39	8	9

Yearly GeoMean for all stations

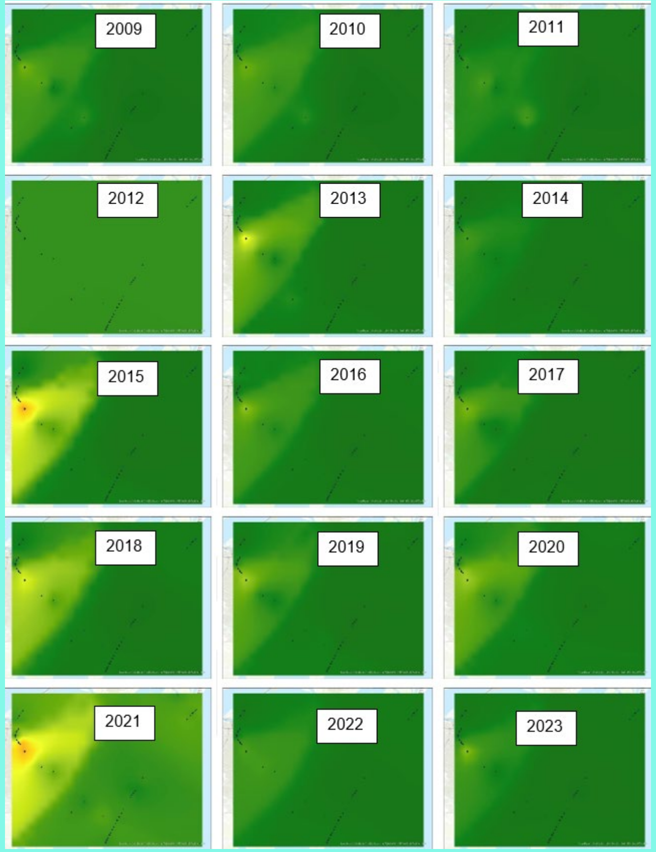
Color Scale

Inverse Distance Weighting tool (IDW)

Growing trend with time

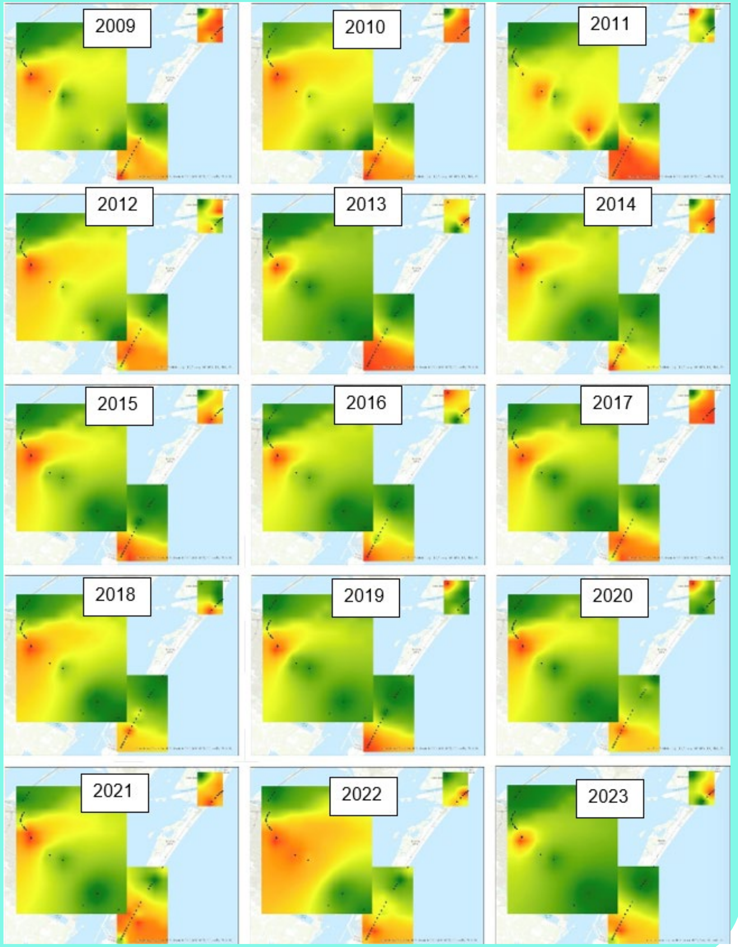
North-West consistently higher

Outlier #29 in 2020 (1 sample 1,497 MPN/100 mL)



Values stretched between 5 and 212 MPN/100 mL

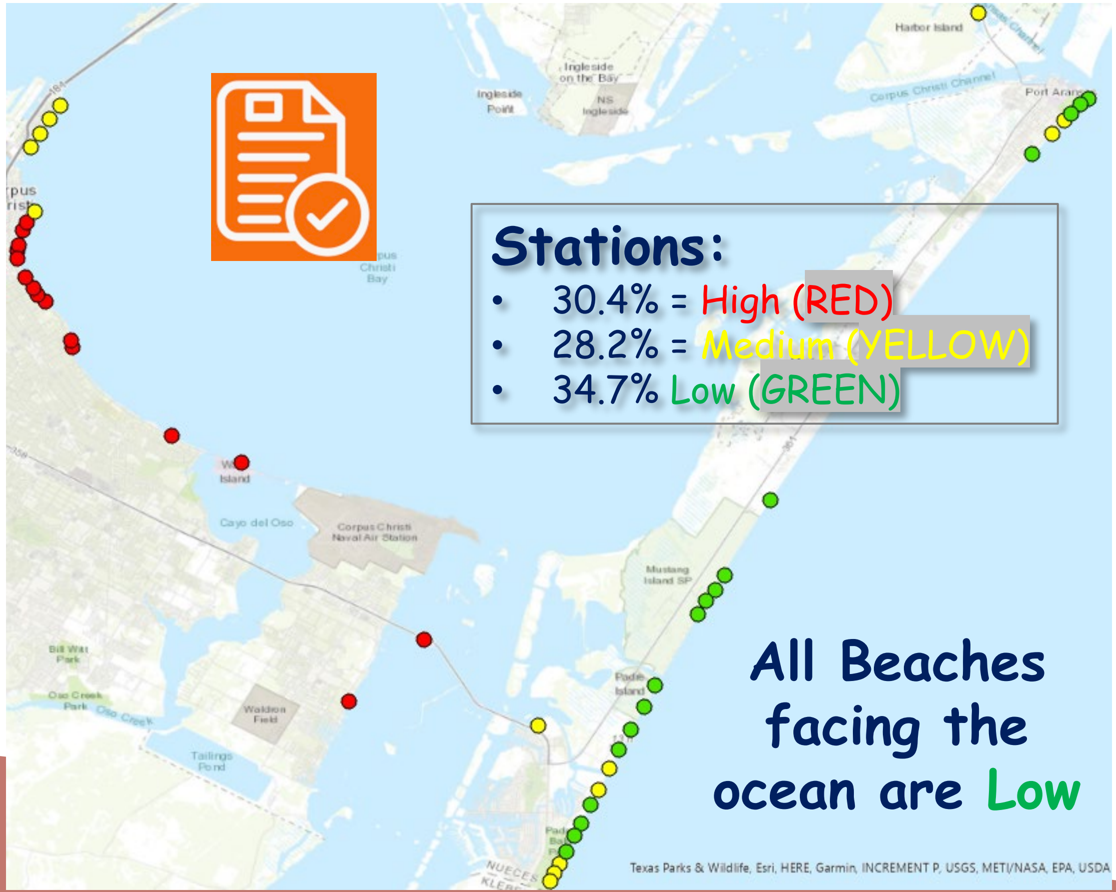
Relative differences within nearby stations



Ranking of Beaches and Sampling Stations

- Ranking of beaches and sampling stations based on levels of bacterial pollution, i.e., the exceedance percentage calculated in T1D2
- Based on the recreational water quality limit of 104 MPN/100mL.
- Three categories: **low (< 5%), medium (5 – 10%), and high (> 10%)**; as done by Powers et. al. (2021) for the entire Coastal Zone

$$\textbf{Exceedance} = \frac{\textbf{Count>104}}{\textbf{Total Count (n)}} \times \textbf{100} = \textbf{Percentage of Exceedance}$$



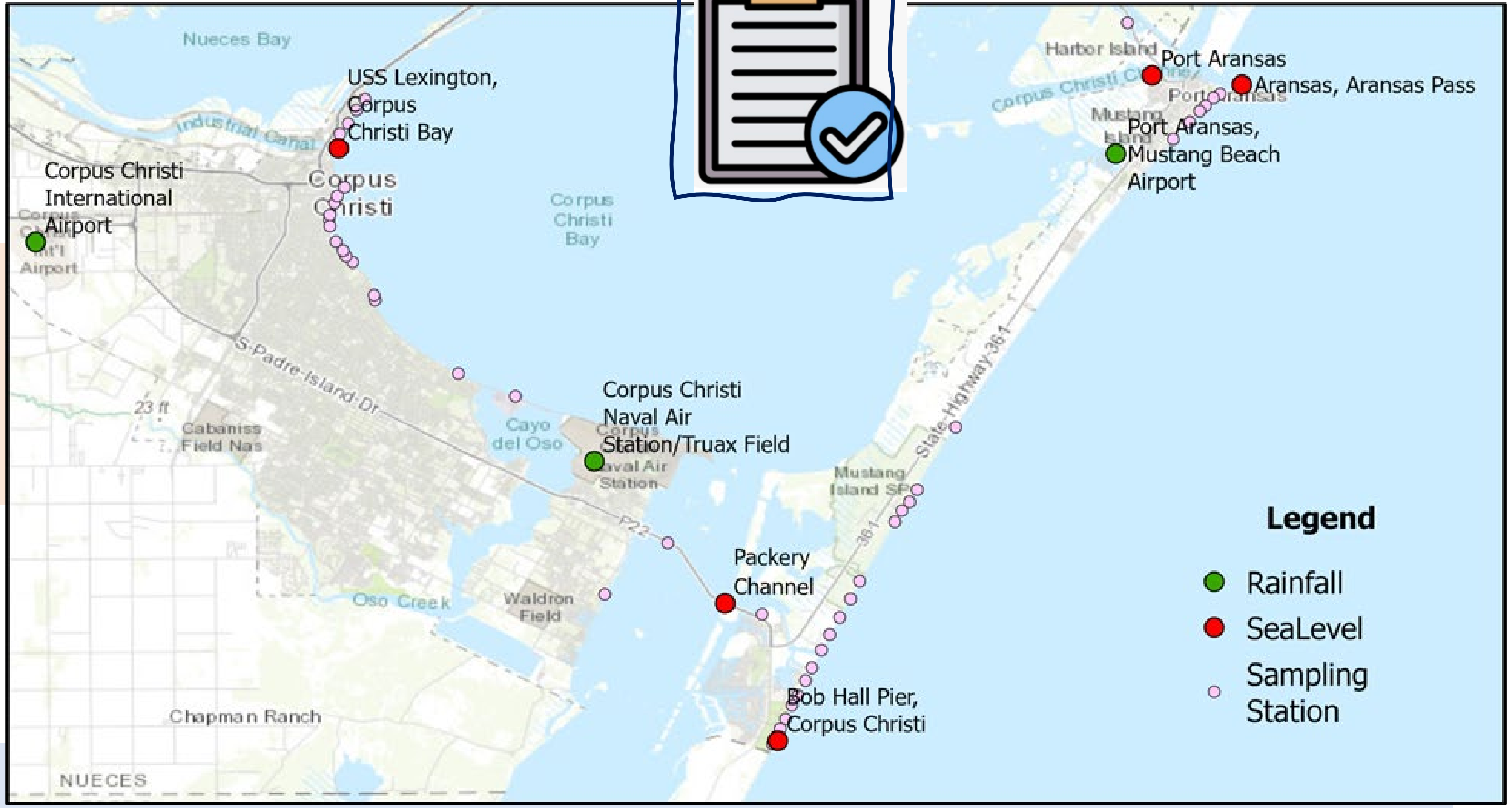
ID		Exceedance % Result>104	
Site	Beach	Site	Beach
NUE001	Port Aransas Park	4.47	4.16
NUE002		3.79	
NUE003		2.87	
NUE004		5.51	
NUE005	Port Aransas - South	5.23	4.75
NUE006		4.27	
NUE007	Mustang Island State Park	0.87	1.91
NUE008		2.44	
NUE009		1.4	
NUE010		2.02	
NUE012		2.82	
NUE013	JP Luby Park	3.55	3.88
NUE014		2.878	
NUE015		3.02	
NUE016		6.08	
NUE017	Padre Balli Park	5.59	4.84
NUE018		3.67	
NUE019		3.59	
NUE020		4.99	
NUE021		4.94	
NUE022		5.03	
NUE023		5.55	
NUE024		5.4	
NUE025	TAMUCC - University Beach	13.8	13.8
NUE026	Poenisch Park	23.93	23.93
NUE028	Ropes Park	38.9	39.09
NUE029		39.29	
NUE031	Cole Park	36.8	31.65
NUE032		35.06	
NUE033		30.45	
NUE035		24.31	
NUE036	McGee Beach	13.1	12.04
NUE037		10.97	
NUE038	North Beach	6.3	6.7
NUE039		7.77	
NUE040		5.92	
NUE041		6.84	
NUE042	JFK Causeway - SW	10.45	10.45
NUE043	Laguna Shores	11.46	11.46
NUE044	Packery Channel Park	6.47	6.47
NUE045	Corpus Christi Marina	20.43	12.97
NUE046		12.4	
NUE047		6.08	
NUE048	Mustang Island	1.66	1.66
NUE049	Lighthouse Lake	5.27	5.27
NUE050	Emerald Beach	17.93	17.93

Nueces County

T2D3 - Environmental Metadata

Report on:

- Sources, format, processing steps
- Rainfall and sea level data
- Eight datasets (3 for rainfall and 5 for sea level)



RAINFALL

- TexMesonet (NOAA)
- 1/1/2009 - 12/31/2023
- <CODE>_Master_Rainfall_Data_<YEARS>.XLSX
- Hourly

1) KCRP: Corpus Christi International Airport
2) KNGP: Corpus Christi Naval Air Station/Truax Field
3) KRAS: Port Aransas, Mustang Beach Airport

SEA LEVEL

- GCOOS (large gaps); used NOAA source
- Different ranges (~1/2015-12/2023)
- NOAA_MASTER_WATER_LEVEL_DATA_<STATION CODE>_MSL
- Recorded at 6-minute intervals, downloaded hourly

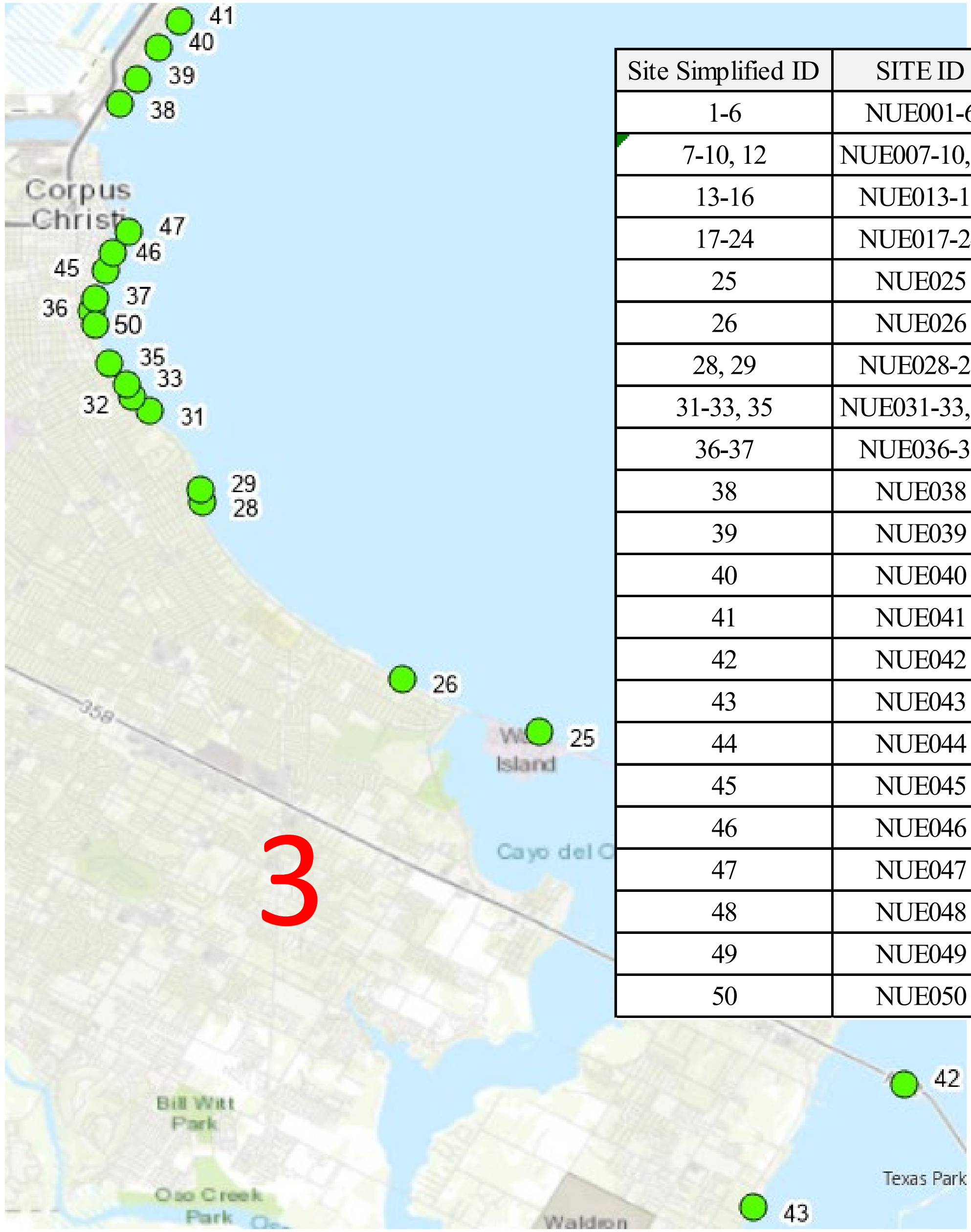
1) 8775237: Port Aransas (1/2016 to 12/2023)
2) 8775241: Aransas Pass (1/2017-12/2023)
3) 8775296: USS Lexington, Corpus Christi Bay (1/2016-12/2023)
4) 8775792: Packery Channel (1/2015-12/2023)
5) 8775870: Bob Hall Pier, Corpus Christi (1/2009-12/2022)

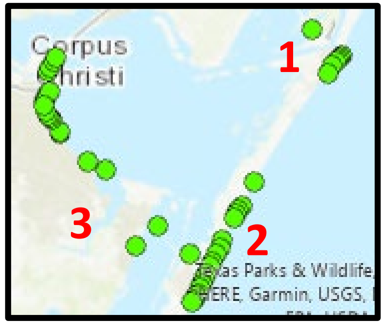
Nueces County

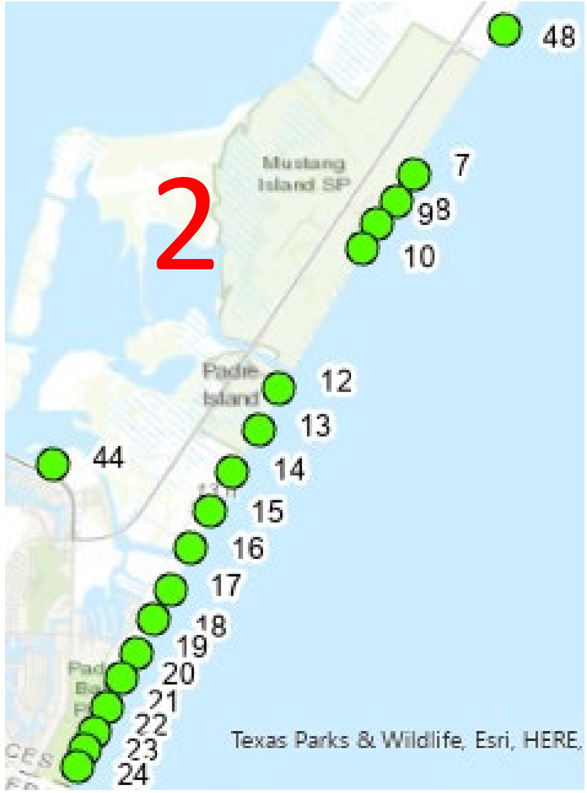
T2D3 - Environmental Metadata

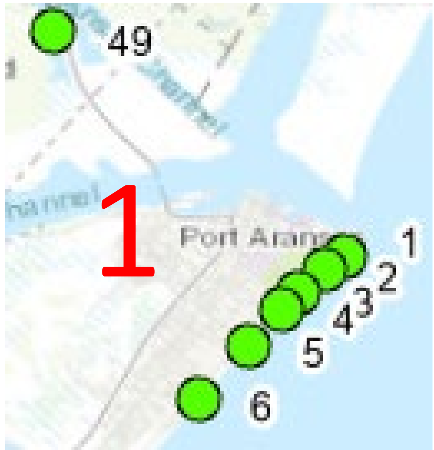
Beach Watch Sampling Stations

Site Simplified ID	SITE ID	BEACH STATION NAME
1-6	NUE001-6	Port Aransas #1-6
7-10, 12	NUE007-10, 12	Mustang Island SP #1-4, 6
13-16	NUE013-16	J.P. Luby Park #1-4
17-24	NUE017-24	Bob Hall Pier/Seawall #1-8
25	NUE025	University Beach
26	NUE026	Poenisch Park
28, 29	NUE028-29	Ropes Park #2
31-33, 35	NUE031-33, 35	Cole Park#2-4, 6
36-37	NUE036-37	McGee Beach #1-2
38	NUE038	North Beach - Coastal
39	NUE039	North Beach - Breakers
40	NUE040	North Beach - Gulfspray
41	NUE041	North Beach - Gulden
42	NUE042	JFK-A
43	NUE043	Laguna Shores
44	NUE044	Park Road 22
45	NUE045	Corpus Christi Marina - South
46	NUE046	Corpus Christi Marina - Center
47	NUE047	Corpus Christi Marina - North
48	NUE048	Mustang Island
49	NUE049	Lighthouse Lake
50	NUE050	Emerald Beach









Nueces County

T2D3 - Statistical Outputs from Enterococci Dataset and Environmental Metadata Comparisons

Report on:

Enterococci dataset from Task 1 vs Environmental dataset

Methods

1) Environmental Metadata

- Trends
- Comparing datasets with T-tests

2) Enterococci dataset vs environmental metadata

- Each Enterococci result is compared to the same day or 2-7 days sum of **rainfall** observed, and to the hourly average of **sea level** observed on the same hour of sampling
- For each sampling station (and for each rainfall sum), a **Kendall's** correlation coefficient is calculated
- Correlation **strength**:
  - ±(0 - 0.10), Very Weak (VW)
  - ±(0.10 - 0.19), Weak (W)
  - ±(0.20 - 0.29), Moderate (M)
  - >± 0.30: Strong (S)

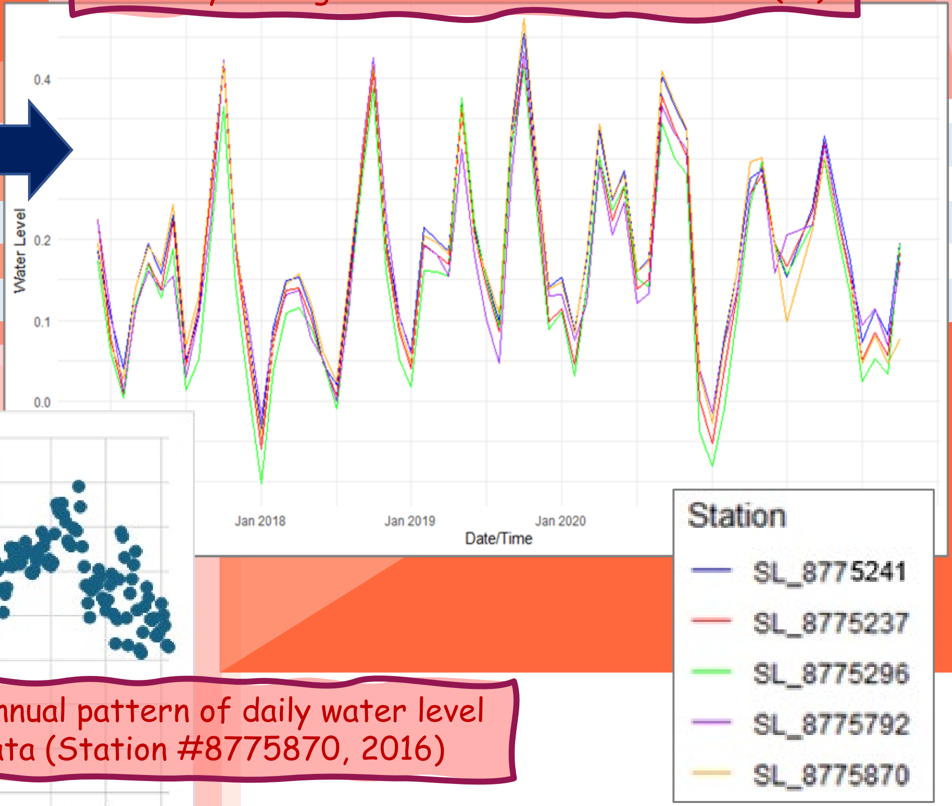
Results

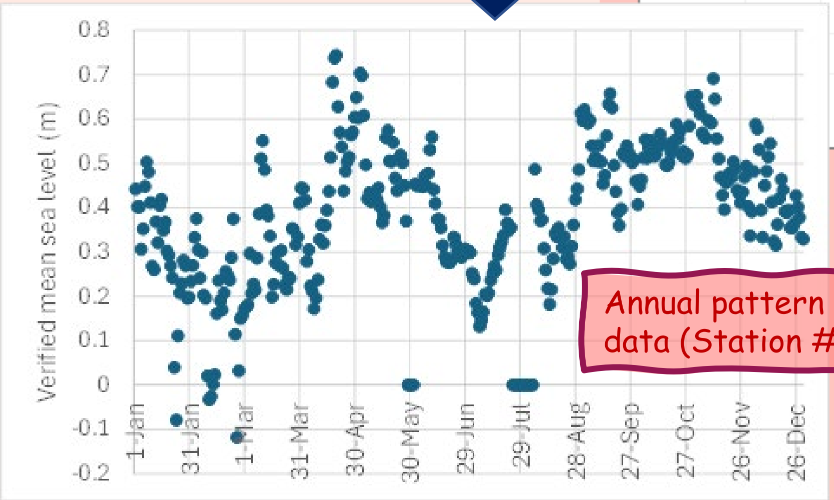
1) Data

Rainfall:
- Available without gaps for the entire period addressed in this report

Sea level:
- Stations differ from each other (two-sided pairwise t-tests)
- Differences are small
- Slightly increasing trend
- Annual pattern of daily data (higher in spring and fall)

Monthly average water Level for all stations (ft)





Annual pattern of daily water level data (Station #8775870, 2016)

Nueces County

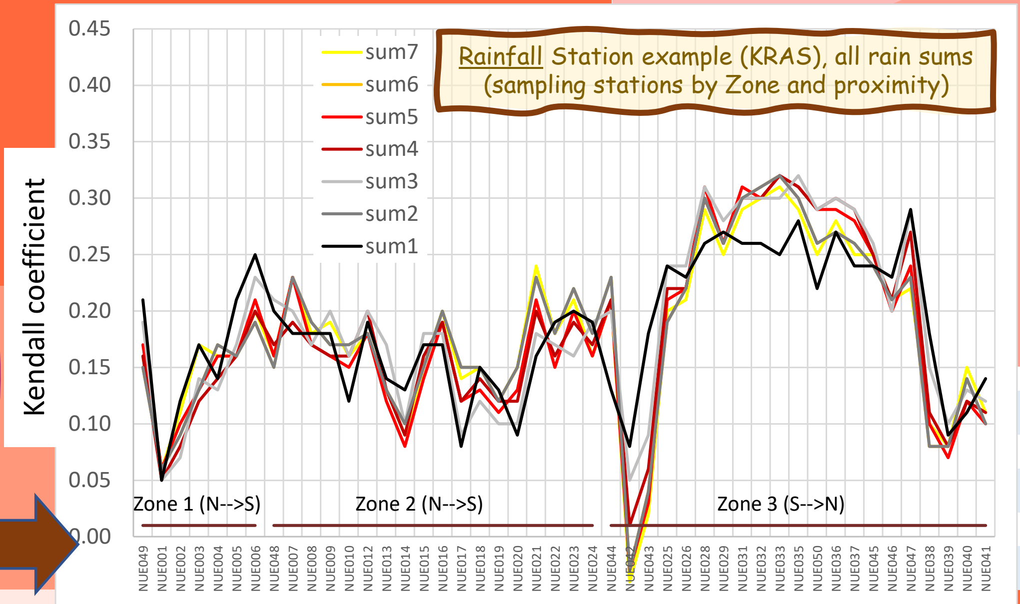
T2D3 - Statistical Outputs from Enterococci Dataset and Environmental Metadata Comparisons

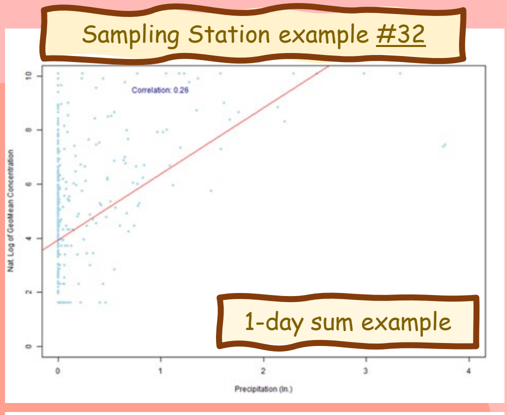
Results (cont.)

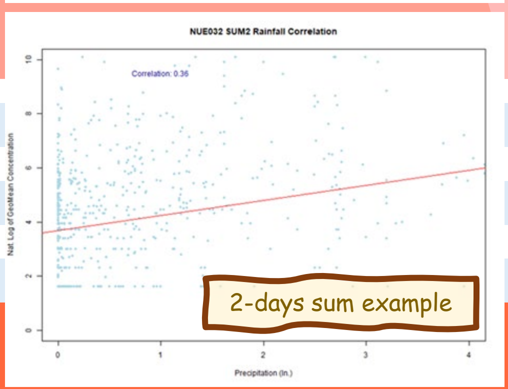
2) Kendall Tau-B Correlation

Rainfall:

- M or S for 33% (KCRP) to 41% (KRAS) of the sampling stations/rain sums
- Higher coefficients in Zone 3
- Increases when using 2-7 days rainfall sums for sampling stations ranging from #28 to #37,
- Not consistently, but in some cases, it appears to increase for "nearby" (same Zone) rainfall stations

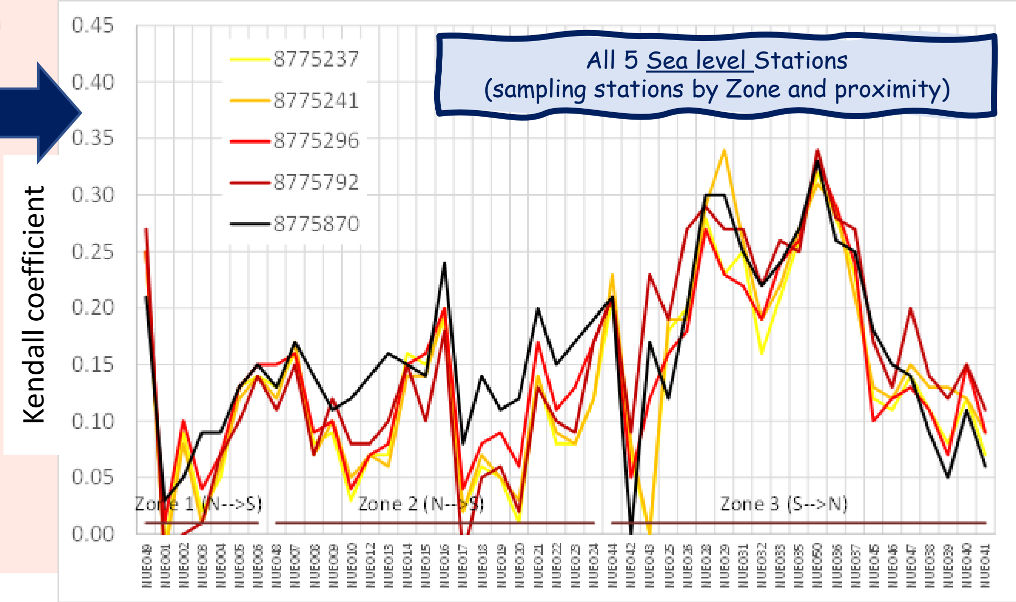


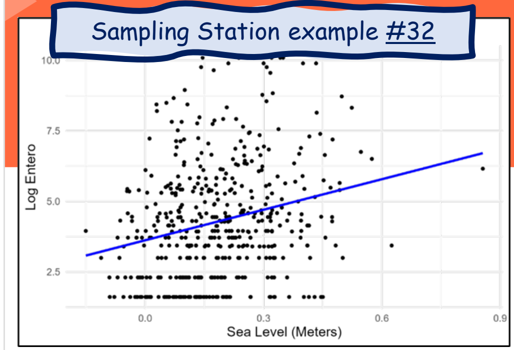




Sea level:

- M or S for 24% (8775237) to 33% (8775792) of the sampling stations
- Pattern is similar among water level stations
- Higher coefficients in Zone 3
- Not consistently, but in some cases, it appears to increase for "nearby" (same Zone) rainfall stations



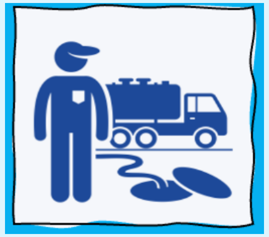


Nueces County

WATERSHED WITH MARKED POTENTIAL SEWAGE CONTAMINATION SOURCES

T3D3

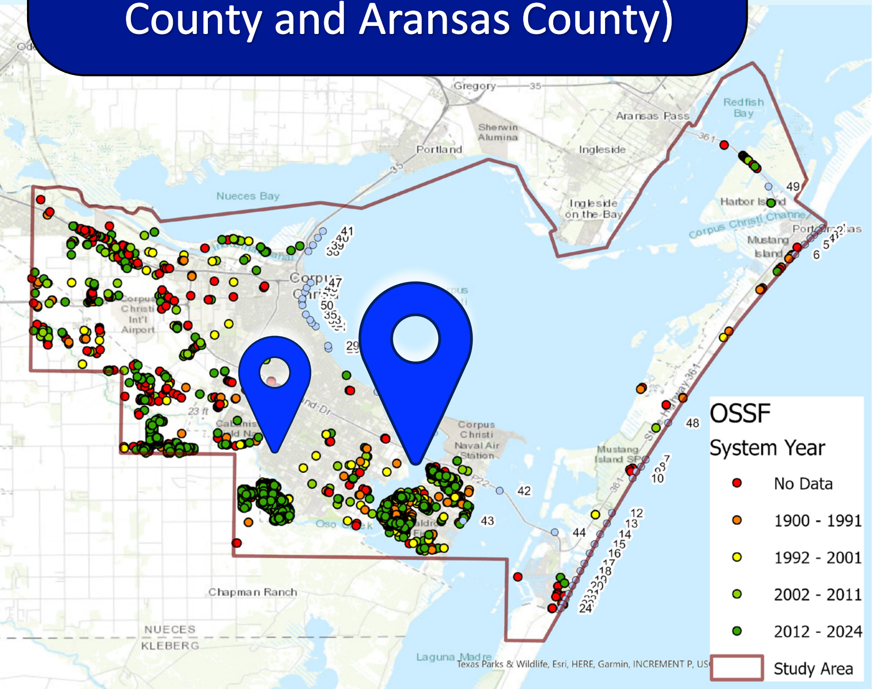
Analysis of micro-watersheds and potential sources of pollution



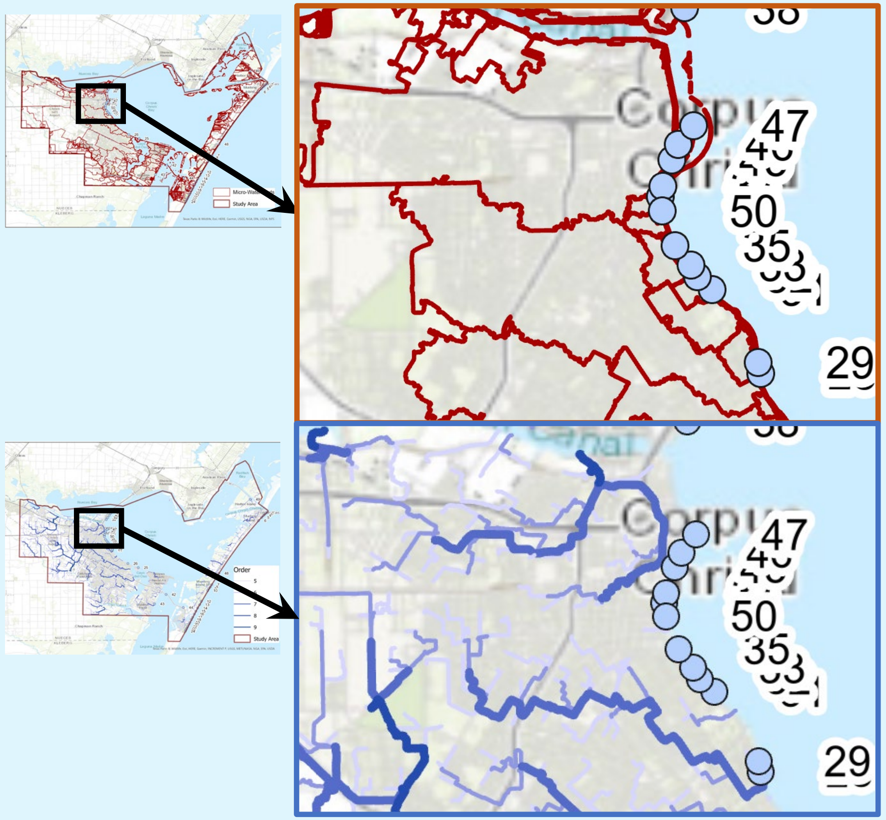
On site sewage facilities (OSSF)

Most systems:

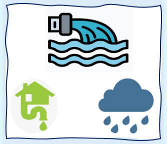
- Along Oso Creak
- North portion of the Corpus Christi Bay (San Patricio County and Aransas County)



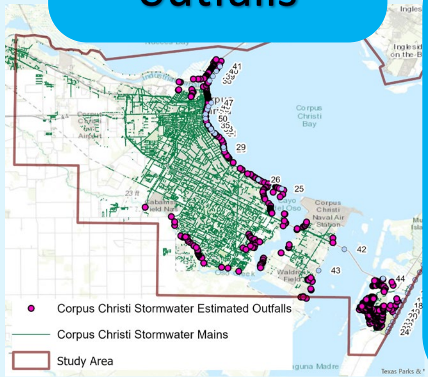
Micro watershed map with LiDAR (2018 Light Detection and Ranging)



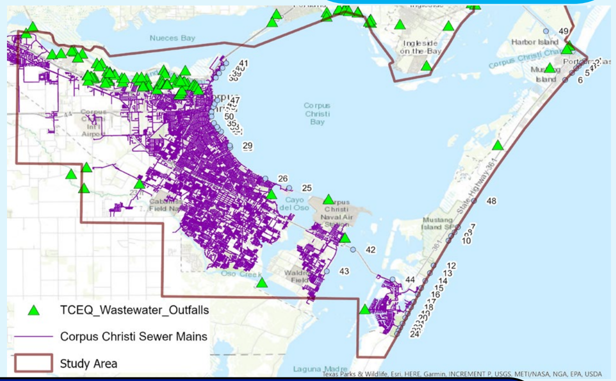
Most drainage estimated toward the bay



Stormwater estimated outfalls



Wastewater Treatment Plants (WWTP) pipelines and outfalls



Toward the Bay:

- Most Stormwater outfalls
- All WWTP outfalls

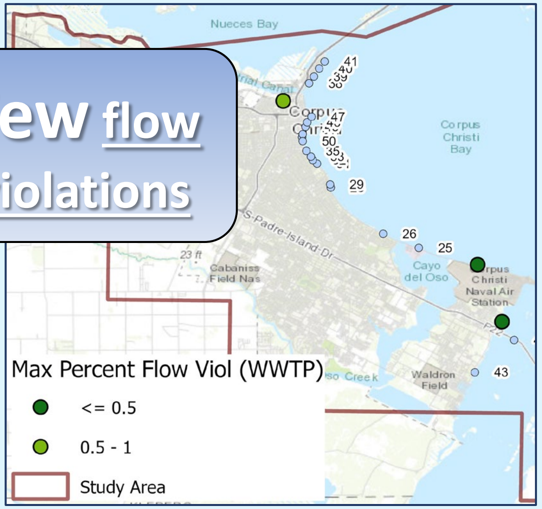
Nueces County

WATERSHED WITH MARKED POTENTIAL SEWAGE CONTAMINATION SOURCES

T3D3

Analysis of leaks and spills

Few flow violations



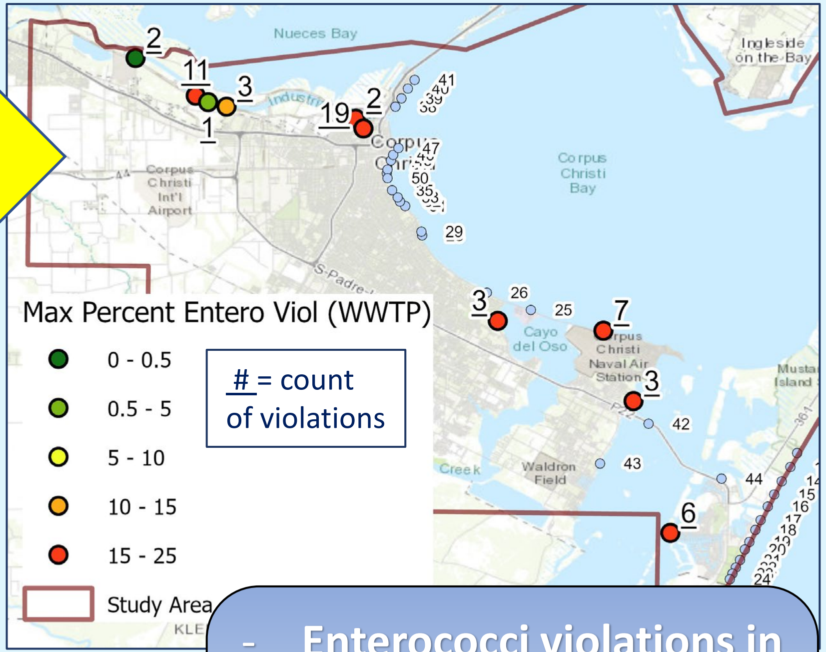
From Enforcement and Compliance History Online (ECHO) database, 2000-2023

Flow violations

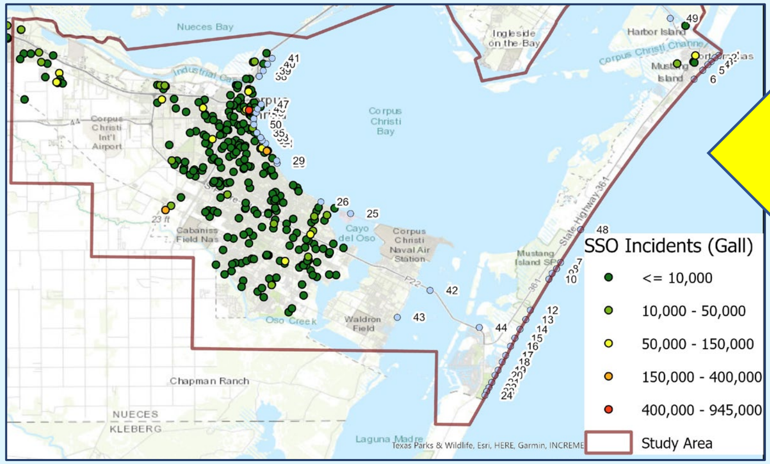
&

E. Coli / Enterococci violations

E. Coli violations only near GLO sampling stations 1-6 (Aransas Pass)



497 incidents; 10% not located; 0.01% draining in the ocean



Outflow incidents

From Sanitary Sewer Overflows (SSO) database, 2016-2022

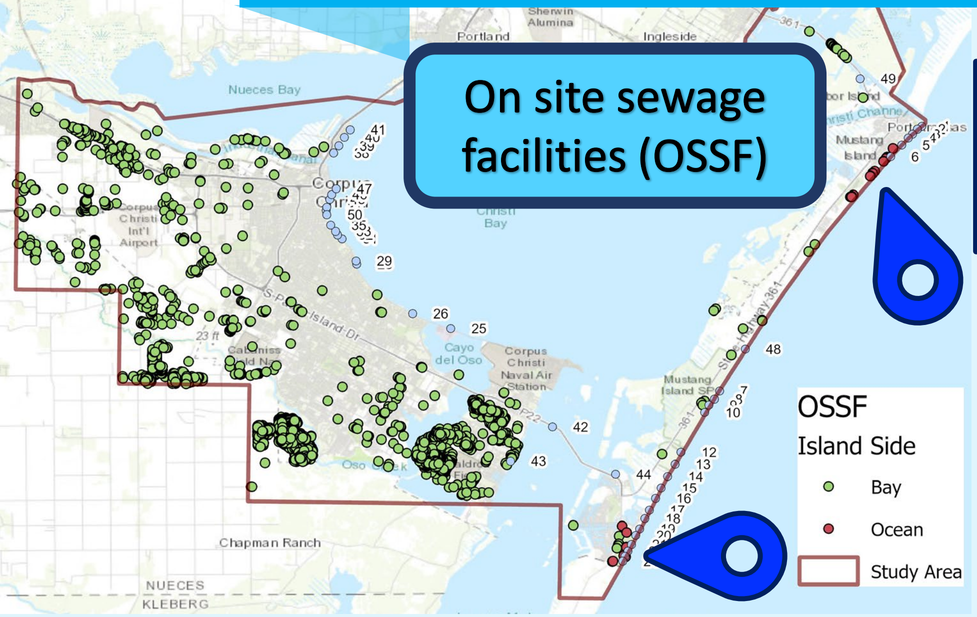
- **Enterococci violations in Corpus Christi**
- **Highest exceedance at exit of Industrial Canal**

Nueces County

STATISTICAL OUTPUTS: ENTEROCOCCI DATASET & POTENTIAL SEWAGE CONTAMINATION SOURCES

T3D3

On site sewage facilities (OSSF)



- No date → **not comparable** to GLO samples
- Few in micro-watershed draining toward the ocean (GLO Exceedance category "Medium")
- Most along the Oso Creek (Beach Watch Exceedance category "**High**");
- Some correlation is possible

Enterococci violations

Slight positive correlation with GLO sampling stations outside Industrial Canal (example **NU050**)

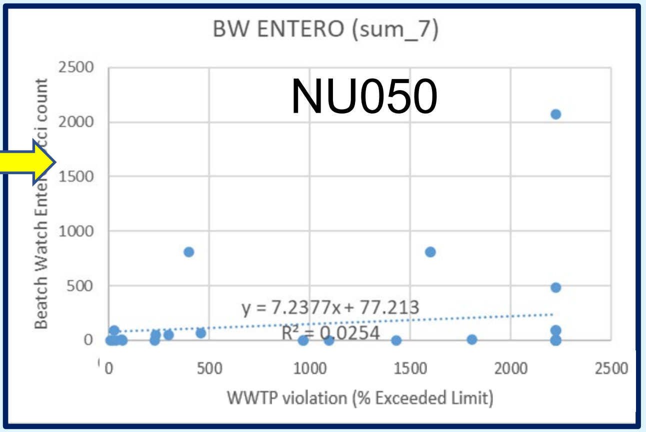
- ECHO and SSO have date and location → **comparable** to GLO samples
- Only selected locations (**groups**) are compared to a nearby GLO station
- Correlation is done with 7-days and 21-days GLO count sums after violation, but results did not show any evident differences

Flow violations

No correlation (few and low violations)

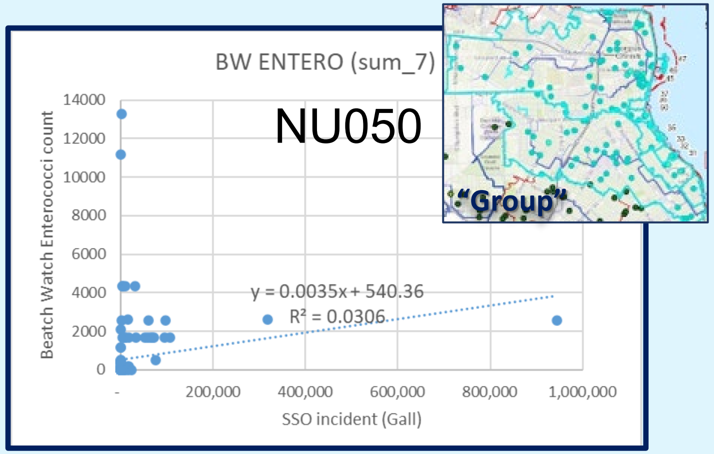
E. Coli violations

- Two cases only
- Possible correlation (**NU001-6**, Aransas Pass)



Outflow incidents

- Most incidents in Corpus Christi (GLO Exceedance category "**High**")
- "Infiltration/inflow" larger average volume
- Compared groups "nearby" GLO station **NU035** and **NU050**
- Weak correlation
- Need to refine analysis approach
- Incident solved in < 5 days (99%)



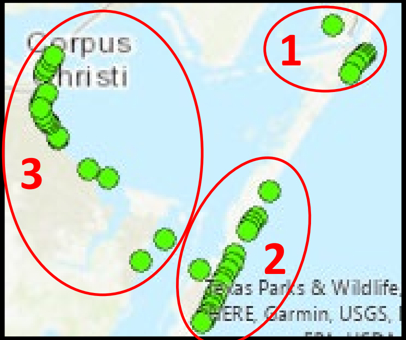
Nueces County

T4D3

RECREATIONAL BEACH ATTENDANCE ESTIMATES

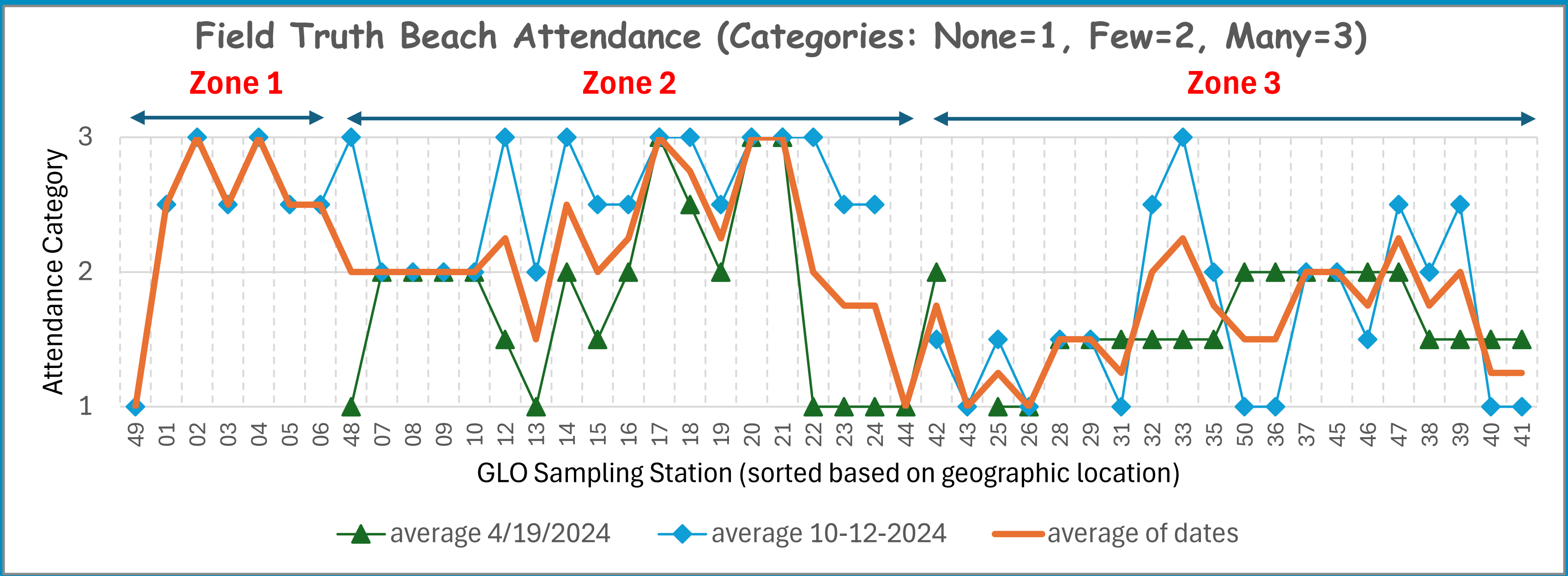
- Direct Estimates

- **Field truth visits**
  - Friday, 4/19/2024, and Saturday, 10/12/2024; P.M.
  - All sampling stations (200 yards)
  - Average of people and cars
  - Attendance Categories: None=1, Few=2, Many=3
- Texas Beach Watch: not used as only early morning



- Zones 1 and 2:
  - Higher than Zone 3
  - Higher in North and South of Mustang Island (easy access)
- Zone 3: Higher in Northern portion

Site Simplified ID	SITE ID	BEACH STATION NAME
1-6	NUE001-6	Port Aransas #1-6
7-10, 12	NUE007-10, 12	Mustang Island SP #1-4, 6
13-16	NUE013-16	J.P. Luby Park #1-4
17-24	NUE017-24	Bob Hall Pier/Seawall #1-8
25	NUE025	University Beach
26	NUE026	Poenisch Park
28, 29	NUE028-29	Ropes Park #2
31-33, 35	NUE031-33, 35	Cole Park#2-4, 6
36-37	NUE036-37	McGee Beach #1-2
38	NUE038	North Beach - Coastal
39	NUE039	North Beach - Breakers
40	NUE040	North Beach - Gulfspray
41	NUE041	North Beach - Gulden
42	NUE042	JFK-A
43	NUE043	Laguna Shores
44	NUE044	Park Road 22
45	NUE045	Corpus Christi Marina - South
46	NUE046	Corpus Christi Marina - Center
47	NUE047	Corpus Christi Marina - North
48	NUE048	Mustang Island
49	NUE049	Lighthouse Lake
50	NUE050	Emerald Beach



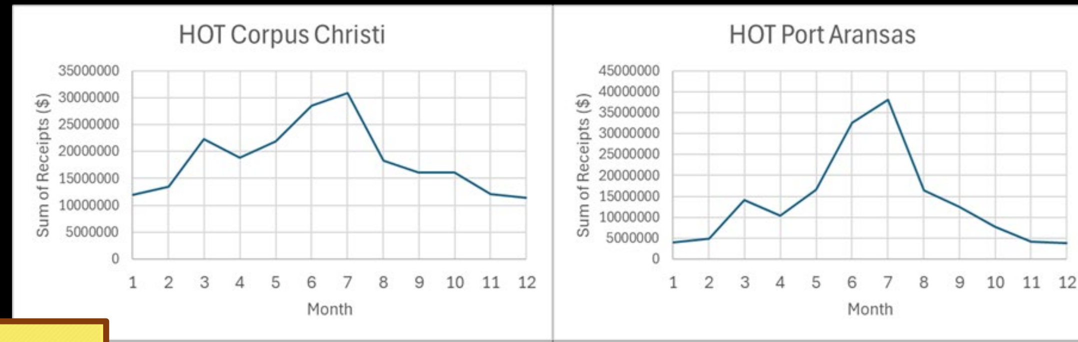
Nueces County

T4D3

RECREATIONAL BEACH ATTENDANCE ESTIMATES

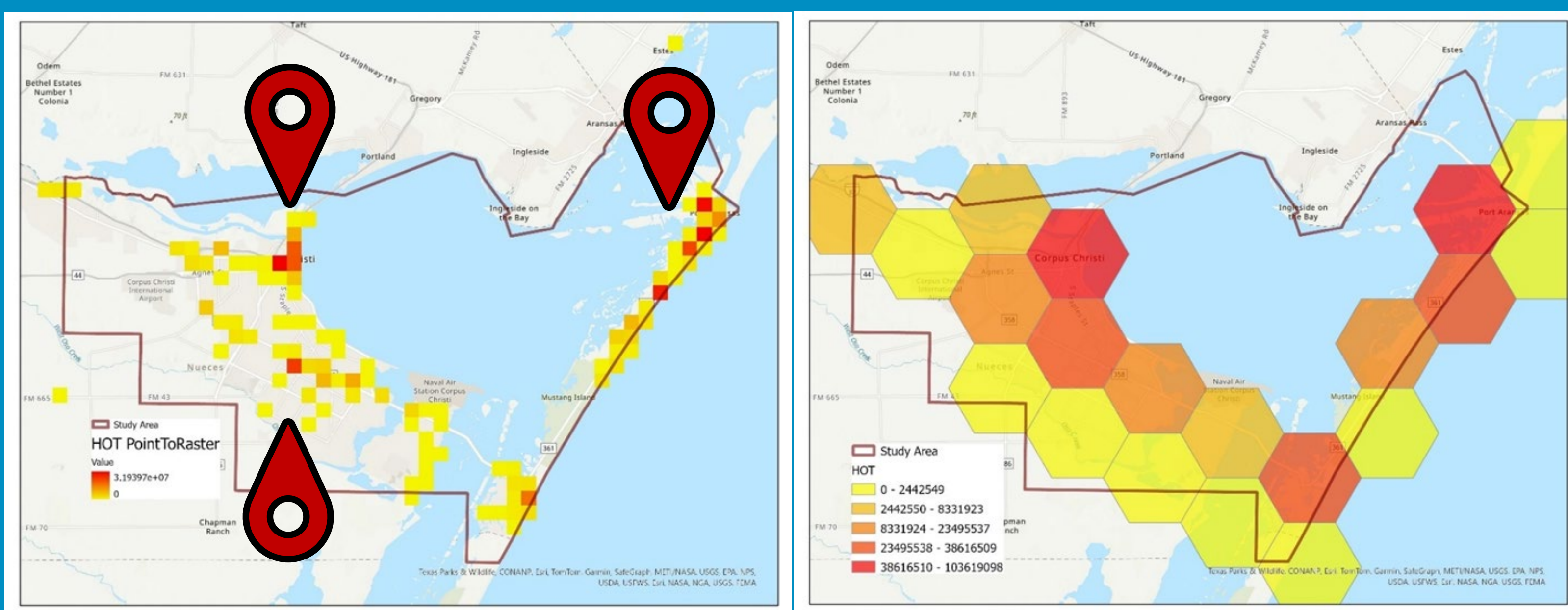
- Indirect Estimates

- **Hotel Occupancy Tax (HOT)**
- Office of the Texas Governor (2023)
- 2,983 locations
- Receipts (monthly sums)
- Tessellation (hexagons 16 sq. mi)



Peaks in March, June, and July

- Confirmed in North and South of Mustang Island and northern Bay
- Highest in Port Aransas and exit of Industrial Canal
- Zone 3 bay front has mostly private homes anduniversity rather than hotels.



Nueces County

T4D3

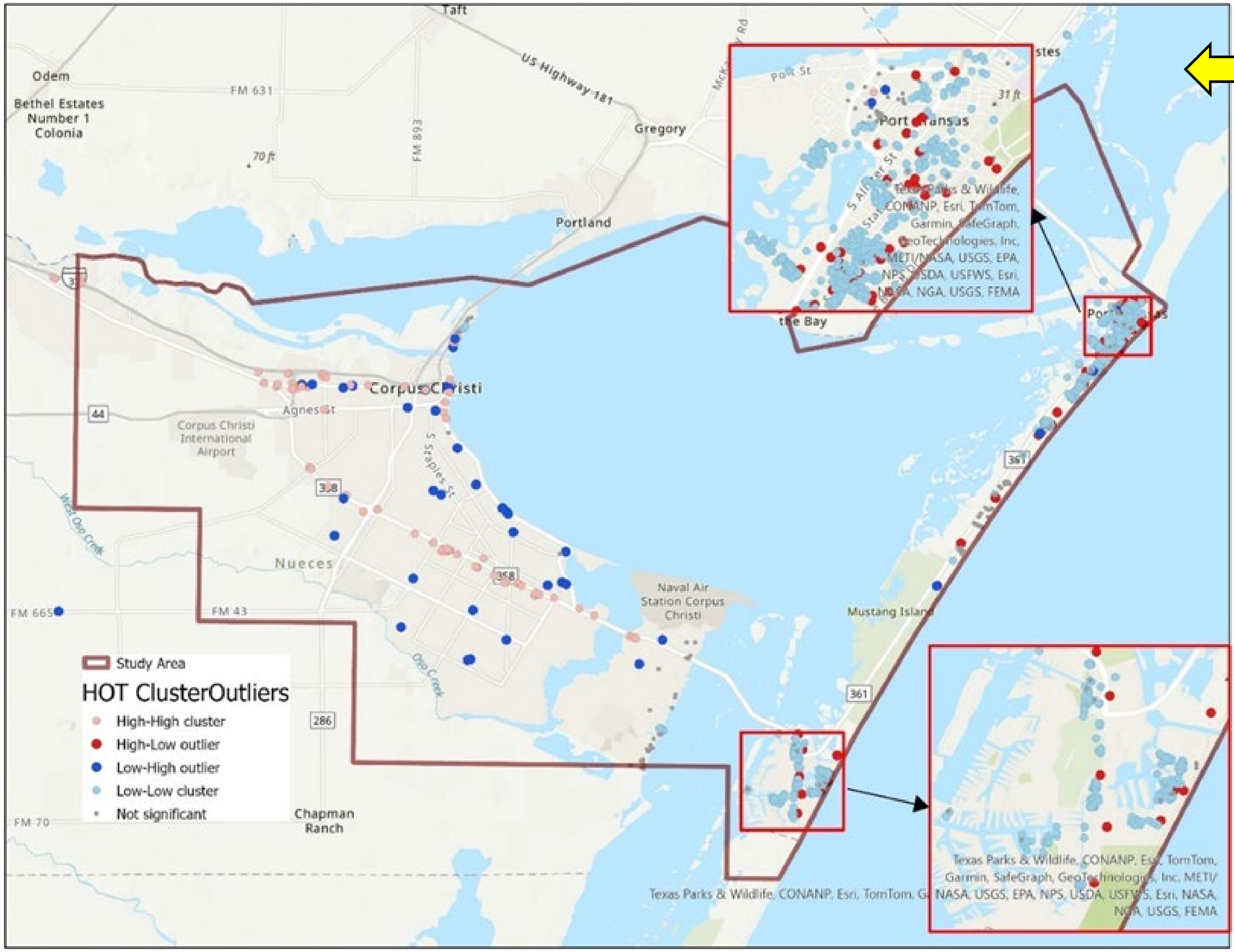
CLUSTERING AND SPACE-TIME PATTERN ANALYSES

VARIABLE

- Hotel Occupancy Tax (HOT)
- Info: location, spatial variability
- Year 2023

ANALYSIS

1) Cluster and Outlier (Spatial cluster = concentrations of high or low values and outliers = low values in a high concentration area or vice versa
2) Hot Spot



1) Clusters and Outliers

- "high": along 358 Corpus Christi and Industrial Canal
- "low": Mustang Island

2) Hot Spots

- along 358 in Corpus Christi
- outlet of the Industrial Canal

Nueces County

T4D3

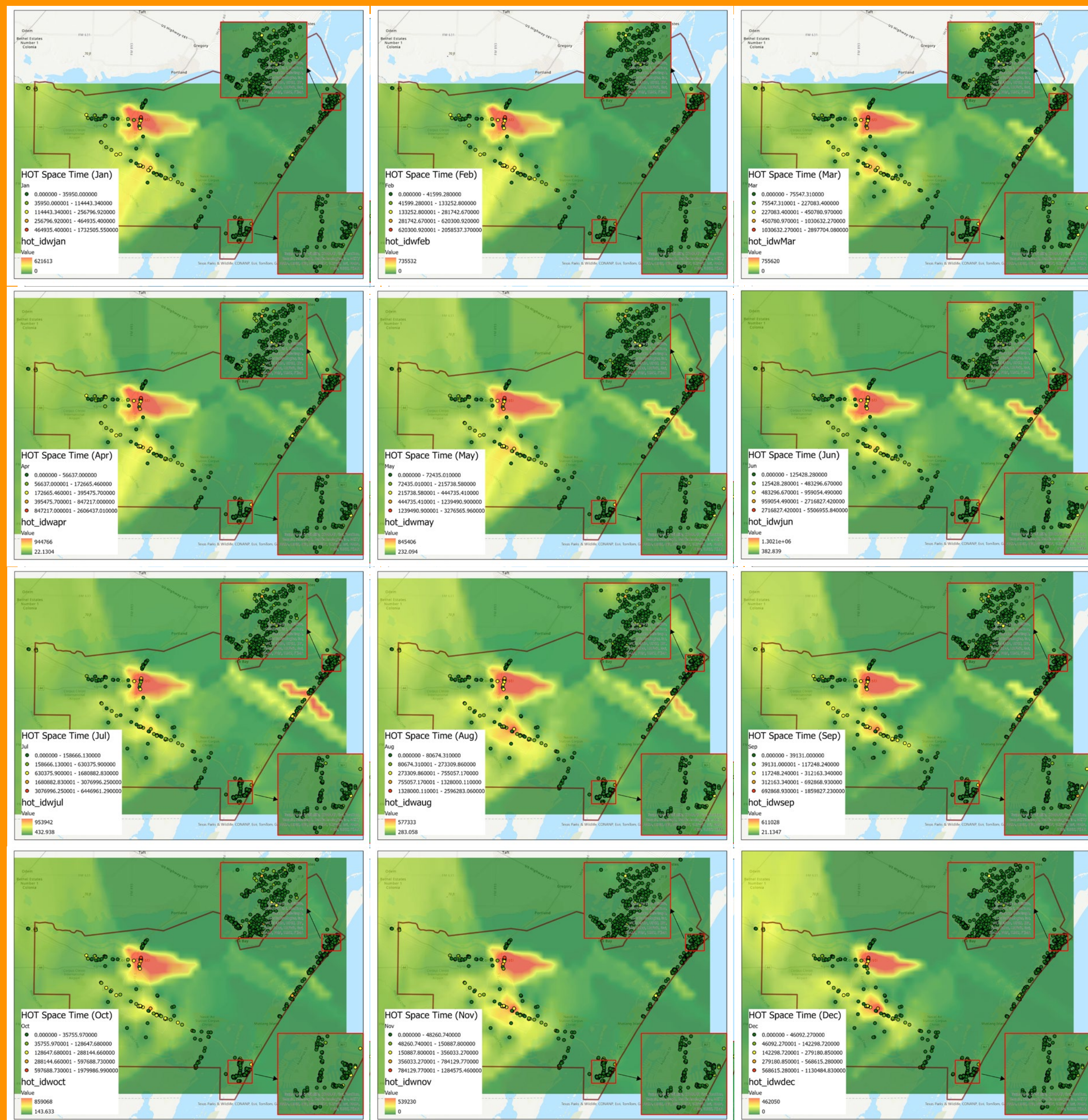
CLUSTERING AND SPACE-TIME PATTERN ANALYSES

VARIABLE

- Hotel Occupancy Tax (HOT)
- Info: location, spatial variability
- Year 2023

ANALYSIS

3) Space-Time Pattern



- Continuous attendance South of the Industrial Canal exit
- May to August middle of Mustang Island
- Intermittent attendance without clear time pattern along 358

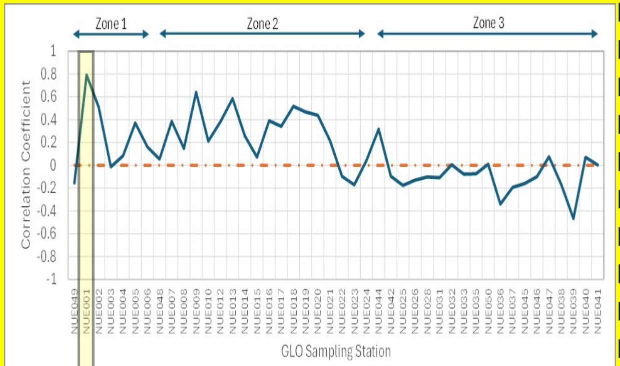
Nueces County

T4D3

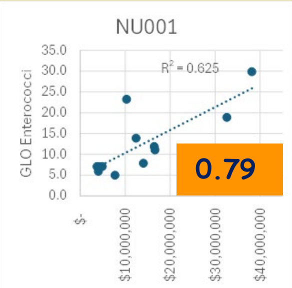
Statistical Outputs from Enterococci Dataset and Estimated Recreational Beach Attendance

Correlation

- HOT 2023 vs 2023 monthly Entero GM (T1)
  - Port Aransas HOT compared to Zone 1
  - CC HOT compared to Zones 2 and 3



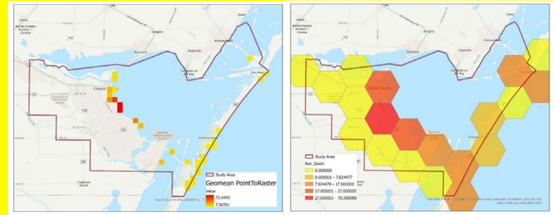
- Good correlation Zone 1 and 2
- No correlation in Zone 3
  - See GM peaks in T1D3
  - More private homes/university?



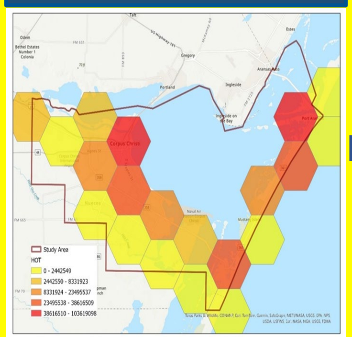
Spatial Regression

- HOT 2023 vs 2009-2023 monthly Enterococci GM (T1)
- Preliminary step (tessellation in hexagons) for Enterococci data
- Geographical Weighted Regression (GWR)
- HOT = explanatory variable
- Enterococci = dependent variable

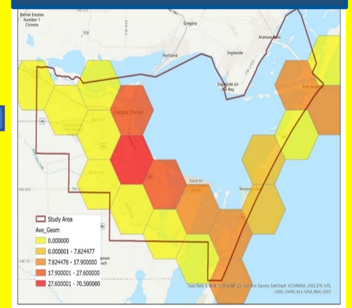
Highest values northern CC Bay



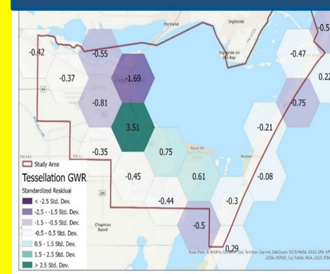
HOT 2023

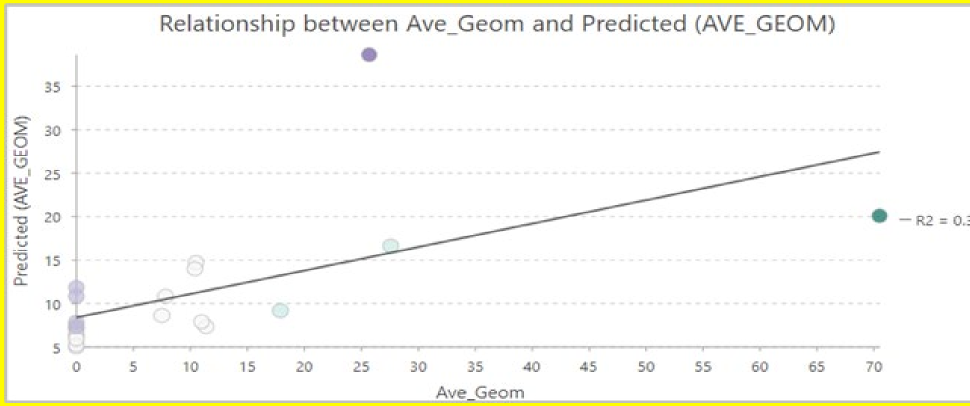


Enterococci 2009-2023



Cold-to-hot map of standardized residuals



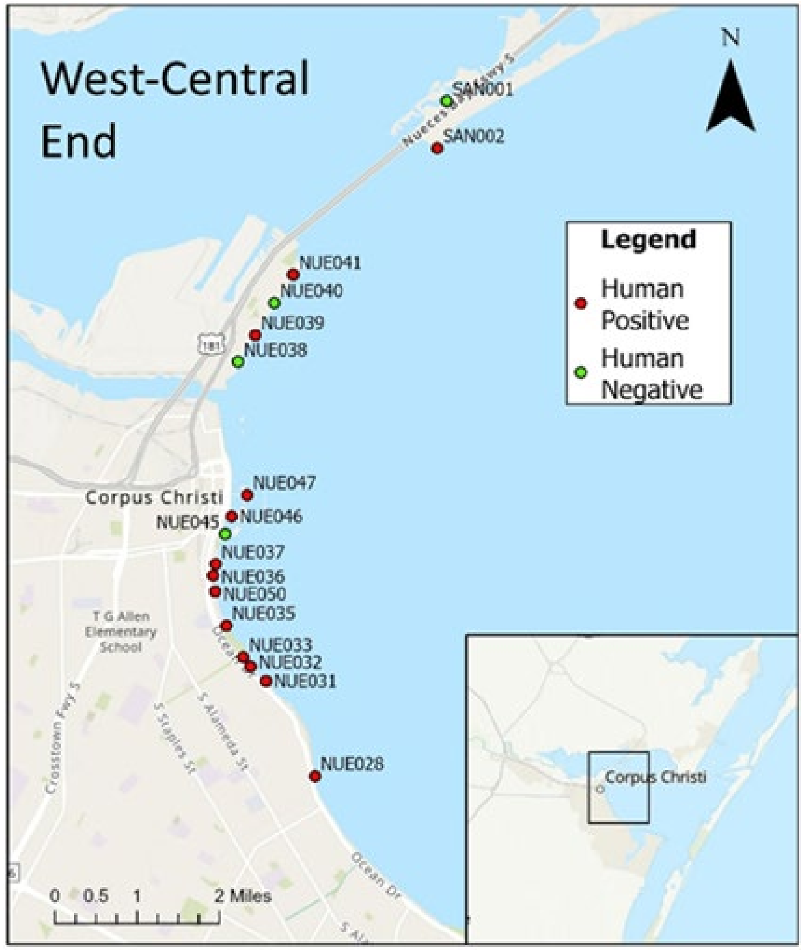


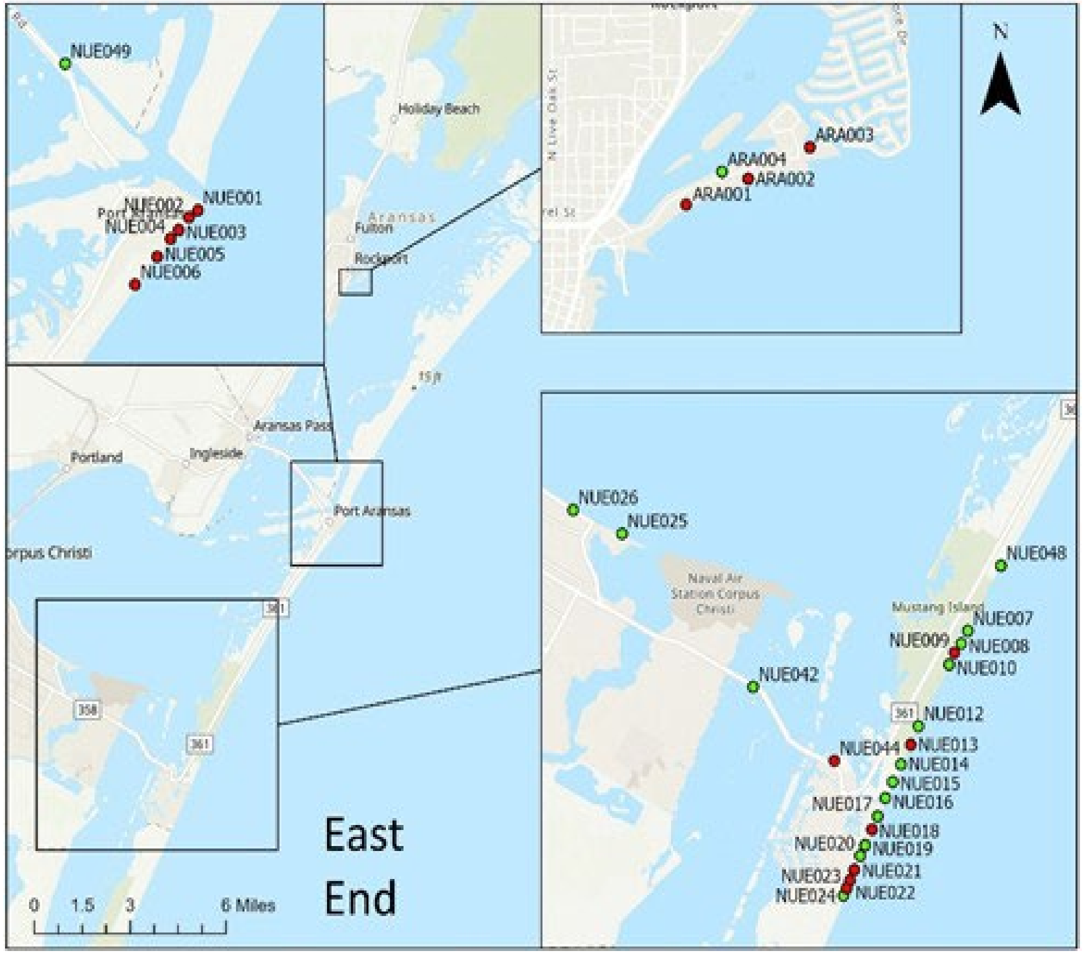
GWR plot of observed vs predicted geomean shows good fit

Nueces County

T5D3

Environmental, Enterococci,and Molecular Marker Dataset-HF183



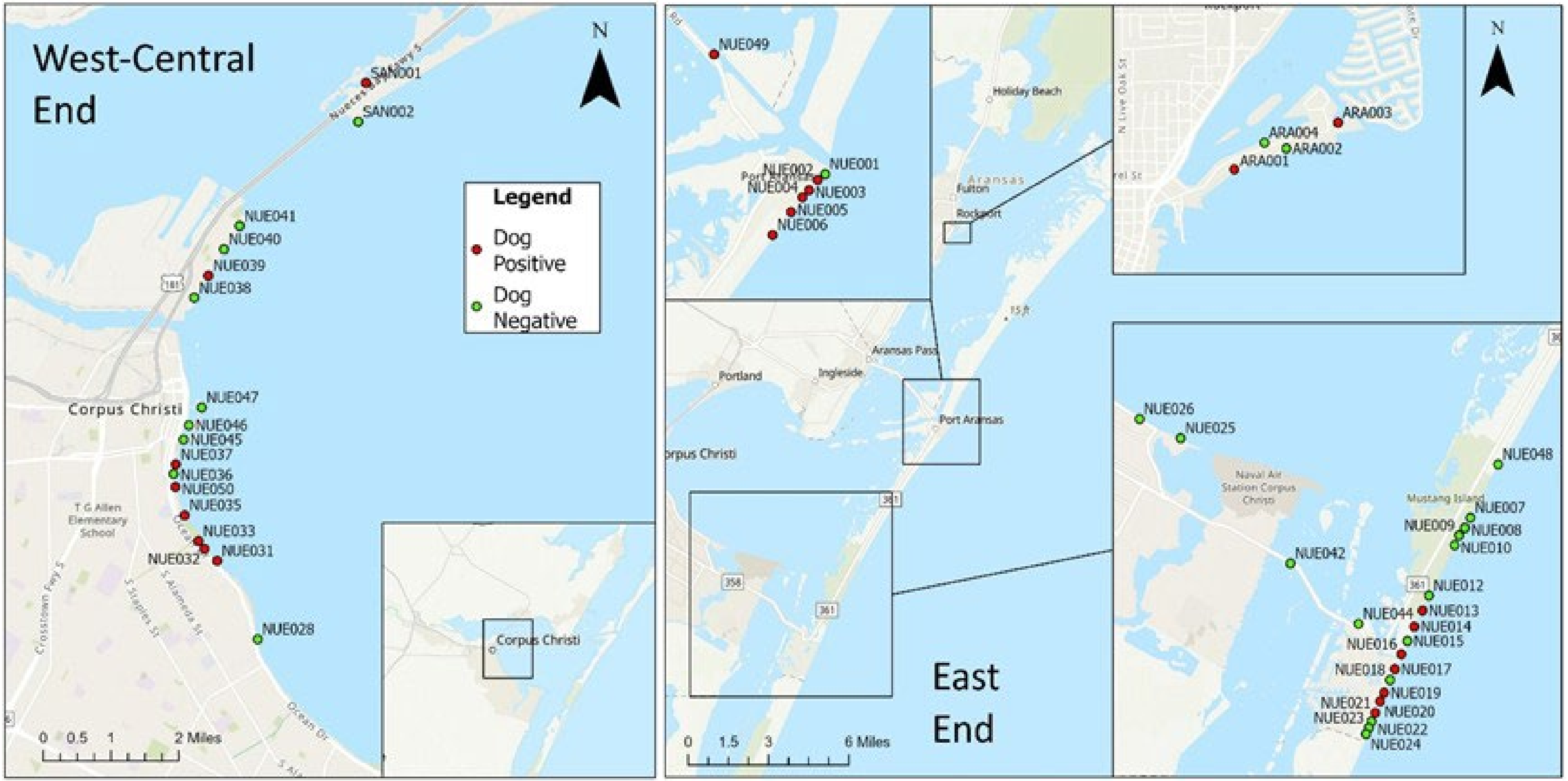


- No Significant link between the HF183 marker and Enterococci values
- Human-source contamination was seen in low levels
- HF183 was more common in samples from sites near densely populated areas (e.g. NUE001-006, NUE031-037, NUE046-047, and NUE050)

Nueces County

T5D3

Environmental, Enterococci, and Molecular Marker Dataset-DogBact

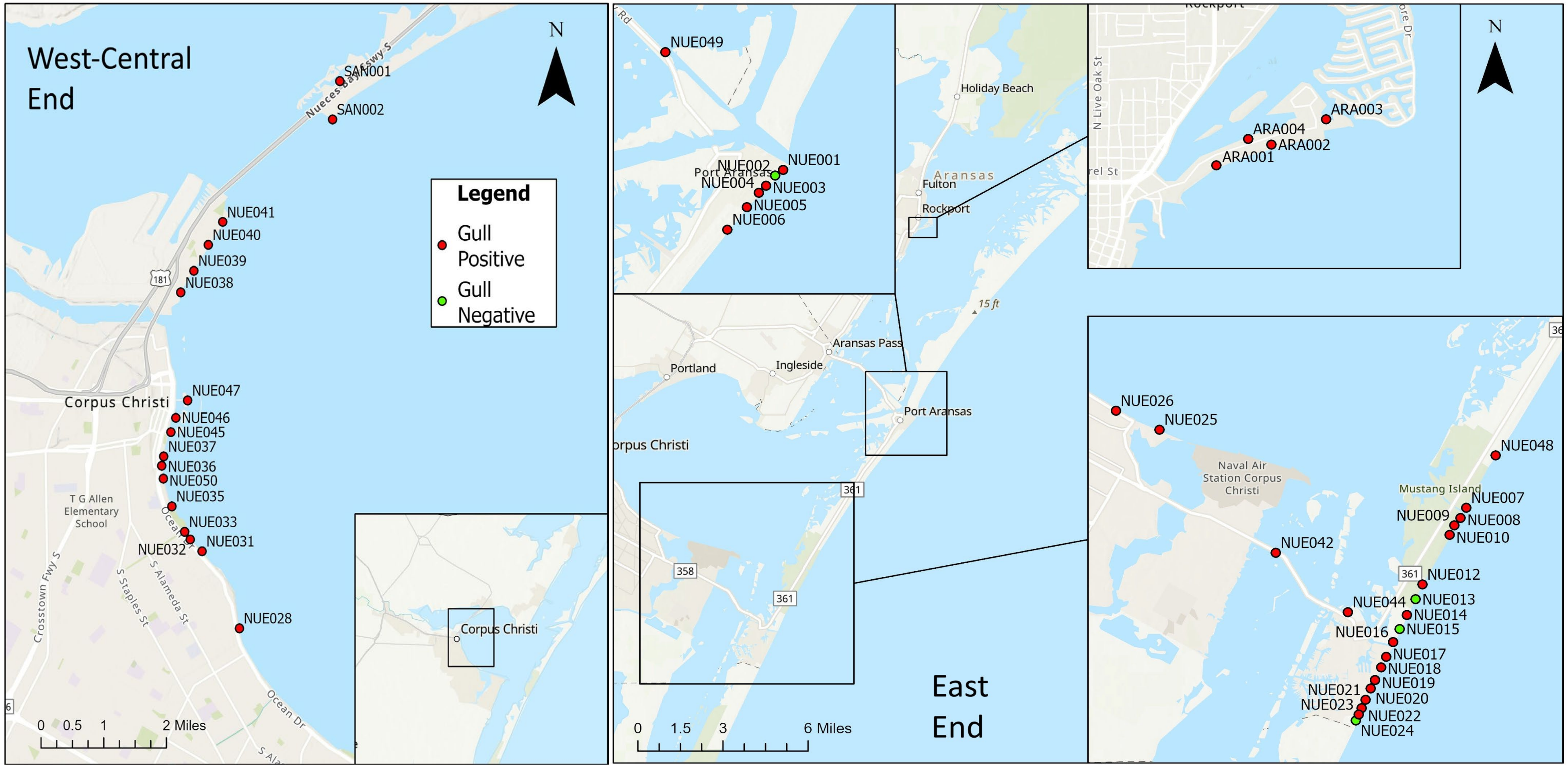


- Showed a strong correlation between DogBact abundance and Enterococci levels
- Notably higher than levels of HF183

Nueces County

T5D3

Environmental, Enterococci, and Molecular Marker Dataset-LeeSeaGull



- Most common marker found (87% of samples)
- Higher than both human and dog markers
- Strong correlation between marker and enterococci levels

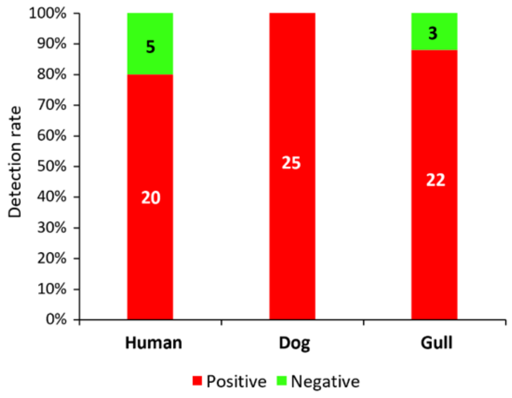
Nueces County

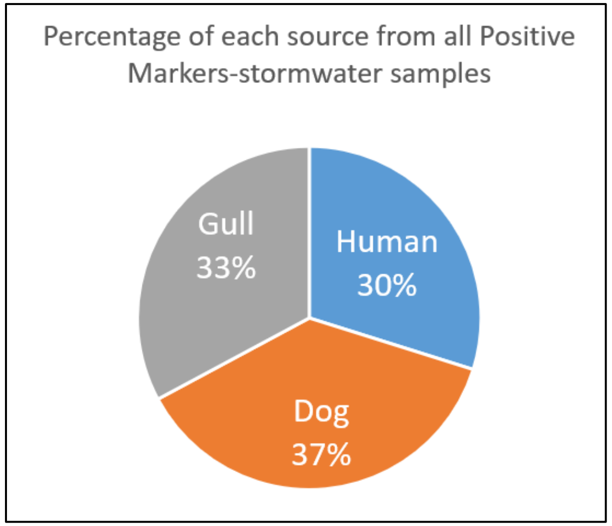
T5D3

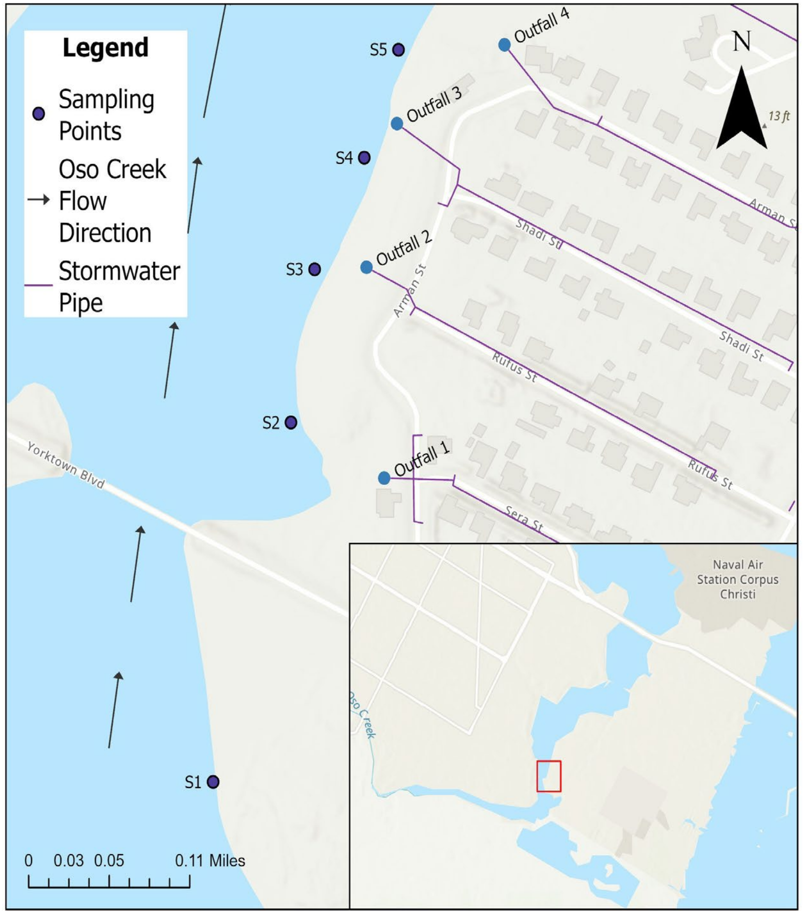
Oso Creek and Subdivision Stormwater Runoff Analysis

Stormwater Analysis

The DogBact marker was detected in **ALL** stormwater samples at the **highest** concentrations

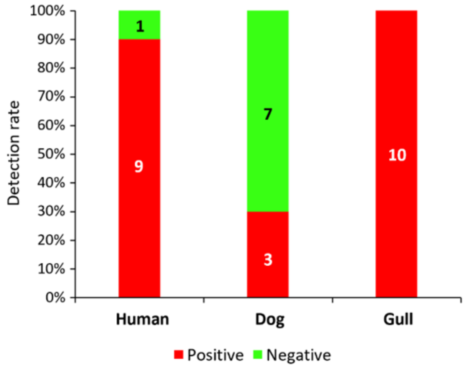


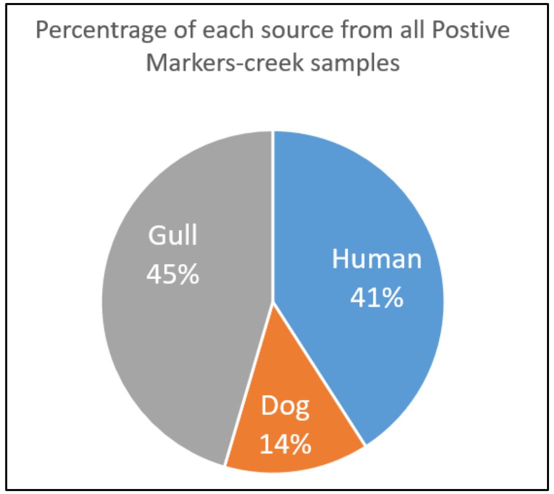




Oso Creek Analysis

- Gull was the **most** present marker
- Human contamination was widespread of samples, while dog contamination was **less** frequent





Nueces County

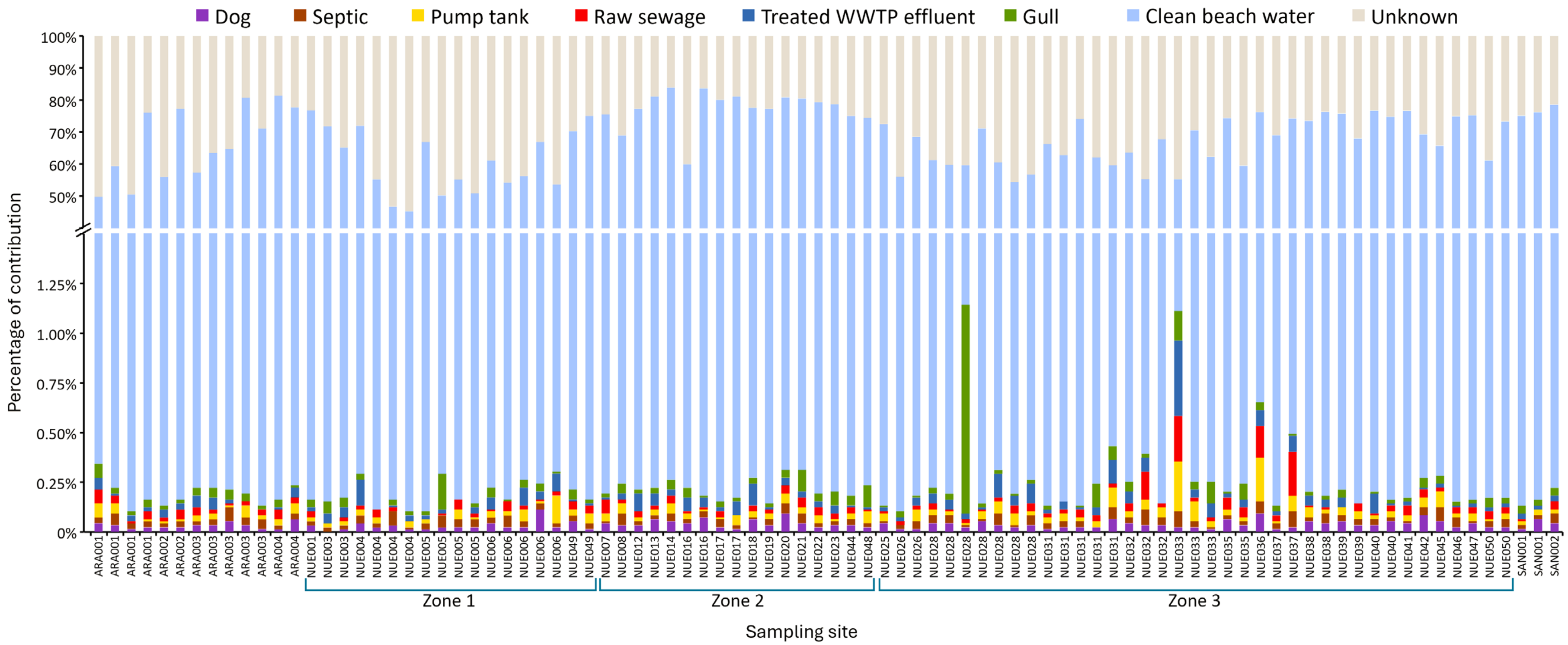
T5D3

Environmental, Enterococci, and Molecular Marker Dataset

DNA-based Microbial Source Tracking

Gull was the most frequently detected and largest source overall

Low contributions from human-associated sources and dogs



Samples from October 2024 through April 2025 were used for DNA-based source tracking. This process compares the bacterial community in potential sources (e.g., sewage) to that in environmental sinks (e.g., water).

Potential Sources Examined: Gull, Human (septic and WWTP sewage), Treated WWTP effluent (outlet), Dog

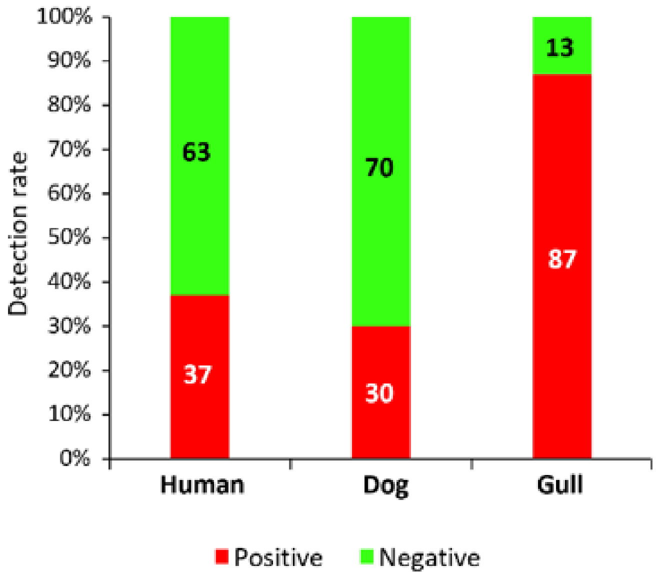
"Unknown" sources likely represent bacteria from soils and other environmental sources

Nueces County

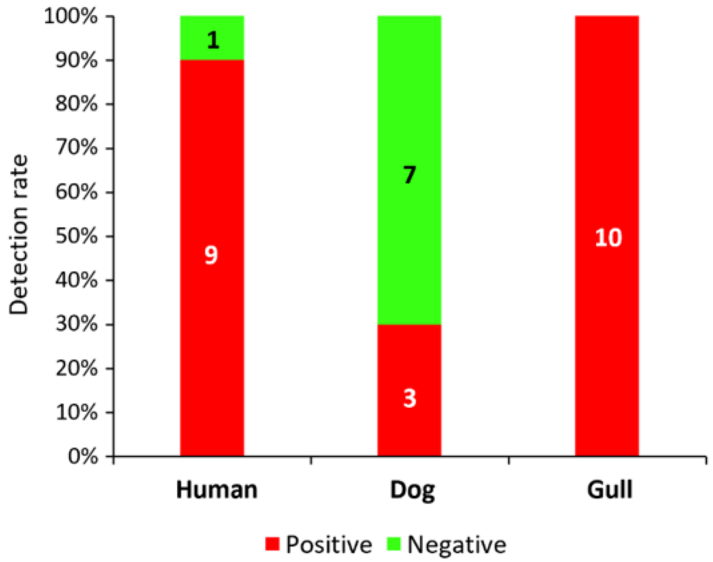
T5D3

Beach Watch and Subdivision Sampling Marker Comparision

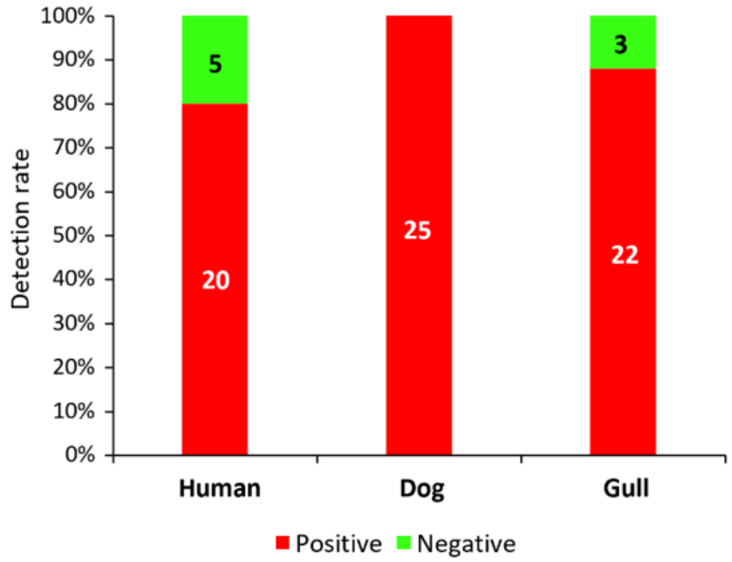
Beach Watch Samples



Oso Creek Samples



Stormwater Runoff Samples



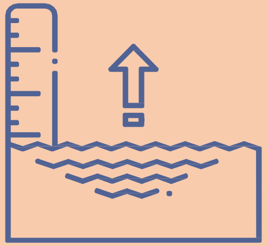
- The human marker was higher in creek and stormwater samples, showing a higher degree of influence than in beach watch samples
- Gull was the most abundant in beach watch samples and creek samples in comparison to the other markers
- Dog marker in stormwater indicates higher level of contamination in comparison to beach watch and creek samples

Nueces County

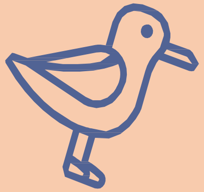
T5D3

Statistical relationship between Enterococci, molecular marker and environmental metadata (split samples Task 5)

Samples with the **dog marker** showed the **highest correlation** with rainfall data



The **gull marker** showed the **most correlation** with water level data



With the **human marker**, **no significant correlation** was found with either rainfall or water level data

Enterococci abundance, source-specific molecular, abundance and environmental metadata **showed some significant correlation**